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SEVERE VISUAL HANDICAP AND KINESTHETIC FIGURAL AFTEREFFECTS*

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Relationships between visual processes and kinesthetic figural aftereffects (KFAE) can be approached in several ways. For example, Jaffe (1952) showed that KFAE can be induced by presentation during the inspection period of visual stimuli contrasting in size with a visual stimulus presented during the standardization and test periods. Again, Wertheimer (1955) found KFAE and visual figural aftereffects (VFAE) to be correlated in a heterogeneous group consisting of psychotic and nonpsychotic men and women, although Rich (1957), working with senescent men, and Axelrod and Eisdorfer (1961), working with young-adult and senescent men, have obtained low and generally nonsignificant within-group correlations between KFAE and VFAE.

In the present study, normally-sighted and severely visually-handicapped high-school students were compared in the amount of KFAE induced by a 60-sec "inspection" period at several postinspection times.

METHOD

Apparatus. The apparatus was modelled after that of Koehler and Dinnerstein (1947). It consisted of a 3-, a 2-, and a 1/2-in. wide plastic strip, each 1/2 in. thick, and a fourth strip of the same thickness, which varied in discrete steps of 1/12 in. from 3 to 7/12 in.

Procedure. All *S*s were blindfolded throughout. *S* stood between two tables on each of which two strips were rigidly mounted. On the left-hand table, the 2-in. (standard) and the 1/2-in. (narrow) strips were placed parallel to each other, with the 2-in. strip nearer *S*. On the right-hand table, the graduated (scale) and the 3-in. (wide) strips were placed, with the graduated strip nearer *S*; this strip had its narrow end "pointing" behind *S*. The strips were 30.5 in. from the floor. *S*'s left hand was guided to the standard strip, and his right to the scale with his thumb on the "inside"

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(near *S*'s body) and his fingertips on the "outside" of the strips. He was asked to find a width on the scale which matched that of the standard. He made six such matches, three in the ascending (A) direction alternating with three in the descending (D) direction. He was asked to make his judgments quickly and not to be too concerned with any one match. Immediately following the sixth match, *E* guided *S*'s left hand to the narrow inspection strip and his right hand to the wide inspection strip. *S* was instructed to run his hands back and forth along these strips, with thumbs and fingertips riding along the edges. After 60 sec of inspection, *E* replaced *S*'s left hand on the standard and his right hand on the narrow part of the scale and asked him to make a match in the A direction, as before. Then *S*'s hands were placed so that his right hand was on the wide part of the scale, and he was asked to make another match, this time in the D direction. *S* was then told to drop his hands to his sides. Similar A and D matches (in that order) were made at 1, 2, 4, and 6 min after inspection. Aftereffect for any postinspection interval was defined as postinspection match (average of A and D) minus preinspection match (average of last two A and D matches in the preinspection period).

Subjects. Thirty-three students (21 male, 12 female) from 13.3 to 20.3 years of age (mean age 17.9) enrolled at the N. C. State School for the Blind at Raleigh constituted the visually-handicapped (VH) group.* Thirty-three normally-sighted high-school students (21 male, 12 female) from 13.8 to 20.1 years of age (mean age 17.9) served as controls.

RESULTS AND DISCUSSION

The inset of Figure 1 shows the mean aftereffects of the VH and sighted groups as functions of time since inspection. Aftereffects in both groups are negatively-accelerated decreasing functions of time since inspection; the curves are almost parallel; and the curve for the VH group is consistently below that for the sighted group. The effect of time since inspection was significant at better than the .001 level ($F = 16.46$, $df = 4/256$); the F for interaction between time and group was 0.03; and the effect of group was significant at the .05 level ($F = 4.67$, $df = 1/64$).

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* *All of these* S*'s were legally "blind." Legal blindness is defined as either (a) vision no better than 20/200 Snellen in the better eye with maximum correction, or (b) a central field in the better eye of less than 20°. One* S*, with a central field of less than 10°, fell into the latter category. Amounts of residual vision of the visually-handicapped students were obtained from ophthalmologists' records; ages at onset were obtained from these records, supplemented by information provided by Mrs. Rachel Rawls, psychologist at the school for blind children. Detailed characteristics of* Ss *and a transcript of raw data may be obtained by ordering Document No. 6841 from the Library of Congress, Photoduplication Service, Auxiliary Publications Project, Washington 25, D.C. Remit $1.25 for photoprints or 35-mm microfilm.*

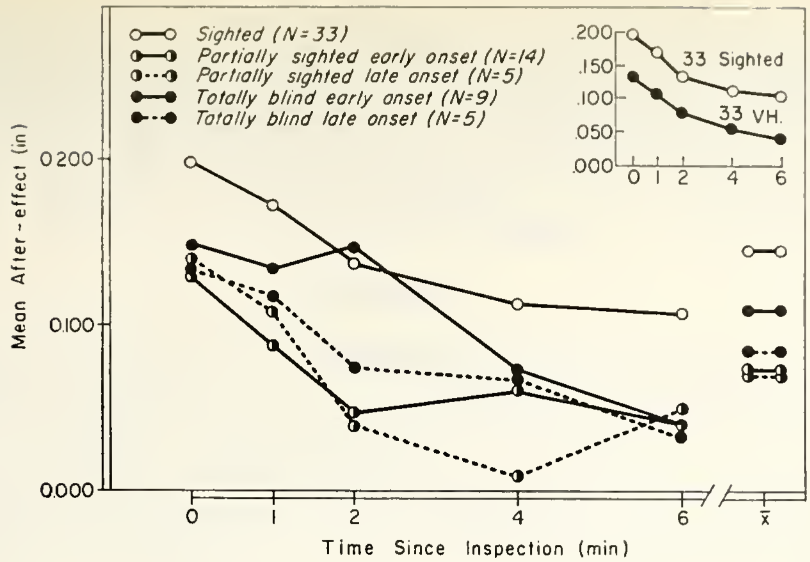

Figure 1. Mean Aftereffects (in in.) of Sighted Students and Four Subgroups of Visually-Handicapped Students As Functions of Time Since Inspection (in min.)

Ordinates at X represent mean aftereffects over all five times since inspection. Inset: Mean aftereffects (in in.) of sighted and *all* visually-handicapped *S*s as functions of time since inspection (in min.).

Only when all the VH *S*s were thus treated as a single group and compared with the sighted group was a significant group effect obtained. The VH group was analyzed into four subgroups, according to degree of residual vision and age at onset: total blindness of early onset, total late, partial early, and partial late. An *S* was considered "totally blind" if, with maximum correction and in his better eye, he had no more vision than enough to report movement of the examiner's hand before his eye; "partial sightedness" was defined as at least enough vision to count the examiner's fingers when they were held stationary before the eye. "Early onset" was defined as occurring within the first few months of life; "late onset" was onset at or after four years of age. As shown in the larger part of Figure 1, the late-onset subgroups had smaller mean aftereffects than the early-onset ones, and the partially-sighted subgroups had smaller aftereffects than the totally-blind ones. However, a three-group analysis of variance (Sighted *vs.* Total *vs.* Partial) yielded a nonsignificant group effect ($F = 2.56$, $df = 2/63$, $.10 > P > .05$); an analysis of Sighted *vs.* Early *vs.* Late yielded $F = 2.33$, $df = 2/63$, $.20 > P > .10$. Boys had higher mean aftereffects than girls, but neither the sex effect ($F = 1.94$, $df = 1/62$, $.20 > P > .10$) nor the interaction between sex and vision (VH *vs.* Sighted) ($F = 0.18$) was significant.

The most parsimonious explanation of the one significant group difference, *viz.*, the smaller aftereffects in the visually-handicapped group, seems to be one which emphasizes the greater attention necessarily paid to tactual-kinesthetic stimuli by visually-handicapped persons, and the adaptiveness for such persons of resistance to, or compensation for, induced illusions of tactile-kinesthetic extents.

SUMMARY

Thirty-three severely visually-handicapped (legally-blind) high-school students were compared with 33 normally-sighted students in amount of kinesthetic figural aftereffect (KFAE) at 0, 1, 2, 4, and 6 min after a 60-sec inspection period. KFAE for both groups were negatively-accelerated decreasing functions of time since inspection. KFAE for the visually-handicapped group were significantly smaller than for the controls. Differences due to degree of residual vision, age at onset of visual loss, and sex, were not significant.

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AN EXPERIMENTAL INVESTIGATION TO DETERMINE WHETHER THE READING OF COLOR BY TRANSFORMING HUES INTO AUDIOFREQUENCIES WILL AFFECT THE ANXIETY LEVEL OF THE VISUALLY HANDICAPPED*

John L. Edwards

ABSTRACT

It was the objective of this study to determine whether legally blind pupils could learn to read color via audiofrequencies produced by the colorscope, an electronic instrument designed and standardized especially for this study, and to determine whether learning this skill had an effect upon the anxiety level of the pupils. The investigator wanted also to formulate an effective method of instructing the visually handicapped in learning to read color via audiofrequencies.

The investigator selected the colors of the visible spectrum and acquired matte paper that represented the visible spectrum. The color paper was measured according to the Munsell color system.

The investigator obtained a sample of legally blind pupils who represented a cross section of the elementary-school population located in the Greater Phoenix, Arizona, metropolitan area. The pupils were selected on the basis of availability and divided into control and experimental groups on the basis of feasibility. Each group consisted of nine pupils representing three school districts and involving seven schools two of which had two pupils each.

The Maico Audiometer Sweep Check Test of hearing acuity was administered to the experimental group, and the resource teachers for the blind administered the Children's Form of the Manifest Anxiety Scale (CMAS) as a pretest and a posttest to both the experimental and control groups. The statements were read to the pupils and they responded "yes" or "no."

All color-sound training and evaluation was administered on a one-to-one relationship which lasted six weeks and totaled nine sessions of 45 minutes each. Training and evaluation included practice and tests on color squares, color disc, color angle bars left and right, color spots, color cone and pyramid, and the color maze. These terms were coined to describe the training charts and the method of instruction.

The experimental design of nonequivalent control group arrangement was employed in the research procedure with the nonparametric Mann-Whitney U *Test as a means to accept or reject the null hypothesis. The confidence limit was arbitrarily set at the .05 level.*

*An abstract of a dissertation presented to the College of Education, Arizona State University, in partial fulfillment of the requirements for the degree of Doctor of Education.

The null hypothesis, that there is no significant difference in the anxiety level as measured by the Children's Form of the Manifest Anxiety Scale between the visually-handicapped pupils who learn to read color via audiofrequencies and visually-handicapped pupils who are not exposed to this method of reading color, was rejected. Apparently the difference in anxiety level can be attributed to presence or absence of the reading of color via audiofrequencies.

A U test was computed for the pretest and the posttest for both the control and experimental groups. Statistical analysis revealed that significance was not obtained at the .05 level of confidence.

Means and standard deviations of errors on the color tests were computed for the experimental group; and means, standard deviations, and the rate of learning was calculated for the six color sounds for this group.

The training procedure, as used in the investigation, was an effective instructional approach to the degree that it enabled the visually handicapped to read color via audiofrequencies.

Chapter 1

THE PROBLEM AND DEFINITION OF TERMS USED

The basic elements of the problem devised for this project include (*1*) the statement of the problem, (*2*) the definition of the problem, and (*3*) the evaluation of the problem.

Statement of the problem. The problem of this investigation presented the following objectives:

1. To determine whether visually-handicapped pupils can learn to read color via audiofrequencies, and whether this will affect their anxiety level.
2. To determine what methods or approaches should be used to instruct the visually-handicapped pupils in learning to read color via audiofrequencies.

The null hypothesis. There is no significant difference in anxiety level, as measured by the *Children's Form of the Manifest Anxiety Scale*, between the visually-handicapped pupils who learn to read color via audiofrequencies and visually-handicapped pupils who are not exposed to this method of reading color.

Adapter. The color sensitized filters located in the reading head of the probe of the colorscope.

Angstroms. A unit of measurement that equals 10^{-8} centimeters, or .00000001 of a meter.

Audiocolor translation. The process of translating colors into audiofrequencies.

Color angle bars left and right. The six colors placed at angles left or right on a white matte surface.

Color cone. The six colors divided into equal and unequal parts placed horizontally on a white matte surface.

Color disc. The six colors on a circular disc, six inches in diameter, with the radius separated into three equal parts of one inch, and with the entire circle pie-sliced into six equal parts composed of the six colors used in this investigation.

Color maze. A network of pathways in the six colors, but with the major pathway in the color red, which the visually-handicapped pupil is to follow while using the probe of the colorscope.

Color pyramid. An inverted cone consisting of the six colors divided into equal and unequal parts, placed horizontally on a white matte surface.

Colorscope. An electronic instrument used for the conversion of colored areas into corresponding audiofrequencies.

Color sound time. The amount of time that a pupil hears a sound representing a color.

Color sounds. The sound that is produced by a particular color.

Color squares. The two-by-two-inch squares in one solid matte color representing the six colors as used in this investigation.

Color spots. The six colors spaced at random on a white matte surface.

Hue. The quality that distinguishes one color from another.

Intensity. The degree of purity or grayness of a color (2). In the Munsell system, intensity is called "chroma," which indicates the strength of a color (3).

Legally blind. This term will be used synonymously with visually-handicapped.

Reading head. The tip of the reading probe.

Value. The lightness or darkness of a color (1).

Visually handicapped. The visually-handicapped, according to Farrell, are, "those pupils who have visual acuity of 20/200 or less in the better eye with proper correction or limitation in the field of vision such that the widest diameter of the visual field subtends an angular distance no greater than twenty degrees" (4).

Limitations

The investigator used a sensitized color adapter in the reading head of the colorscope to teach the visually-handicapped pupils to translate colors via audiofrequencies.

Red, orange, yellow, green, blue, and violet, were the six colors translated via audiofrequencies, utilizing the colorscope as the basic instrument for discrimination. In transforming hues, wavelengths of light were measured in angstroms with the following units of length in the visible spectrum:

6,700-6,500	red
6,300-6,100	orange
6,000-5,800	yellow
5,600-5,400	green
5,000-4,800	blue
4,600-4,400	violet

This study was limited to learning to read color via audiofrequencies and its effect upon the anxiety levels of visually-handicapped pupils divided into an experimental group and a control group. All pupils who participated in this study were enrolled in the elementary school districts of the greater Phoenix, Arizona, metropolitan area.

The study was limited further by the investigator to devise or formulate an effective method of instruction for teaching the visually-handicapped pupils to read color via audiofrequencies while using the colorscope as the basic instrument for discrimination.

Assumptions

The objective of American education is the development of pupils who will participate in, and contribute to, the democratic way of life to the maximum of their abilities. The responsibility of helping children to attain this objective lies with the public schools. Many exceptional children are being integrated into the regular classrooms, and the schools must make changes in certain facets of the instructional program to provide these pupils with well-rounded educations, which are more in harmony with their individual needs. Visually-handicapped pupils may gain a greater sense of independence, and release their creative potentials to approximate closely those of sighted pupils if the changes are expedited in early education and continued during the formal years of education.

If the visually-handicapped pupil can learn to distinguish additional hues, values, and intensities, the greater effect this auding power will have in enhancing his life and in moving him from the dark world of self-pity and uncertainty to a world of improved well-being. Consequently, audiocolor translation will add a new dimension of perception which will permit the individual to increase his knowledge of our colorful environment.

A visually-handicapped pupil, as he learns to read colors, will be in a more favorable position to utilize this skill as a tool of communication. Although a congenitally blind pupil may never perceive color as we know it, he will be able to associate an experience with a color sound in much the same manner in which a visually-handicapped pupil would react to reading a color name in braille. This new skill would facilitate exploration and manipulation of his environment.

An assumption of the educative process is that as anxiety is reduced, learning will be facilitated. In order for a pupil to learn, he must be free from severe anxiety so that his energies and abilities can be directed toward meaningful education goals. As visually-handicapped pupils learn, their feelings of adequacy will increase. Consequently, these pupils may become independent rather than dependent entirely upon society and add breadth and depth to our information on learning to understand their limitations and potentialities.

Evaluation of the Study

The need and value of the study. In our democratically defined society we consider the human being as a unique individual regardless of his shortcomings or handicaps. Human beings are unique in physical features, unique in the way they learn to perceive and abstract, unique in tastes, likes, and dislikes, unique in mannerisms and idiosyncrasies, and most of all unique in sensing and learning about the world around them. Because of this uniqueness, educators, to perpetuate this ideal, must continue to consider each person as an individual and to provide him with academic tools so that he may flourish to his full capacity as an individual. This objective can be accomplished by giving timely and effective experiences in the educative process. Before effective aid can be given to many visually-handicapped individuals, means must be provided which utilize the latest in technology to integrate more fully these pupils into the educative process and to permit them to develop as much as is humanly possible, as normal children.

The forces of change today are major influences on the curriculum of the school. Special classes and provisions have been set up or devised for the academically endowed, the hard of hearing, the physically handicapped, the mentally retarded, the emotionally disturbed, the culturally deprived, potential school drop-outs, and the disabled reader in an attempt to meet more fully the needs of the individual pupils and to permit them to attain greater heights and to strive for aspirations according to their own abilities. The modern era has ushered in media that educators must utilize to stay abreast of our rapidly changing society. Technology has played a tremendous role in the new education, and a greater role is predicted for the future; but, since the invention of braille, only a few effective methods for the instruction of the visually-handicapped have been instituted in the educative process.

The challenge of change directly faces the educators. They must meet its impact by bringing the instruction of the blind up to a level comparable with that of other exceptional children. This can be accomplished, at least in part, by providing the visually-handicapped child with means to read and translate audibly, colors that will add depth and breadth to his personality, enhance his academic status, and permit him to approximate successfully the life of a child with normal sight.

The blind child, by living in a world of darkness, has many barriers to overcome. If a blind child could receive and read sensations of color, his darkened view would instill in him a real-live world--a world in which he could participate color-wise in proper dress, and in art. He could create art, appreciate art by reading colors via audiofrequencies as a method of color translation, and converse intelligently. His self-concept would be enhanced by knowing that he is properly dressed. He would feel more acceptance from peers, which would increase his security. Audio-color translation can add a new dimension to the educative process of the visually handicapped.

It is apparent, as of the present time, that totally blind people cannot have any real idea of color, but researchers assume that they acquire associative ideas for color because they live in a world of sight which makes frequent use of color observations and color verbalizations in day-to-day communication. Berthold Lowenfeld states (5):

> *These ideas are based on verbal, sensory and emotional associations. The color red, for example, may be determined in a child by the pleasant sensory and emotional associations of this color with a dress in which she was admired by her seeing friends and which also gave her the pleasant experience of the soft and smooth quality of its material. Another child, or the same child at a different time, may associate "red" with "blood," and the unpleasant experiences of pain and stickiness may determine his or her substitutive idea for the color red. Thus it can be seen that these ideas vary from individual to individual and in the same individual from time to time. These substitutive color ideas exist not only as components of the blind person's world of imagery, but also as a part of his vocabulary needed to communicate with the seeing world in common terms.*

Medical science has made great strides in assisting many handicapped persons; but until a major breakthrough is made for the totally blind and severely visually-handicapped persons, scientists, psychologists, and educators will have to train them to use their remaining senses to aid in approximating sight. Karl S. Lashley states (6):

> *For reception of signals, hearing is evidently superior to other senses in number of discernible steps of the intensity and pitch, in reaction time, in absence of negative adaption, in capacity to sort out combined stimuli by*

harmonic analysis, and in the ready memorization of melodic line. It is also superior in dominating attention and probably in producing the least fatigue with continued attention.

Because of their limited sensory range, blind individuals have very little incentive to explore; and the blind child is likely to make little effort to acquaint himself with his immediate environment. One responsibility of educators is to stimulate the blind child's intellectual curiosity and to provide ways and means of satisfying his natural inquisitiveness (7).

