AUDITORY CHANNEL CAPACITY FOR PITCH AND LOUDNESS IN NORMAL HEARING ADULTS & CHILDREN

A Dissertation completed in paRt fulfilment
of IV Semester M.Sc Speech and Hearing, 1981
University of Mysore

CERTIFICATE

This is to certify that the Dissertation "Auditory Channel Capacity for Pitch and Loudness in Normal hearing Adults and Children" is the bonafide work in part fulfilment for IV Semester M.Sc.(Speech & Hearing), carrying 100 Marks, for the student with Register No. 10.

(Dr. N.Rathna)
Director
AIISH, Mysore

CERTIFICATE

This is to certify that this Dissertation has been prepared under my supervision and guidance.

(M.N. Vyasamurthy)
Guide

DECLARATION

This Dissertation is the result of my own study undertaken under the guidance of Mr. M.N.Vyasamurthy, Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

- Reg. No. 10

Mysore

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C O N T E N T S

CHAPTER I

INTRODUCTION

'Information' is a measure of one's freedom of choice when one selects a message. Amount of information is measured by the logarithm of the number of available choices when the choices are equally probable, i.e., $H=\log_2 n$, where n is the number of available choices.

In an ensemble, if the events occur with unequal probabilities, the average amount of information of the ensemble is equal to

$$H= -[P_1\log_2 P_1 + P_2\log_2 + P_3\log_2 P_3 + \ldots\ldots. P_n\log_2 P]$$

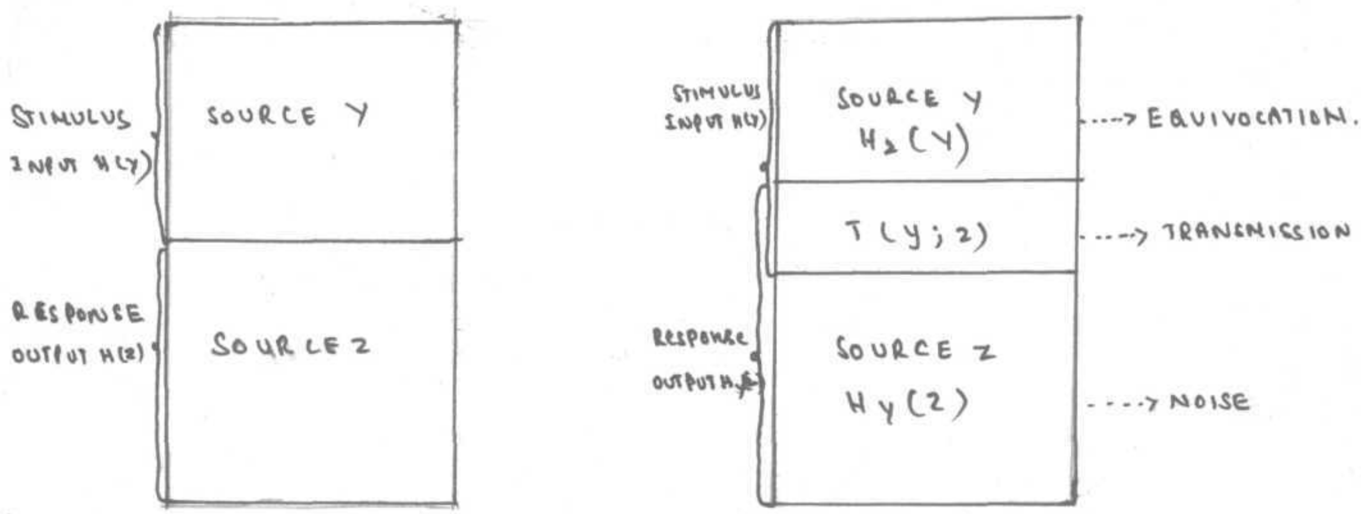
$$\text{or } H = - \sum_{x=l}^{n} p_x \log_2 P_x$$

Where P_1, P_2, $P_3 \ldots\ldots P_n$ are probabilities of 1st, 2nd, 3rd........nth events in the ensemble.

The above description of 'information' is concerned with a source or ensemble of outcomes (events) in which the various possible outcomes are independent. The probability of the occurrence of one outcome has no effect upon or is not affected by the outcome of any other event in the ensemble, i.e., it is concerned with a probability distribution of a single variable and deals with only whether the independent probabilities (summing to 1.00) were equal or unequal.

Let us consider the probability distribution defined in terms of 2 variables. The essential point of the bi-variate case is that 2 sources of uncertainty must be considered and these sources may be independent or non independent.

A Independent sources (System X)	B Independent sources (System X')



Total information in System X	Total information in System X'
$H(x)=H(y,z)-H(y)+H(z)$	$H(x')=H(y,z) \quad H(y)+H(z)$

Schematic representation of the different quantities of information in a communication system. Part A, independent sources of information and Part B, nonindependent or related sources of information. As applied in a psychological setting, one source may be considered as the stimulus input to the subject and the other, the response output.

The figure shows the schematic representation of the different quantities of information in a communication system. Part A, independent sources of information and Part B, non-independent or related sources of information. As applied in a psychological setting, one source may be considered as the stimulus input to the subject and the other, the response output.

In Part A, it is shown graphically and algebriacally that the amount of information H(x) associated with two independent sources is the sum of the information of the constituent sources, source Y and source Z. If Y and z are not statistically independent as in Part B, then $H(x^1)$ H(Y) + H(Z). This is intuitively reasonable; some of the information in source Y gives information about source Z and so that segment of information in source Z provides no new information.

In Part B, the two non-indepdndent sources of information or uncertainty may be considered in terms of a typical psychological situation. Assume that the system represents a human subject in an experimental situation. We have a series of stimuli and a series of responses; these are linked by the information channel, which is the subject. The two uncertainties H(in) and that of responses H (out) are related and are composed of the following parts:

H(Y) or H(in) is the uncertainty of stimulus input

H(Z) or H(out) is the uncertainty of response output

$H_2(Y)$ or $H_{out}(in)$ is the information which is in the input but is not contained in the output and is lost in the communication system. This term may be regarded as the uncertainty associated with the stimulus when the response is known and is called "equivocation".

$H_Y(2)$ or $H_{in}(out)$ is the information which is in the output but was not in the input. This term may be regarded as the uncertainty associated with the response when the stimulus is known and is called 'noise' or 'ambiguity' generated in the system itself.

T(Y;2) or T (in;out) is the information common to both input and output and is therefore called 'transmission .

H(Y,Z) or H (in, out) is the total amount of information in the system or the average uncertainty of all the possible states within the system and is the sum of H_{out} (in), T(in; out), and H_{in} (out).

It may be seen that numerous relationships hold between the various uncertainties, by referring to the geometry of the figure:

1. The input uncertainty consists of two parts: the part which is transmitted and the part which is lost H(Y) - T(Y;Z) + H(Z)Y

2. Stimulus equivocation is the difference between the input uncertainty and the information transmitted. $H_Z(Y) = H(Y) - T(Y;Z)$.

3. The output of the system is the sum of transmission and noise:

$$H(Z) = T(y;Z) + H_y(Z)$$

4. The total information in the system is the sum of the input uncertainty and noise:

$$H(Y;Z) = H(Y) + HY(Z)$$

5. The total information in the system is in the output except for the information which is lost:

$$H(Y;Z) = H(Z) - H_Z(Y)$$

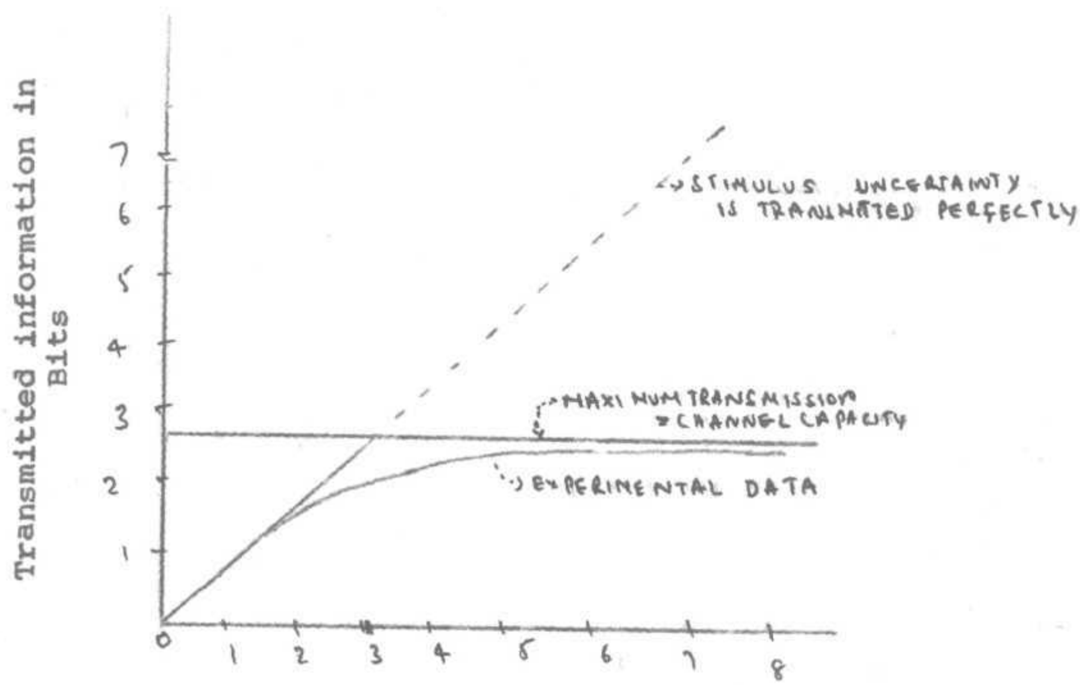
6. The total information in the system is the sum of equivocation, transmission and noise.

$$H(Y;Z) = H_Z(Y) + T(Y;Z) + H_Y(Z)$$

7. The information transmitted is the sum of the input and output uncertainties minus the total information in the system.

$$T(Y;Z) = H(Y) + H(Z) - H(Y,Z).$$

These are the primary ideas of information theory. For our purpose only one further concept remains to be defined, 'Channel Capacity'. Channel Capacity is the upper limit in the amount of information which can be transmitted in a system. Channel Capacity is often symbolised by C. With increases in the input information in a system, there are increases in the amount of information that is transmitted; however, there is a point beyond which transmission no longer increases. As H(Y) increases, T(Y; Z) approaches an upper limit C, which is the Channel Capacity of the system. From the figure it may be seen that the ability of a communication system to transmit information cannot exceed the input or stimulus uncertainty in a given situation.



Input information in Bits

A hypothetical curve for a human subject on a discrimination task. The channel capacity of the subject is defined as the maximum amount of information which can be transmitted under the conditions of the experiment. With a channel capacity of 2.58 bits, this subject can discriminate perfectly among six equally likely alternatives (After Miller, Amer.Psychol., 1953)

The figure shows the amount of transmitted information as a function of stimulus uncertainty in a hypothetical discrimination task with a human subject. When the input information is less than the channel capacity, the subject may discriminate perfectly and the transmitted information would equal the input information, thereby producing a diagonal straight line. Then, as the input information approaches the channel capacity, discrimination will not be perfect and the transmitted information would be less than the input information, producing a departure from the diagonal. Finally, when the stimulus information exceeds the channel capacity the transmission values will yield an approximately horizontal line which denotes the channel capacity.

From (3) HZ = T(Y;Z) + HY(Z), it can be written T(Y;Z) = H(Z) - HY(Z). HY(Z) is called conditional uncertainty and is the average uncertainty and is the average uncertainty in the variable Z when the variable is held constant. This is obtained by solving the equation:

$$HY(Z) = -\sum_{y}(P(Y) \sum_{z} PY(Z) \log PY\ (Z)$$

H(Z) is the uncertainty of response output.

Many studies have been performed in the areas of sensory psychology in which contingent uncertainty T(Y;Z) or amount of information transmitted has been computed. The model in this case is usually one of considering a set of stimuli as the input to a human subject, the set of responses as the output, and the nervous system as the communication system. The stimuli comprise one variable and responses the other. Thus the information transmitted may be considered a measure of the human subjects ability to discriminate among stimuli.

For a given system and a given set of circumstances the maximum amount of information transmitted is termed as the channel capacity of the system.

Pollack (1952) found that on the average human subjects could transmit a maximum of only 2.3 bits, given a set of 8 alternative tones ranging in frequency from 100 Hz to 8000 Hz. This is equivalent to perfect discrimination for five categories of frequency and seems rather small for a human subject with normal hearing. Particularly when these results are contrasted with data which show that at moderate loudness levels there are approximately 1800 just noticeable differences in pitch for pure tones between 20 Hz to 20,000 Hz. These findings can be explained on the basis of two different judgements, viz., absolute and relative judgements. Auditory Channel Capacity for pitch refers to absolute judgements of pitch. Garner (1953) reports that the absolute judgements for loudness in his subjects as approximately 2.1 bits.

Need for the present study: A review of literature on Auditory Channel Capacity for pitch and loudness shows that there are not many studies done in this particular area of research. As far as the investigator's knowledge is concerned, there seems to be not a single study done in our country with regard to auditory channel capacity for pitch and loudness. Thus there is an urgent need for this type of study in our country. The present study was undertaken to certify the following null hypotheses:

Hypotheses: 1. There is no significant difference between children and adults with regard to auditory channel capacity for pitch.

2. There is no significant difference between children and adults with regard to auditory channel capacity for loudness.

3. There is no significant difference in auditory channel capacity for pitch and loudness in adults.

4. There is no significant difference in auditory channel capacity for pitch and loudness in children.

5. There is no significant difference in auditory channel capacity for pitch and loudness with regard to sex in adults.

<u>Brief plan of the Methodology</u>: This study consists of 2 experiments, the auditory channel capacity for loudness and auditory channel capacity for pitch. In both the experiments 14 normal hearing adults (7males and 7 females) and 5 children were tested. All equipment was calibrated to ISO (1964).

Both the experiments were conducted at 4, 6, 8 and 10 number of events. In the experiment for auditory channel capacity for loudness, different tones, varying in intensity with a 10 dB increment from one tone to the other, were presented at 1000 Hz. In the second experiment for auditory channel capacity for pitch, different frequencies at 60 dB HL were presented. First, the subjects were familiarised with the tones and their corresponding code numbers. Then the tones were presented in a random order one at a time so that each tone was presented 10 times and the subjects were asked to indicate which number tone was heard at each time. Their responses were recorded.

<u>Definition of the terms used:</u>

<u>Channel Capacity</u>: With increase in the input information in a system, there are increases in the amount of information transmitted; however, there is a point beyond which transmission no longer increases. Channel capacity is the

upper limit in the amount of information which can be transmitted in a system.

Bit: Whenever a choice is made between two alternatives which on a priori basis are equally likely, it is specified that the choice has transmitted one unit of information. This unit is called the bit - a contraction of the words "binary digit".

Information Transmission: Contingent uncertainty is a measure of information transmission. The amount of information is determined by the amount by which the uncertainty is reduced. Uncertainty and information are quantitatively equal in a given situation.

Normal hearing: For the purpose of this study, subjects are considered as having normal hearing if they had a threshold of 20 dB HL (ISO 1964) or less than 20 dB HL (ISO 1964), and had no complaint of ear pain, ear discharge or ear infection.

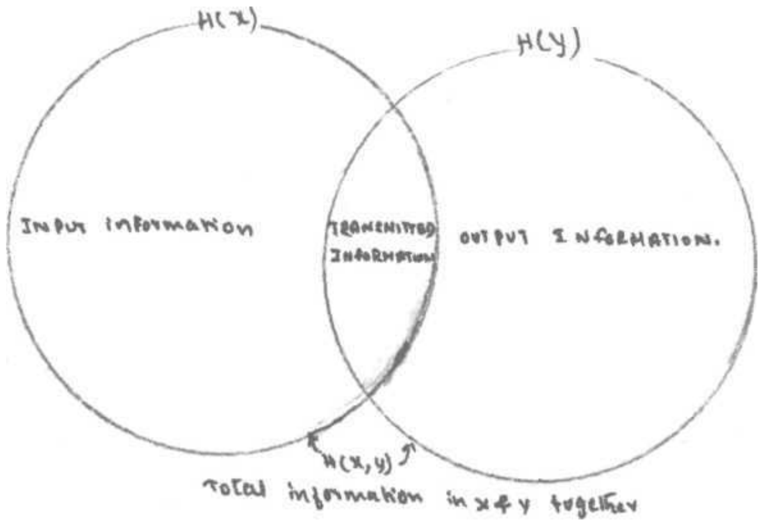
CHAPTER II

REVIEW OF LITERATURE

Channel Capacity

In recent years a few psychologists whose business throws them together with communication engineers drop words like 'noise', 'redundancy' or 'channel capacity' into surprising contexts and act like a new slant on some of the oldest problems in experimental psychology. The reason for this is that information theory provides a yardstick for measuring organization. A well organized system is predictable - almost what it is going to do before it happens. When a well-organized system does something, you learn little that you didn't already know - you acquire little information. A perfectly organized system is completely predictable and its behaviour provides no information at all. The more disorganized and unpredictable a system is, the more information is got by watching it. Information, organization and predictability room together in this theoretical house. The key that unlocks the door to predictability is the theory of probability, but once this door is open we have access to information and organization as well. Information, organization, predictability and their synonyms are not rare concepts in psychology. Each place they occur now seems to be enriched by the possibility of quantification.

In a communication system there is a great deal of variability about what goes into the system and also a great deal of variability about what comes out. The input and the output can therefore be described in terms of their variance (or their information). If it is a good communication system, however, there will be some systematic relation between what goes in and what comes out. That is to say, the output will depend upon the input, or will be correlated with the input. If we measure this correlation, then we can say how much of the output variance is attributable to the input and how much is due to random fluctuations or 'noise' introduced by the system during transmission. So a measure of transmitted information is simply a measure of the input-output correlation. This situation can be explained graphically in the figure:



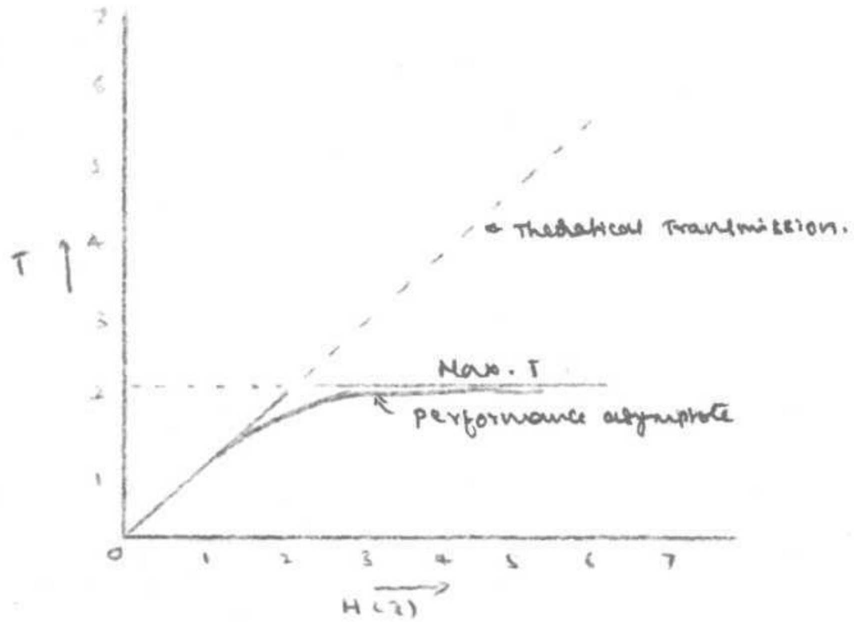
Schematic representation of several quantities of information that are involved in absolute judgements (After Miller, 1953)

The left circle can be taken to represent the variance of the input, the right circle the variance of the output, and the overlap the covariance of input and output, i.e., the left circle the amount of input information, the right circle the amount of output information and the overlap the amount of transmitted information.

A measure of information transmission provides a means of specifying perceptual or judgmental occuracy in situations where absolute judgements about various categories on a stimulus continuum are required. This measurement allows the determination of the maximum number of the stimulus categories which could be used with perfect accuracy without the necessity of sampling all the possible numbers of categories. However, this use of information transmission requires the assumption that the inherent judgemental accuracy is independent of the number of stimulus categories used experimentally.

In the experiments on absolute judgements, the observer is considered to be a communication channel. Then the left circle would represent the amount of information in the stimuli, the right circle the amount of information in his responses, and the overlap the stimulus response correlation as measured by the amount of transmitted information. The experimental problem is to increase the amount of input information and to measure the amount of transmitted information. If the observer's absolute judgements are quite accurate, then nearly all of the input information will be transmitted and will be recoverable from his responses. If he makes errors, then the transmitted information may be considerably less than the input. A characteristic of most communication channels is that there is an upper limit to the amount of information they can transmit, i.e., as the amount of input information to the human is increased, the amount of information transmitted by the human (both in bits/stimulus) will increase at first and then level of at some asymptotic value. This asymptotic value is the maximum amount of information transmitted (Max. Ht) under the specific set of experimental conditions employed when conditions are optimized for a specific task, Max Ht will attain its highest possible value; it may then be called the channel capacity for X, where X is the specific psychological function or task studied (e.g.,auditory discrimination of loudness, auditory discrimination of pitch,etc.). When X is an absolute judgement task, the antilogarithm of the channel capacity may be treated as an estimate of the span of absolute judgements of that stimulus dimension, i.e., as an estimate of the number of categories of stimulations that can be discriminated absolutely with an arbitrarily small percentage of errors.

The obvious psychological analogy to the transmission situation is between the subject in an experiment and a communication channel, between stimuli and inputs, and between responses and outputs. Then H(X) is the stimulus information, H(Y) is the response information, and T measures the degree of dependence of responses upon stimuli Thus as H(X) increases T approaches an upper limit, C. This is shown in the f where T is plotted as a function of H(X).



It turns out that T can be considered as a measure of discrimination and C is the basic capacity of the subject to discriminate among the given stimuli. This C is the channel capacity which represents the greatest amount of information that the observer can give us about the stimulus on the basis of absolute judgement.

The unit of measurement for channel capacity is 'bit' stands for binary digit, which is a measure of the amount of information. A perfectly good way to measure the amount of information is to count the number of possible outcomes that the information eliminates. Every time the number of alternatives is reduced to half, one unit of information is gained. This unit is called the 'bit' of information. If one message reduces K to K/X it contains one bit less information than does a message that reduces K to K/2X. Therefore, the amount of information in a message that reduces K to K/X is $\log_2 X$ bits. Two bits of information enable us to decide among 4 equally likely alternatives. Three bits of information enable us to decide among 8 equally likely alternatives. Four bits of information decide among 16 alternatives, five among 32 and so on. The general rule is: every time the number of alternatives is increased by a factor of two, one bit of information is added.

There are two ways we might increase the amount of input information. We could increase the rate at which we give information to the observer, so that the amount of information per unit time would increase. Or we could ignore the time variable completely and increase the amount of input information by increasing the number of alternative stimuli. In the absolute judgement experiment the second alternative is made use of. We give the observer as much time as he wants to make his response; we simply increase the number of alternative stimuli among which he must discriminate and look to see where confussion begin to occur. Confusions will appear near the point that we call his "Channel Capacity".

The problem of information transmission for various sensory continua under a wide variety of conditions has been studied quite extensively in psychology. Several reviews of selected studies are now available, for example, Allusi (1957), Attneave (1959a), Broadbent (1958), Corso (1967), Garner (1962) and Miller (1956). The results of these investigations are strikingly similar, and they reveal a surprisingly small channel capacity for absolute judgements in discriminating unidimensional stimuli.

In an early study, Hake and Garner (1951) studies information transmission in a situation which required the subject to make judgements of the position of a pointer on a line. There were four different numbers of possible pointer positions (5, 10,20 and 50) within a single interpolation interval on the scale; also, under one set of instructions the subjects restricted their responses to values given by the discrete positions on the scale and, under another set of instructions, they were permitted to use 101 different responses (zero to 100) regardless of the number of stimulus categories. There were two main findings in this experiment. (1) The amount of information transmitted was least for the 5 pointer positions (approximately 2.3 bits) and remained essentially constant for the 10, 20 and 50 pointer positions (approximately 3.2 bits or about 9 points along a line), regardless of the instructional set. This established the validity of the concept of channel capacity forhuman subjects in a perceptual discrimination task. (2) The two different response conditions (instructional sets) gave the same result in terms of information transmission, but the unlimited response condition yielded greater errors. This indicated that contingent uncertainty is a stable measure, easily interpretable, and not affected by the magnitude of errors. These properties make contingent uncertainty a useful measure in dealing with discriminatory ability in perceptual tasks.

Studies on vision using information measures are somewhat fewer than in audition, but some experiments involving hue, brightness and areal size have been reported. Halsey and Chapanis (1951) presented various numbers of categories of single spectral hues (7 mu bandwidth) to 2 or 4 subjects; holding intensity constant at 2.8 candles/Sq.meter, they found that a selected series of twelve such hues could be discriminated with 96 percent accuracy. In a later study, Chapanis and Halsey (1956) estimated the information transmission in hue discrimination to be about 3.6 bits, or the equivalent of about twelve different categories. Munsell hues at maximal saturation yielded approximately the same value of information transmission (3.5 bits) for a set of twentyfive stimuli (Conover 1959).

Eriksen & Hake (1955) also used Munsell papers to determine the accuracy of discrimination of hue, brightness and areal size. For the hue and brightness series 7/8 inch squares of Munsell papers were used, while the stimuli for the size series were cut from dark gray paper and varied from 1/8 inch sq. to 20/8 inch sq. There are twenty sizes of squares, twenty hues ranging from red through orange, yellow, green blue and red-purple and seventeen brightness values ranging from 1 through 9 in the Munsell system. For all the series, the test patches were mounted in the center of a 3 inch square of white cardboard. Each of 6 subjects made 100 judgements to each stimulus in the three series, with as many response categories permitted as there were stimuli per series. The results indicated that the best information transmission was 3.08 bits for hue (a value slightly less than that obtained in later studies by other investigators who used practiced subjects); for size, the information transmission was 2.84 bits; and for brightness

2.34 bits. This indicates that the maximum number of stimuli which could be selected from the three dimensions of hue, size and brightness to satisfy the criterion of perfect discriminability under conditions of absolute discrimination is eight, seven and five respectively. The number for brightness (five) is essentially the same as that for the pitch and loudness dimensions. The three psychological characteristics of pitch, loudness and brightness are, unidimensional, or at least involve judgements based upon psychological processes that are approximately similar in complexity.

In a study on the channel capacity for concentrations of salt and sucrose (Beebe-Center, Rogers, and O'Connel 1955), there were 3, 5, 9 and 17 different concentrations of salt solutions, ranging from 0.3 to 34.7 gm Nacl per 100 CC tap water, in equal subjective steps. The maximal amount of information transmitted was approximately 1.7 bits or slightly less than four discriminable concentrations. For sucrose, a maximum of 1.69 bits of information transmission was obtained. This indicates that in terms of absolute judgements the taste sense (for salt and for sucrose) is relatively poorer in discrimination than vision or hearing.

The ability of the human subject to transmit information about odor intensity was studied by Engen and Pfaffann (1959).

Four odorants were used (amyl acetate, n-heptanal, n-heptane and phenylethyl alcohol) and were preponed in a geometric dilution series of five steps (100, 50, 25, 12.5 and 6.5 percent) with Mallinkrodt's Benzyl Benzoate as the diluent. After the subject was given a practice period in which he learned to identify the rank order of the intensities of a given substance by sniffing the contents of full test tubes arranged in order of dilution, each of the five stimuli was presented singly in a random sequence and the subject was required to identify its rank order among the five stimuli. Fifty judgements were made for each stimulus value by each of five subjects (except for n-heptanal, N=4) who were informed of the correct rank order immediately after each judgement. The results of this study indicate that the information transmission for the four sets of odorants was slightly more than 1.5 bits, or about three levels of intensity. Small but reliable improvements in discrimination were obtained by increasing the intensity level of the stimulus series and by increasing the size of the step between stimuli; increasing the number of alternative stimuli beyond five had no effect. Data on three new subjects indicated that mith practice information transmission could be increased to approximately 1.9 bits or about 4 levels of intensity.

Some data are also available for cutaneous sensitivity (Geldard 1961). Although the findings in the cutaneous modality have not been obtained directly from research stemming from information theory, the investigation of the possibilities of cutaneous communication has provided data. The primary dimensions of mechanical vibration that may be used for a cutaneous language are location of stimulation, intensity of stimulation, and duration of stimulation. It has been determined that a good observer can discriminate perfectly among seven vibrators spaced on the ventral rib cage (2.8 bits), three intensities of stimulation between 5p and 400 microns of 'trip-hammer action' of the vibrators (about 1.6 bits) and approximately five durations of stimulation between 0.1 sec and 2.0 sec (about 2.3 bits).

Auditory channel capacity for loudness

The finding that information transmission varies as a function of the spacing used between the stimuli has been corroborated by Garner (1953). It required the observers to identify different intensities of a 1000 CPS tone, by assigning numbers to the different tones. The number of stimulus categories used were 4, 5, 6, 7, 10 and 20. For each experiment observer was given the practice session during which he tried to learn which numbers went with which loudness. The first analysis of judgemental accuracy was made by determining information transmission between stimulus being judged on a particular presentation and the judgemental response made by the observer. Essentially perfect accuracy was maintained with 4 or 5 categories. The information transmission in bits per stimulus presentation are slightly less than 2.00 an 2.32 bits for 4 and 5 categories respectively if no errors had been made, the small difference represents recording and scoring errors. For large number of stimulus categories, however, judgemental accuracy becomes progressively poorer being 1.62 bits for 20 categories. The information transmission, averaged for several subjects, was found to be approximately 2.1 bits that is between four and five tones.