According to many individuals, aid and devices have little or no effect upon the blind, but Lashley states (8):

> *The adaptation of instrumental aids to uses that are not strictly utilitarian has been little considered, yet perhaps they will find their greatest value in widening the range of contacts and contributing new aspects to their knowledge of common things. The guidance devices, in spite of their limitations, have provided interesting new experiences to their users. The stylus of the direct translation reader may, with slight minor changes, be used to explore maps and pictures, and for such diverse purposes as reading the thermometer and discovering the markings on a butterfly's wings. A probe excited by ambient light or by different colors should give access to a still wider range of experiences. . . . Their use, as toys, for exploration of whatever catches interest may be the most effective method both of discovering new ways in which they may be applied and for training in the perceptual patterns which must be acquired before they can be put to any effective use. Although the instrumental aids are far from perfected and have fallen short of the efficiency and utility desired, they may even so contribute a great deal to the enrichment of experience and extension of the world of the blind.*

Charles G. Ritter corroborates Lashley by stating (9):

> *Often, however, a device will give the needed reassurance an individual requires to tackle a new area. . . most gadgets will have served their major role if they simply encourage. The central point to be borne in mind at all times is the individual. Devices are of enormous value in encouraging him to develop along the lines he would have taken with sight. Anything is a device for the blind if it helps along these lines. This point of view, simple as it is, appears to have had a most stimulating effect on blind people everywhere.*

The objectives of the study. It was an objective of this study to determine whether visually-handicapped pupils could learn to read colors via audiofrequencies produced by the colorscope, an electronic instrument especially designed for this study, and to determine whether this skill has any impact upon the pupils' level of anxiety.

Also, the investigator wanted to devise an effective method of assisting the visually handicapped in learning to read color via audiofrequencies.

The investigator, in conducting this research, attempted to set the stage for additional research along longitudinal lines, probing this vital area for the visually handicapped in the educative process.

Summary

This section defined the problem of this investigation as an experimental investigation. The main points considered in the problem were:

1. To determine whether visually-handicapped pupils could learn to read color via audiofrequencies.
2. To determine what methods or approaches should be used to instruct the visually-handicapped pupils in learning to read color via audiofrequencies.

One null hypothesis was stated: there is no significant difference in the anxiety level as measured by the *Children's Form of the Manifest Anxiety Scale* between visually-handicapped pupils who learn to read color via audiofrequencies and visually-handicapped pupils who are not exposed to this method of reading color.

The investigator worked within the framework of the limitations of the color-sensitized adapter, the visible spectrum, with eighteen visually-handicapped educable pupils divided into experimental and control groups.

The definitions include 19 terms used throughout the study. Attention was focused on the assumptions inherent in the study, the need and value of the study, and the objectives of the study.

Chapter 2

REVIEW OF THE LITERATURE

A blind spot has existed in American education regarding the total education of the visually handicapped and integrating them more fully into the main stream of our educational system. Ways and means of providing approximations of sight have been tried by numerous researchers. For many years color perception by tactile sense was believed possible, but later was disregarded because the subjects were able to distinguish the surfaces of the objects and associate the correct colors by memory.

Some researchers have reported that a reduction in anxiety facilitates learning. Also, it is believed that nonanxious pupils perform better than anxious pupils in learning certain tasks and in school achievement. Some studies show a relationship between anxiety and self-concept. Since it has been purported that anxiety affects pupils positively and negatively, the investigator reviewed the literature pertaining to anxiety as well as the literature on skin sensitivity to color.

Literature on the Sensitivity of Skin to Color

Research conducted by I. M. Goldberg in the Soviet Union has suggested some revealing data on tactile sensitivity and the cutaneous optical sense in man (1).

The cases of Rosa Kuleshova (2), Patricia Stanley (3), and the Barnard College students (4), have added new information regarding the sensitivity of skin to wavelengths of light; and D. M. Stevens summarized several studies pertaining to skin sensitivity to light for some species of aquatic and amphibious organisms (5).

> 1. *Dermal light reactions are responses to illuminations of the body surface of animals due to stimulation of diffusely distributed photoreceptors.*
> 2. *They are found in all major phyla, being most common in aquatic animals with nonwaterproof skins. They are rare in terrestrial arthopods, cephalopods, and amniotes.*
> 3. *An animal may possess a dermal light sense in addition to eyes or other localized photoreceptors.*
> 4. *Responses to dermal stimulation may be local or general, graded, or all-or-none. They include direct responses to light of some chromatophores, slow orientations by bending movements, and many fast withdrawal reflexes.*
> 7. *Reaction times of dermal responses are relatively long. . . .*
> 8. *Dermal and optic responses exhibit similar physiological characteristics. Dermal light reactions adapt to repeated and continuous stimuli, show considerable powers of dark adaptation and obey Weber's Law over a limited range of intensity.*
> 9. *The absolute sensitivity of dermal photoreceptor systems is several thousand times less than that of well-developed eyes.*
> 10. *Action spectra are generally similar to those of eyes, with maximum sensitivity usually between 470 and 530 μ. The photochemical systems responsible for all light reactions are believed therefore to be of a similar nature.*
> 11. *No single receptor system at the cellular level of organization can account for all types of dermal light reactions.*
> 14. *There is no convincing evidence of fundamental differences in the processes responsible for dermal and optic light responses, nor for the existence of more than one type of dermal photoreceptors in any species.*
> 15. *A common structural basis for all light reactions, if it exists, must be sought in the fine structure of cells.*

Relative to skin being sensitive to light, Dr. Richard P. Youtz states (6):

> *. . . it is not so unlikely that the skin could be sensitive to light in a way which would allow response within 30 seconds to three minutes, not only on the basis of heat,*

but possible on the basis of wavelength, in the range that we ordinarily call "light." Since the human organism is a product of evolution, it seems not impossible that sensitivity may have survived in some human beings as a kind of nonadaptive, evolutionary by-product.

In extending this frame of reference, Youtz concluded that it seemed reasonable that skin sensitivity to light and color is a strong possibility which necessitates further investigation (7). He further concluded: ". . . several portions of the electromagnetic spectrum, that is, x-rays, visible light, and the near infrared, do penetrate the skin to a depth which would make possible the detection of such radiation" (8). Also, the eyes are sensitive to the portion called light (9). The longer wavelengths in the infrared region cause the skin to respond with a "warm" sensation (10). Garcia and others in their experiments reported: ". . . rats have been trained to respond to signals consisting of very low doses of x-ray directed to the head" (11). Ganong and others corroborate the experiments of Garcia and others on the penetration of light in mammalian skin (12). Youtz states: ". . . apparently light can penetrate the skin and tissues to a considerable depth in measurable quantities" (13). Hardy and Muschenheim measured the depth that infrared radiation would penetrate mammalian skin. They concluded that: ". . . the skin, in appreciable thickness, is quite opaque to radiation of wavelengths greater than three microns, whether the tissue is living or dead" (14).

Tactile sensitivity: the case of Margaret McAvoy. The Soviet experiments in the area of tactile sensitivity touched off, once again, the old myth or phenomenon of people with the ability to discriminate colors by merely making contact with the surface. Sitwell speaks of Margaret McAvoy who perceived the world through four senses. She was born in Liverpool on June 28, 1800, and became totally blind at the age of sixteen. She could distinguish color by touching with her fingers. This exceptional ability varied with circumstances because, when her hands were cold, ". . . she declared that the faculty was altogether lost, and that it was exhausted" (15). Margaret was examined by a committee of doctors and scientists and it was concluded that her ability was physical sensibility alone (16).

Prismatic colors gave her the greatest pleasure. Violet rays were unpleasant to her and red rays appeared warmer. The lightest colors gave her a "pleasurable feeling," and black gave her a "shuddering feel" (17). She could also detect colors and letters through glass (18).

Tactile sensitivity: the case of Rosa Kuleshova. In 1962, Dr. I. M. Goldberg, physician and neuropathologist, reported the observations of one of his patients, Rosa Kuleshova, who could read ordinary print with the fingers of the right hand and could determine various colors on paper and objects with her hand. The subject could accomplish these extraordinary tasks with her eyes bound (19). Vasillii B., a young man who was blinded seven years prior to his examination, also could accomplish this task (20).

Rosa, age 21, was classified as a second-class invalid due to rheumatic arachnoiditis and who had had attacks of epilepsy; she had been observed since 1959. She had the usual childhood diseases of measles and whooping cough and later, during her years in school, she became a victim of jaundice and rheumatism. She had attacks, loss of consciousness, and convulsions. Rosa felt that her sickness was due to her affection for her grandmother who raised her and who appeared alive in her dreams. At first she had only a few attacks each year, but later these attacks increased in number until she was hospitalized. Objective examination showed (21):

> *. . . normal body structure, a pulse beat of 68 per minute, satisfactory and rhythmic heartbeat, diastolic blood pressure 110/90, heart sounds somewhat muffled. No other internal pathology found. Neurology: slight smoothness of the left nasolabial fold. Tongue deflects to the right upon extension. Knee reflexes elevated, no pathologies therein. Stable in the Romberg position. Skull x-ray shows cloudlike thickening of bones of occipital-parietal region along the seam of the fornix cerebri. No pathology of fundus oculi. Visual acuity, 1, 0; blood analysis, 80 percent HB; leukocytes, 5,000; erythrocyte sedimentation rate, 5 mm/hour. Urine analysis normal.*

In 1960/61, Rosa worked for almost a year for the Society of the Blind. She imitated the blind and learned to read to the blind in braille. She read regular printed books with her eyes blindfolded or closed. "According to her, blind people taught her to identify the meaning of drawings and color" (22). A number of experiments were conducted to discover how Rosa could accomplish this. In order to eliminate extraneous factors, her eyes were screened from her hands and also blindfolded (23). Several experiments were conducted in dark rooms (24). Objects of various colors were placed in a sack and she identified particular colors by touch (25).

It is interesting to note that in the cases of Margaret McAvoy (26), Rosa Kuleshova (27), and Patricia Stanley (28), when the fingers were cold, sensitivity was impaired. Also, in the case of Rosa Kuleshova, the reading of texts became impossible (29). Her perceptional ability (30):

> *. . . improved under quiet conditions and under working conditions, and when she feels attention and confidence of others, and when the sensing surface of the fingers has been heated. Perception sharply diminished when she is excited, when there is noise, and when the environment is hostile. Perception diminished sharply in a dark room.*

Rosa was not able to explain how she sensed text, drawings, and color. "She says that she perceives red as little crosses, blue as strips, and green as smoother than yellow" (31). Ironically, the "slight heating or cooling of the object had no effect upon color perception when the experiment was conducted in the light (32).

Several experiments were conducted in a room with light and in the dark room or while the subject placed her hands in a sack. In a lighted room Rosa could read a book, newspaper, or magazine text. She could read a text with large type face, headlines in newspapers, magazine article titles, and the texts of children's books as fluently as with the eyes (33). Her performance with newspaper type face was poorer. Type face smaller than newspaper type was beyond her faculties (34). While attempting the same task in a dark room, she could identify only large letters and occasionally single words (35). With her hands in a sack she was not able to read the headlines of a newspaper (36). In determining drawings on various types of paper in a lighted room, Rosa could identify pictures well and quickly; however, she was not as proficient with pictures on match boxes, but was good with pictures on cigarette boxes and newspapers that contained larger pictures. Ironically, she could distinguish color, single letters, and numbers on postage stamps, and in the Lenin series of postage stamps, she was able to identify, by tactile sense, stamps bearing the portrait of the Ulianov family and Lenin reading *Pravda*, but she could not identify small drawings as well. The identification of pictures was better if they were on thick smooth paper (37). When this task was tried in a dark room, she was able to identify, but with less facility than in a lighted room. To select pictures in a dark room, the pictures had to be larger than those she could identify in a lighted room (38). The subject could identify images on photographs, including those with glossy surfaces while in a lighted room; but she was slower and less accurate while trying to accomplish the same task in a dark room or with her hands in a sack (39).

In a room with light Rosa could identify, skillfully, white, red, black, yellow, dark blue, and green. However, her results with the brown and orange were poorer. She also had some difficulty in identifying light brown and gray. The primary colors were readily identified in colored pictures. She had less success with shadings and halftones (40). In a dark room and/or with her hands in a black sack, her ability to identify colors was considerably poorer than in a lighted room. In some cases she often confused one color with another (41).

In the process of identifying the color of pencils and aniline dyes she achieved the same success as she did when determining colors on paper in a lighted room and a dark room or determining colors with her hands in a black sack (42).

In identifying colors of fabric, threads of muslin, and tapestries, Rosa was more successful in determining color on cambric in a lighted room and less proficient with silk, wool, and staple fibers. While in a dark room, she was far less successful in trying to accomplish this task (43). However, on certain days she could define the color of ties, handkerchiefs, and shirts. While being limited to the black sack, she could select the primary colors of fabrics and threads. However, she confused the off-shades, such as lilac, crimson, and violet. These shades she called lilac (44).

In the more complicated tasks of determining colors of a picture painted with oils, colored glass, and plastics, she failed to identify the colors. She was not able to determine colors through celluloid film and glass, or to determine colors of moist material and threads (45).

In a summary, Goldberg states (46):

> *We may draw the following conclusions: local hyperatrophied superficial (tactile and, possibly, temperature) sensitivity making it possible to read ordinary printed text with the fingers and to identify the colors of objects is, in the case we observed, the result of long and purposeful training. The subject perceived, with her fingers, differences in the structure of the color-bearing substance applied to the surfaces of objects, and this enabled her to identify letters, pictures, and color tones. Significant, probably, in the acquisition of these properties were both the hysterial aspects of Rosa K's character and behavior, and the higher nervous activity disturbance as a consequence of organic brain disease which apparently increased tactile sensitivity to an extraordinary degree.*

The cutaneous optical sense in man. Eighty subjects were involved in the experiments conducted by A. S. Novomeiskii at Nizhnii Tagil Teachers College, on the cutaneous optical sense in man (47). Each subject was masked to prevent visual perception. Squares of paper of different colors, but identical in texture, were given to each subject. As the investigator called each color, the subject attempted to run his fingers over the colored paper to determine the characteristics of the surface: "smoothness, roughness, tackiness, ease of, and resistance to sliding, attracting and repulsion, hardness, moistness, etc." (48). Double protection was taken to insure no visual perception by screening the subject from the colors by placing cardboard or double sheets of heavy white paper between the subject and the table. Precautions were taken also to rule out suggestion by not letting the investigator know what colored squares were touched by the subject, and in each case only the investigator knew the results (49).

It was concluded that only one person in six could identify the colors of a pair of color squares after twenty to thirty minutes of practice (50). Youtz, who conducted a similar study at Barnard College, Columbia University, estimated that ". . . 10 percent of the female college population shows this ability in rudimentary form after twenty hours or more of practice" (51).

Novomeiskii found, also, that if color-sensing exercises were repeated systematically for two or three weeks, five to seven of the colors in the spectrum could be learned by some subjects (52). After this two-or-three-week period, "a transfer phenomenon," was noticed (53). The subjects could identify the same colors on papers of various textures and on thread and wood surfaces (54). Rosa Kuleshova also demonstrated this ability with threads of muslin and tapestries (55). The subjects at Nizhnii Tagil Teachers College had difficulty in differentiating, by tactile sense, some pairs of colors: "light blue and yellow, red and green, dark blue and green, orange and violet, yellow and white, violet and black" (56). The following pairs were readily differentiated: "light blue and red, yellow and red, light blue and orange, yellow and orange, white, and black . . ." (57).

In this investigation the colors were differentiated by touch and the degree of smoothness, roughness, and resistance to the fingers as the subjects ran their fingers over the colored surfaces. The colors were divided into three groups as follows (58):

> *Group I. "Smooth" colors: (a) light blue, which is the smoothest of all, offering no resistance to the hand; (b) yellow, a very slippery color, but not as smooth as light blue.*
>
> *Group II. "Tacky" colors: (a) red--tacky, adherent, attracting color; (b) green--tackier than red, but less coarse to the touch; and (c) dark blue--the most adherent of this group, but harder.*
>
> *Group III. "Rough" colors: (a) orange--interferes with motion, very rough; (b) violet--interferes even more and is rougher than orange.*

Novomeiskii concluded that (59):

> *The group of "smooth" colors is comprised of transitional colors in the middle of the spectrum: light blue and yellow. The "viscous" colors are the primary colors: red, green, and blue. The "rough" colors are transitional at the ends of the visible spectrum: orange and violet. If we analyze the tactile characteristics of colors on both sides of green, we see, without difficulty, that the sense viscosity and roughness rise as one moves from the middle to both ends of the visible spectrum.*

The subjects had some difficulty in identifying colors through glass and cellophane because the sensing characteristics of the colors partially disappeared (60). Margaret McAvoy had a similar problem when colors were enclosed in a cold phial, and when one glass was before the object, she could feel the color of the object, but it appeared "more faint" (61).

In the investigation involving the eighty students at Nizhnii Tagil Teachers College, the subjects did not name the colors *per se*, but they responded (62): "This is a smooth color--that means it is light blue. The color is slippery, so it appears that it is yellow. The color is sticky, tacky, which means it is red. Greatly brakes, restrains, clings--this color is black."

Novomeiskii confirmed Goldberg's finding that tactile sensitivity is practically extinguished in the dark (63). However, two of Novomeiskii's subjects could discriminate color in the dark, and their ability to accomplish this task improved when they ran their hands over silk (64). One other subject, Iurii O., could discriminate in the dark after rubbing the colored paper (65).

Novomeiskii suggests that the increased sensitivity to color in the dark by the subjects after rubbing the hands over silk and paper ". . . may develop not only as a result of irradiation by light, but as a consequence of electrical charging of the skin and the colored surface of the paper in some other manner" (66). This theory was substantiated by additional experiments in which the subjects felt colored paper while a screen of paper of another color was brought to his hand. Because his perception changed, it was felt that cutaneous optical perception is electrical in nature (67). Novomeiskii states (68):

> *The different colors of the paper are capable of "storing" electrical energy in rays of red light in the same proportion as in rays of white light. The ratio between the electrical potentials of the different colors remains the same, and this enables the subject in the final analysis correctly to compare colors by degree of smoothness and roughness and in the vivid rays of red light.*

Other tasks were performed which further indicated that this sense is electrical in nature. For example, when a "smooth" color, such as yellow, was placed on a surface that was rough, such as red or orange, "the color characteristics of the paper being touched changed in the direction of the color of the support (69). Rosa Kuleshova was able to adjust her pressure on the paper to determine the top sheet or the base sheet (70). Novomeiskii and his associates believe that the penetrating property is based upon the consecutive loss of charge by the colored sheets; as pressure with the fingers is applied on the top sheet, the surface beneath the fingers is discharged and the subject begins to feel the effects of the electrical field of the base (71). When Rosa Kuleshova determined the color of the base sheet, she applied additional pressure; but when identifying the surface sheet, she applied very little pressure (72).

Similar experiments were conducted with various colored lights which changed cutaneous optical perception. At first, the subjects made mistakes, but after exercises, cutaneous optical perception was established (73).

In another experiment the subjects could tell the color of paper while having their hands located high in the air and when metal, such as aluminum foil, brass, and copper, was placed on top of the sheets of colored paper. According to Novomeiskii and his associates: "This suggested the conclusion that an electrical color field developed above the colored paper surface when it rested on an insulated base" (74). The color barrier, which is the upper boundary of the color field, in a vertical position from the color surface, could be located by the subjects. This barrier was determined by the color of the paper, but generally it ranged from twenty to eighty centimeters above the colored surface (75). Red paper had the highest barrier, and green or light blue were the lowest. Between twenty and eighty centimeters, all the other colors in sequence were in accord with the color sequence in the optical color wheel (76).

It was concluded by Novomeiskii and his associates that some people learn to determine characteristics of colors by two methods, by touch and by distance (77).

Blind subjects and the cutaneous optical sense. Prior to these experiments with sighted subjects, Novomeiskii and his associates conducted experiments with blind subjects; but positive results generally did not ensue because the blind subjects did not use cutaneous optical sensations, but oriented themselves by identifying the textural properties of the paper and the structure of the coloring material (78). Ironically, when insulating materials were used, the blind subjects were better at cutaneous optical perception than the sighted (79). All the blind subjects had the same regularities as the sighted in cutaneous optical perception. Three totally and partially blind subjects were given special training when an insulated barrier was used. These subjects developed both contact and distance color discrimination quicker than the sighted, "as well as the capacity to recognize colors with certainty and transfer phenomenon" (80). It is interesting to note than when insulating material was not used, the totally or partially blind subjects could not differentiate colors accurately (81).

These investigations with the blind subjects supported the hypothesis of Novomeiskii and his associates that cutaneous optical perception is electrical in nature (82). One blind subject, Vasillii B., stated that "the perception of color fields was so strong that on each occasion he involuntarily had a visual image of a red or light blue surface" (83).

The case of Patricia Stanley. Youtz, in his work at Barnard College, investigated color sensing of Mrs. Patricia Stanley, when it was discovered by her high-school teacher and confirmed by Professor Marion Gilliam that the subject, while blindfolded, could name the color of objects after rubbing them with her fingers for 30 to 60 seconds (84). In April, 1963, Mrs. Stanley agreed to scientific investigation with the hope that she could aid the blind if the ability could be learned. Youtz found that the subject could discriminate and identify colors with her hands when both her hands and the stimuli were in the dark and in a light-tight experimental box (85). The box was approximately 30 inches wide, 20 inches deep, and 15 inches high, with a front panel 30 inches wide and 20 inches high made of 1/2-inch plywood painted black inside and out. The front panel had two armholes fitted with double thickness velveteen sleeves with elastic at the wrists. Other sleeves ran up to the elbow (86). The subject was blindfolded while seated in front of the box with her hands and arms in the gloves. She had no knowledge of the stimulus card before, during, or after the test, and was not informed of the results (87). The investigation involved selecting two cards of the same color and putting them together while placing the third card of the set aside. In addition to this she was supposed to name the color of the card. This test was taken five times with each set of colored cards. Mrs. Stanley was not able to name the colors or match them when the stimuli was covered with 1/16-inch picture glass or when fingertip temperature was below 75°F, or when plastic stimuli and hands were submerged in water (83).

When Mrs. Stanley was tested in January, it was found that her ability was less than in July and August. One of the hypotheses was "that the lesser amount of blood in the skin-layers in the wintertime is related to the sensitivity" (89).

Dermal color discrimination. Youtz conducted experiments with 133 Barnard College students to estimate the percentage that had ability to make dermal color discrimination. Each student was given one hour's training and testing combined. From the 133 students, 26 were given further training and paid $1.25 an hour. Eight of the 26 students received 20 hours or more of training and three students received 30 hours or more of training. Subject H reported temperature as the cue when discriminating three pairs of colors: red-white, blue-white, and red-blue. Subject B scored at chance after 435 trials (90).

Youtz stated tentatively, and pending further confirmation (91):

> *1. This is a real phenomenon--dermal color discrimination occurs in man, in ways similar to those reported by Russian experimenters.*
>
> *2. An estimated 10 percent of the female college population shows this ability in rudimentary form after twenty hours or more of practice.*
>
> *3. The ability is most likely an extension or variation of the temperature in the skin.*

Paroptic perception, or extraretinal vision. Jules Romains, in his paroptic perception or extraretinal vision, has stated that under normal illumination, the qualitative perception of color is perfect (92). Paroptic perception, according to Romains, ". . . may occur in man, which seem equivalent, in a certain degree, to phenomena of visual perception, and into which the ordinary mechanism of vision does not appear to enter" (93). These phenomena ". . . are concerned with certain perception of optical conditions of external environment besides or parallel to the normal mechanism of perception" (94).

Romains' experiments were different to a degree from those of the Russians, Mrs. Stanley, Margaret McAvoy, and the Barnard College students, because in paroptic perception the subject does not come in contact with the material (95). Although Romains conducted his experiments in the early twenties, in the absence of present-day scientific controls, the investigator in the present study could not ignore the parallels of his extraretinal vision to recent investigations involving color discrimination by tactile sense.

In extraretinal vision "perception is absent in absolute darkness" (96). Perception is, "more sharp, precise, and easy, as the object to be seen is placed in a brighter light" (97). Rosa Kuleshova's perception was impaired while the experiments were conducted in a dark room or while her hands were in a sack (98).

According to Romains, paroptic perception works well, "under normal illumination" and "the qualitative perception of colours is perfect" (99). He further states: "When the light is very faint, the perception of colours becomes more hesitating. . ." (100). Ironically, he states: "paroptic perception of colours continues noticeable beyond the lowest illumination with which visual perception of colours can occur" (101).

The experiments conducted by Romains led him to hypothesize that the skin played a tremendous part in paroptic perception (102), and he also stated: ". . . perhaps light is accompanied by radiations as yet unknown, very analogous to light in certain of their properties, but passing easily through the bandage and the eyelids and also through screens of wood or metal" (103). This information was corroborated by Goldberg, Novomeiskii, Stevens, Garcia and others, and Ganong and others in their experiments.

Romains' experiments included recognizing objects (such as a bronze statuette, shoes, water jug, figures under glass), naming colors of objects, reading printed material, identifying symbols and other printed indicia. His experiments were witnessed by other individuals representing the fields of science, medicine, and education (104).

Literature on Anxiety

O. H. Mowrer believes that the reduction of anxiety is positively reinforcing, consequently facilitating learning (105). He states (106):

> *. . . by positing anxiety as a kind of connecting link between the complete well-being and active organic discomfort or injury, it is possible to reconcile the fact that much, perhaps most, of the day-to-day behavior of civilized human beings is not prompted by simultaneously active organic drives and the fact that the law of effect (principle of learning through motivation-reduction) is apparently one of the best-established psychological principles. This is accomplished by assuming (i) that anxiety, i.e., mere anticipation of actual organic need or injury, may effectively motivate human beings and, (ii) that reduction of anxiety may serve pwoerfully to reinforce behavior that brings about such a state of "relief" or "security."*

Considering this frame of reference, several research investigations involving anxiety have been studied to determine the relationship of anxiety to accomplishing certain tasks as school achievement and intelligence (107), complex learning, performance, and task difficulty (108), complex learning and conditioning (109), performance in serial learning (110), serial rote learning (111), anxiety reduction and stress (112), intraserial duplication (113), and tasks as determiners of verbal performance (114).

Achievement and intelligence. *The Children's Form of the Manifest Anxiety Scale* was adapted from the *Taylor Manifest Anxiety Scale* which was used primarily to measure the anxiety levels of adults (115). Boyd, McCandless, and Alfred Castaneda conducted research on correlations between anxiety from scores on the CMAS academic achievement as measured by the *Iowa Every Pupil Test*, and intelligence as measured by the *Otis Quick Scoring Mental Ability Test, Form B*. The subjects were fourth, fifth, and sixth grade pupils. Only the sixth grade groups had intelligence test data (116). The correlations between CMAS scores and academic achievement, as measured by the *Iowa Every Pupil Test* (IEPT) showed that of 30 computed relationships between anxiety and school achievement, 13 were significant at or below the .05 and .01 levels of confidence (117). With the more complicated skills of reading, arithmetic, and composite performance, anxiety interfered, but anxiety did not affect the mnemonic skills, such as spelling (118). Consequently, the relationship of anxiety, achievement, and intelligence might be useful in predicting school achievement (119). McCandless and Castaneda concluded that (120):

> *Both the anxiety and the L score from the* Children's Form of the Manifest Anxiety Scale *were found to be related to school achievement, most strongly for the sixth grade portion of a fourth, fifth, and sixth grade public school population. The anxiety score was also significantly related to intelligence for sixth grade girls, but, for both sixth grade girls and boys it retained significant relationships with school achievement when the intelligence was partialled out. A small contribution to prediction of academic achievement by the anxiety score, over and above the predictive efficiency of intelligence alone, was found for sixth grade boys and girls.*

Complex learning and performance. Castaneda, Palermo, and McCandless studied complex learning and performance as a function of anxiety in children and task difficulty. The CMAS was used as the criterion measure. The apparatus consisted of a response panel containing five pushbuttons. Located behind the aperture were five colored lamps. The objective was to see if the subjects could learn which buttons were associated with the colored lights (121). The data showed that high-anxious subjects performed better on a comparative basis than the low-anxious subjects when easy combinations were involved, but the high-anxious subjects did more poorly on the difficult combinations (122). However, it was noted, ". . . the performance of the high-anxious children appeared to be more affected by the differences in the difficulty of the two sets of combinations than for the low-anxious children" (123). The investigators pointed out that ". . . the effects of anxiety are dependent on the degree of difficulty involved in the task" (124). This interaction was found to be statistically significant. The high-anxious subjects were prone to be superior on the less difficult tasks, but inferior in comparison with the low-anxious subjects in the more complicated tasks (125).

Palermo, Castaneda, and McCandless also investigated the relationship of anxiety or motivation in children in more complex learning situations where one or more competing incorrect response was dominant (126).

An apparatus with two pushbuttons and a jeweled reflector illuminated by a pilot lamp was used in this investigation. The design of the experiment was to see whether the subjects could learn which button turned off each light in twenty choices. The order of lights was random, and no one light could be activated two times in succession (127). The results of this investigation showed that the anxious or high motivation subjects would make significantly more errors in the learning task (128).

Farber and Spence studied the performance of anxious and nonanxious subjects in the learning of a ten-choice stylus maze involving response competition. The level of difficulty of the maze had been determined in another investigation ten years earlier (129).

A modified form of the *Taylor Anxiety Scale* was used, and the subjects were selected from undergraduate psychology courses on the basis of their scores on the scale (130). The results indicated that "the nonanxious *S*'s were superior to the anxious in terms of both number of errors and number of trials to the criterion of mastery" (131). A nonparametric test of significance was analyzed because the groups departed from normality in the distributions for the two measures with similar results (132). Farber and Spence stated that the findings ". . . are consonant with the theoretical expectations that nonanxious *S*'s would perform better than anxious *S*'s in a complex learning situation" (133).

The number of errors at each choice point of the maze was recorded for the anxious and nonanxious subjects. According to the investigators, the anxious were inferior at every choice point but one, and the extent of this inferiority varied with the difficulty of the choice point as determined by the performance of an unselected group (134).

Not only were the nonanxious better at the difficult choice points than at the easier ones; they all made fewer errors even at the less difficult choice points (135). Farber and Spence concluded (136):

> *. . . that the anxious and non-anxious groups in this study differed with respect to drive level (d) rather than general learning ability, and that the effect of variations in the drive level upon performance is a function of specific characteristics of the given task.*

Taylor and Spence conducted research which corroborates the theoretical expectation that the anxious or high-drive subjects would make significantly more errors and require more trials to reach the learning criterion of two successive errorless trials in twenty choices (137). The subjects in this investigation were students in an introductory psychology course and were selected on the basis of their extremely high and extremely low scores obtained from the modified form of the *Manifest Anxiety Scale* developed by Taylor (138). The results supported the theoretical expectation that the nonanxious, or low-drive, subjects would be superior to the anxious, or high-drive, subjects in a serial learning situation involving a series of choices between two verbal responses in which the subject responded by saying "left" or "right" at each point of choice in a memory drum setup (139).

Montague also used a memory drum to determine the effect of anxiety upon performance of three verbal learning tasks involving three lists of three-letter nonsense syllables. The first list contained items of high similarity and low association value. The second list contained items of low similarity and low association value, and the third list contained items of low similarity and high association value. Each list had a total of twelve syllables. All subjects were selected on the basis of scores obtained on a modification of the anxiety scale devised by Taylor. The Lie Scale of the Minnesota Multiphasic Personality Inventory was used to detect the falsification of the anxiety scale (140).

The results indicated that in the learning task of list one the nonanxious subjects were generally superior to the anxious subjects. List two also indicated the superiority of the nonanxious subjects over the anxious subjects but to a lesser degree; however, on list three, the anxious subjects were superior to the nonanxious subjects (141). The findings of this investigation substantiate the findings of other researchers about anxiety and learning.

Learning under stress. Deese, Lazarus, and Keenan explored the relationship of anxiety, as a personality variable, and learning under various conditions of stress (142). The subjects were divided into three experimental groups, and they learned twelve consonant nonsense syllables by anticipation for twelve trials (143). The groups were, a control group, an avoidance-learning group, and a nonavoidance-learning group. The control group was treated without threat or punishment. The avoidance-learning group received an electric shock for no responses or incorrect responses. The nonavoidance learning group received an electric shock regardless of whether the response was correct (144).

The results showed that in the avoidance situation in which the subjects were shocked for incorrect responses there was a large difference in learning curves between the high-scoring and low-scoring groups in the "neuroticism" and the "anxiety" inventories (145). In the nonavoidance group, in which shock treatment was given randomly, there was a smaller difference between these groups (146). A small difference, although considered consistent between these conditions, was shown by the control group (147). It should be pointed out here, however, that Lazarus, Deese, and Hamilton conducted another investigation which was actually a repetition of the earlier study on serial learning and personality variables under conditions of stress produced by electric shock (148). The only difference between the studies is that the nonsense syllables in the latter study were used with a high degree of intraserial duplication (149). In the previous study there was a minimum of duplication (150).

The results of this study indicated that there were no significant differences between the performance of the low-anxiety and high-anxiety groups, but the obtained mean differences between the groups were in the opposite direction. Consequently, the findings support the hypothesis that task difficulty reverses the anxiety-avoidance learning (151).

Drive level and performance. Ramond investigated the relationship between drive level and performance in a learning situation involving verbal responses as a function of the relative strengths of incorrect and correct responses in the initial hierarchies (152). The subjects were selected on the basis of their extreme scores on a modified form of the Taylor Manifest Anxiety Scale, and were divided into two groups--one anxious, or high-drive, group and one nonanxious, or low-drive, group. Each subject received 32 learning trials. The presentations consisted of three two-syllable adjectives. One adjective was located on the left and two adjectives were located on the right of cloth tape and appeared simultaneously in the aperture of a Hull-type memory drum (153). The task involved learning, in each case, which of the two words on the right was the correct response to the stimulus word on the left (154).

In the initial response hierarchy, the relative strength of the correct response was controlled by forcing the subjects to choose on each presentation one of two responses, and one of these two responses was made stronger than the other by scaling techniques (155).

Ramond states (156):

> *(a) non-anxious* S*'s responded correctly significantly more often than did anxious* S*'s on those presentations in which the weaker response was correct; (b) there was no significant difference between the performance of the anxious and nonanxious* S*'s on those presentations in which the stronger response was correct.*

Anxiety and the self-concept. Some studies show a relationship between anxiety and the self-concept. McCandless and others used a two-teacher-administered technique and the Children's Form of the Manifest Anxiety Scale to determine the relationship between anxiety in children and social status. They concluded that the more anxious boys and girls were less popular. There was a high relationship for fifth graders, a moderate relationship for fourth graders, and approximately zero for the sixth graders (157).

Coopersmith conducted a study involving 102 fifty and sixth grade children. The CMAS was used to determine the levels of anxiety and the Self-Esteem Inventory to rate the children. He concluded that children who had high self-esteem were significantly less anxious than those with low self-esteem (158).

Bledsoe and Garrison concluded also that anxiety is related to self-concept in a significantly negative way. Their findings concluded that the children who tested high on the CMAS tended to assign themselves a lower self-concept rating (159).

Summary

The recognition of objects, printed material, and colors by individuals blindfolded or totally blind or individuals located in a dark or lighted room formerly was considered impossible. Within the past few years, however, experiments conducted under scientific controls have increased our knowledge of this phenomenon. Experiments conducted by Goldberg and Novomeiskii of the Soviet Union created skepticism in the Western world. When pages of history and scientific research were reviewed together, certain parallels were noted. As skepticism mounted over lay and professional publications, experiments in the United States were instituted to prove or disprove the Soviets' findings on the cutaneous optical sense in man and tactile sensitivity. Researchers, after reviewing related literature in other areas, investigated by Garcia and others, Ganong and others, Hardy and Muschenheim, and D. M. Stevens, concluded that the sensitivity of skin to light seemed possible. Youtz's experiments closely parallel those of Novomeiskii and Goldberg.

The cases of Rosa Kuleshova, Patricia Stanley, Margaret McAvoy, the eighty subjects of Nizhnii Tagil Teachers College, the Barnard College students, and even the work of Jules Romains, have added new information related to skin sensitivity in determining colors and printed materials.

A review of the literature on anxiety revealed that the relationship of anxiety, achievement, and intelligence might be useful in predicting school achievement. Several studies, in which the CMAS was used, or a modified form of the Taylor Scale, revealed that high-anxious subjects make significantly more errors in learning certain complicated tasks. However, the effects of anxiety were generally dependent on the degree of difficulty involved in the task.

A relationship was shown between anxiety and the self-concept. The investigators concluded that more anxious boys and girls were less popular. Also, childred who had high self-esteem were less anxious than children with low self-esteem. Finally, anxiety was related to the self-concept in a negative way.

Chapter 3

METHODS AND PROCEDURES

This chapter describes the methods and procedures used in obtaining the data for the descriptive interpretation and experimental analysis of the study. The major phases considered were (*1*) selection of colors, (*2*) the sample, (*3*) the research procedures, (*4*) the training procedures, (*5*) the training evaluation, (*6*) the experimental design, and (*7*) the statistical method employed.

Selection of Colors

The investigator selected the colors of the visible spectrum for this investigation and acquired matte colored paper which, in the investigator's opinion, represented the visible spectrum. The colored paper was measured according to the Munsell color system as shown in Table 1 (1). These colors served as the standard colors for this investigation, although the hue orange does not appear by name in the Munsell system (2), but is called orange in the visible spectrum (3).

The investigator used the visible spectrum as the frame of reference and measured all colors according to the Munsell system. The hue orange in the visible spectrum is noted as yellow-red in the Munsell system, and the hue violet in the visible spectrum is noted as purple (4).

All colors selected for this investigation were matched and classified under natural daylight with the temperature 90°F.

Table 1

Measurement of Colors Based on the Munsell System*

Color	*Notation*
Red	5.0R 4/14
Orange	1.5 YR 6/14
Yellow	2.5Y 8/12
Green	5.0G 5/8
Blue	5.0B 4/8
Violet	5.0P 4/12

**In using the Munsell notation, the symbol for hue is recorded first. The hue and the fraction form, with the numerator designating the value of the color and the denominator designating the chroma, is recorded as follows: H V/C. To illustrate, 5.0 blue in hue, 4 in value, and 8 in chroma is recorded 4.0B 4/8.*

The Sample

In order to determine whether the reading of color by transforming hues into audiofrequencies would aid the visually handicapped in the educative process, the investigator obtained a sample of legally blind pupils with the aid of resource teachers for the blind. The sample represented a cross section of the elementary-school population in the Greater Phoenix, Arizona, metropolitan area. Because of the limited number of legally blind elementary pupils integrated into this public-school system, the pupils were selected on the basis of availability and divided into control and experimental groups on the basis of feasibility. The experimental group consisted of nine pupils representing three school districts and involving seven schools, of which two schools had two pupils each.

One resource teacher for the blind was responsible for six pupils. Two pupils were associated with a special class for the partially sighted, and one pupil had not been assigned to a special class or resource teacher during the course of this investigation. The control group also consisted of nine pupils representing three school districts and involving seven schools, of which two schools each had two pupils. Two resource teachers for the blind were responsible for the nine pupils. One teacher was assigned four pupils and the other was assigned five pupils.

The investigator used every legally blind pupil enrolled in the six districts and the fourteen schools involved.

The experimental group was called the E group, and the control group was called the C group. Each pupil was assigned the letter for his group, plus a letter of the alphabet as the pupils were listed alphabetically within each group. For instance, the double letter designation of "ED" indicates the fourth pupil listed alphabetically in the experimental group. A letter designation of "CB" indicates the second pupil in the control group.

Research Procedure

The investigator preceded the initiation of the experimental investigation by administering the Maico Audiometer Sweep Check Test of hearing acuity to the experimental group. The results of this test were recorded on the Maico Audiogram, and the entire experimental data was recorded in Table 2.

The resource teachers for the blind administered the Children's Form of the Manifest Anxiety Scale to all the pupils in the experimental and control groups for both the pretest and posttest, with the exception of pupil EC, who was not assigned to a resource teacher. The regular classroom teacher administered this test. The 53 statements of the Children's Form of the Manifest Anxiety Scale were read to the pupils and, as the pupils responded, the resource teacher recorded a circle around the "yes" or "no."

All color-sound training was administered on a one-to-one relationship. All color-sound training and evaluation covered six weeks. Each pupil in the experimental group received the same amount of training, which involved nine training sessions of 45 minutes each.

Legally blind pupils, who had acuity of hand movements, finger counting, and light perception in one or both eyes had their remaining vision blocked. The investigator used cardboard collars which fitted around the pupils' necks and extended outward parallel to the table in a manner that made visual contact with any color impossible.

Training Procedures

At the beginning of the first session the pupils were given a general orientation as to the objective and nature of the research investigation and were familiarized with the colorscope in reading color electronically. An earphone was inserted in an ear of each pupil and the volume was increased to the point that the

Table 2

Auditory Acuity Ratings for the Experimental Group Hearing Level in Decibels

Frequency	*125*		*250*		*500*		*750*		*1,000*		*1,500*		*2,000*		*3,000*		*4,000*		*6,000*		*8,000*	
Pupils	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*
EA	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EB	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EC	25	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20	15	20
ED	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EE	30	15	25	15	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EF	20	25	15	25	20	25	20	25	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EG	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EH	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
EI	15	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15	25	25	25	45	50	45

investigator could hear the color sounds as the color probe made contact with the colored surface. The purpose was to acquaint each pupil with the sounds produced by the six colors. As the sounds were played, the investigator named the sound that the color produced. The sounds were played for approximately five seconds. An interval of five seconds elapsed before the name of the color was revealed, and approximately five additional seconds were allowed after naming the color sound and the beginning of the five-second span of the succeeding color sound. This procedure was followed until the six color sounds were auded, starting with red and continuing to violet in the visible spectrum.