The finding that information transmission varies as a function of the range of stimulation used has been definitely corroborated by Schipper (1953), whose experiment had 2 conditions. In one condition the number of intensities of a 1000 CPS tone judged by observers was varied from 2 through 4, 6, 8 and 10 tones with a fixed 5 dB interval between stimuli. In the second condition stimuli were selected at equal dB intervals to divide a fixed 45 dB range into 4, 6, 8 and 10 tones;this fixed range was equal to that used with 10 tones in the first condition. The amount of information transmitted by the average observer in the first condition was found to vary from 0.47 to 1.29 bits stimulus as the number of tones judged varied from 2 to 10. In the second condition, no significant differences in the amounts of information transmitted by the average observer (about 1.26 bits/stimulus) were found for the different number of tones.

These results imply 2 things. First there is an optional spacing of stimuli that will maximize the measured Max Ht (maximum amount of information transmitted) for a given stimulus dimension. The second implication is that the asymptotic value of information-handling performance obtained with any given stimulus dimension is dependent upon the range of stimulation used in obtaining Max Ht. The greater the stimulus range, the closer will Max Ht approach the channel capacity for the function being studied. This means, further, that even when optimal stimulus spacing is used, the inherent judgemental accuracy of observer is independent of the numbers of stimulus categories used experimentally only in so far as a fixed range of stimulus variation is employed.

Auditory channel capacity for pitch

Pollack (1952) had observers identify frequencies by assigning numbers to different tones. The tones differed in equal logarithmic steps in the range from 100 to 8000 CPS. Knowledge of results was given after each response, i.e., after each response observer was told which of the tones had been presented. The average amount of information transmitted by the observer was found to increase linearly upto about 2 bits/stimulus, and then to approach an asymptote of about 2.5 bits/stimulus, as the number of alternative tones within the stated range was increased from 2 to 14 (i.e., as input information was increased from 1 to 3.8bits/ stimulus). This Max Hl of 2.5 bits/stimulus seems to imply that the span of absolute judgements of frequency differences in auditory stimuli is in the neighbourhood of about five categories.

Pollack also found, however, that information transmission varied as a function of both the total range of frequencies used and the spacings used between stimuli. For eight tones, the mean amount of information transmitted with three closely spaced series was only 1.73 bits/stimulus, whereas it was 1.90 bits/stimulus with three widely spaced series when the entire range of from 100 to 8000 CP5 was used, the mean amount of information transmitted with 8 tones was 2.00 bits/stimulus, but when only part of this range was used it dropped to 1.725 bits/stimulus. The actual values for the 8 tone data ranged from 1.6 to 2.1 bits/stimulus for the different conditions.

Pollack (1953) in a two dimensional test varied the frequency and intensity of a series of tones. The frequency was varied in five equal logarthmic steps between 125 and

70C0 CPS; the intensity was varied in five equal loudness steps between loudness levels of 20 and 90 dB. This provided a total of 25 stimulus tones. The information transmission for the simultaneous pitch and loudness judgements was 3.1 bits. When these same stimuli were presented in a undimensional situation, the information transmission in pitch was 1.8 bits and for loudness, 1.7 bits. Sum of the undimensional tasks presented alone is 3.5 bits, and exceeds the information transmission in the 2 dimensional situation (3.1 bits). However, when the two dimensional unique responses were analyzed into separate components of frequency and intensity the information transmission per dimensions was less: 1.6 bits for frequency and 1.3 bits for intensity, with a total of 2.9 bits. This indicates that when two dimensions are used, there is an increase in information transmission over one dimension, but at a decrease in the amount of information transmitted per dimension.

In this way, researchers have determined the channel capacities for absolute judgements in several sensory modalities. The results of these investigators are strikingly similar, and they reveal a surprisingly small channel capacity for discriminating unidimensionai stimuli

Amount of information in absolute judgements of several stimulus dimensions.

Stimulus dimensions	Investigator	Channel capacity in bits	Approx. no. of stimuli discriminated
Brightness	Ericksen (1952)	1.7	3
Duration	Murphy (1966)	2.8	7
Hue	Chapanis & Halsey (1956)	3.6	12
Loudness	Garner (1953)	2.3	5
Odor intensity	Engen & Pfaffman (1959)	1.5	3
Pitch	Pollack (1953)	2.5	6
Position on a line	Hake & Garner (1951)	3.2	9
Saltiness	Beebe-Center et al (1955)	1.9	4
-Shock intensity	Hawkes and Warm (1960 b)	1.7	3
Vibration intensity	Geldard (1961)	1.6	3

The channel capacities calculated in these studies vary from 1.5 bits for odor intensity to approximately 3.6 bits per signal for the Hue discrimination. This range is equivalent to perfect identification of about 3 to 12 different stimuli of a given class. For any specific task studied, the exact value of the maximum channel capacity depends upon several experimental factors. Despite some differences, the general nature of these results has been so consistent that Miller (1956) described them as reflecting "the magical number seven plus or minus two". By this Miller meant that because of prior experience or the design of our nervous system, or both our ability to distinguish accurately between unidimensional stimuli on an absolute judgement basis is fixed 7 ± 2 or around 5 to 9 items.

There are several factors which account for this variation in channel capacity for absolute judgements on a single stimulus continuum. These factors include the following:

Facors affecting channel capacity

Duration of the tone: Doughty and Garner (1949) determined the direction and magnitude of pitch changes as a function of duration over a wide range of durations, frequencies and intensities. They used both a method of constants and a method of average error and the major difference between the methods was in terms of the magnitude of the effects. They conclude that:

1. As the duration of tones is decreased, there is a tendency for all tones to lose pitch.

2. The amount of pitch loss is related to intensity and frequency:

(a) Pitch loss is greater for high intensities and is somewhat less for lower intensities.

(b) Low frequencies show the greatest amount of pitch loss.

(c) High frequencies at low intensities show actual pitch gain at short durations.

3. These relationships can be explained in terms of the ear's responding to the geometric mean of all the frequency components involved in a short tone.

Range of stimulus variation: The amount of information transmitted with (or the estimated span of absolute judgements of) any given stimulus dimension is dependent upon the range of stimulus variation used experimentally. In general the greater the stimulus range, the greater the amount of information transmitted in bits/stimulus. Range seems to be the largest overall determinant of information transmission with a given stimulus dimension.

Spacing of stimuli: The maximum amount of information transmitted with a given stimulus range and a given number of stimulus and response categories may be reduced by use of nonoptimal spacings between stimulus categories.

Number of response categories: The number of response categories seems to interact with the number of stimulus categories. In general, when the number of response categories is fewer than the number of stimulus categories, the amount of information transmitted appears to be lower than when the number of response categories is equal to (or greater than) the number of stimulus categories.

Knowledge of results: The amount of information transmitted when knowledge of results is given to observer after each response appears to be greater than when no knowledge of results is given.

There are intersubject differences between experiments which may be accentuated by differing amounts of practice, subjects selected randomly from a given population may vary in the amount of information transmitted for a given dimension by a factor of 2, approximately (Allusi 1957).

CHAPTER III

METHODOLOGY

This study consists of 2 experiments:

Experiment No. I: To find the auditory channel capacity for loudness.

Experiment No.II: To find the auditory channel capacity for pitch.

Experiment No. I

Subjects: Two groups of subjects were chosen for this study. First group consisted of 14 normal hearing voluntary subjects; 7 males and 7 females. The second group consisted of 5 normal hearing children, whose age ranged from 7 to 9 years with a mean age of 8.4 years. Adults age ranged from 19 years to 25 years with a mean age of 20.8 years. All subjects had a threshold of 20 dB HL (ISO 1964) or less than 20 dB HL (ISO 1964) in their right ear.

Equipment: All the experimental data were gathered using a Madsen OB 70 clinical audiometer. A TDH 39 earphone mounted in an MX 41/AR cushion was utilised for testing in this study. Only channel I of the Madsen OB 70 audiometer was used for the purpose of this study.

Calibration of the equipment: The audiometer was calibrated using Bruel and Kjaer instruments. Block diagram for calibration is given in the Appendix.

Audiometer earphone output data for the right ear phone of the Madsen OB 70 audiometer at different frequencies are given in the Appendix. (Table A)

Internal calibration was done to get the approximate values. Linearity of the dial was checked at 1 KHz and was found to be inorder. Frequency response characteristic of the right ear phone was flat.

Test environment: All the tests were done in a sound treated room. The noise levels in the audiometric room were within the maximum allowable noise level in dB SPL according to proposed standard (ISO 1964) specifications (Martin Hirschorn 1967). Noise levels in the audiometric rooms in octaves are given in the Appendix (Table B).

Procedure: All the subjects were first screened at 20 dB HL to ensure normal hearing. They were devoid of any complaint of ear illness like ear pain, ear discharge or ear infection.

The experiment of auditory channel capacity for loudness consisted of 4 parts:

Part I; when n=4, i.e., when the number of events is 4.

Part II: When n=6, i.e., when the number of events is 6.

Part III: When n=8, i.e., when the number of events is 8.

Part IV: When n=10, i.e.,when the number of events is 10.

Since the whole experiment took 60 minutes for each subject it was conducted in 2 sessions, with Part I and Part II in one session (25 minutes) and Part III and Part IV in second session (35 minutes). All the 4 parts were conducted at 1000 Hz tone. Only right ear was selected for the purpose of this study.

Instructions for screening: "You are going to hear a tone in your right ear through the earphone. Whenever you hear the tone,raise your finger. The moment you hear the tone raise your finger and the moment you don't hear the tone drop your finger. Even if the sound is faint you have to respond".

Part I: Here 4 tones of 1000 Hz were presented at 30 dB HL, 40 dB HL, 50 dB HL and 60 dB HL. These tones were coded as 1, 2, 3 and 4 respectively.

Instructions: "You are going to hear 4 tones of same frequency but of different intensity. I will number the tones as 1, 2, 3 and 4. They will be in increasing order of loudness. I will present a particular tone and I will show the particular number with it. I will give this practice trial twice. You have to remember the loudness of each number. If you want the practice trial once more, you can ask for it. Then I will present the 4 tones one at a time in a random order several times. You have to indicate which number tone was heard by you at each time. Listen carefully and respond".

Each tone was presented 10 times i.e., a total of 40 tones were presented, the order of presentation was randomised using the random number table of J.G. Peatman's and R. Schafer. The duration of the tone was 2 secs. The order of presentation and the duration of the tone were maintained constant for all the subjects. The order of presentation for 4 events is given in the Appendix (Table D). The responses of the subject were recorded in the following table.

	30db	40db	50db	60db
Stimuli No. Respond No.	1	2	3	4
1				
2				
3				
4				

Part II: Here 6 tones of 1000 Hz were presented at 30 dB HL, 40 dB HL, 50 dB HL, 60 dB HL, 70 dB HL and 80 dB HL. These tones were coded as 1,2,3,4,5 and 6 respectively. Instructions were same as in Part I except that the subjects were told that there would be 1 to 6 tones with increasing order of loudness. 60 tones of 2 secs duration were presented with each tone 10 times randomised using random number tables of Peatmans and Schafer. The duration of tone and the order of presentation were maintained constant for all the subjects. The order of presentation for 6 events is given in the Appendix (Table E). The responses were recorded in a similar table as in part I, with 6 stimuli numbers and 6 response numbers.

Part III: 8 tones of frequency 1000 Hz, ranging in intensity from 30 dB HL to 100 dB HL with 10 dB difference between successive tones were presented. They were numbered from 1 to 8 in increasing order of loudness. Instructions were same as in Part I, except that they were told that there would be 8 tones instead of 4 tones. 80 tones of 2 secs were presented with each tone for 10 times and randomised using random number tables of Peatmans & Schafer. The duration of the tone and the order of presentation were maintained constant for all subjects. The order of presentation for 8 events is given in Appendix (Table F).

The responses were recorded in the same way as in Part I with 8 stimuli numbers and 8 response numbers.

Part IV: This is similar to the first 3 parts except that 10 tones of 1000 Hz were presented ranging in intensity from 30 dB HL to 120 dB HL with a difference of 10 dB HL between 2 successive tones. Instructions are same except for the number of tones. The randomised order of presentation of 100 tones of 2 secs duration for all subjects is given in the Appendix (Table G). The responses were recorded in a similar way as in the previous parts of the experiment I.

Experiment No. II

Subjects: Same number of subjects as in Experiment No. I was selected. 14 normal hearing adults, 7 males and 7 females with an age range of 18yrs to 25 yrsand with a mean age of 21.21 yrs hearing children whose age ranged from 7 years to 12 years with a mean age of 9.8 yesrs comprised the second group of subjects. All subjects had a threshold of 20 dB HL (ISO 1964) or less than 20 dB HL (ISO 1964) in their right ear.

Equipment: The same Madsen OB 70 audiometer with a TDH-39 earphone mounted in a MX 41/AR cushion was used to gather the experimental data. Channel I of the audiometer was used.

Calibration of the equipment: The Madsen OB 70 clinical audiometer was calibrated using frequency counter type Radart 203. Frequencies from 125 Hz to 10,000 Hz were calibrated. Internal calibration was done to get the approximate values, and found to be within the maximum allowable limits of 3% variation. Calibrated values at different frequencies are given in the Appendix (Table C).

Frequency response characteristic of the right ear-phone was flat. Linearity of the dial was checked and found to be in order.

Test environment was same as in Experiment No. I.

Procedure: All the subjects were screened at 20 dB HL (from 125 Hz to 10,000 Hz) to ensure normal hearing in their right ear. They had no complaint of ear illness such as ear infection, ear discharge or ear aches.

This experiment was also conducted in 4 parts:

Part I: When the number of events is 4
Part II: When the number of events is 6
Part III: When the number of events is 8
Part IV: With 10 number of events.

In this experiment also, only right ear of all the subjects was tested. All the 4 parts were tested at 60 dB HL.

This experiment was also conducted in 2 sessions for each subject, with Part I and Part II in first session and Part III and Part IV in the second session.

Instructions for screening is same as in Experiment No. I. All the subjects were screened at 20 dB HL from 125 Hz upto 10,000 Hz.

Part I: In this experiment 4 tones of 125 Hz, 250 Hz, 500 Hz and 1000 Hz were selected. All the 4 tones were presented at 60 dB HL. They were coded as 1,2,3 and 4 respectively.

Instructions: "You are going to hear 4 tones of different frequency at the same intensity level. These tones are numbered as 1,2,3 and 4. They will range from low pitch to high pitch. I will present the particular tone and I will show the particular number with it. I will give this practice trial twice. You have to remember the pitch of each number. If you want the practice trial once more, you can ask for it. Then I will present the 4 tones, one at a time, in a random order several times. You have to respond which number tone was heard by you at each time. Listen carefully and respond".