Because the visually-handicapped pupils should utilize their sense of hearing, this procedure was repeated several times so that the pupils could acquire the auding skill and become proficient in reading colors by sound.

Then, color-sound time was reduced to approximately three seconds, and color names were given by the pupils. The sounds were produced in sequence from red to violet in the visible spectrum. The time allowed between color sounds was determined by the investigator as responses were given. The investigator had complete control over this operation by manipulating the "off" and "on" switch on the colorscope and repeating sounds upon request. In cases when the wrong color name was given for the color sound, the investigator corrected the pupils and replayed the sound or sounds in question.

Next, color-sound time was reduced to approximately two seconds and color names were given by the pupils. Color sounds now ran in no particular pattern; however, every color sound was covered within the framework of this investigation. Again, the time permitted between color sounds was determined by the investigator. As the pupils progressed, color-sound time was reduced to approximately one second and color names were given by the pupils. Color sounds were random, covering the six selected colors.

After the pupils completed the initial phase of color-sound translation, they were permitted to manipulate the original colorscope and explore their clothing and their immediate surroundings and respond to the various color sounds.

At this point in the actual manipulation of the instrument, two-by-two-inch color squares were placed before the pupils (see Appendix A). The color squares included the basic colors used in this investigation, plus color squares not previously auded by the group. The pupils were asked by the investigator to read the color squares via audiofrequencies as sounded by the colorscope. The distracter color squares were added to insure accurate reading of the colors, and were discarded as the pupils responded correctly to previously auded colors. The pupils were instructed that if an unfamiliar sound was auded they were not to name a color sound, but were to place the color square to the side. The color squares were shuffled in the same manner that a person would shuffle a deck of playing cards, and, consequently, color squares were random. The pupils were asked to hold the color squares in one hand or to place them on the table and to scan or explore the surface by making direct contact with the color square. At this point, the pupils were cautioned to hold the probe perpendicular to the area being explored for more accurate results.

This procedure was continued in most cases until the pupils could name all the colors auded and discard the distracter color squares not named. After the distracter color squares were removed from the deck of color squares the investigator reshuffled the basic six color squares without the pupils' being cognizant of this operation. Then the pupils were asked again to name all color sounds--red, orange, yellow, green, blue, and violet--and to discard all color sounds not auded previously.

To acquaint the pupils with various patterns and configurations the color disc was offered for exploration (see Appendix B). The pupils were asked to explore the paper by locating the top edge of the paper and estimating the center and move the probe downward until a known color was auded. At this point, the pupils were asked to explore in the same manner by locating the approximate center of the left edge of the paper and to explore with the probe moving slowly in a left-to-right direction. As the pupils explored in this manner, they were asked to respond to the various color sounds as the probe made color-sound contact in each pie slice of the circles within circles. After completing this step, the pupils were asked to explore in a circular fashion and to respond by giving the color-sound names.

At this point, the investigator became aware that the pupils had difficulty in keeping the color probe perpendicular to the colored surface and in moving it either up or down the paper in a straight or near-straight line. When the pupils became negligent with this procedure, the investigator assisted them by correcting the position of the probe or realigning the route of travel.

In exploring the color angle bars left, the pupils were instructed to scan the paper by the previously-mentioned method of locating the approximate center of the top edge by touch and moving the probe downward until a known color sound was auded (see Appendix C). The pupils then explored in the previously-described manner, moving from left to right until a known color sound was auded. The pupils were instructed further to change the direction of the probe if there appeared to be an unknown sound which was caused by the two oscillators sounding, one on one color, and one on another color, because of the angles of the bars if the probe was moved in a left-to-right or up-and-down manner. The purpose of this chart was to discover whether the pupils could change the position of the probe to correspond to the degree of angles and to name the color sounds as emitted by the colorscope while moving from top left and progressing downward to bottom right or vice versa.

In exploring the color angle bars right, the pupils were given the same directions as with the color angle bars left (see Appendix D). The purpose of this chart was to find whether the pupils could change the position of the probe to correspond to the degree of angles and to name the color sounds as emitted by the colorscope while moving from top right and progressing downward to bottom left or vice versa.

The color spots were to be explored, utilizing the previously-mentioned procedure for exploration and, while in the process, naming the color sounds as the probe made direct contact with the colored surface spots after moving across the white surface. The color spots are presented in Appendix E. This chart gave the student freelance exploration because of the randomization of the color spots.

The color pyramid and the color cone are the reverse of each other, with the exception of the colored area of the various colors and the color pattern. These charts are presented in Appendixes F and G. The purpose of these two patterns was to reemphasize the angles and to add the horizontal bars which varied in length and width. The pupils were asked to name the various colors as proper direct contact was made and a color sound was emitted by the colorscope.

The color star was to be explored in the usual manner with the probe (see Appendix H). The pupils were to name the colors of the visible spectrum as contact was made with the colored surface. The purpose of this chart was to utilize the six colors without repetition and to use a common pattern which could be recognized readily by sound or tactile sense, but at the same time was reversible in several positions to complicate the memory factor in color-sound reading by rotating the chart after the pupil had made proper contact with the surface.

The color maze was designed to be a challenge in reading colors and in determining whether the pupils could follow the color sound for red through the maze after being placed at the starting point (see Appendix I). If the pupils heard another color sound, they became aware they were on the wrong pathway. Color sound names were not given in completing this task.

Training Evaluation

Color square testing. After the color training, the pupils were tested over the various colors in the training charts. The first test involved naming the color sounds of 36 color squares equally represented in the visible spectrum and discarding 14 distracter color squares and not naming them. An error was recorded by the investigator if the pupil gave the wrong color name for a color sound and when a distracter color square was named as one of the six colors used in this investigation.

Color disc testing. The second test of learning to read color was the naming of the three colors in the six pie-sliced areas of the color disc by manipulating the probe in a circular manner or moving the probe from the outer circle to the innermost circle. Each colored area had to be explored and the color name supplied. In cases in which the wrong color name was given for a color sound, an error was recorded.

Color angle bars left-and-right tests. The third and fourth test of reading color was the naming of the colors in the color-angle-bars-left and color-angle-bars-right charts. The usual scanning pattern was followed and the probe was turned to correspond to the angles of the charts. As the probe moved across and downward or vice versa the pupil responded to the color sound by naming the color. An error was counted if the color sound and color name were not the same.

Color spots test. The color spot test was administered to determine whether the pupils could explore a white matte surface and respond to color sounds as the probe made direct contact with the various colored areas. As contact was made with each area, the pupils were required to respond by correctly naming the color that the sound represented. If a pupil responded to a color sound by giving the wrong color name, an error was recorded.

Color cone and color pyramid tests. The pupils were instructed to explore the white matte surface in the previously-described procedure and name the colors emitted by the probe as direct contact was made. As the probe traversed in an upward or downward manner over the colored areas, the pupil responded and named the sounds that represented the colors utilized in this investigation. In cases in which the incorrect name was given for a particular color, an error was recorded.

Color star test. This was administered to prepare the pupils more adequately for the color maze test. Exploration of the white matte surface was conducted in the usual way except that the pupils were instructed to stop as soon as the color sound for red was auded and to move outwards from the center to the five colored points and name the color sounds. An error was recorded if the pupils responded by giving the wrong name for a particular color sound or when they failed to return to the color sound for the red after exploring the points of the star.

Color maze test. The color maze chart was not explored in the usual manner. The investigator assisted the pupil to the starting point on red and instructed the pupil to follow the color sound for red throughout the maze. An error was recorded when the probe, while being manipulated, made contact with another color and the pupil did not alter the direction of travel to the approximate area on the red pathway where the sound had changed in moving through the maze. Also, an error was recorded when the pupils "short-cut" the red pathway by passing over a portion of the white matte surface to another red pathway or color without retracing his original movements to the sound for red. This test did not require the pupils to name color sounds.

Experimental Design

The investigator used the nonequivalent control group design to conduct the research study because the experimental and the control groups were selected on the basis of availability and the assignment of the experimental treatment was random. The design was as follows:

```
O  X  O
-------
O     O
```

This illustration shows that both groups were administered a pretest and a posttest designated by letters "O," and the "X" indicates the experimental treatment. The control group received no experimental treatment (5).

The investigator recognized that complete control over all the conditions of this study was not possible. Because of intervening variables, the investigator attempted to control those factors that were pertinent and feasible during the time of the investigation.

Statistical Method

In the statistical treatment of the data collected for this study, the investigator used the Mann-Whitney U Test as a means to accept or reject the null hypothesis. According to Siegel, this test is one of the most powerful of the nonparametric tests and may be used to study two independent small samples (6).

The investigator arbitrarily set .05 as the confidence limit for this investigation.

Summary

This chapter described the selection and the measurement of the colors according to the Munsell system, the procurement of the sample primarily on the basis of availability, and the research procedure.

The training procedure was implemented to determine whether visually-handicapped pupils could learn to read the colors via audiofrequencies and the evaluation was used as a check on learning skills.

The training evaluation included tests on color squares, color disc, color angle bars left, and right, color spots, color cone, color pyramid, and the color maze.

The experimental design of nonequivalent control group arrangement was employed in the research procedure, with the Mann-Whitney U Test, as a means to accept or reject the null hypothesis. The confidence limit was set at the .05 level.

Chapter 4

FINDINGS

This chapter presents the findings of the statistical treatment relative to the effect that reading color by transforming hues into audiofrequencies had upon the anxiety level of the visually-handicapped pupils in the experimental group.

The null hypothesis, that there is no significant difference in the anxiety levels as measured by the Children's Form of the Manifest Anxiety Scale between the visually-handicapped pupils who are not exposed to this method of reading color, was rejected.

The Mann-Whitney *U* Test was used in the statistical treatment to determine significance. The ratings assigned to both the experimental and control groups are shown in Table 3. For these data, $R_1 = 108.5$, $R_2 = 62.5$, and $U = 17.5$.

The formula used to calculate the data is

$$U = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} - R_1$$

or, equivalently,

$$U = n_1 n_2 + \frac{n_2 (n_2 + 1)}{2} - R_2$$

where R_1 = sum of the ranks assigned to group whose sample size is n_1 and R_2 = sum of the ranks assigned to group whose sample size is n_2.

Table 3

Trials to Criterion of Experimental and Control Pupils

E Score	*Rank*	*C Score*	*Rank*
38	1.0	46	5.5
40	2.0	47	7.0
44	3.0	51	10.0
45	4.0	52	11.0
46	5.5	53	13.5
49	8.5	53	13.5
49	8.5	53	13.5
53	13.5	54	16.5
54	16.5	61	18.0
R_2 =	62.5	R_1 =	108.5

From the statistical analysis *U* value of 17.5 was obtained. The data yielded a significance beyond the .05 level of confidence in using the one-tailed test. The investigator changed from H_0 (null hypothesis) to H_1. Siegel states (2):

> *Since* H_1 *predicts the direction of the difference, the region of rejection is one-tailed. It consists of all values of* z. . . *which are so extreme that their associated probability under* H_0 *is equal to or less than = .01.*

Pretest and posttest of the experimental group. A *U* test for significance was made to determine the level of anxiety between the pretest and posttest of the experimental group to the criterion measure of the Children's Form of the Manifest Anxiety Scale. The ratings assigned to both the pretest and the posttest are shown in Table 4.

For these data, R_1 = 73.0, R_2 = 98.0. The *U* test for significance yielded a value of 28. The *U* score indicated that a level of significance of .05 was not obtained. A *U* score of 21 or less is necessary to have significance at the .05 level of confidence. This indicated that the level of anxiety was not reduced significantly according to the criterion measure of the CMAS between the pretest and the posttest for the experimental group.

Pretest and posttest of the control group. A test of significance was made to determine the level of anxiety between the pretest and the posttest of the control group to the criterion measure of the CMAS. The ratings assigned to both the pretest and the post test are shown in Table 5. For these data, R_1 = 94.5, and R_2 = 76.5. The *U* test for significance gave a value of 49.5. The *U* score indicated that a level of .05 significance was not obtained. A *U* value of 21 or less is necessary to have significance at the .05 level of confidence.

Table 4

Trials to Criterion of Pretest and Posttest for the Experimental Group

Pretest	*Rank*	*Posttest*	*Rank*
12	2.5	6	1.0
14	5.5	12	2.5
19	9.0	13	4.0
21	11.0	17	6.5
24	13.0	17	6.5
24	13.0	18	8.0
24	13.0	20	10.0
25	15.0	27	16.5
27	16.5	28	18.0
R_2 =	98.0	R_1 =	73.0

Table 5

Trials to Criterion of Pretest and Posttest for the Control Group

Pretest	*Rank*	*Posttest*	*Rank*
9	1.0	11	3.0
10	2.0	13	6.0
12	4.5	14	7.0
12	4.5	15	8.5
15	8.5	19	12.0
16	10.0	20	13.0
17	11.0	24	14.0
28	17.5	25	15.0
28	17.5	26	16.0
	R_2 = 76.5		R_1 = 94.5

The means and standard deviations of errors on the color test. Table 6 shows the means and standard deviations of errors on the color tests for the visually handicapped in the experimental group. On the color squares test the mean number of errors was 6.67, and the standard deviation was 4.42. The color disc test results indicated that the mean number of errors was 2.67, with a .94 standard deviation.

The color angle bars left test results indicated that the mean number of errors was 2.22 with .94 as the standard deviation. The opposite test of color angle bars left, which is color angle bars right, showed that the mean number of errors was 3.11 and the standard deviation was 1.45. The color spots tests indicated that the mean number of errors was 2.89 and the standard deviation was 1.10. The color pyramid and the color cone tests indicated that means for these two tests were 3.22, with the standard deviations of 1.41 and 1.63, respectively. The color star test was apparently the easiest. The mean number of errors was 1.33 and the standard deviation was .94. The final test, the color maze, had a mean number of errors of 3.00 and a standard deviation of 1.56.

The means and the standard deviations of the rate of learning. Table 7 shows the means and the standard deviations of the rate of learning in minutes for the six color sounds for the experimental group. Violet was the easiest of all the colors for the visually-handicapped pupils. The other colors in the visible spectrum ran in the following order of difficulty, based on the amount of time required in the learning processes: blue, red, orange, yellow, and green. The color green presented the greatest challenge for all the pupils. The mean amount of time for this color was 25.22 minutes and the standard deviation was 9.61. A further inspection of the table shows the means, standard deviations, and the rate of learning for the other colors in the visible spectrum.

Table 6

Means and Standard Deviations of Errors on the Color Test for the Visually-Handicapped Pupils in the Experimental Group

Color Tests	*Means*	*Standard Deviations*
Color squares	6.67	4.42
Color disc	2.67	0.94
Color angle bars (left)	2.22	0.94
Color angle bars (right)	3.11	1.45
Color spots	2.89	1.10
Color pyramid	3.22	1.41
Color cone	3.22	1.63
Color star	1.33	0.94
Color maze	3.00	1.56

Table 7

Means, Standard Deviations, and Rate of Learning for the Six Color Sounds Recorded in Minutes for the Experimental Group

Color Squares	*Means*	*Standard Deviations*
Red	6.67	2.70
Orange	7.22	2.66
Yellow	7.78	3.83
Green	25.22	9.61
Blue	5.67	2.98
Violet	5.11	2.96

Summary

This was an experimental investigation to determine the effects of reading color by transforming hues into audiofrequencies upon the anxiety level of visually-handicapped pupils.

The Mann-Whitney *U* Test was used to determine the significance of the experimental treatment on the experimental group. The null hypothesis that there is no significant difference in the anxiety level as measured by the Children's Form of the Manifest Anxiety Scale between the visually-handicapped pupils who learn to read color via audiofrequencies, and visually-handicapped pupils who are not exposed to this method of reading color was rejected. Statistical evidence indicated that the visually-handicapped pupils who had training in reading color showed a decrease in anxiety and the amount of decrease was significant beyond the .05 level of confidence.

A *U* test was computed for the pretest and the posttest for both the experimental and control groups. Statistical analysis revealed that significance was not obtained at the .05 level of confidence.

Means and standard deviations of errors on the color tests were computed for the experimental group and means, standard deviations, and the rate of learning was calculated for the six color sounds for this group.

The training procedure, as given in Chapter 3, has been an effective instructional approach to the degree that it enabled the visually handicapped to read color via audiofrequencies.

Chapter 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objectives of this investigation were to determine whether visually-handicapped pupils could learn to read color via audiofrequencies and whether this would affect their anxiety level and to determine what methods or approaches should be used to instruct the visually-handicapped pupils in learning to read color via audiofrequencies.

This investigation seemed appropriate because tremendous advancements are being made to up-grade education in a rapidly changing society where technology is playing a vital role. While man is on the threshold of conquering outer space, the visually-handicapped are trying to master their immediate environments because of the natural drives inherent in man. The role of education is to prepare these handicapped pupils to participate in our society as fully as possible.

The investigator believed that the findings of this research investigation would add a new dimension to assist visually-handicapped pupils in learning more about the world around them. No attempt was made to equate the harmonic tones of the selected colors to a person's sight, but merely to serve as a supplement to his tactile sense by making the individual aware that objects and materials not only feel differently but also are seen differently by a sighted person.

This investigation was an attempt to find plausible answers to the following:

1. To determine whether visually-handicapped pupils could learn to read colors via audiofrequencies, and whether this would affect their anxiety level.
2. To determine what methods or approaches should be used to instruct the visually handicapped in learning to read color via audiofrequencies.

Several terms were coined to describe adequately the training charts and the teaching procedure to facilitate the understanding of this research endeavor. These terms were defined in Chapter 1.

The investigator believed that the Children's Form of the Manifest Anxiety Scale was an adequate instrument to determine anxiety level before and after the experimental treatment for the experimental group as well as a pretest and a posttest for the control group. Also, the investigator believed the pupils in the experimental and control groups responded with honesty in answering the statements on the Children's Form of the Manifest Anxiety Scale.

Review of literature. An extensive review of the literature revealed no information on visually-handicapped pupils learning to read color via audiofrequencies and its effect upon their anxiety level. The literature did reveal a limited number of research investigation on tactile sensitivity to printed materials and colors, the cutaneous optical sense in man, the dermal light sense, and extraretinal vision. A careful analysis of these investigations showed that some species of aquatic and amphibious organisms were sensitive to light. Some investigators concluded that some portions of the electromagnetic spectrum did penetrate the skin which made possible the detection of such radiation. The temperature of the object or of the hands of the individual affected the accuracy of the person, especially when the temperature fell below 75°F. Conclusions were made that perception of colors was electrical in nature. The Soviet researchers claimed that about one person out of six has this exceptional ability, while another researcher estimated that about 10 percent of the female college population showed some ability after several hours of practice.

Research conducted by Romains more than forty years ago was not ignored completely because certain pertinent parallels were noted as having a scientific relationship with the hypotheses of present-day researchers.

Methods and procedures. The investigator selected the colors of the visible spectrum as the basic colors for this investigation and measured these colors according to the Munsell system. Throughout the investigation a matte colored paper was used.

The sample was selected on the basis of availability encompassing six school districts and fourteen schools and involving eighteen visually-handicapped pupils and three resource teachers for the blind. The sample was divided into experimental and control groups on the basis of feasibility.

The research procedure entailed the administration of a hearing acuity test to the experimental group and the administration of the Children's Form of the Manifest Anxiety Scale to both the experimental and the control groups. The CMAS was administered as a pretest and as a posttest for both groups.

All color training was administered on a one-to-one relationship which lasted six weeks and involved nine training sessions of 45 minutes each. The training procedure involved the six colors of the visible spectrum--red, orange, yellow, green, blue, and violet. The pupils manipulated the electronic probe of the colorscope and responded to the color sounds as they progressed in their training. Special training charts were designed to present a challenge to these pupils and later, these charts were used for evaluation. The charts were: color squares, color disc, color angle bars left, color angle bars right, color spots, color pyramid, color cone, color star, and the color maze.

Experimental design and statistical method. The investigator used the nonequivalent control group design to conduct the research study, and the Mann-Whitney *U* Test as a means to accept or reject the null hypothesis. The null hypothesis was evaluated by a *U* test of significance and the confidence limit was arbitrarily set at the .05 level.

Conclusions. The investigator wishes to point out that generalizations from experimental investigations of this nature, which use small samples, should be made with caution. The researcher was interested in setting the stage in this area for additional research that may bridge the "educational gap" in the educative process for the visually-handicapped.