A total of 40 tones were presented with each tone 10 times. Duration of the tone was 2 seconds. The order of presentation was randomised (same order as in Part I of experiment I) and kept constant for all subjects. Responses were also recorded as in Part I of Experiment No. I.

Part II: This is similar to Part II of Experiment No. I, except that 6 tones presented were 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz at 60 dB HL.

Part III: 8 tones, viz., 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz and 6000 Hz at 60 dB HL were presented. The procedure followed was similar to that of Part III of Experiment No. I.

Part IV: 10 tones, viz., 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, 8000 Hz and 10000 Hz at 60 dB HL were presented. The procedure followed was similar to that of Part IV of experiment No. I.

CHAPTER IV

ANALYSIS OF RESULTS - (A COMPUTATIONAL EXAMPLE)

In calculating the auditory channel capacity for the most part 'contingent uncertainty' is considered as a measure of information transmission, given a joint probability distribution involving a set of stimuli and responses. By referring to the following equations such as:

1) $H(y) = T(y;z) + H_Z(y)$
2) $H(z) = T(y;z) + H_y(z)$
3) $T(Y;z) = H(y) + H(z) - H(y,z)$ etc.

it may be seen that with some rearrangement of terms the amount of information transmitted, that is, $T(y;z)$ or contingent uncertainty may be computed. Regardless of the formula used, the answer will be the same, except for rounding errors that may be introduced.

Starting with the equation,

$$H(z) = T(y;z) + H_Y(z)$$

Rearranging the terms, we obtain,

$$T(y;z) = H(z) - H_y(z)$$

when $T(y;z)$ is contingent uncertainty, and $H_Y(z)$ is called a conditional uncertainty and is the average uncertainty in the variable Z when the variable Y is held constant. This value can be obtained by solving the equation

$$H_y(z) = - \sum_y P(y) \sum_z P_y(z) \log P_y(z)$$

Example: In an experimental situation in which 6 tones of different loudness are presented to a subject one at a time and are exposed for a fixed duration. Each tone is presented 10 times in random order so that, there is a total of 60 trials. The task of the subject is to identify each tone as he hears it by assigning a number from 1 to 6, according to a prearranged code. For example, if the loudness of the tones are 30 dB, 40 dB, 50 dB, 60 dB, 70 dB and 80 dB, the tones are assigned numbers 1,2,3,4,5,and 6 respectively. During the experiment, the experimenter records the responses (numbers) given to each of the 6 tones.

In analysing the data, the judgements of the subject are summarized as in the table; the entries in the table show the total number of times each stimulus was identified by a particular response.

Joint occurrence of stimuli and responses for one subject when the number of tones are 6:

Response Number	Stimuli (Tones)						
	30 dB	40 dB	50 dB	60 dB	70 dB	80 dB	
	1	2	3	4	5	6	Total
1	10	1					11
2		9			1		10
3			10	2			12
4				8	3		11
5					6	1	7
6						9	9
Total	10	10	10	10	10	10	60

To calculate T(y;z), first we need to calculate H(z) and $H_Y(z)$.

To calculate H(z):

To calculate H(z), each cell frequency should be converted into a conditional probability by using the relationship:

$$P_S(R) = \frac{n\,(RS)}{n\,(S)}$$

where R refers to responses and S to stimuli, and $P_S(R)$ is the conditional probability of R, given S; n(RS) is the number of outcomes that belong simultaneously to Class S and to Class R; and n(S) is the number of outcomes in Class S alone. For example the conditional probability of response 2, given stimulus 2, is equal to 9/10=0.9. Conditional probabilities for all the responses are given in the following table. To find the amount of information transmission, i.e., T(y;z), we need determine H(z) which depends upon the absolute probability of each response. This is obtained from

$$P(R) = \frac{n(R)}{N}$$

where the probability of a given response (R) is given by P(R); n(R) is the frequency of that response; and N refers to the total number of responses. For example, the probability of response 1 is equal to ll/60=0.1%.

Conditional probabilities for the data in the table and absolute probabilities P(R)

Response Number	1	2	3	4	5	6	P(R)	-P(R) log P(R)
1	1	0.1					0.18	0.445
2		0.9	-		0.1		0.16	0.423
3			1	0.2			0.20	0.464
4				0.8	0.3		0.18	0.445
5					0.6	0.1	0.16	0.423
6						0.9	0.15	0.411

H(z) = 2.611

The value of $H(z)$ is 2.611

To calculate $H_Y(z)$

$H_Y(z)$ is calculated using the formula:

$H_Y(z) = - \underline{1}\ E\ E\ P_y(z) \log P_y(z)$

S Y Z

where S is the number of alternative stimuli in this ensemble 6.

Substituting appropriate values in the above equation, we obtain:

$H_Y(z) = 1/6\ (1.00 \log 1.00 + 0.1 \log 0.1 + 0.9 \log 0.9 +$

$+ 1.00 \log 1.00 + 0.2 \log 0.2 + 0.8 \log 0.8 +$

$+ 0.1 \log 0.1 \log + 0.3 \log 0.3 + 0.6 \log 0.6 +$

$+ 0.1 \log 0.1 + 0.9 \log 0.9)$

$= 1/6\ (0 + 0.332 + 0.137 + 0 + 0.464 + 0.258$

$+ 0.332 + 0.521 + 0.442 + 0.332 + 0.137)$

$= 1/6\ (2.955) = 0.4925$

Substituting in the formula $T(y;z) = H(z) - H_Y(z)$

$T(y;z) = 2.611 - 0.4925$

$= 2.1185$ bits

In this particular example, the amount of information transmitted by the subject through his auditory system is 2.1185 bits.

Following the same procedure given above, the auditory channel capacity for each subject at all events 4, 6, 8 and 10 are calculated.

Statistical analysis: To compare statistically, the difference between various groups, the significance of difference between means for small sample was used.

CHAPTER V

RESULTS

Auditory channel capacity calculated at 4, 6, 8 and 10 number of events for both loudness and pitch are given in the results.

Auditory channel capacity for loudness

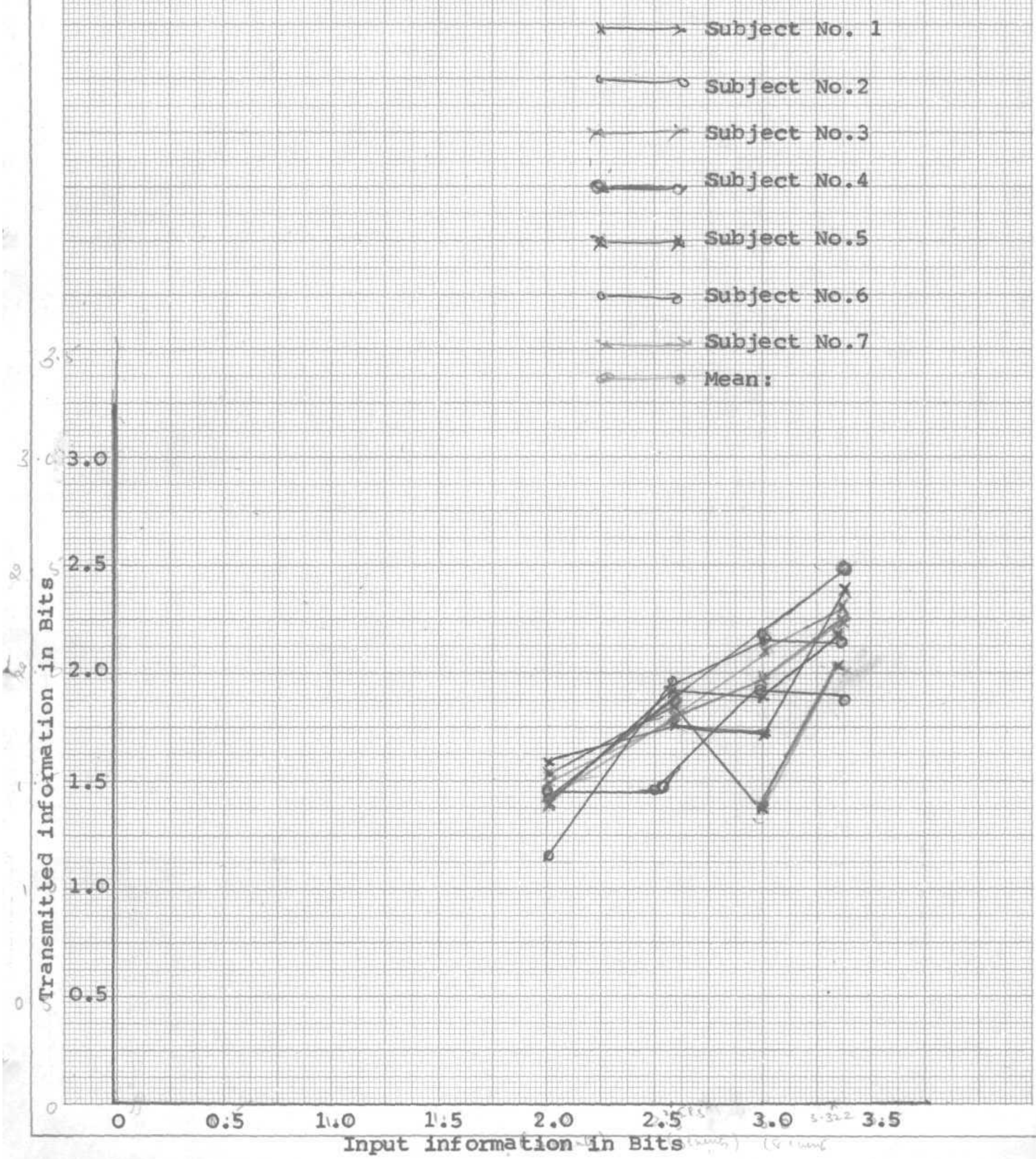
Experiment No. I: The amount of information transmitted at different input informations for both adults and children are given.

Table I shows the amount of information transmitted in bits at 4, 6, 8 and 10 number ef events, i.e., when the input information values are 2 bits, 2.585 bits, 3 bits and 3.322 bits for 7 normal hearing female adults.

Table I: Transmitted information for female adults

Subjects	Age in yrs	Input information in bits 4(2 bits)	6 (2.585 bits	number of events 8 (3 bits)	10 (2.322 bits)
1	19	1.379	1.946	1.873	2.198
2	20	1.474	1.436	1.90	1.824
3	21	1.529	1.838	1.352	2.090
4	21	1.394	1.934	2.229	2.53
5	19	1.540	1.788	1.713	2.436
6	19	1.151	1.96	2.21	2.173
7	21	1.465	1.789	2.186	2.346

Graph 1: Transmitted information against input information values of female adults for loudness



The results of Table I are plotted in Graph I.

Table II gives the amount of information transmitted in bits for loudness of 7 normal hearing male adults when the input information values are 2 bits, 2.585 bits, 3 bits and 3.322 bits or when the number of events are 4, 6, 8 and 10.

Table II: Transmitted information for male adults

Subjects	Age in yrs.	Number of events : Input information in bits			
		4 (2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
1	21	1.127	1.643	2.216	2.055
2	20	1.459	2.108	2.007	1.60
3	21	1.053	1.810	2.215	1.956
4	25	1.330	1.891	2.061	2.124
5	20	1.684	2.004	1.997	2.171
6	24	1.58	2.13	2.232	2.359
7	20	1.462	1.792	2.213	2.415

Graph 2 is plotted to show the amount of information transmitted in bits at different input information for each of the subjects in Table II.

Table III shows the results obtained in 5 normal hearing children. It gives the amount of transmitted information in bits at different input information values.

Graph 2: Transmitted information against input information values of male adults for loudness

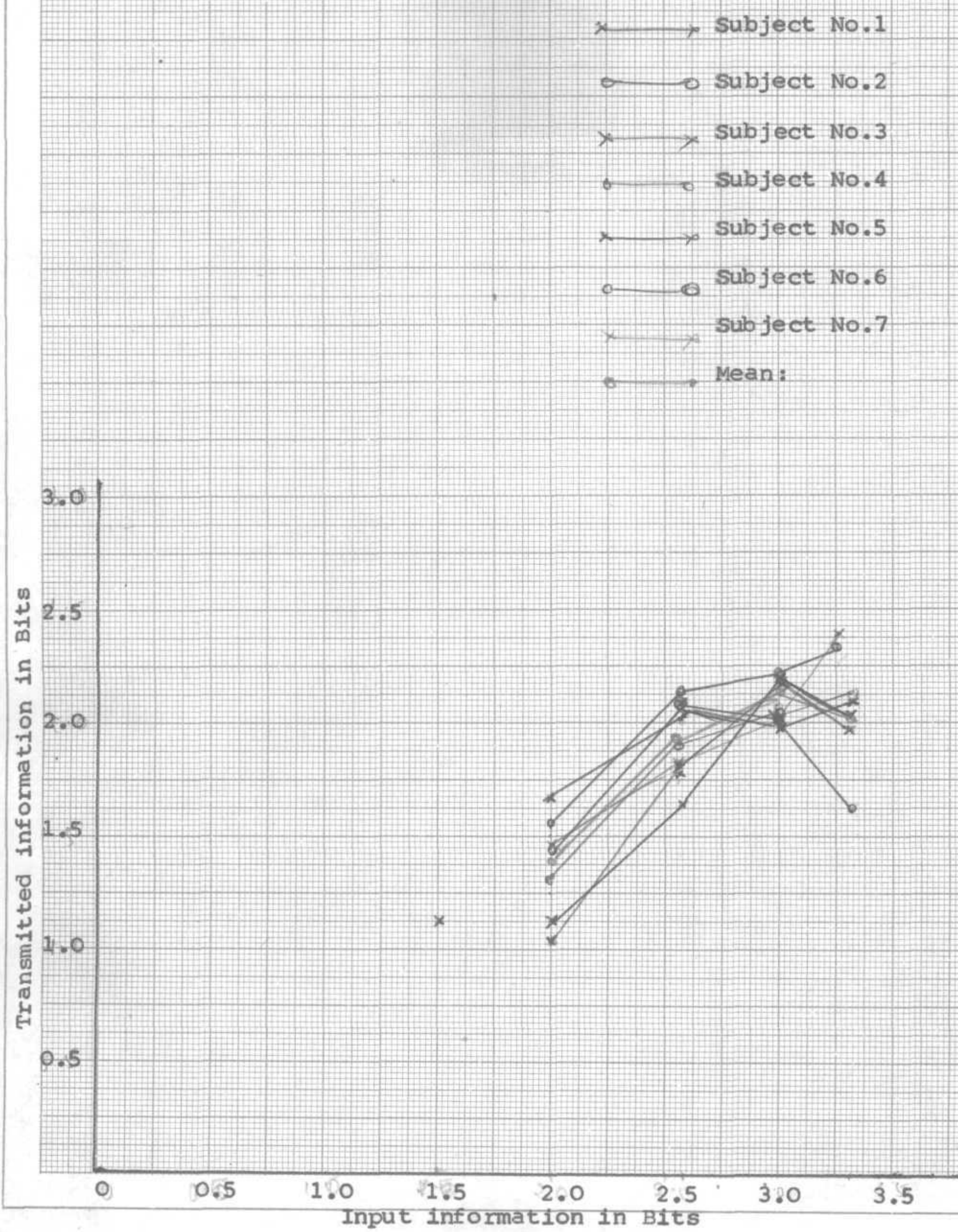


Table III - Transmitted information in children

Subjects	Age in yrs	Number of events: Input information in bits			
		4(2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
1	8	1.53	1.966	2.132	2.095
2	7	1.059	1.951	2.023	2.12
3	9	1.337	1.762	2.112	2.212
4	9	1.132	1.711	2.172	2.094
5	9	1.121	1.678	2.012	2.09

Graph 3 shows the results of these 5 children.

In Table IV, the mean values of transmitted information for both male and female adults are given.

Table IV: Mean values of transmitted information for adults

Subjects	Mean age in yrs	Number of events/Input information			
		4(2 bits)	6(2.585 bits	8(3 bits)	10(3.322 bits)
Males	21.5	1.3804	1.9163	2.135	2.097
Females	20	1.4188	1.813	1.9233	2.28

Table V gives the mean values of transmitted information for adults and children.

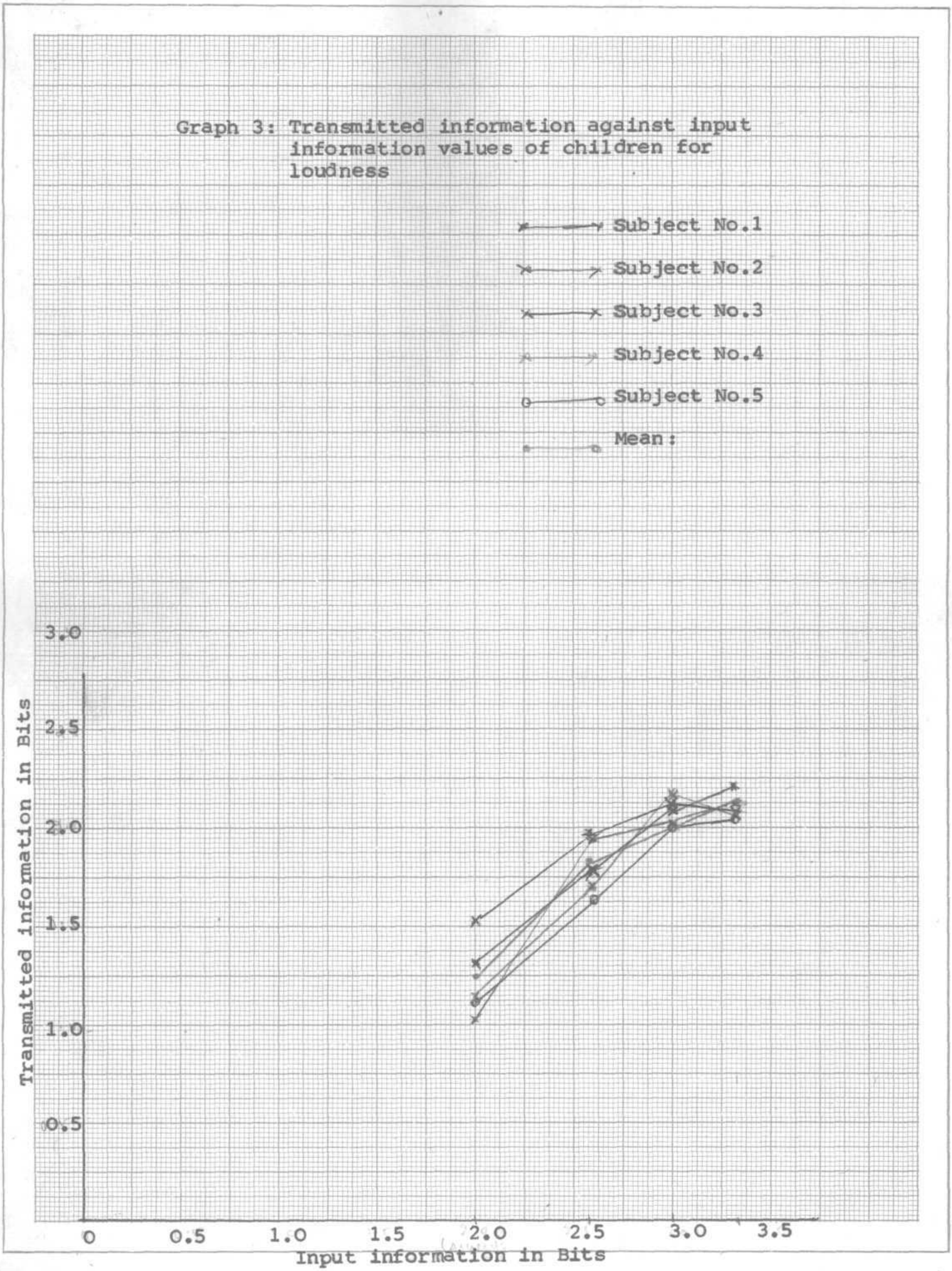

Graph 3: Transmitted information against input information values of children for loudness
Subject No.1
Subject No.2
Subject No.3
Subject No.4
Subject No.5
Mean :
Transmitted information in Bits
3.0
2.5
2.0
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Input information in Bits

Table V: Mean values of transmitted information for adults and children

Subjects	Mean age in yrs	Input information or number of events			
		4(2 bits)	6(2.585 bits	8(3 bits)	10(3.322 bits
Adults	20.75	1.399	1.865	2.028	2.163
Children	8.4	1.2358	1.813	2.09	2.123

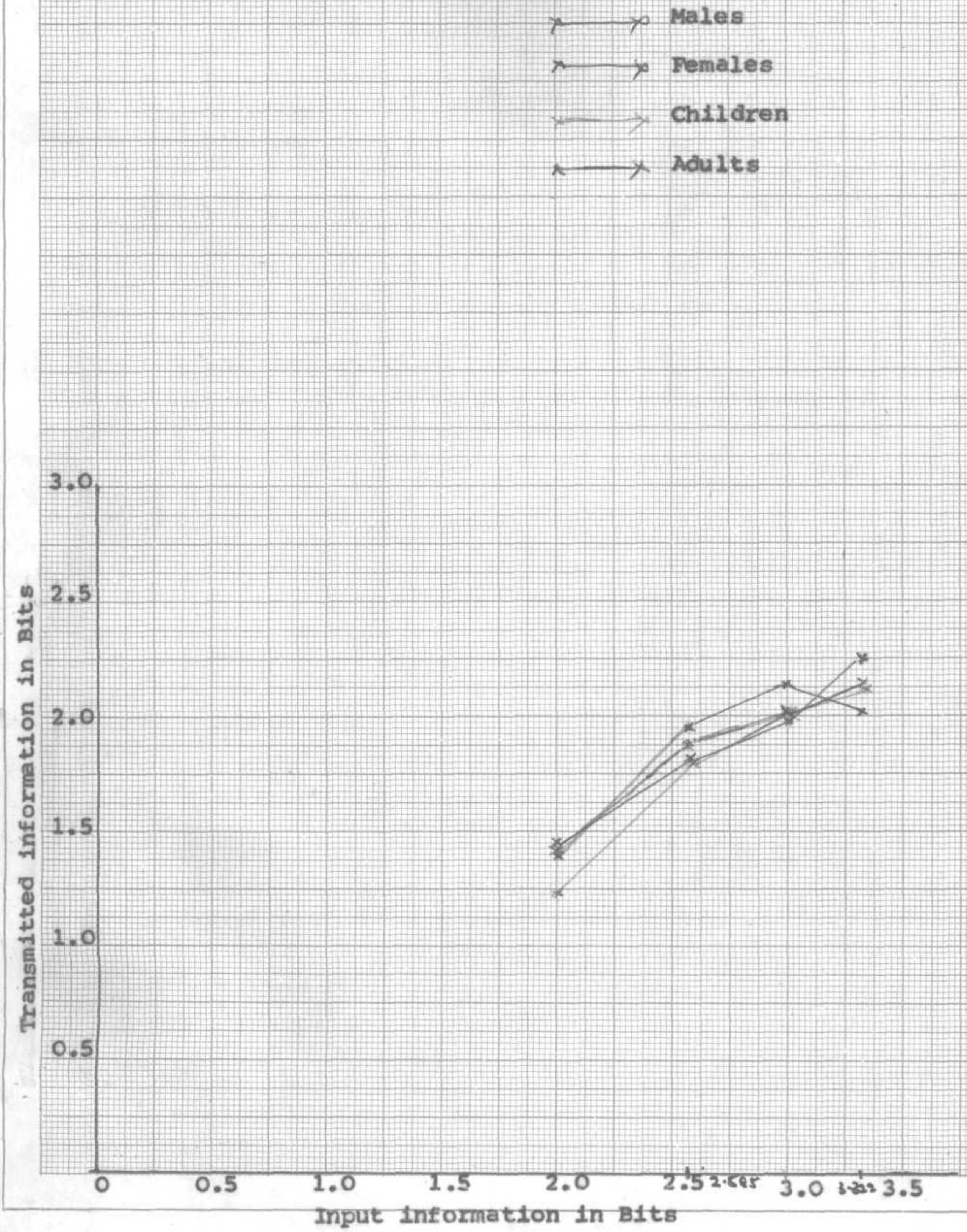
Graph 4 shows the mean values of transmitted information at different input information values for adults (males and females) and for children. Transmitted information is plotted on Y-axis and the input information on X-axis.

Statistical analysis: To find whether any difference exists in auditory channel capacity between males and females and between adults and children; the significance of difference means for small samples was used.

When males and females were compared for the auditory channel capacity of loudness a critical ratio of 1.653 was obtained. This is below 2.18 and 3.06 at 0.05 and 0.01 levels seen from the t-table. so there is no significant difference between males and females for auditory channel capacity for loudness.

When the auditory channel capacity for loudness was

Graph 4: Mean values of transmitted information for loudness against input information values for adults and children



compared between adults and children a critical ratio of 0.423096 was obtained. This is very much below the values 2.23 and 3.17 at 0.05 and 0.01 levels obtained from t-table. So there is no significant difference between adults and children for auditory channel capacity for loudness.

Experiment No. II: Auditory channel capacity for pitch

The amount of information transmitted in bits for pitch at different input information values for both adults and children are given this experiment.

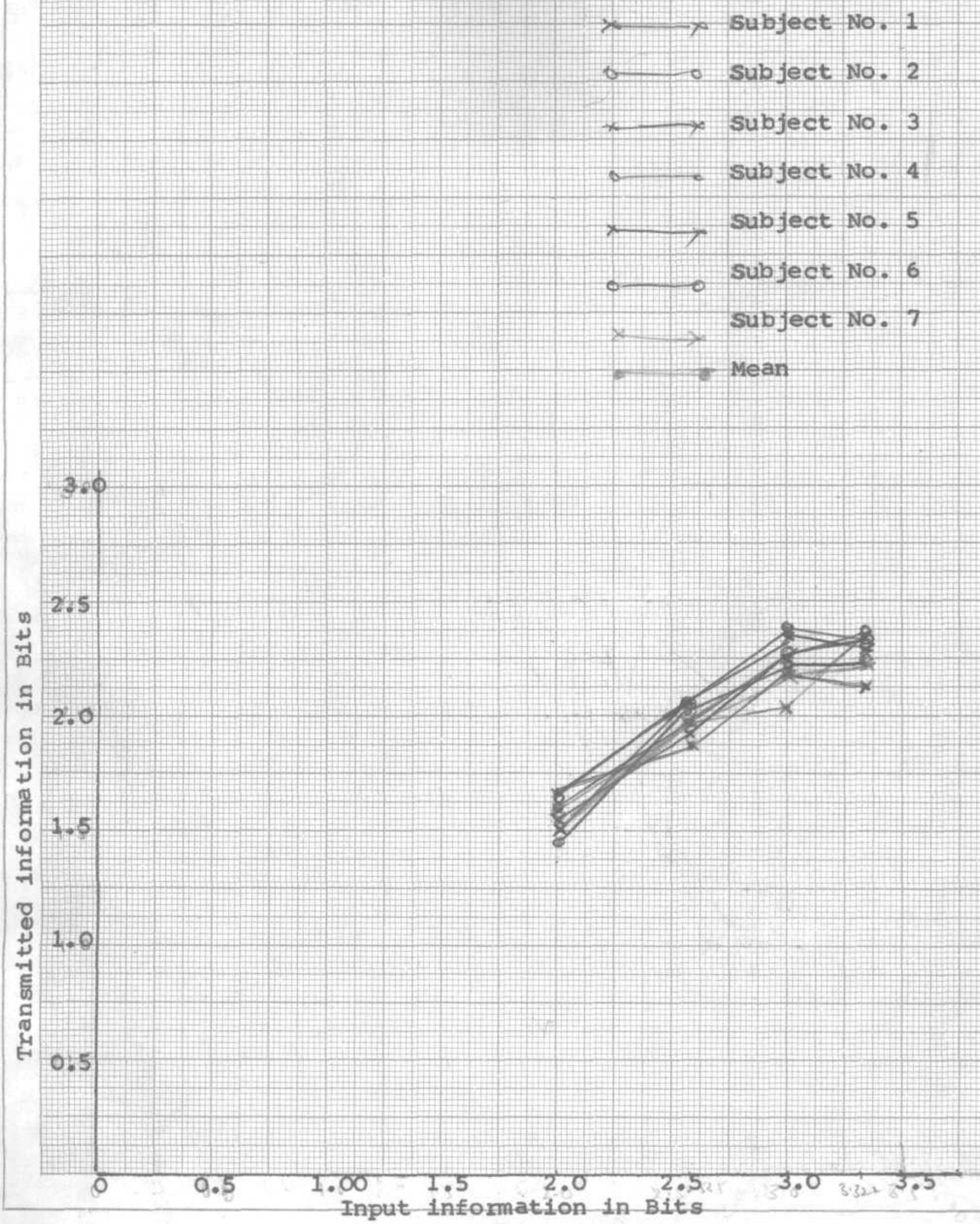
Table VI gives the transmitted information in bits for pitch for 7 normal hearing female adults when the input information values are 2 bits, 2.585 bits, 3 bits and 3.322 bits or when the number of events are 4, 6, 8 and 10.

Table VI: Transmitted information for pitch in adult females

Sub-jects	Age in yrs	Number of events or input information in bits			
		4(2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
1	21	1.553	1.931	2.253	2.335
2	21	1.473	2.020	2.250	2.249
3	21	1.699	1.899	2.241	2.301
4	21	1.597	1.998	2.253	2.368
5	18	1.542	2.097	2.324	2.289
6	20	1.643	2.065	2.327	2.315
7	19	1.582	1.985	2.002	2.332

Graph 5 shows the results of 7 adult females with the

Graph 5: Transmitted information against input information values of female adults for pitch



transmitted information on Y-axis and input information values on X-axis.