The objectives of the problem and the null hypothesis are presented with the conclusions drawn from the findings of this investigation:

1. To determine whether visually-handicapped pupils can learn to read color via audiofrequencies and whether this will affect their anxiety level. This objective was achieved by the visually-handicapped pupils in the experimental group, although some pupils had more difficulty than others in learning to read color via audiofrequencies.

2. To determine what methods or approaches should be used to instruct visually-handicapped pupils in learning to read color via audiofrequencies. It is concluded, therefore, on the basis of the findings that the training procedure as outlined in Chapter 3 was an effective approach to the degree that it enabled the visually-handicapped to read color via audiofrequencies.

The null hypothesis tested was that there is no significant difference in the anxiety level as measured by the Children's Form of the Manifest Anxiety Scale between the visually-handicapped pupils who learn to read color via audiofrequencies and visually-handicapped pupils who are not exposed to this method of reading color. Since the difference in anxiety between the two groups was significant beyond the .05 level of confidence, the null hypothesis was rejected. It is concluded, therefore, that the difference can be attributed to presence or absence of the reading of color via audiofrequencies.

Recommendations. As a result of this study, the investigator recommends additional research which could aid the visually-handicapped in the educative process. The recommendations are as follows:

1. An investigation to teach art appreciation, creative art, and color harmony by utilizing a device of this nature.
2. An investigation to teach map reading by using a similar device.
3. An investigation to teach music by colors using a similar device.
4. An investigation to determine the effects of age, sex, IQ, and decibel loss upon the rate of learning to read colors.
5. An investigation to determine the relationship between anxiety and the process of integrating the visually-handicapped into the regular classroom environment.

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The writer is indebted to the committee chairman, Dr. Donald E. O'Beirne, and the committee members, Doctors Garth Blackham, Maurice Lewis, William Podlich, and Robert Roessel, for their cooperation.

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The writer also expresses his sincere appreciation to the inventor of the colorscope, Thomas E. Thorpe, who rendered unlimited assistance in the field of electronics for this study, and to my wife and son for their patience and consideration.

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38. *Ibid.*

39. *Ibid.*

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41. *Ibid.*

42. *Ibid.*

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46. *Ibid.*, pp. 21, 23.

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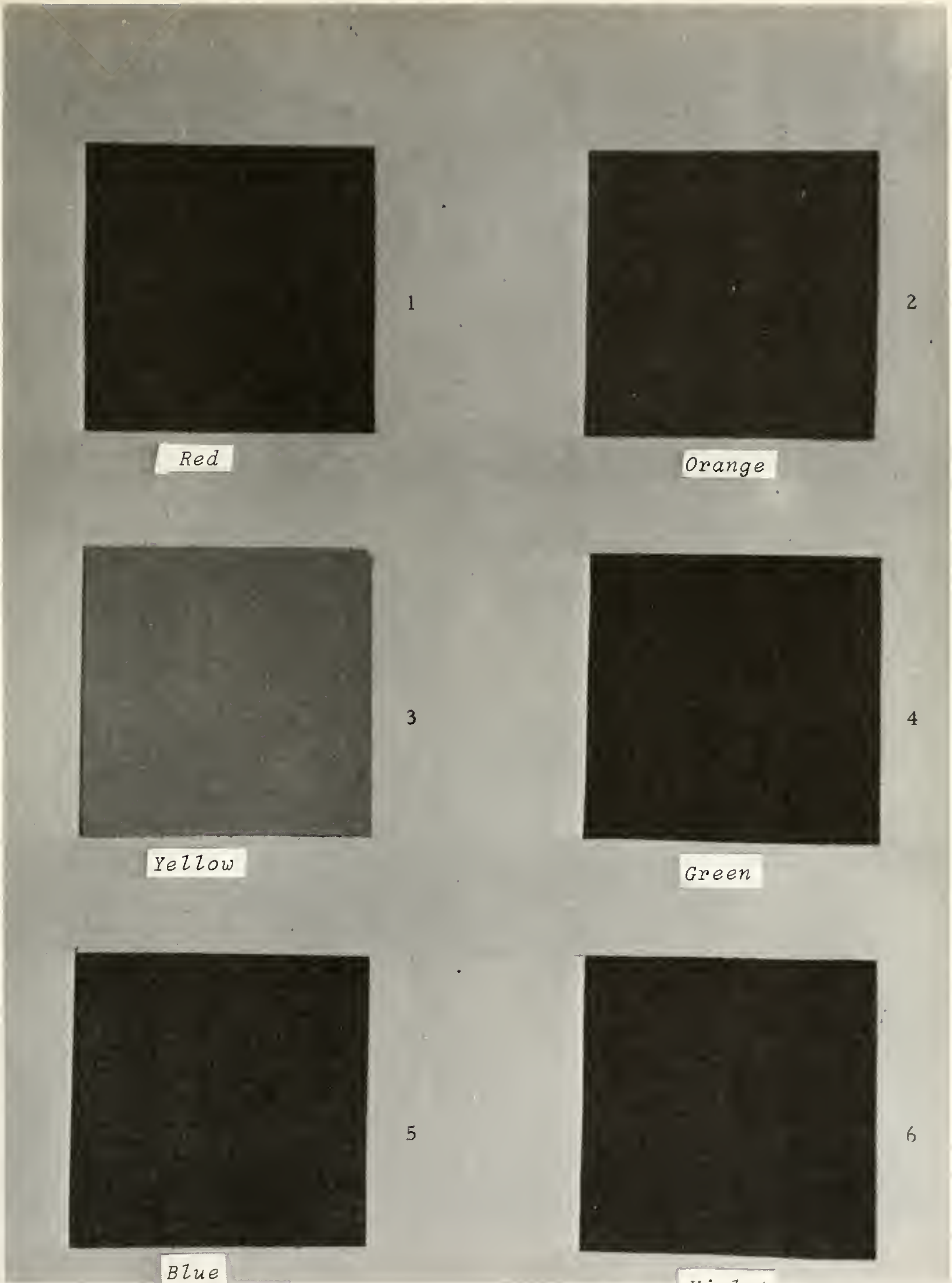
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3
Yellow
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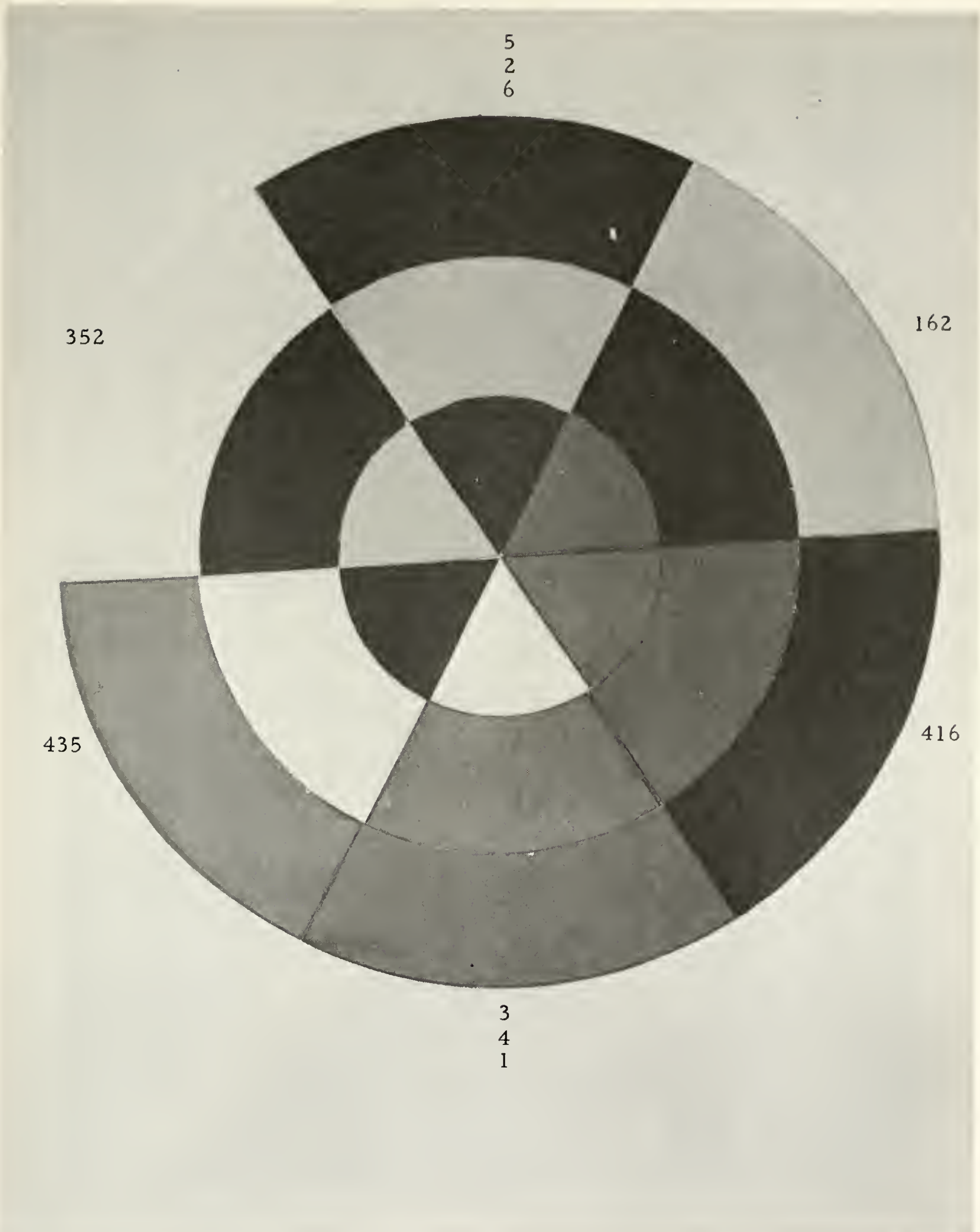
Blue
6
Violet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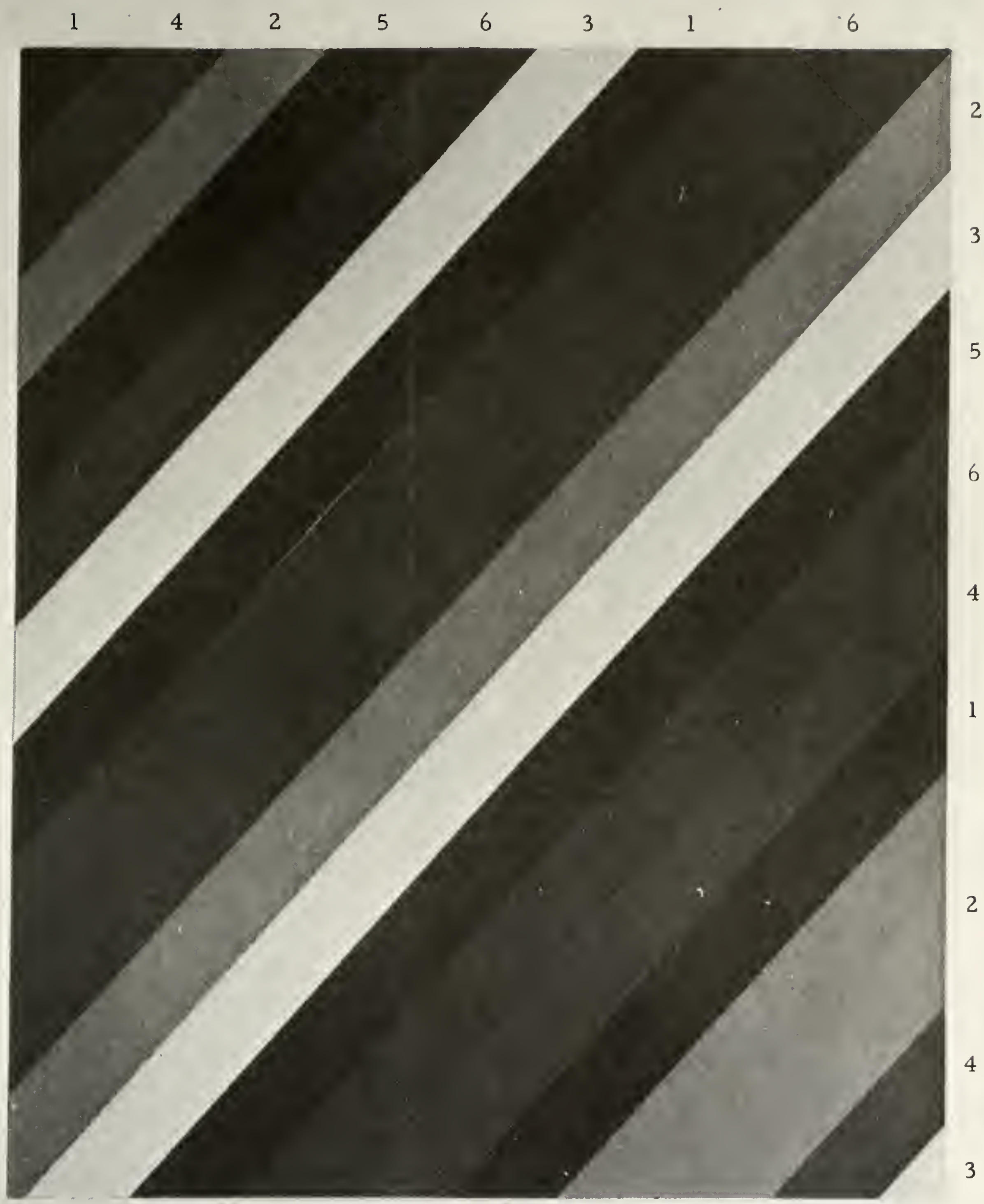
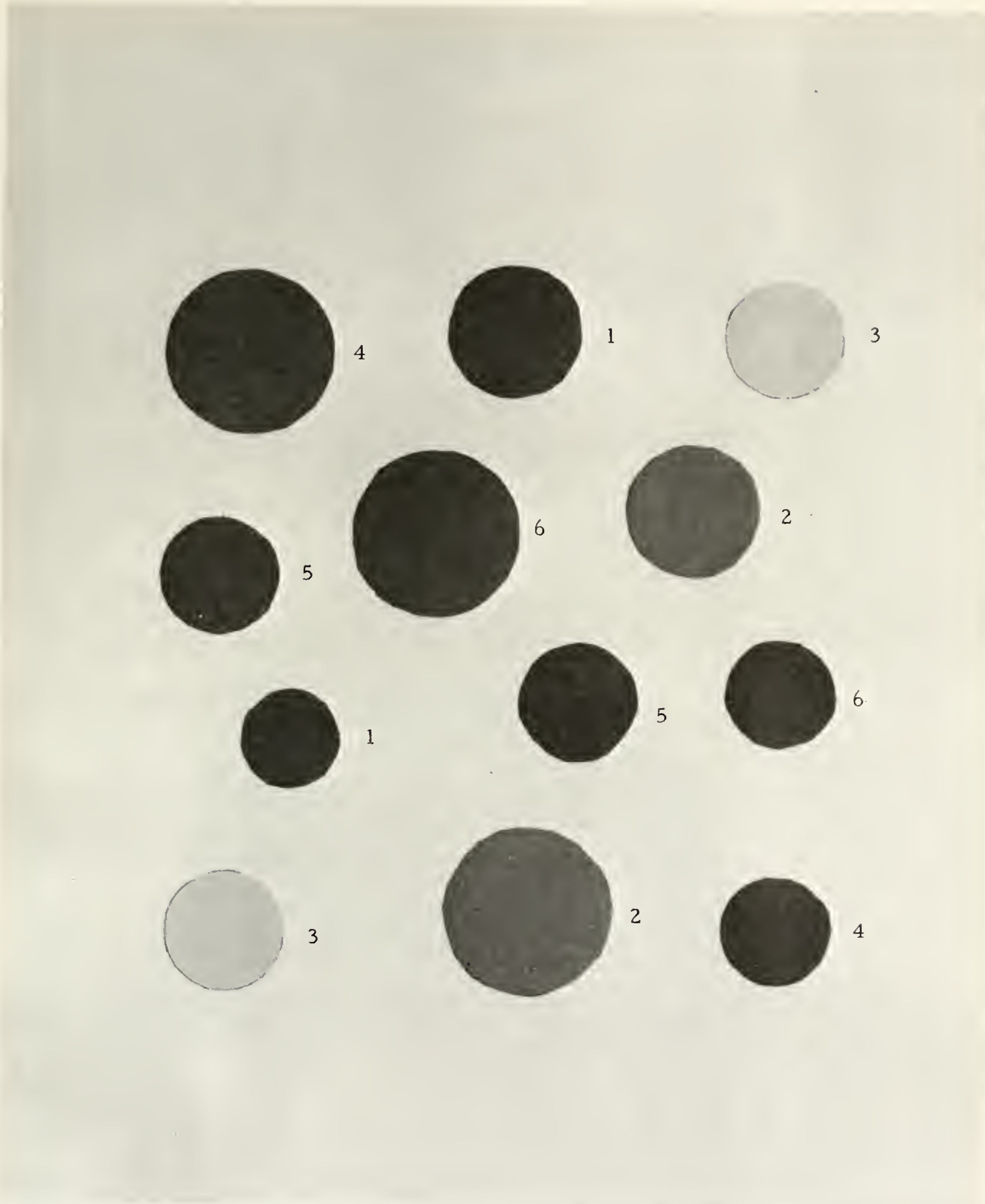
1

Appendix C. Color Angle Bars Left



Appendix D. Color Angle Bars Right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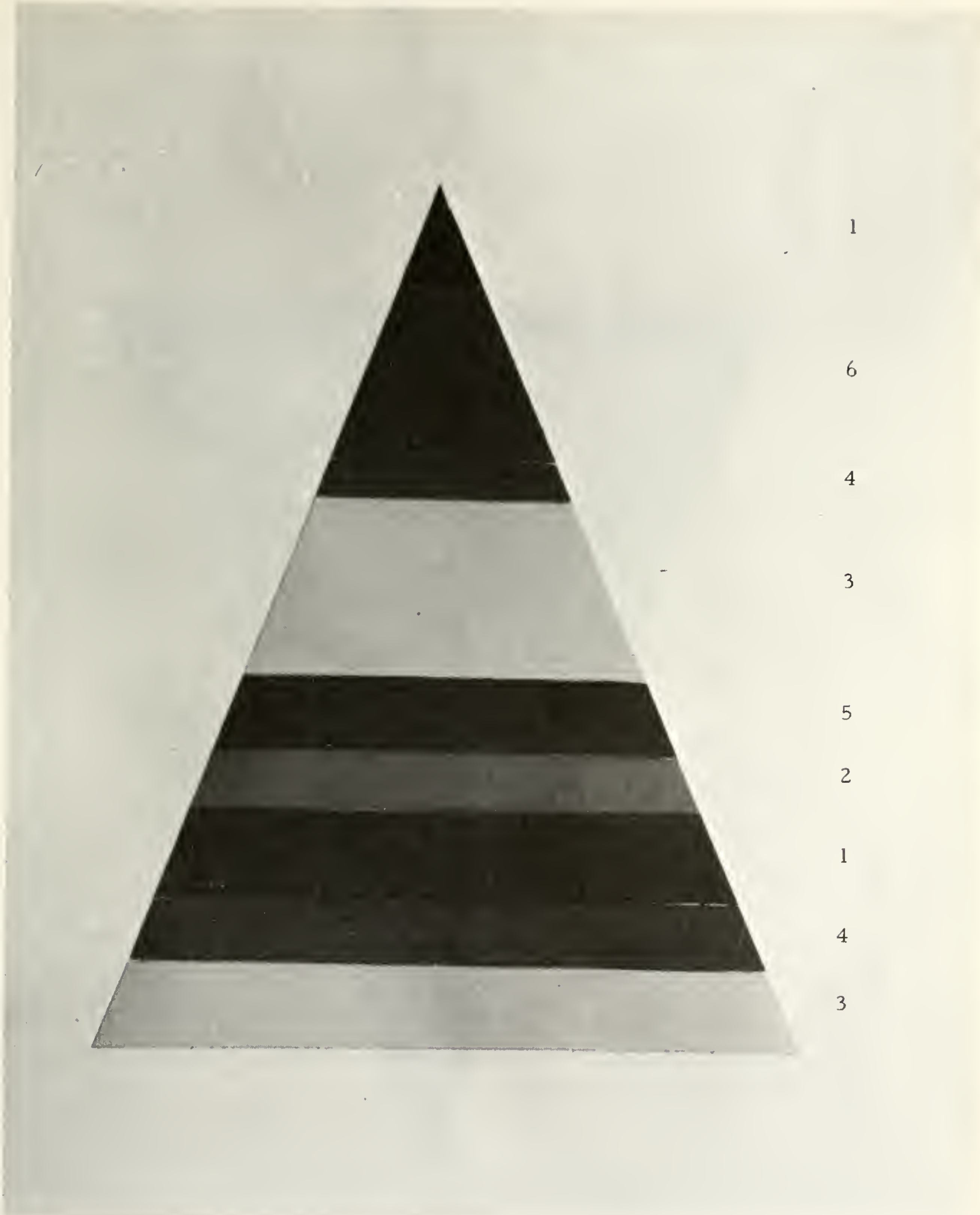
Appendix F. Color Pyramid