The amount of information transmitted in bits at different input information values for 7 male adults are given in Table VII.

Table VII: Transmitted information in bits for male adults

Subjects	Age in yrs	Number of events or input information in bits			
		4(2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
1	24	1.571	1.898	2.337	2.352
2	24	1.524	2.113	2.522	2.678
3	21	1.439	1.983	2.270	2.355
4	25	1.648	2.084	2.411	2.321
5	21	1.530	2.125	2.448	2.531
6	18	1.691	1.926	2.413	2.428
7	23	1.607	1.889	2.313	2.458

The graphical representation of these data given in Table VII are shown in Graph 6.

Table VIII gives the amount of information transmitted in bits for pitch in 5 normal hearing children at different input information values.

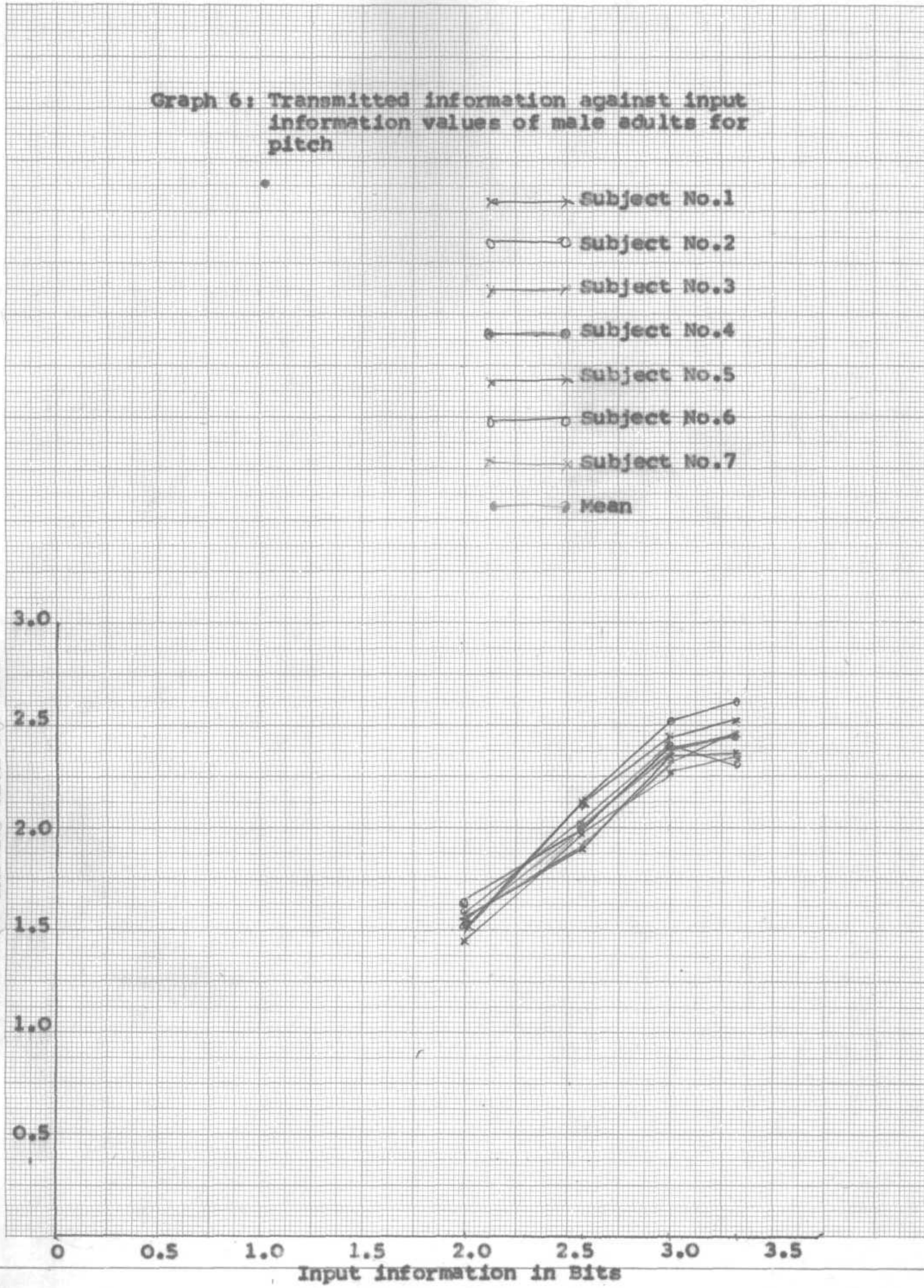

Graph 6: Transmitted information against input information values of male adults for pitch
Subject No.1
Subject No.2
Subject No.3
Subject No.4
Subject No.5
Subject No.6
Subject No.7
Mean
Transmitted information in Bits
3.0
2.5
2.0
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Input information in Bits

Table VIII: Transmitted information for children

Sub-jects	Age in yrs	Number of events/Input informatior			
		4(2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
1	7	1.250	1.773	2.002	2.112
2	9	1.518	1.824	2.312	2.301
3	12	1.584	1.889	2.120	2.021
4	9	1.289	1.569	2.101	2.121
5	12	1.345	1.678	1.89	1.98

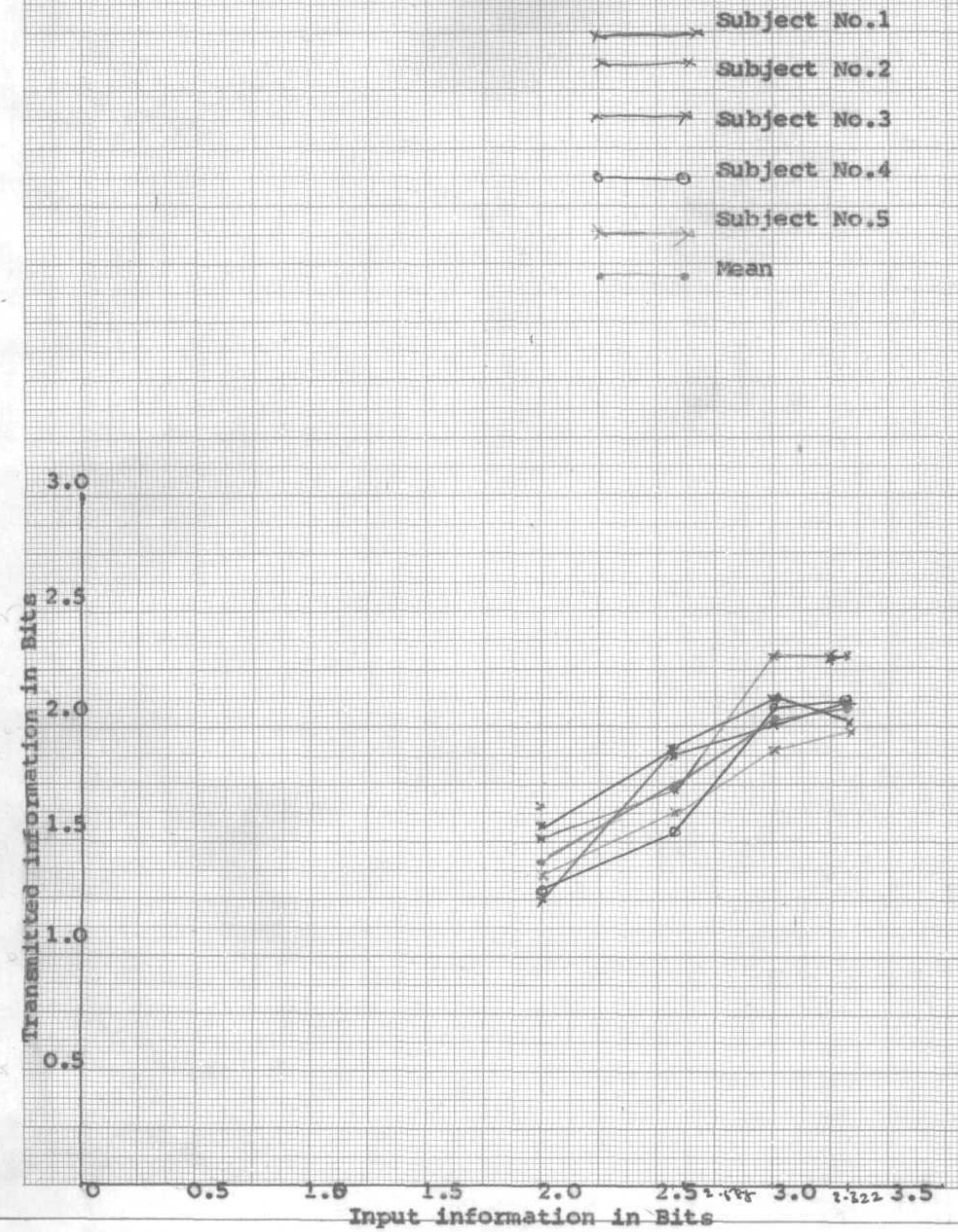
Graph 7 shows the amount of information transmitted in bits at different input information values for each of the subjects of Table VIII.

Table IX gives the mean values of transmitted information for male and female adults.

Table IX: Mean values of transmitted information for adults

Sub-jects	Mean age in yrs.	Number of events/input information			
		4(2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
Males	22.28	1.573	2.003	2.3877	2.446
Fe-males	20.14	1.581	1.999	2.236	2.313

Graph 7: Transmitted information against input information values of children for pitch



In Table X, the mean values of transmitted information for adults and children are given.

Table X: Mean values of transmitted information for adults and children

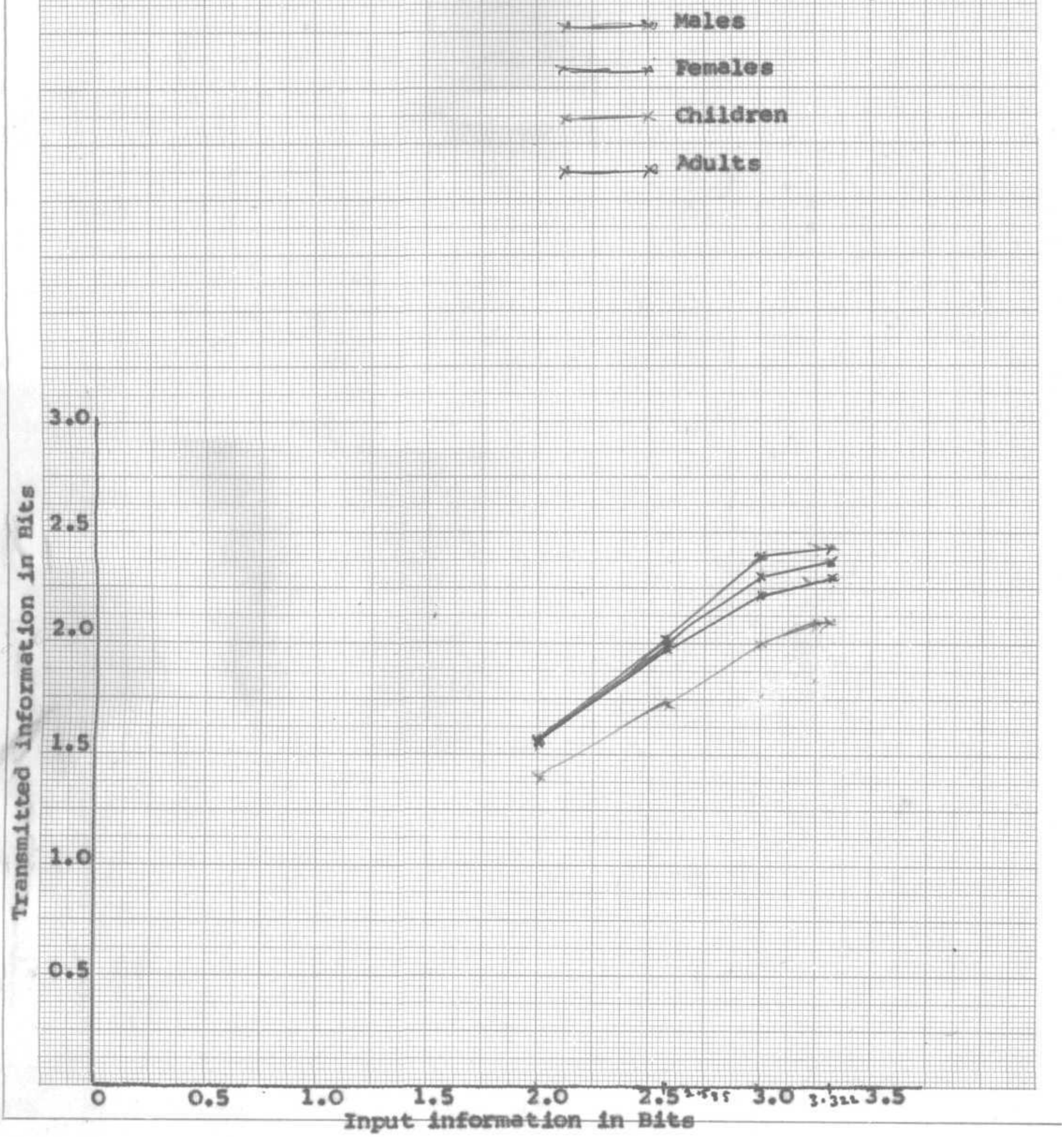
Subjects	Mean age in yrs.	Number of events or input information in bits			
		4(2 bits)	6(2.585 bits)	8(3 bits)	10(3.322 bits)
Adults	21.21	1.577	2.001	2.312	2.379
Children	9.8	1.393	1.746	2.085	2.107

Graph 8 shows mean values of transmitted information for adults (males and females) and for children. Transmitted information is plotted on Y-axis and the input information is plotted on X-axis.

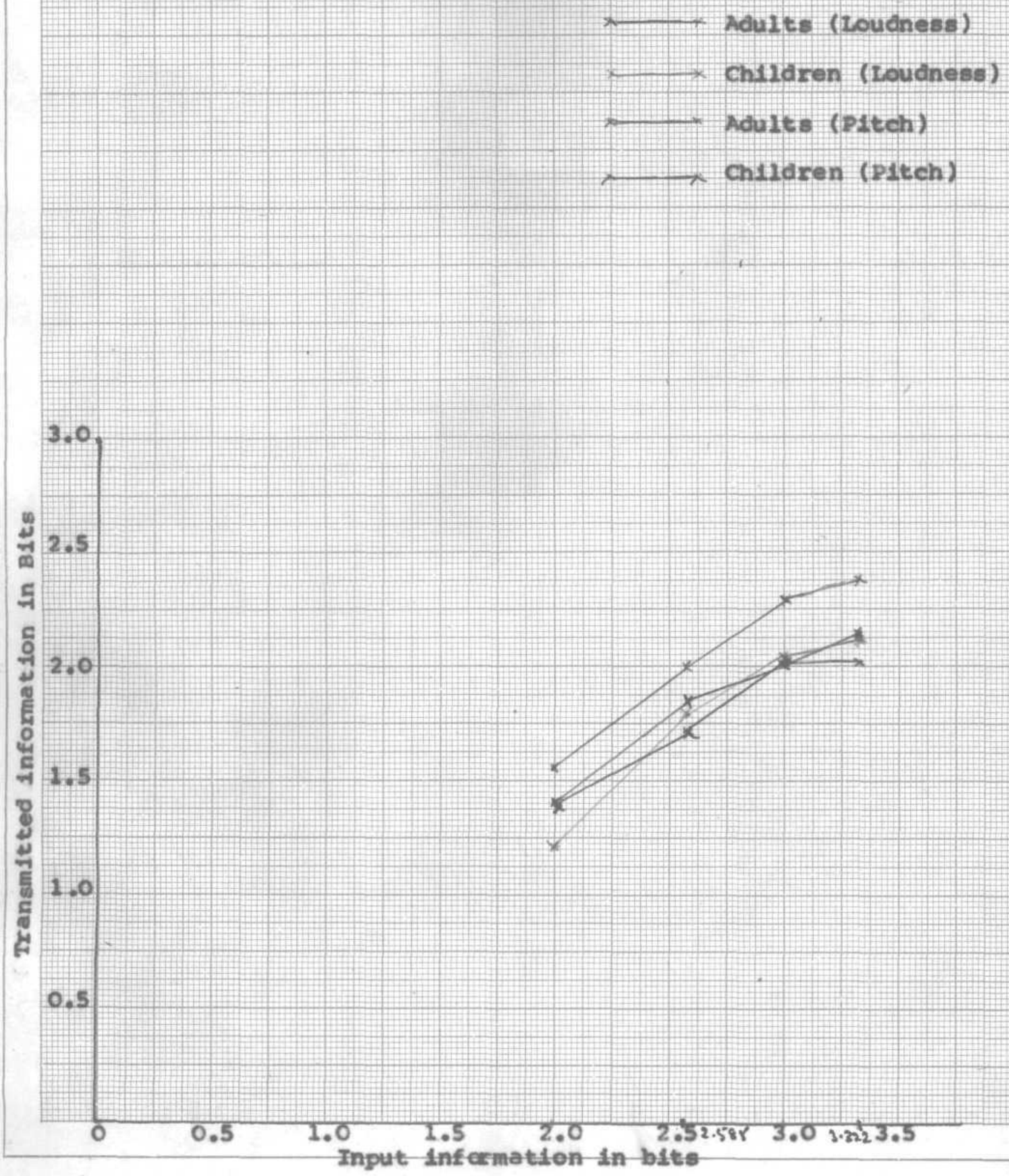
Graph 9 is plotted to compare the auditory channel capacity for pitch and loudness. On this are plotted the amount of information transmitted for adults and children for pitch and for adults and children for loudness at various input informations.

Statistical analysis: The critical ratio obtained is 2.18 when males and females were compared for auditory channel capacity of pitch. This when compared with the values of

Graph 8: Mean values of transmitted information for pitch against input information values for adults and children



Graph 9: Mean values of transmitted information for loudness and pitch against input information values for adults and children



2.18 and 3.06 at 0.05 and 0.01 levels respectively shows the difference to be significant at 0.05 levels and not significant between means at 0.01 level.

When comparing the auditory channel capacity for pitch between adults and children, a critical ratio of 3.24 was obtained which is higher than 2.23 and 3.17 at 0.05 and 0.01 levels. So the difference between adults and children is significant at both levels.

When Experiment No. I was compared with Experiment No. II for adults and children between auditory channel capacity for pitch and loudness, the following results are obtained.

When children were compared between auditory channel capacity for pitch and loudness a critical ratio of 0.026 was obtained which is very much lower than 2.31 and 3.36 at 0.05 and 0.01 levels. So the difference in children between auditory channel capacity for pitch and loudness is not significant.

A critical ratio as high as 4.06 is obtained when adults were compared for auditory channel capacity between pitch and loudness. This is very much higher than 2.06 and 2.78 at 0.05 and 0.01 levels. So the difference in auditory channel capacity between pitch and loudness for adults is significant.

CHAPTER VI

DISCUSSION

The results of the 2 experiments are discussed separately first and then the comparison between the results of the 2 experiments are discussed.

Experiment Mo. I: Auditory channel capacity for loudness.

The mean values of transmitted information at different input information values for female adults are 1.4188 bits when the input information was 2 bits, 1.813 bits, 1.9233 bits and 2.28 bits at 2.585 bits, 3 bits and 3.322 bits respectively. Graph 1, in which these different values are plotted shows that the amount of information transmitted increases with increase in input information. At first there is an abrupt increase in the amount of information transmitted but later the increase is not much. So the auditory channel capacity for female adults can be set around 1.92 bits when the input information was 3 bits, with an ability to distinguish between 4 events. The subjects who deviate from the mean results are subject No. 3 and Subject No. 5. These 2 exceptions can be attributed to lack of motivation or concentration on the part of these subjects during testing.

For male adults the mean values of transmitted information are 1.3804, 1.9163, 2.135 and 2.097 bits when the input information values are 2 bits, 2.585 bits, 3 bits and 3.322 bits respectively. The results of male adults are shown in Graph 2. It can be seen from the graph that the amount of information transmitted increases with increase in input information until the input information is 3 bits. When the input information is increased beyond 3 bits, there is no further increase in the amount of information transmitted. So, the auditory channel capacity for loudness for male adults is around 2.1 bits with an ability on the part of these subjects to distinguish 4 to 5 events. The exception to this is subject No. 2 in whom the transmitted information decreased when the input information was 3.322 bits; this could be attributed to lack of concentration on the part of the subject during this testing. In subject No. 7, there was increase in the amount of information transmitted when the input information was 3.322 bits. This needs further investigations.

The results of the present study showed that there is no significant difference between males and females with regard to auditory channel capacity for loudness.

When the data are combined and adults are taken as a whole the mean values of transmitted information obtained are 1.399, 1.865, 2.028 and 2.163 bits at input information values of 2 bits, 2.585 bits, 3 bits and 3.322 bits respectively. On Graph 4 are plotted these mean values. The auditory channel capacity for loudness in adults may be considered as around 2 bits, with an ability on the part of these adults to discriminate 4 to 5 events.

When the data on children are taken into consideration, the mean values of transmitted information are 1.2358, 1.813, 2.09 and 2.123 bits, at different input information values of 2 bits, 2.585 bits, 3 bits and 3.322 bits. The graphical representation of the data of these children are given in graph 3. It shows that the transmitted information reaches a limit of 2 to 2.1 bits when the input information is 3 bits. So the auditory channel capacity for loudness in children is somewhere around 2.1 bits. There are no deviations observed from the mean graph.

The adults and children are compared for their channel capacity for loudness graphically (Graph 4). It can be seen from the graph that not much difference exists between adults and children in their auditory channel capacity for loudness. Statistically no significant difference was obtained between adults and children at both 0.05 and 0.01 levels. So the hypothesis that there is no significant difference between children and adults with regard to auditory channel capacity for loudness (2nd hypothesis) is accepted.

Experiment No. II: Auditory channel capacity for pitch

The mean values of transmitted informations at different input information values for female adults are 1.5814 bits, 1.9992 bits, 2.2357 bits and 2.3127 bits respectively. Graph 5, in which these different values are plotted, shows that the amount of information transmitted increases with increase in input information. This increase is seen only upto 3 bits of input information. Then, when the input information is increased, the amount of transmitted information no longer increases but reaches a plateau. This is the auditory channel capacity for pitch for female adults which is around 2.23 bits. This means an ability on the part of these subjects to discriminate 5 events. Only subject No. 7 deviates from the typical graph, where the transmitted information reaches a plateau at 6 events (2.585 bits), the reasons for such deviations needs to be further investigated.

For male adults the mean values of transmitted information are 1.5728, 2.0025, 2.387 and 2.446 bits when the input information values are 2 bits, 2.585 bits, 3 bits and 3.322 bits respectively. On graph 6, are plotted the results of male adults. It can be seen from the graph that the amount of information transmitted increases with increase in input information till the input information is 3 bits. Then, a plateau is observed which shows that the transmitted information no longer increases but remains constant. This constant value is the auditory channel capacity for pitch in male adults which is around 2.38 bits. This implies an ability on the part of these subjects to distinguish somewhere around 5 events. No exceptions from the typical graph are seen here.

When males and females are compared for their channel capacity for pitch, a significant difference between mean values is observed at 0.05 level but no significant difference between mean values is seen at 0.01 level. So the 6th hypothesis that there is no significant difference between males and females with regard to auditory channel capacity for pitch is partly accepted.

When the adults as a whole are considered, the mean values of transmitted information are 1.577 bits, 2.0008 bits, 2.3117 bits and 2.3793 bits, at different input information values of 2 bits, 2.585 bits, 3 bits and 3.322 bits respectively. On graph 8 these results are plotted. The auditory channel capacity for pitch in adults is around 2.3 bits with an ability to distinguish about 5 events.

For children, the mean values of transmitted information are 1.3932 bits, 1.746 bits, 2.085 bits and 2.107 bits at different input information values of 2, 2.585, 3 and 3.322 bits. From Graph 7, it can be seen that a plateau is obtained when the input information in bits, with a channel capacity in these children around 2.085 bits. No subject is much deviant from the mean values.

Graph 8 gives a clear picture comparing the channel capacities for adults and children. A clear gap can be seen between the 2 curves. When compared statistically a significant difference is seen at both 0.05 and 0.01 levels. So the null hypothesis that there is no significant difference between children and adults with regard to auditory channel capacity for pitch is rejected.

To enable a comparison of these 2 experiments, Graph 9 is plotted.

When the auditory channel capacity for pitch was compared with the auditory channel capacity for loudness in adults, it was observed that there was significant difference between the two mean values. Thus, the null hypothesis that there is no significant difference between auditory channel capacity for pitch and auditory channel capacity for loudness in adults is rejected at both levels (hypothesis 3).

There was no significant difference between auditory channel capacity for pitch and auditory channel capacity for loudness, in children. So, the 4th null hypothesis is accepted at both levels of significance.

Pollack (1952) found that on the average, human subjects could transmit a maximum of only 2.3 bits, given a set of 8 alternative tones ranging in frequency from 100 CPS as high as 8000 CPS.

The results of the present study agrees with Pollack (1952) study.

The results obtained in the present study differ from the results reported by Garner & Hake (1953) and Pollack (1953) regarding auditory channel capacity for pitch and loudness. The results of the present study shows lower values. Lower values may be due to the fact that subjects in the present study were not given feedback, i.e., they were not informed about their response.

As it is known that the knowledge of results improves the performance of the subjects and as the present study did not provide knowledge of results to the subjects, it is reasonable to conclude that the lower values obtained in the present study might be due to the absence of feedback (knowledge of results).

CHAPTER VII

SUMMARY

The present study consisted of finding auditory channel capacity for pitch and loudness in 38 subjects (19 subjects for pitch and 19 subjects for loudness). Among the 19 subjects, 5 subjects were children - the remaining 14 subjects were adults.

All the subjects were first screened at 20 dB HL (ISO 1964) to ensure normal hearing.

The auditory channel capacity for loudness was found at 1 KHz. Testing was done at 4, 6, 8 and 10 events, intensity varied from 365 dB SPL to 126.5 dB SPL with 10 dB difference between successive numbers - the input information values were 2 bits, 2.585 bits, 3 bits and 3.322 bits respectively. Amount of information transmitted at each of the input information value was calculated.

The auditory channel capacity for pitch was done at 60 dB HL (ISO standard), with frequency ranging from 125 Hz to 10 KHz. The test was administered at input information values of 2, 2.585, 3 and 3.322 bits. Amount of information transmitted was calculated at each input information value.

Auditory channel capacity is the amount of transmitted information which does not increase even with increase in input information or channel capacity in the maximum amount of information transmitted.

The study was designed to find out whether males and females differ significantly in auditory channel capacity for pitch and loudness and also to find out whether the auditory channel capacity for pitch and loudness would be same or different. In addition to the above, the study was conducted to throw light on the influence of age on auditory channel capacity for pitch and loudness.

The following are the conclusions of the present study:

1. The auditory channel capacity of adults for pitch was found to be around 2.3 bits, and the auditory channel capacity of children for pitch was around 2.1 bits.

There is a significant difference between adults and children with regard to auditory channel capacity for pitch at both 0.05 and 0.01 levels of significance.

2. There is significant difference between males and females with regard to auditory channel capacity for pitch

at .05 level.

3. The auditory channel capacity of both adults and children for loudness was around 2.1 bits and there was no significant difference between adults and children.

4. There was no significant difference between males and females with regard to auditory channel capacity for loudness.

5. There was significant difference between auditory channel capacity for pitch and auditory channel capacity for loudness in adults at both 0.05 and 0.01 levels.

6. There was no significant difference between auditory channel capacity for pitch and auditory channel capacity for loudness in children at both 0.05 and 0.01 levels.

Limitations

1. More number of subjects could not be tested because of limited time available for dissertation study.

2. Test-retest reliability could not be done

Recommendations for further research

1. The same experiments may be repeated with more number of subjects to corroborate the findings of the present

study.

2. Auditory channel capacity for pitch and loudness may be determined in old people above 50 years of age.

3. Auditory channel capacity may be determined in mild to moderate sensorineural hearing loss cases.

4. Multidimensional stimuli may be used to determine auditory channel capacity (e.g., speech stimuli, by varying both pitch and loudness).