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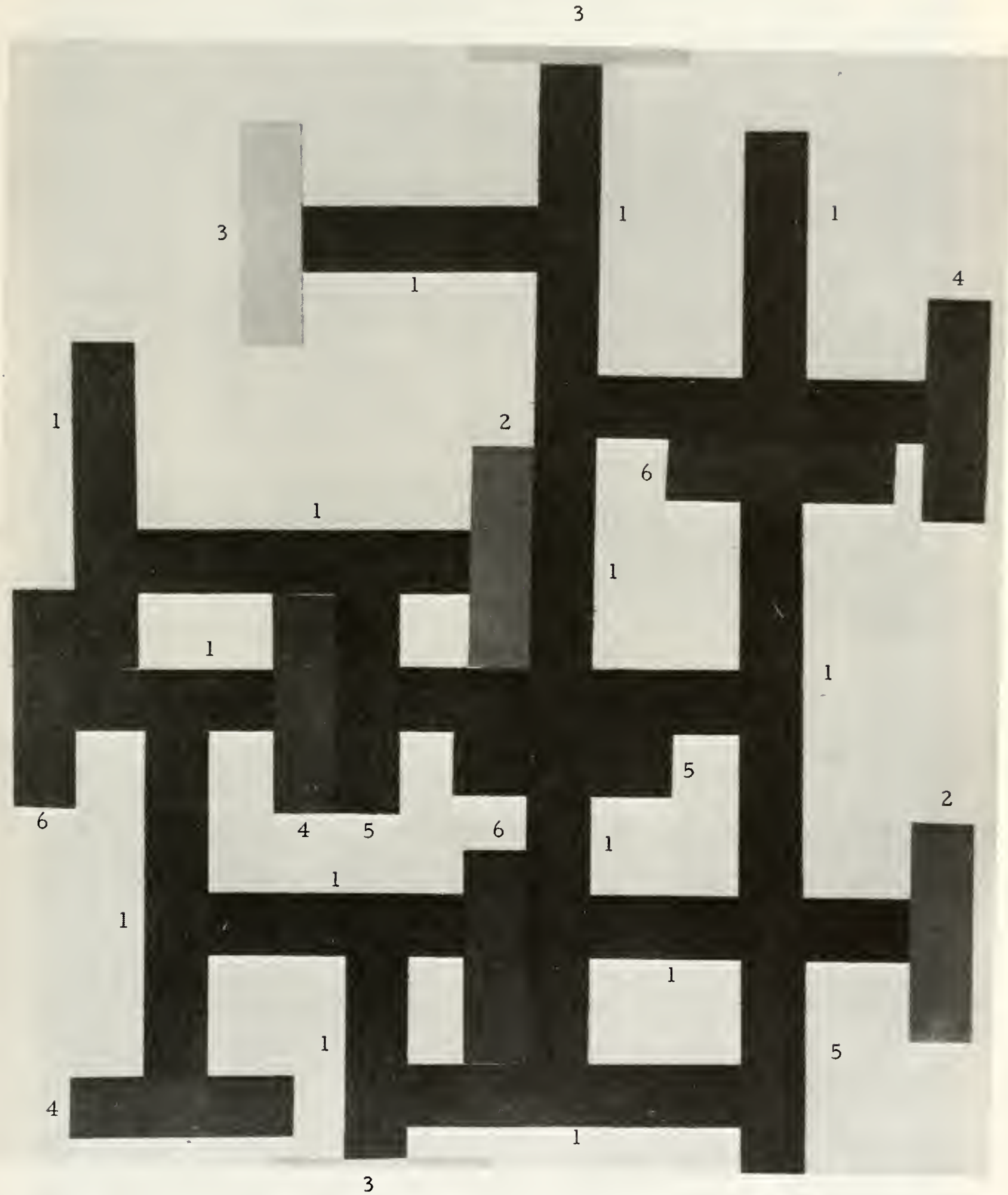
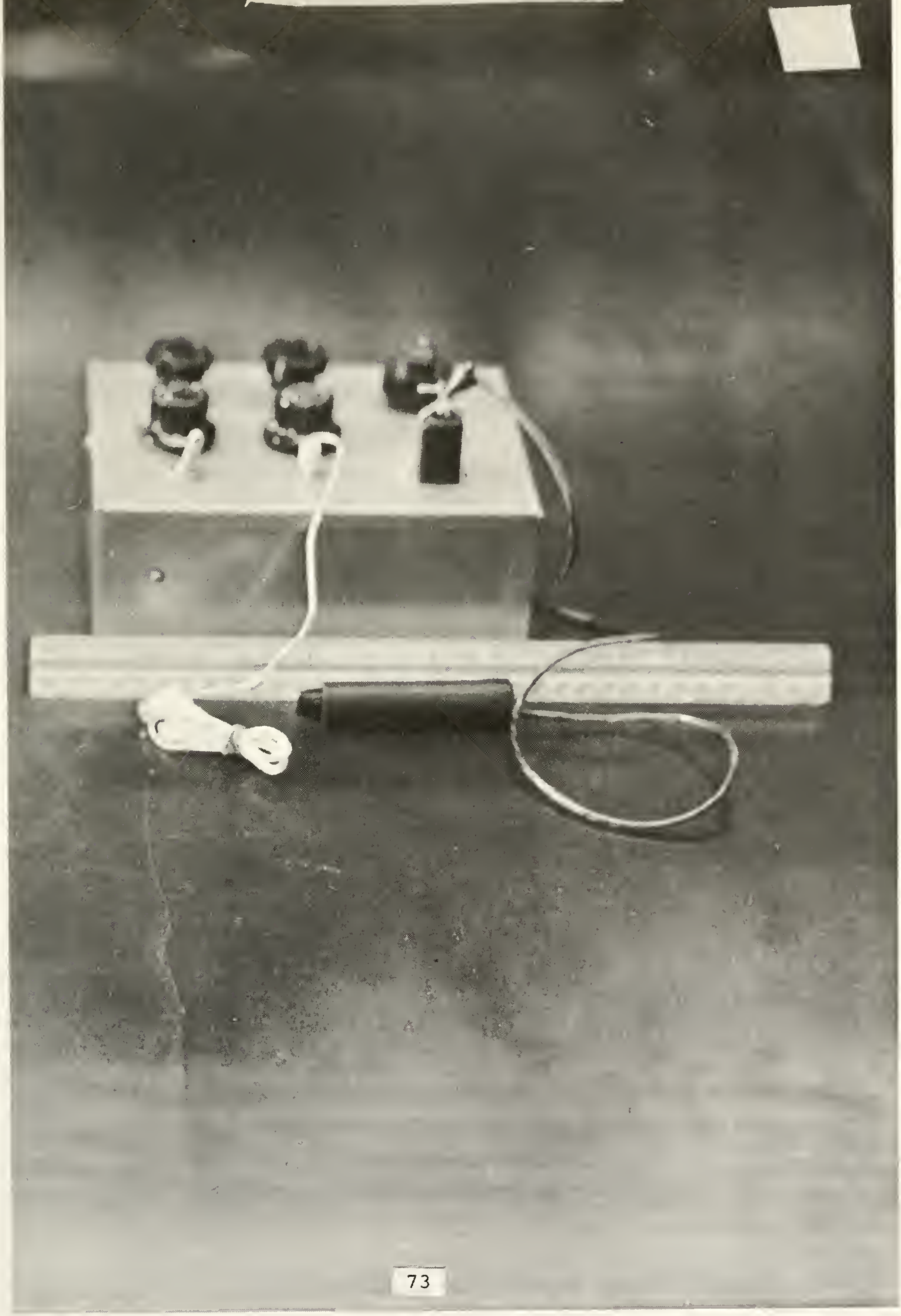
Appendix I. Color Maze



Appendix J. The Colorscope



QUESTIONNAIRE

NAME ______________________________ CIRCLE ONE: BOY GIRL

SCHOOL ____________________________ AGE ________ GRADE ______

INSTRUCTIONS

Read each statement carefully to the student and ask the student to answer YES if the student thinks the statement is true about him (her), and NO if the student thinks the statement is not true about him (her). Circle each answer.

YES NO 1. It is hard for me to keep my mind on anything.

YES NO 2. I get nervous when someone watches me.

YES NO 3. I feel I have to be the best in everything.

YES NO 4. I blush easily.

YES NO 5. I like everyone I know.

YES NO 6. I notice my heart beats very fast sometimes.

YES NO 7. At times I feel like shouting.

YES NO 8. I wish I could be very far away from here.

YES NO 9. Others seem to do things easier than I can.

YES NO 10. I would rather win than lose in a game.

YES NO 11. I am secretly afraid of a lot of things.

YES NO 12. I feel that others do not like the way I do things.

YES NO 13. I feel alone even when there are people around me.

YES NO 14. I have trouble making up my mind.

YES NO 15. I get nervous when things do not go the right way for me.

YES NO 16. I worry most of the time.

YES NO 17. I am always kind.

YES NO 18. I worry about what my parents will say to me.

YES NO 19. Often I have trouble getting my breath.

YES NO 20. I get angry easily.

YES NO 21. I always have good manners.

YES NO 22. My hands feel sweaty.

YES NO 23. I have to go to the bathroom more than most people.

YES NO 24. Other children are happier than I.

YES NO 25. I worry about what other people think about me.

YES NO 26. I have trouble swallowing.

YES NO 27. I have worried about things that did not really make any difference later.

YES NO 28. My feelings get hurt easily.

YES NO 29. I worry about doing the right things.

YES NO 30. I am always good.

YES NO 31. I worry about what is going to happen.

YES NO 32. It is hard for me to go to sleep at night.

YES NO 33. I worry about how well I am doing in school.

YES NO 34. I am always nice to everyone.

YES NO 35. My feelings get hurt easily when I am scolded.

YES NO 36. I tell the truth every single time.

YES NO 37. I often get lonesome when I am scolded.

YES NO 38. I feel someone will tell me I do things the wrong way.

YES NO 39. I am afraid of the dark.

YES NO 40. It is hard for me to keep my mind on my school work.

YES NO 41. I never get angry.

YES NO 42. Often I feel sick in my stomach.

YES NO 43. I worry when I go to bed at night.

YES NO 44. I often do things I wish I had never done.

YES NO 45. I get headaches.

YES NO 46. I often worry about what could happen to my parents.

YES NO 47. I never say things I shouldn't.

YES NO 48. I get tired easily.

YES NO 49. It is good to get high grades in school.

YES NO 50. I have bad dreams.

YES NO 51. I am nervous.

YES NO 52. I never lie.

YES NO 53. I often worry about something bad happening to me.

Appendix L. Instrumentation and Standardization of the Colorscope

Instrumentation. The two photoresistors in the reading head of the colorscope were filtered optically in the color of light to which they responded. One unit responded primarily to red and the other responded primarily to blue. This was accomplished by the insertion of the color sensitizing head which filtered the light reflected by the material that was being investigated. The color red controlled the bias of the voltage-sensitive oscillator which, in turn, produced a predetermined sound. The sound produced was considered the base for red. In a similar operation the upper section oscillator was calibrated by placing it on a piece of blue matte paper and adjusting it to a known tone. These two adjusting operations were done in much the same way a person would tune a musical instrument. Consequently, this tone was the base for the color blue. During the time the oscillator was being adjusted for the color red, the volume of the lower section's oscillator was attenuated to zero level to prevent interference by it responding to a harmonic component. When tuning the upper oscillator to calibrate the colorscope to blue, the lower oscillator was attenuated to a null response.

Standardization of the instrument. The colorscope was tuned to a standardized audiooscillator, with the primary standard being station WWV of the Central Radio Propagation Laboratory of the Bureau of Standards, National Bureau of Standards, near Washington, D.C. The color violet was tuned to "A," 440 cycles per second with a carrier of 5.00 m.c. received by a National HRO-7 Communicator Receiver located at West High School's physics laboratory, Phoenix, Arizona.

Appendix M. Age, Sex, and Grade for the Experimental Group

Pupils	*Sex*	*Age*	*Grade*
EA	F	12.10	7
EB	M	9.11	2
EC	M	8.20	2
ED	F	10.11	5
EE	F	10.90	3
EF	F	9.40	3
EG	M	7.10	3
EH	M	10.10	3
EI	M	13.90	7

Appendix N. Age, Sex, and Grade for the Control Group

Pupils	*Sex*	*Age*	*Grade*
CA	F	10.60	5
CB	F	13.50	8
CC	F	13.90	3
CD	F	9.80	2
CE	M	7.80	2
CF	F	13.30	8
CG	M	12.00	5
CH	M	8.10	3
CI	F	14.50	7

PRELIMINARY REPORT ON RESEARCH COMPLETED IN 1966 USING THE KAY ULTRA AID FOR THE BLIND

H. F. Priest

This experiment involved the use of the Kay Ultra Aid by 24 subjects over a period of about 13 weeks. For the purposes of comparing different sorts of training, the sample was split into three groups: one received training with movement, another received training with no movement, and the third group received no training. After the training sessions all subjects made approximately 2,000 judgments, spread over 16 to 20 half-hour sessions, of the size and distance of test objects. In general, distance judgments were much more precise than size judgments and they also were less affected by changes in the total stimulus situation. In particular, perceptual constancy, a main interest of this study, was found to operate more with distance than with size judgments. Differential training had little or no effect, probably because the training period was so brief.

AIMS

The Kay Ultra Torch most often has been used in outdoor-obstacle-course investigations of ease and accuracy of navigation. Hitherto there has been no attempt to explore the psychophysics of the torch. Hence the aims of this study are somewhat different from those of previous investigations. They were:

1. To discover the influence of movement relative to the environment during training on later performance with the aid.

2. To obtain quantitative measures of the following aspects of size and distance perception in the use of the aid.
   a. Discrimination thresholds for size and distance--that is, the difference between two test objects which would be just-noticeable to the subject under various conditions
   b. The extent to which estimation of size and distance remains constant when changes are made in the remaining variables (size, distance, texture, respectively). Measures were taken with and without the existence of a background to the stimulus objects.

3. To determine the relationship, if any, of measures of personality, auditory acuity, and auditory discrimination in another setting (Seashore Measures of Musical Talents), to ability in using the aid.

EXPERIMENTAL DESIGN AND PROCEDURE

Subjects

Twenty-four student volunteers from undergraduate psychology classes of the University of Canterbury were used as subjects. All were sighted and were blindfolded for the purpose of the experiment. Each attended two approximately half-hour sessions per week for which they were paid five shillings per session. The number of sessions ranged from 16 to 27 because there was a certain program of work to be got through, rather than a certain number of sessions.

Equipment

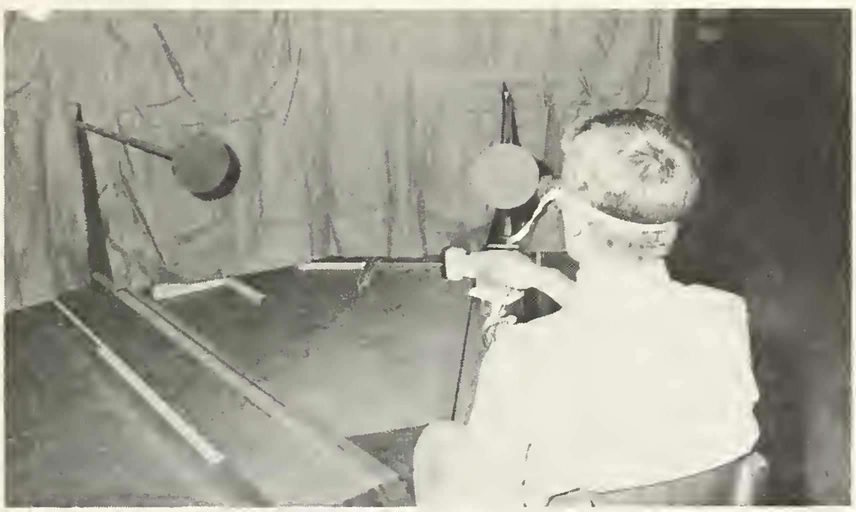
For the training period, stimuli were discs with various surfaces (hardboard, carpet, and gravel) mounted on doweling stands. For the experimental period a rig was used consisting of movable trolleys and poles. This equipment allowed stimuli to be presented normally to the beam of the torch at known distances with a constant angle of separation and with minimal interference from the supports of the stimuli. Changes in stimuli and in distances could be made rapidly, quietly, and accurately.

The size of disc used ranged from 2.5 in. to 18 in. in 1/4-in. steps. The main base distances used in making judgments were 3, 5, and 7 ft. The three textures were not represented in all sizes.

Method

Training sessions. Two groups of eight subjects each were given training, the remaining eight subjects being the "no-training group." The two training groups differed only in that one group was required to move relative to the environment using the torch while the other group was not permitted so to move. The training task for all these subjects was that of learning to recognize different sizes, distances, and textures with verbal feedback after every judgment. For distance training, the subject was presented with stimuli at seven different distances (2 to 8 ft inclusive, at 1-ft intervals) using discs of 4.5, 9, and 18 in. diameter faced with hardboard, carpet, or gravel. For size training, five different sizes (4.5, 7, 9, 14, and 18 in. diameter) faced with hardboard, carpet, or gravel were presented at 3, 5, and 7 ft. from the subjects. For texture training, the three different textures in diameters of 4.5, 9, and 18 in. were presented at distances of 3, 5, and 7 ft from the subject.

In the first six training sessions, successive judgments of each variable were made with only the judged variable changing. On the seventh session, the stimuli could change on all three variables between each two judgments. Measures were taken only on the last two training sessions; we were interested in the differential influence of training on later performance, not in the learning process during these training trials.



Experimental session. This involved all 24 subjects. All measures were taken using the method of limits, with modifications, with a step of 1/4 in. in both size (diameter) and distance. With constancy judgments the series was stopped after two equal judgments were given in that series, whereas with the other judgments each series was continued through the equality judgments to two successive larger or smaller judgments, depending on whether it was an ascending or descending series.

Measures of discrimination (as opposed to constancy measures) were obtained both before and after the block of trials concerned with constancy to check whether learning had occurred during the constancy period. Distance discrimination judgments were made using 9-in. hardboard discs with standards of 3, 5, and 7 ft distance from the torch, and all size discrimination judgments were made using 4.5-, 9-, and 18-in. diameter discs as standards 5 in. from the torch. Twelve series of judgments were made at each level of both variables before constancy and eight series of judgments at each level of both variables after the constancy trials. All possible order effects were controlled by counterbalancing the order of presentation over subjects.

Discrimination measures were calculated for each subject in each situation by halving the difference between the experimental upper and lower thresholds using the upper threshold from descending series and the lower threshold from ascending series. This was thought desirable because response bias could undoubtedly affect other ways of arriving at this figure.

In the constancy session size judgments were made comparing hardboard variables at 5 ft with 9-in. diameter hardboard standards at 3 and 7 ft and with 9-in. carpet standards at 3, 5, and 7 ft. In this same constancy series distance judgments were made comparing a 9-in. diameter hardboard variable with 4.5- and 18-in. diameter hardboard standards and 4.5-, 9-, and 18-in. diameter carpet standards at 3 ft. Half the subjects made their judgments with minimal background cues, as was the case with all previous judgments and half made their judgments with a constant background provided by a hessian screen 6 ft high and 15 ft wide, slit to allow the test stimuli to show through.

Four series of judgments were obtained from each subject under each condition and an estimate of subjective equality was obtained by averaging the four thresholds. The area of uncertainty associated with each estimate of subjective equality was found by taking the distance between the two ascending and two descending thresholds from each set of four.

When the experiment proper was completed, all subjects were asked to rank the size and distance judgments as to the ease with which they could make them. The training groups also ranked texture judgments. The subjects were also asked to specify, if they could, the cues they were using in making different kinds of judgments, given that the possible cues were pitch, loudness, scanning width, timber, or any other. If more than one cue was specified, they were asked to rank them in order of importance.

Measures of Individual Differences

All subjects plus a control group of 19 were tested on the pitch, loudness, and time tests of the Seashore Measures of Musical Talents both before and after the experiment. The timber subtest of the Seashore was also included in the afterexperimentation session. These tests were given to obtain measures of the subjects' ability to discriminate relevant auditory variables.