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BIBLIOGRAPHY

Abron, M., and Rubensten, H. Information theory and immediate recall. J., Exp., Psychol., 1952, 44, 260-266

Allusi, E.A., Conditions affecting the amount of information in absolute judgements. Psychol., Rev., 1957, 64, 97-103

Boring, E.G., Auditory theory with special reference to intensity, volume and localization. Amer., J., Psychol., 1926, 37, 157-188

Corso (John, F.), Experimental psychology of sensory behaviour. New York, Holt, Rinehart and Winston, 1967

Corso, J.F., The neural quantum in discrimination of pitch and loudness. Amer., J., Psychol., 1951, 64, 350-368

_____________ The neural quantum theory of sensory discrimination. Psychol., Bull., 1956, 53, 371-393

Dember (William, N.) and Warm (Jole, S.) Psychology of perception., Ed., 2, New York, Holt, Rinehart and Winston, 1979

Doughty, J.M., The effect of psychophysical method and context on pitch and loudness functions. J., Exp., Psychol., 1949, 39, 729-745

Doughty, J.M., & Garner, W.R., Pitch characteristics of short tones. II pitch as a function of tonal duration. J., Exp., Psychol., 1948, 38, 478-494

Engen, J., and C. Pfaffmann. Absolute judgements of odor intensity. J., Exp., Psychol., 1959, 58, 23-26

______________________________Absolute judgements of odor quality. J., Exp., Psychol., 1960, 59, 214-219

Ericksen, C.W., and H.W. Hake. Multidimensional stimulus differences and accuracy of discrimination. J., Exp., Psychol., 1955, 50, 153-160

Garner, W.R., and H.W. Hake. The amount of information in absolute judgements. Psychol., Rev., 1951, 58, 446-459

Garner, W.R. An informational analysis of absolute judgements of loudness. J., Exp., Psychol., 1953, 46, 373-380

______________An equal discriminability scale for loudness judgements. J., Exp., Psychol., 1952, 43, 232-238

Garrett (E. Henry). General Psychology. New Delhi, Eurosia, 1964

Licklider, J.C.R. Basic correlates of the auditory stimulus. In S.S. Stevens (Ed.), Handbook of experimental psychology,New York, Wiley, 1951

Long, L. A study of the effect of preceding stimuli upon the judgement of auditory intensities. Arch., Psychol., 1953, 45, 15-19

Miller, G.A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychol., Rev., 1956, 63, 81-97

Miller, G.A. What is information measurement? Amer., Psychol.,1953, 8, 3-11

Raisbeck (Gordon). Information theory: An introduction for scientists and engineers. Cambridge, M.I.T., 1965

Merle, W. Tate. Statistics in education and psychology. The Macmillan Company, New York

Stevens, S.S., Morgan, C.T., and Volkmann, J. Theory of neural quantum in the discrimination of loudness and pitch. Amer., J., Psychol., 1941, 54, 315-335

Welford (A.T.) Fundamentals of skill. London, Methuen, 1971

APPENDICES

APPENDIX A

(a) Description of the instruments used for calibration

(b) Block diagram showing the experimental set up for calibration of the audiometer

APPENDIX B

Table A: Audiometric earphone output data for right earphone of Madsen OB 70

Table B: Noise levels in dB SPL in the audiometric room

Table C: Calibrated frequency values for right earphone of Madsen OB 70

Table D: Order of presentation for 4 events

Table E: Order of presentation for 6 events

Table F: Order of presentation for 8 events

Table G: Order of presentation for 10 events

Table H: $\log_2 n$ for numbers from 1 to 100

Table I: Table of p $\log_2(I/P)$

APPENDIX 'A'

(a) Description of the instruments used for calibration

(i) Artificial ear type 4152: Artificial ear type 4152 is designed to enable acoustical measurements on earphones to be carried out under well-defined acoustical conditions (ISO). It consists basically of a replaceable acoustical coupler and a 2 sockets for the mounting of a condenser mic cartridge type 4132 and a cathode follower amplifier type 2163, connected to the A.F. Analyzer type 2107.

A spring arrangement is provided to fulfil certain standard requirements regarding the force applied to the object under measurement. To enable acoustical tests, to be made on headphones used in audiometers, a 6 cm cube acoustical coupler is provided in this type.

The artificial ear satisfies the ISO specifications.

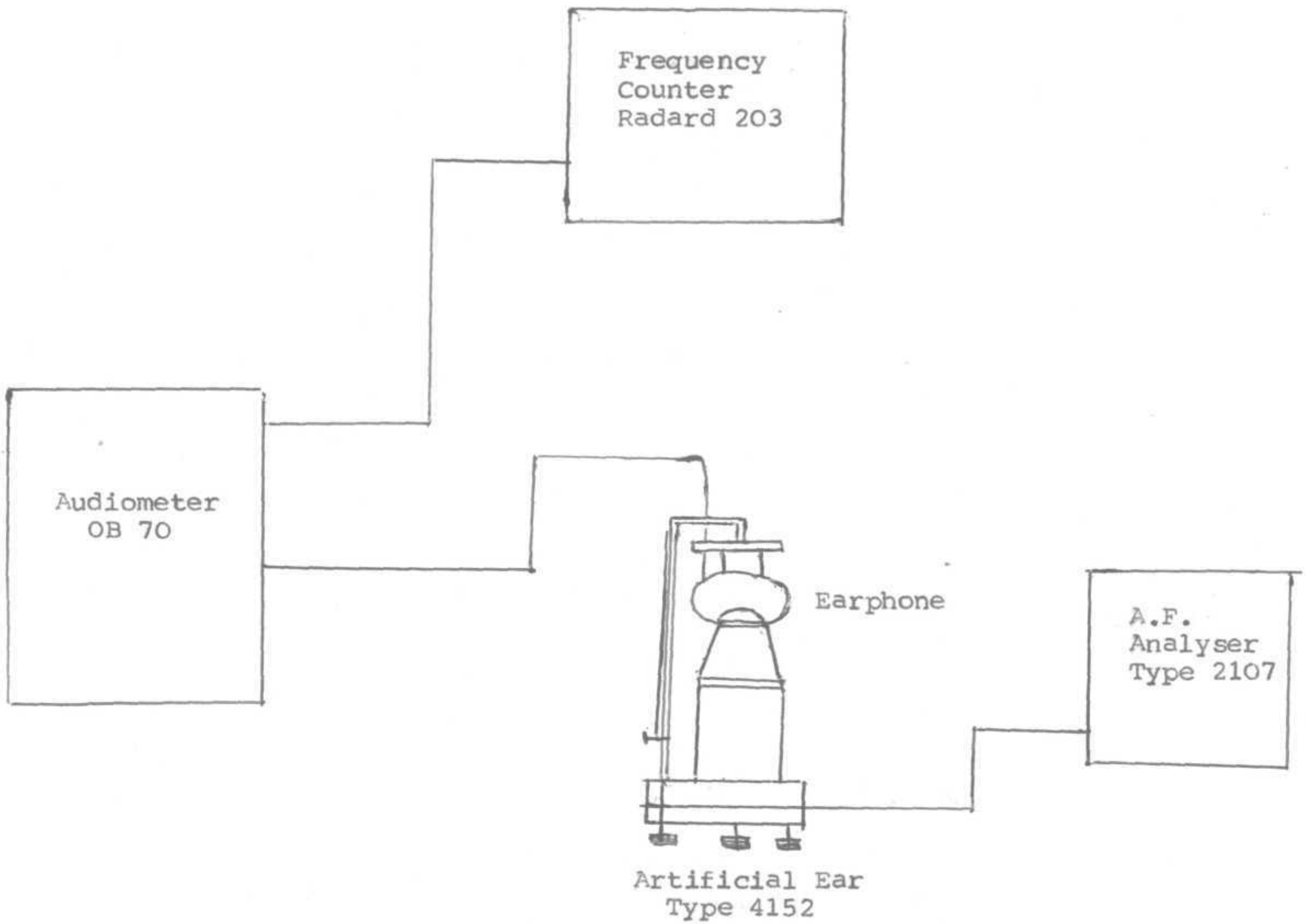
(ii) Audio-frequency Analyzer B & K Type 2107: Type 2107 is an alternating current operated A.F. Analyzer of the constant percentage band width type.

It has been designed especially as a narrow band sound and vibration analyzer, but may be used for any kind of frequency analysis and distortion measurement within the specified frequency range.

(iii) Impulse Precision Sound Level Meter Type 2209: This portable sound level meter complies with all existing standards for impulse and precision sound level meters. It is equipped with: an individually calibrated condenser microphone; an internal reference voltage for calibration; "Lin", "A", "B", "C", and "D" weighting networks; impulse and peak detectors with "Hold" circuits, as well as "Fast" "Slow" and "Impulse" meter responses; overload warning lamps; and an AC and DC output for connection to recorders, etc. The 2209 can handle crest factors as high as 40, and has a selectable low-frequency cut-off. External filters can be directly attached, and a wide range of acce-ssories is available.

The 2209 can also be connected to an accelerometer for the measurement of vibration. An interchangeable meter scale and a range of attenuator scales facilitate the direct reading of vibration (as well as sound or voltage) over a wide range.

This is used to measure noise level in the audiometric room.



BLOCK DIAGRAM FOR THE CALIBRATION OF AUDIOMETER

APPENDIX "B"

TABLE A: Audiometric earphone output data for right earphone of Madsen OB 70

Frequency in Hz	Input level in dB HL	Reference in dB SPL	Expected output in dB SPL	Obtained output in dB SPL
250	60	24.5	84.50	83.00
500	60	11.0	71.00	71.00
1000	60	6.5	66.50	66.00
2000	60	8.5	68.50	69.00
4000	60	9.0	69.00	67.00
6000	60	8.0	68.00	74.50
8000	60	9.5	69.50	73.00

Instruments used

Audiometer : Madsen OB 70
Earphone Type : TDH 39
Cushion Type : MX 41/AR
Artificial ear
Type : 4152
Condenser Microphone Type: 4144
A.F. Analyzer Type : 2107

TABLE 'B'

Noise levels in dB SPL in the audiometric room

Octave bands in Hz	Maximum allowable noise level in dB SPL	Noise level in the room in dB SPL
75-150	31	14
150-300	25	18
300-600	26	10
600-1200	30	12
1200-2400	38	10
2400-4800	51	11
4800-9600	51	11

Using the A,B, and C weighting networks, the noise levels in the room were 32C, 22B and 18A dB SPL. The noise level in the room was measured using SPL meter type 2209 with half an inch condenser mic Type 4165.

TABLE 'C': Calibrated frequency values for right earphone of Madsen OB 70

Frequencies in Hz	Intensity in dB HL	Calibrated frequency value
125	60	126
250	60	251
500	60	498
1000	60	1003
2000	60	2001
3000	60	3003
4000	60	4006
6000	60	6010
8000	60	8021
10000	60	9872

TABLE 'D': order of presentation for 4 events

1	2	3	4	1
2	1	4	4	2
3	1	2	3	4
3	3	1	2	3
3	4	1	1	2
2	2	2	2	4
1	1	4	4	4
4	3	3	3	1

Loudness: 1 - 30 dB HL
2 - 40 dB HL
3 - 50 dB HL
4 - 60 dB HL

Pitch: l - 125 Hz
2 - 250 Hz
3 - 500 Hz
4 - 1000 Hz

TABLE 'E': order of presentation for 6 events

1	2	7	3	8	4
8	6	7	5	4	2
2	7	1	8	4	3
3	1	2	4	5	6
2	1	3	4	6	5
3	7	2	1	4	5
3	1	2	4	5	6
3	1	2	4	7	6
8	5	6	7	1	2
3	5	6	2	1	4

Loudness	Pitch
5 - 70 dB HL	5 - 2000 Hz
6 - 80 dB HL	6 - 3000 Hz

TABLE 'F': Order of presentation for 8 events

1	3	4	5	8	7	6	2
3	5	7	2	1	4	8	6
5	2	4	6	3	7	1	8
2	6	8	7	1	3	5	4
5	4	1	3	7	8	6	2
2	8	3	4	6	7	1	5
1	6	3	2	8	4	7	5
6	1	2	3	4	8	5	7
7	5	4	8	3	2	6	1
1	4	5	3	6	8	7	2

Loudness	Pitch
7 - 90 dB HL	7 - 4000 Hz
8 -100 dB HL	8 - 6000 Hz

TABLE 'G': Order of presentation for 10 events

1	9	2	7	3	8	4	10	5	6
8	7	6	5	4	10	9	2	1	3
9	2	7	1	8	4	3	5	6	10
3	1	2	4	9	10	5	6	8	7
2	1	3	1	9	4	6	5	7	8
3	7	2	1	4	9	5	6	8	10
10	3	1	2	4	9	7	8	6	5
2	4	7	3	1	10	9	6	5	8
8	5	6	9	7	1	2	4	10	3
10	3	5	6	2	7	1	9	4	8

Loudness:

9 - 110 dB HL
10- 120 dB HL

Pitch:

9 - 8000 Hz
10 - 10000 Hz

TABLE 'H': Log_2 n for numbers from 1 to 100

n	$\log_2 n$	n	$\log_2 n$	n	$\log_2 n$	n	$\log_2 n$
1	0.000	26	4.700	51	5.672	76	6.248
2	1.000	27	4.755	52	5.700	77	6.267
3	1.585	28	4.870	53	5.728	78	6.285
4	2.000	29	4.858	54	5.755	79	6.304
5	2.322	30	4.907	55	5.781	80	6.322
6	2.585	31	4.954	56	5.807	81	6.340
7	2.807	32	5.000	57	5.833	82	6.358
8	3.000	33	5.044	58	5.858	83	6.375
9	3.170	34	5.087	59	5.883	84	6.392
10	3.322	35	5.129	60	5.907	85	6.490
11	3.459	36	5.170	61	5.931	86	6.426
12	3.585	37	5.209	62	5.954	87	6.443
13	3.700	38	5.248	63	5.977	88	6.459
14	3.807	39	5.285	64	6.000	89	6.476
15	3.907	40	5.322	65	6.022	90	6.492
16	4.000	41	5.358	66	6.044	91	6.508
17	4.087	42	5.392	67	6.066	92	6.524
18	4.170	43	5.426	68	6.087	93	6.539
19	4.248	44	5.459	69	6.109	94	6.555
20	4.322	45	5.492	70	6.129	95	6.570
21	4.392	46	5.523	71	6.150	96	6.585
22	4.459	47	5.555	72	6.170	97	6.600
23	4.524	48	5.585	73	6.190	98	6.615
24	4.585	49	5.615	74	6.209	99	6.629
25	4.644	50	5.644	75	6.229	100	6.644

TABLE I: p $\log_2$ (I/P)

p	P $\log_2$(I/P	P	P $\log_2$(I/P))
.01	.066	.51	.495
.02	.113	.52	.491
.03	.152	.53	.485
.04	.186	.54	.480
.05	.216	.55	.474
.06	.244	.56	.468
.07	.269	.57	.462
.08	.292	.58	.456
.09	.313	.59	.449
.10	.332	.60	.442
.11	.350	.61	.435
.12	.367	.62	.427
.13	.383	.63	.420
.14	.397	.64	.412
.15	.411	.65	.404
.16	.423	.66	.396
.17	.435	.67	.387
.18	.445	.68	.378
.19	.455	.69	.369
.20	.464	.70	.360
.21	.473	.71	.351
.22	.481	.72	.341
.23	.488	.73	.331
.24	.494	.74	.321
.25	.500	.75	.311
.26	.505	.76	.301
.27	.510	.77	.290
.28	.518	.78	.280
.29	.518	.79	.269
.30	.521	.80	.258
.31	.524	.81	.246
.32	.526	.82	.235
.33	.528	.83	.223
.34	.529	.84	.211
.35	.530	.85	.199
.36	.531	.86	.187
.37	.531	.87	.175
.38	.530	.88	.162
.39	.530	.89	.150
.40	.529	.90	.137

...contd.

contd.

p	p $\log_2$ (I/p)	P	p $\log_2$ (I/p)
.41	.527	.91	.124
.42	.526	.92	.111
.43	.524	.93	.097
.44	.521	.94	.084
.45	.518	.95	.070
.46	.515	.96	.057
.47	.512	.97	.043
.48	.508	.98	.029
.49	.504	.99	.014
.50	.500	1.00	0.0