The audiometric test was also given to all experimental subjects to obtain a measure of auditory acuity. They were also given the Eysenck Personality Inventory, Form A, to obtain some measure of personality variables.

RESULTS

Training

Differential training, or in fact any training at all, had little if any effect on later performance. It now seems likely that the period allocated to training was far too short. Significant effects were found with distance judgments in the seventh training session, the training group which moved relative to the test stimuli showing the greatest amount of error. Also there was an interaction with background cues on the area of uncertainty associated with size constancy judgments. The training group not allowed movement had the smallest area of uncertainty when background cues were introduced. Thus it appears that in this situation training without movement leads to more accurate judgments when the objects differ in more than one way in those situations where there are no background cues. This skill is disturbed by the introduction of background cues. A plausible reason for this could be that those who were allowed movement in the initial training session were, in fact, overloaded with information and became confused thereby. In the same way, those subjects not allowed movement were perhaps overloaded by the introduction of background cues, the previous trials being very much closer to the training activity.

Experimental Measures

Discrimination measures (just noticeable differences or jnd) for pooled data on all levels of size and distance are presented in Table 1. Analyses of variance showed that measures before and after the constancy sessions were not significantly different, suggesting that no learning occurred during constancy sessions.

Examination of the relationship between jnds and magnitude of stimuli demonstrated that there is no significant departure from linearity for either size or distance. Thus the data can be said to fit a modified form of Weber's law. The fit to Weber's law indicates that there is much more "perceptual noise" in size judgments than there is in distance judgments, a possible reason being the character of the torch beam.

The results of the constancy session show that for size judgments both perceived equality and the associated areas of uncertainty

Table 1

Discrimination Measure, jnd, in Inches for Size and Distance Judgments

Size jnd (stimuli at 5 ft)			
Diameter of standard in in.	4.5	9	18
jnd in in.	0.576	0.726	0.765
Distance jnd (stimuli of 9 in.)			
Distance of standard in in.	36	60	84
jnd in in.	0.303	0.396	0.587

can change significantly with change in the texture or distance of the object. Distance judgments of perceived equality are significantly influenced by the texture but not the size of the stimuli. The measures of the area of uncertainty associated with distance judgments are influenced significantly by both size and texture. The obtained values of perceived equality are presented in Table 2, together with measures of projective equality for the hardboard standards (that is, the size of object which would subtend an equal angle from the aid). The projective size for the carpet objects is not available because the necessary measures of changes in signal have not been carried out. However, because the carpet texture gives a softer signal than the hardboard discs, the projective size match would be expected to be smaller and the distance match would be expected to be closer. Thus it can be seen that all changes in subjective equality estimates are in the direction of a projective size match, although never an exact projective match. Hence it would appear that some constancy at least is demonstrated in this situation. The change in area of uncertainty is to larger values for carpet than for hardboard and also to larger areas of uncertainty when size is changed in distance judgments and when distance is changed in size judgments.

The addition of background cues does not significantly affect the subjective equality judgments but does give significantly greater areas of uncertainty for size judgments, indicating that the additional information hinders rather than helps (possibly an overload) as subjects have had, in this case, no previous experience of background cues.

On the rankings of ease of making judgments almost every subject ranked distance as the easiest and the size as the most difficult judgment to make. Pitch was given as the most important cue for distance by almost all subjects. Scanning width and loudness were both reported as cues to size judgments but there was little agreement concerning their relative importance. Eleven subjects

Table 2

Size Judgments in In. When a 9-In. Object of Differing Textures at Different Distances Is Compared with a Variable Size at 5 Ft

Texture of Standard	*Hardboard*			*Carpet*		
Distance of standard	3	5	7	3	5	7
Objective size	9	9	9	9	9	9
Subjective size	10.891	9.009	7.904	8.850	5.850	6.395
Angular size	12.000	9.000	6.000			

Distance Judgments in In. When a 9 In. Object at 3 Ft. Is Compared with an Object of Differing Size and Texture

Texture of Standard	*Hardboard*			*Carpet*		
Size of standard	4.5	9	18	4.5	9	18
Objective distance	36.000	36.000	36.000	36.000	36.000	36.000
Subjective distance	37.667	35.972	35.833	39.715	38.178	37.832
Angular distance	72.000	36.000	18.000			

ranked scanning width as most important, twelve ranked loudness as most important, and one gave timber as most important. Eight ranked scanning width as second most important and eleven ranked loudness as second most important. With texture judgments, timber was reported as being the most important cue in all cases where texture was judged.

Thus it would appear that while distance and texture judgments are based on one clearcut cue, size judgments can be based on at least two different cues with little agreement as to which is best. Perhaps this lack of one clearcut cue explains why size judgments were considered the most difficult to make and why they gave rise to larger jnds and less constancy.

Comparisons of performance before and after the experimentation as between the control and experimental groups shows a significant difference. The experimental group improves on the second session and the control group deteriorates slightly. Thus it would seem that at least some aspects of auditory discrimination were improved during the course of the experiment.

The interrelationship between the various external auditory and personality measures and performance with the torch were mostly nonsignificant. The only measure showing a significant relationship with performance in the experiment was the pitch test from Seashore which correlated with the size of the distance discrimination threshold. The twelve possible correlations ranged between .21 and .58, with a mean of .48, all but one being significant.

CONCLUSIONS

The brief training period used in this experiment produced little or no change in ability to make comparative judgments. Hence no conclusions can be put forward as to the advantages of different sorts of training. Within the context of this experiment the additional information provided by movement produced only a small overloading effect.

However, the fact that the training period was ineffective, highlights the very accurate judgments made by these (as-good-as naive) subjects (for example, see Table 2, Distance Judgments, where for two 9-in. hardboard discs the average error is .028 in.).

Distance discrimination is more precise (in in.), is rated as being more easily made, and is less affected by changes in the total stimulus situation than are size judgments. The only factor which upset distance perception in this study was differing textures of objects. Training must aim to correct this perturbation of perception. Size judgments have not shown up at all well. Unless considerably more skill can be induced by training, the aid cannot be said to provide satisfactory size perception in the limited area explored in this experiment. Such a skill may not be a *sine qua non* for navigation but would undoubtedly aid it. It may be tentatively concluded that this difference in accuracy between the size and distance judgments can be due to the fact that distance has one clearcut signal characteristic associated with it, while this is not true for size judgments. As reported, pitch discrimination of the Seashore test gives at least partial prediction of skill in distance discrimination with the aid. Time, loudness, and timber subtests of the Seashore seem not to be related to performance with the aid.

Auditory acuity and the personality variables covered by the Eysenck test do not appear to be related to performance with the aid.

MODELING A TACTILE SENSORY REGISTER[1]

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A detailed analysis was made of the data of a previous paper by Bliss et al. *(6). That paper describes a series of experiments, in which 2 to 12 simultaneous air-jet stimuli were presented on the 24 phalanges of both hands. In addition, new data from an early blind subject, whose performance was significantly better, is compared to the data of the original four subjects. Memory properties of all five subjects estimated by whole- and partial-reporting techniques gave evidence for a tactile short-term memory that* (1) *has a duration of a few seconds,* (2) *varies considerably in size (but not in temporal characteristics) for different* Ss, *and* (3) *has a capacity limited by spatial resolution. Tactile masking did not account for the limited spatial resolution, but a stimulus-spreading or lateral-excitation model did.*

Numerous results from mostly visual experiments have led several investigators to suggest models for human memory consisting of a system of several interacting parts. For example, according to the model of Atkinson and Shiffrin (2), the memory system is divided into three components: a sensory register, a short-term store, and a long-term store. Sperling (24) and Massa's (17) models are similar, but they call the sensory register "visual information storage" or a "short-term memory." In terms of these models, the best known evidence for a sensory register is the short-term visual after-image investigated by Sperling (23), Averbach and Coriell (4), Estes and Taylor (9, 10), and others. When it comes to other sense modalities, Atkinson and Shiffrin (2) point out, "There is not much one can say about registers in sensory modalities other than visual. A fair amount of work has been carried out on the auditory system without isolating a registration mechanism comparable to the visual one. On the other hand, the widely differing structures of the different sensory systems makes it questionable whether we should expect similar systems for registration."

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Figure 1 shows the specific model used as a framework for the analyses described in this paper. According to this model, when a tactile pattern is presented to the system, a filtered image of the pattern is transferred to the sensory register, where it begins to decay. As the image in the sensory register is decaying, a limited amount of this information is processed and transferred to the short-term store or immediate memory. Either the transferral process or the size of the short-term store limits the amount of information retained in the short-term store. This information can be stored without rehearsal for tens of seconds, and with rehearsal for indefinite periods. All responding by the subject is based on the information in his short-term store and thus does not directly reflect sensory register limitations. It is the purpose of this paper to present evidence for a tactile sensory register and to estimate quantitative parameters for its capacity, and its temporal and spatial properties. This evidence evolves from an extensive analysis of data reported in a previous paper (6).

Early in our experiments it became clear that widely different levels of performance could be obtained from different subjects, perhaps because of differences in training or development of the tactile modality. In order to attempt to obtain some idea of the range of performance possible, and yet run only a small number of subjects, we selected our subjects in a special way. Preliminary results from a standard echo-detection test conducted by Dr. Charles E. Rice indicated that the performance of a group of five early blind subjects (blindness occurring before the age of two) was superior to the performance of a group of six late blind subjects. We selected a subject (M_4) from the late blind and a

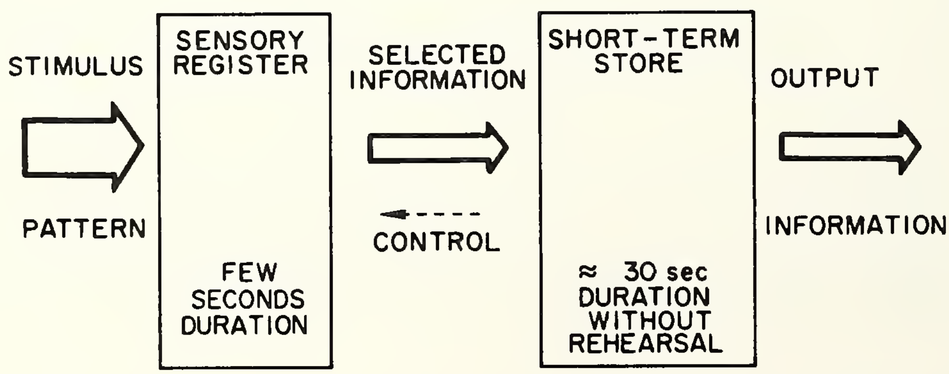

Figure 1. Framework for the Memory-System Model

subject (JK) from the early blind groups used by Rice for our tactile experiment. Obviously, with only two subjects, conclusions regarding the effects of blindness could not be obtained. However, since the memory of blind persons is almost legendary, we felt that an experiment that measured memory properties would be particularly sensitive to any differences among these subjects.

SUMMARY OF PREVIOUS EXPERIMENT

In Bliss *et al.* (6), we described two experiments involving brief (100-ms) tactile point stimuli applied to a number *n* of the 24 interjoint regions of the fingers of both hands (thumbs excluded). The *n* interjoint positions were simultaneously stimulated and *n* was *(1)* varied between 2 and 12, *(2)* always constant during a session, and *(3)* known by the subject. After each stimulus presentation the subject was required to make either a whole report or a partial report. When a whole report was required the subject's task was to name all *n* stimulus locations. In the previously reported experiment (Experiment 2, with which we will be mainly concerned), the interjoint regions of the fingers were labeled as shown in Figure 2 and the subjects, after training, were required to give their responses in alphabetical order. The maximum number of positions that can be correctly reported, after allowance for guessing behavior, is a measure of the short-term store capacity or the span of immediate memory.

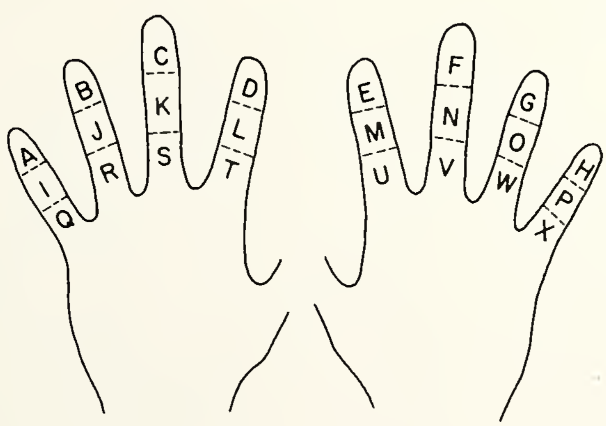

Figure 2. Finger Labeling for Two Hands

When a partial report was required, a marker stimulus occurred at -0.85, 0, 0.1, 0.3, 0.8, or 2.0 seconds following the termination of the tactile stimulus. The marker stimulus, usually one of three lights (or three tones for the blind subjects), indicated which portion of the stimulus positions to name. The upper light indicated that only the fingertips stimulated were to be named, the middle light indicated that only the middle phalanges stimulated were to be named, and the bottom light indicated that only the proximal phalanges stimulated were to be named. The partial report version of the experiment permitted investigation of the properties of any hypothetical tactile after-image or sensory register (that is, an eidetic or pictorial memory lasting a few seconds).

Included in that paper are data from three normally sighted subjects on Experiment 1, and data from three normally sighted subjects and one late blind subject on Experiment 2 (which was similar to Experiment 1 but with improved procedures). All of these subjects gave remarkably similar results except for one of the sighted subjects in Experiment 1. This subject had considerably more experience in tactile experiments than the others.

Below, we report on an analysis of the results of the original four subjects plus an additional subject who participated in Experiment 2. The fifth subject (JK) has been blind since birth and gave results (not previously reported) sufficiently different from the other subjects so as to suggest some modifications and extension of our previous conclusions.

CAPACITY OF THE SHORT-TERM STORE

Since our objective in this paper is to determine the characteristics of sensory mechanisms (in contrast to guessing strategies employed by the subjects) and since we would like to compare these characteristics with analogous characteristics determined from visual experiments, a correction of the data for stimulus-position guessing by the subject is necessary. The probability of responding correctly by guessing alone varies from about 0.08 to 0.5 as n is varied from 2 to 12. To determine the percentage of correct responses that resulted from perception of the stimulus alone requires knowledge of the subject's strategy for responding when he perceives imperfect information about the stimuli. Fortunately most, if not all, reasonable models for guessing behavior yield practically the same results. Guessing Model II, described in Appendix A, was used to correct all the data in this paper.

An analysis of variance was made on the data to test hypotheses regarding the effect of n and the similarity of the subjects. The hypotheses about the subjects were

H_1: The mean number of positions perceived by the late blind subject (M_4) was the same as the mean number of positions perceived by the sighted subjects (M_1, M_2, M_3).

H_2: Same as H_1 except that the early blind subject (JK) is compared to the sighted subjects.

H_3: The number of positions perceived by the late blind subject (M_4) satisfied the same functional relation as the number of positions perceived by the sighted subjects within an additive constant.

H_4: Same as H_3 except that the early blind subject (JK) is compared to the sighted subjects.

A 3 × 6 (sighted subjects × values of n) analysis of variance of the number of positions perceived was performed, the results of which are shown in Table 1. This analysis revealed that the late blind subject did not differ significantly from the sighted subjects in number of positions perceived. However, the data indicated that the early blind subject (JK) perceived a larger number of positions than the sighted subjects ($p < 0.025$) and also differed in the functional relation he produced between number of positions perceived and n ($p < 0.001$).

Table 1

Summary of Analysis of Variance of Positions Perceived in the Whole Report

Source of Variation	*df*	*Mean Square*	F *Ratio*	*Sig*
H_1	1	0.1689	<1	
H_2	1	25.2038	67.66	$p < 0.025$
Between M_1, M_2, M_3	2	0.3735		
Between n	5			
Linear Component	1	7.8807	193.82	$p < 0.001$
Remainder	4	0.0551	1.35	
H_3	5	0.0310	<1	
H_4	5	1.3427	33.02	$p < 0.001$
M_1, M_2, M_3, × n	10	0.0407		

Figure 3 gives the number of positions perceived (estimated by Model II described in Appendix A) as a function of *n* for these subjects. Since the results of the late blind subject were not significantly different from those of the sighted subjects, the results of these four subjects are averaged together. The data for Subject JK are shown separately. Figure 3 also suggests the reason H_4 was rejected; the slope of a line drawn through Subject JK's data is much steeper than the line drawn through the other subject's data.

The number of positions perceived in this whole-report experiment depended mainly on two factors: *(1)* the value of *n*, and *(2)* the length of time that the subject had been on the task. The dependence on time is suggested by the "zig-zag" lines connecting the points in Figure 3. If these points had been connected in the order in which the corresponding sessions occurred (that is, *n* = 2, 6, 10, 12, 8, and 4), the lines would have described an open "hysteresis" loop instead of a "zig-zag" line. That is, the number of positions perceived later in the experiment is greater than interpolation between the earlier values would predict.

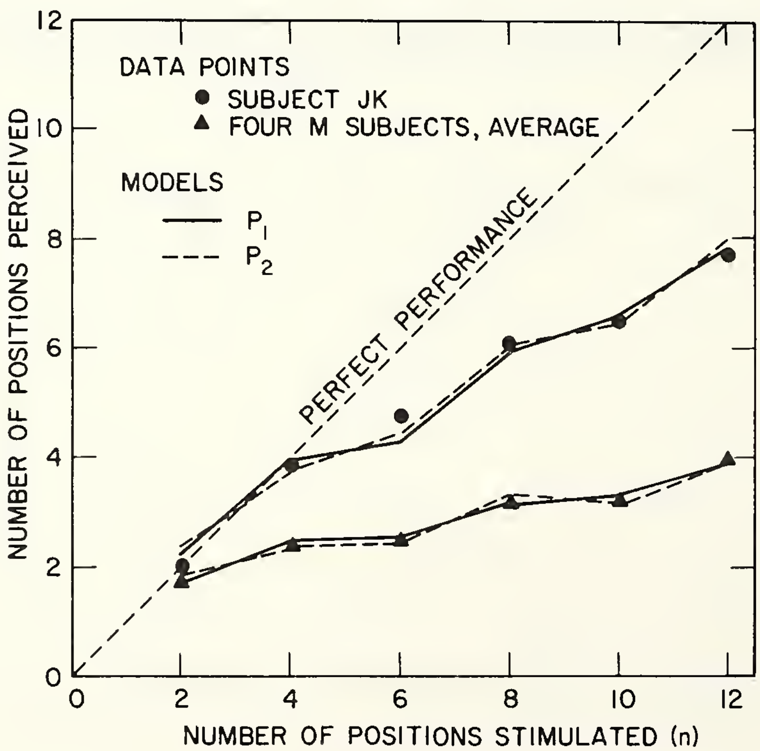

Figure 3. Whole-Report Data and Models

Two models were hypothesized regarding the functional relationship among P (the number of positions perceived), n (the number of positions stimulated), and d (the number of test days the subject had been on the task). A value of d for each value of n was obtained by averaging the number of test days on which n stimuli were presented. The values of d, in numerical order from $n = 2$ through $n = 12$, were 1, 6, 1, 5, 1.67, and 3.5.

The equations corresponding to these two models and resulting from the linear regression on the data from the three sighted subjects (M_1, M_2, M_3) and one late blind subject (M_4) are

$$P_1 = 1.306 + 0.190n + 0.066d$$

$$P_2 = 1.476 + 0.155n(1 + 0.080d)$$

The corresponding equations for the early blind subject (JK) are

$$P_1 = 1.042 + 0.534n + 0.121d$$

$$P_2 = 1.355 + 0.487n(1 + 0.037d)$$

The linear increase in P as a function of n is a major difference between these tactile results and Sperling's (23) results for vision. Sperling found that for n greater than 4, subjects correctly reported about 4.5 letters independent of n. To examine this difference in more detail, the data in the whole report curves of Figure 3 were sorted by phalanx--that is, into fingertip, middle, and proximal interjoint regions. Figure 4 shows the separate plots for each of the three phalanx groups for the average of the four subjects (M_1, M_2, M_3, M_4) and for subject JK. The most striking feature of Figure 4 is that the number of positions perceived on the fingertips increases linearly with n, while the positions perceived on the other phalanges approach a constant value with increasing n. This difference is most marked in the results of Subject JK, for whom the number of positions perceived on the fingertips corresponds to essentially perfect responses and the number of positions perceived on each of the other two groups of phalanges levels off at 1.6 positions. The slope of the positions perceived on the fingertips of the other four subjects was significantly less, and the saturation level of their middle and proximal phalanges was only 0.7 positions. In other words, this sorting separates the interjoint regions into two different groups: one that gives an increasing number of points perceived with increasing n, and another that gives a constant number of points perceived with increasing n. Thus, the upward slope of the curves of Figure 3 is due to the increasing number of positions perceived on the fingertips alone. Learning effects, as indicated by the zig-zags in the curves of Figure 4, seem to be mainly on the middle and proximal phalanges.

In the earlier paper it was suggested that the superior performance of Subject S on Experiment 1 was due to an ability to recode the stimulus patterns into larger units, or "chunks" of information, much as in visual experiments in which enhanced performance is obtained by recoding binary numbers into octal numbers.

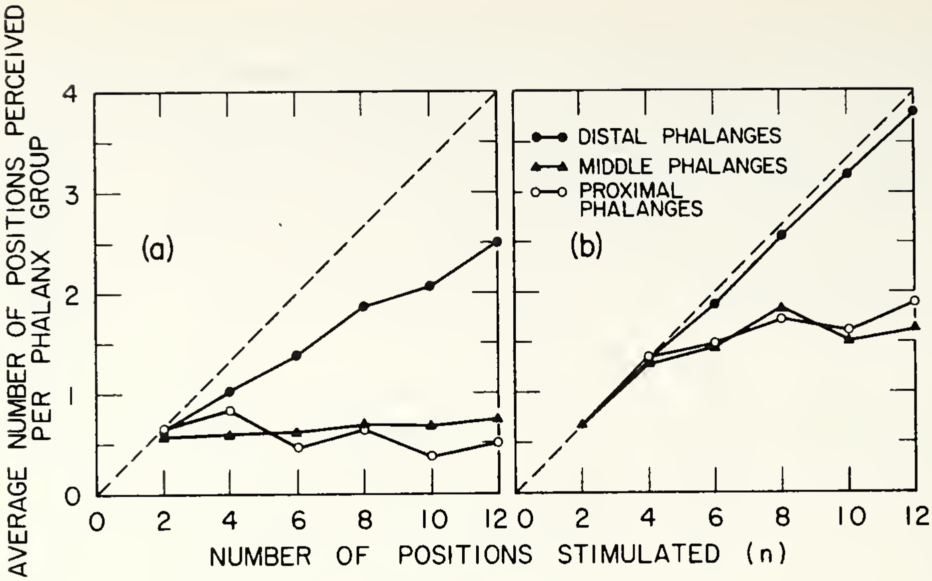

Figure 4. The Number of Positions Perceived by (a) the Four M Subjects, and (b) Subject JK on Each Group of Phalanges

(The dashed line represents perfect perception by each group.)

The effect of pattern organization on the perception of visual patterns has been studied by Attneave (3), Massa (16), and others. Attneave found that subjects perceived random and organized patterns equally well when responses were given immediately after the pattern presentation, while reports made 1/2 to 1 second after pattern presentation show significantly higher reporting accuracy from organized than from random patterns. Massa found that the organized patterns were always reported more accurately than random patterns.

We conducted three different kinds of tests to determine if pattern organization was a significant factor in the performance of the five subjects of Experiment 2. All three tests considered the set of 188 twelve-position patterns presented to each subject in the whole-report experiment. While the tests are described in detail by Hill (12), the major conclusions are *(1)* averaging across subjects, there was a slight increase ($p < 0.01$) of about 0.7 more positions perceived on patterns judged to be the most organized, than on those judged to be the least organized, *(2)* no subject, including JK, utilized pattern organization any more than the others, *(3)* Subject JK's concept of an organized random pattern was similar to that of sighted subjects, and *(4)* there were no groups of patterns more or less accurately reported by any pair of subjects. Thus we have been unable to detect any strong influence of pattern organization in these experiments.

INFORMATION TRANSMITTED BY THE SHORT-TERM STORE

While it is difficult to estimate directly the information that the whole report responses give about the stimuli, five lower bounds on this information are described by Hill (12). These bounds are shown in Figures 5(a) and 5(b). An important feature of Figures 5(a) and 5(b) is that with one or two positions per pattern, almost all the information of the stimuli patterns, $H(S)$, is transmitted, while with increasing n less and less information is transmitted by the correct responses.[2]

The basic difference between the information transmitted by Subject JK and the other four subjects can be described by noting that for all values of n where the information transmitted is not limited by the source, $H(S)$, Subject JK transmits 6 to 7 bits more information than the other subjects.

None of the bounds computed, except the finger-pattern bound, consider the additional information the errors give about the stimulus. In order to more completely specify the information transmitted, an upper bound as well as a lower bound should be obtained. The information content of the source, $H(S)$, serves as one upper bound, but not a very restrictive one. If subjects were made to guess additional locations of the patterns until they had correctly reported the patterns, an upper bound similar to that described by Shannon (20) could be obtained.

CAPACITY AND TEMPORAL PROPERTIES OF THE SENSORY REGISTER

An analysis of variance was made on the partial-report results, to test hypotheses similar to those tested in the analysis of whole-report results. The analysis indicated that the late blind subject (M_4) again did not differ significantly from the sighted subjects (M_1, M_2, and M_3) in the number of positions available. On the other hand, the early blind subject (JK) had a significantly higher ($p < 0.025$) number of positions available than the sighted subjects. The difference between Subject JK and the three sighted subjects can be adequately described by an additive constant. The data showed that Subject JK had 2.29 and 5.88 more positions available with $n = 6$ and $n = 12$, respectively, than did subjects M_1, M_2, and M_3.

Another hypothesis tested was that the number of positions perceived on each row of phalanges was the same. The analysis indicated that there were significant differences between the three rows, the distal phalanges being the most accurate and the middle phalanges the least.[3]

Still another hypothesis tested was that the number of positions available to M_1, M_2, and M_3 was the same for each value of marker delay. The analysis indicated that there were indeed different numbers of positions available with different marker delays for both $n = 6$ and $n = 12$. The data from M_1, M_2, M_3, and M_4 were averaged together and are shown in Figure 6(a). The corresponding

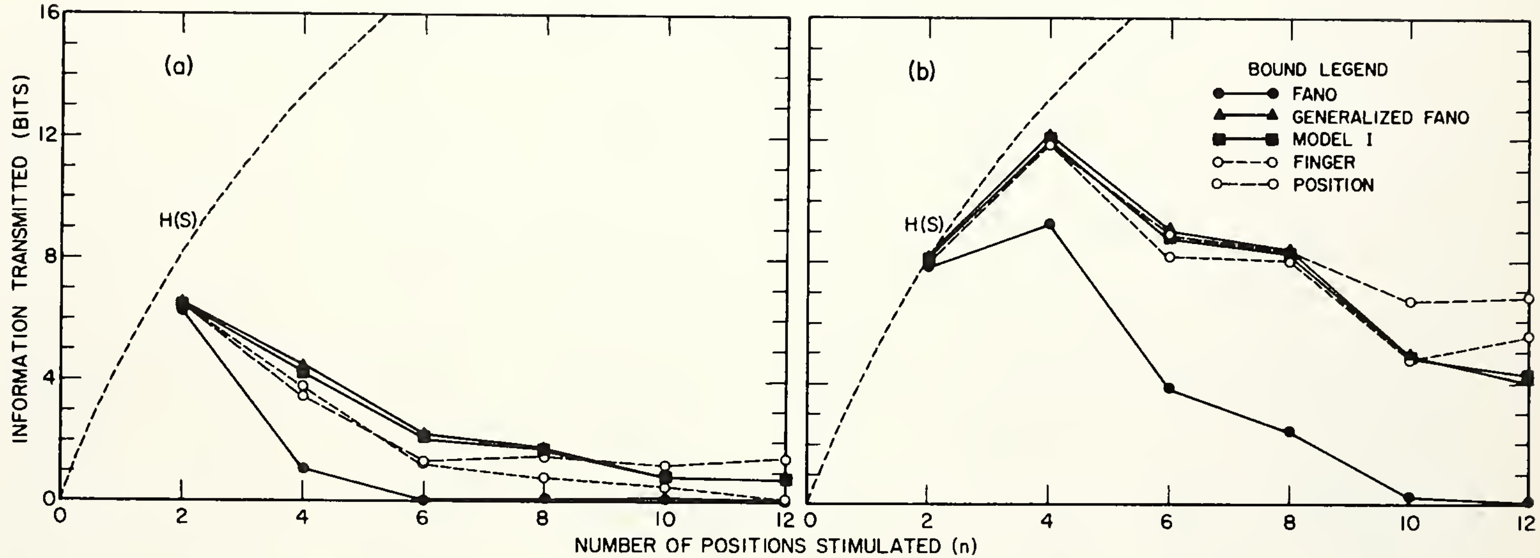

Figure 5. Information Bounds from the Whole-Report Data of (a) Subjects M_1, M_2, M_3, M_4, and (b) Subject JK

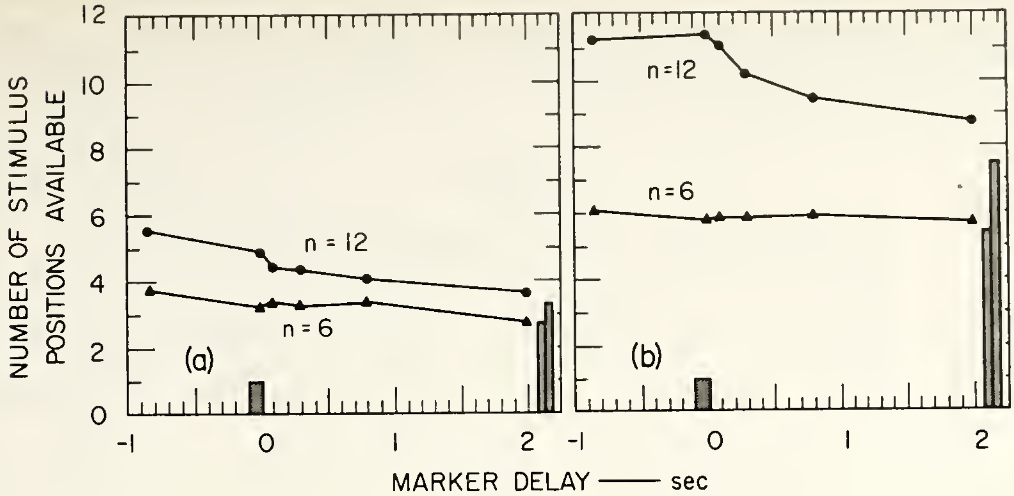

Figure 6. The Number of Positions Available to (a) the Four M Subjects, and (b) Subject JK, as a Function of Marker Delay

The crosshatched bar represents the timing of the stimulus and the solid bars represent the whole report from the partial-report patterns.

data for Subject JK is shown in Figure 6(b). The decreasing number of positions available with marker delay shown in Figure 6 is evidence for a tactile sensory register, and the time course of these curves describes the temporal characteristics of this sensory register.

Since the only variables affecting the number of positions available in this partial-report experiment are marker delay and subject, a simple linear-effects model will adequately describe the data. Such a model is

$$P = P(S) + P(m) + \varepsilon, \qquad (1)$$

where P is the sum of *(1)* a constant, $P(S)$, dependent on the subject, *(2)* an effect dependent on the marker, $P(m)$, and *(3)* a random variable, ε. The random variable is normally distributed with zero mean and standard deviation of 0.3 positions for both $n = 6$ and $n = 12$.

The second term of Eq. (1) can be modeled with the following equation:

$$P(m) = A + B \exp(-m/T), \; m \geq 0 \qquad (2)$$

where m is the time in seconds from the termination of the stimulus to the beginning of the marker, A is the number of positions stored in the immediate memory, B is the difference between the capacity of the sensory register and the capacity of the short-term store, and T is the time constant of the sensory register, arbitrarily assuming that the time course of information loss in the sensory register can be described by an exponential. Table 2 shows model coefficients obtained by fitting the data using the least squares criteria.

Table 2

Partial Report Model Coefficients for Eq. (2)

Subjects	n	*A*	*B*	*T*
JK	6	5.6		
Average of M_1, M_2, M_3, M_4	6	2.7	0.5	
JK	12	7.5	3.9	1.5
Average of M_1, M_2, M_3, M_4	12	3.3	1.6	1.3

The coefficient values shown in Table 2 indicate that the span of immediate memory of Subject JK is greater than seven positions, so that with $n = 6$ this subject perceives all locations of the patterns correctly and the sensory register does not enter into the results. With $n = 6$ the value of *B* for Subjects M_1, M_2, M_3, and M_4 was small (0.5 position), but still significantly larger than zero. With this small value for *B* it was not possible to determine a value for *T*.

For $n = 12$, the sensory register of all five subjects showed two features in common. One was that the capacity of the sensory register was about 50 percent larger than that of the immediate memory (52 percent for Subject JK and 48 percent for the other four subjects). The other common feature was that the time constant of the sensory register *T* was about 1.3 seconds. This compares to a value of about 3 seconds, roughly, estimated from Sperling's data with dark pre- and post-fields (23). The feature not shared by the subjects was memory capacity; Subject JK showed a memory capacity more than twice as great as that of the other four subjects.

LOCALIZATION ACCURACY IN THE SENSORY REGISTER

The detailed stimulus-response data from this experiment also contains information about the subject's ability to detect and locate particular stimulus positions within the patterns of stimuli. This information further characterizes the tactile sensory register and sheds light on properties of the underlying neurological mechanisms. This subsection describes a spread correlation analysis for determining the set of locations where a typical stimulus position will be reported.

When stimulus patterns consisting of only one position are presented to a subject and only one response is given, the subject's ability to localize each position can be estimated in a straightforward manner. For example, the percentage of positions correctly identified, or identified to the right, to the left, upward, downward, and so on, from the stimuli can be simply tabulated. Elithorn, Piercy, and Crosskey (8) made this type of analysis of single tactile stimuli applied to the fingers.

When several positions are stimulated simultaneously and several responses are given, the problem is more difficult. One approach to the problem is to devise a 1-to-1 mapping of the stimulus pattern onto the response pattern. Saslow (18) used this technique in an analysis of patterns with 1, 2, or 3 positions applied to a single fingertip. He matched the stimulus and response patterns by eye to determine the subject's errors in locating the stimulus positions. The difficulty in extending this approach to patterns with a large number of positions is that there are large numbers of mappings. For example, in patterns with n stimuli, there are $n!$ mappings between each particular pair of stimulus and response patterns, and the methods for selecting the most likely mapping from this large set of mappings are somewhat arbitrary. The results of a pattern-matching analysis could depend on the method chosen as on the subject's responses.

To overcome these difficulties, a statistical approach to the problem will be presented here. This method assumes that there is a certain probability that a stimulus presented at one location of a set of locations will be reported at each location in the set. For example, consider the middle and index fingertips of the left hand, Positions C and D (*cf.*, Figure 2). We assume that there is a certain probability, $P(C \rightarrow D)$, possibly zero, that a stimulus presented at Position C will be reported at Position D. The data for the analysis, to continue with the specific example, are a list of occurrences or nonoccurrences of stimuli at Position C with a particular set of patterns, and a similar list for responses at Position D. If there is a relationship between stimuli occurring at Position C and responses occurring at Position D, then we would expect that the probability of a response at Position D, given that a stimulus occurred at Position C, $\Pr(D/C)$, would be different from the probability of a response at Position D, $\Pr(D)$. The relationships among these three probabilities are developed in Appendix B.

Also in Appendix B, a function is developed that permits estimation from the data, of the probability, $P(S \rightarrow R)$, that a stimulus at one particular location causes a position to be reported in another specific location. It is shown that this function bears a strong resemblance to a correlation function, and for this reason the resultant values are termed spread correlations (abbreviated SC in the remainder of this paper). This SC function is shown to have the following properties:

1. If a stimulus (for example, *C*) always results in a response (for example, *D*), then the SC for this stimulus-response pair has a value of one.

2. If the occurrence of a particular response is independent of the occurrence of a particular stimulus, then the SC for this stimulus-response pair has a value of zero.

3. The sum of the SC for a particular stimulus and all 24 response locations is equal to or less than one. This sum represents the fraction of time the stimulus was detected.

A preliminary analysis of the average SC between all possible pairs of positions on the two hands was made using the whole report data of Experiment 2. The two basic results of this preliminary analysis were *(1)* locations separated by three or more finger-phalanx displacements were not confused significantly often, and *(2)* when subjects made location mistakes, they most frequently reported stimuli in the immediate neighborhood of a stimulus.

Because of these results, only the 13 SC values with the shortest displacements between stimulus location and response location were considered in detail. These displacements are as follows, in order of decreasing magnitude of the SC:

1. Zero displacement. SC values computed when stimuli and responses are the same location.

2. One-distal and one-proximal displacement.

3. One-left and one-right displacement.

4. The group of eight SC values that have a total displacement of two. The four orthogonal displacements in this group are two-left, two-right, two-distal, and two-proximal. The four displacements at 45° are one-right and one-distal, one-right and one-proximal, one-left and one-distal, and one-left and one-proximal.

The values of SC for each particular displacement can depend on several variables. Besides the subject and the number of stimulus positions, n, in the whole report, or marker delay, m, in the partial report, there are in general two spatial variables: finger and phalanx. In the SC analysis concerned with the effects of the spatial variables, only the four closest displacements (the most significant displacements) were considered. Since the interaction between the spatial variables were not significant, the SC values across the hands may be adequately represented by the effects of each spatial variable (finger and phalanx) alone. A schematic representation of this analysis of the spatial data of the whole report is given in Figure 7.

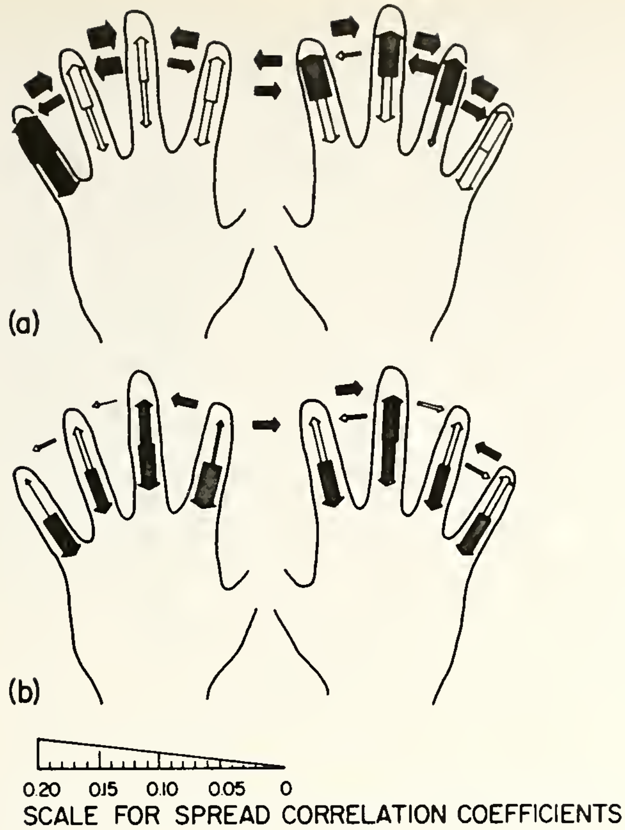

Figure 7. Confusions Made by (a) the Four Subjects, and (b) the early Blind Subject in the Whole Report

The width of the arrows is proportional to the average SC between fingers and phalanges. Dark arrows represent SC significantly greater than zero (5 percent *t*-test), while open arrows represent nonsignificant SC.

Several features of the confusions that subjects made in the whole-report experiments are made clear by comparing Figures 7(a) and 7(b). One is the greater number of left-right confusions made by the four M subjects compared with the number made by Subject JK. Another feature of the data is that, except for Subject JK in the whole report, there are more distal than proximal confusions made by the subjects. The proximal confusions of Subject JK can be explained by the reporting procedure used in the whole report, if this subject tended to repeat distal locations while reporting the middle and proximal stimulus locations. This conjecture is also consistent with the result that Subject JK made more distal confusions than proximal on the partial-report experiment, where responses are from only one phalanx row at a time. Krohn (13) and others also have noted that, in general, tactile location errors on the extremities were in the distal direction.

Thirty-five specific null hypotheses were tested regarding the direction of the subject's spation confusions, and the confusions mentioned in the preceding paragraph were all significant under certain of these hypotheses. In addition, there were significant confusions in the direction from the periphery of the area stimulated on each hand toward the center of this area. These inwardly directed confusions were significant in the left-right directions for all subjects in the whole report; and they were significant in the proximal-distal directions for all subjects in the partial report. Neither of these confusions changed direction in going from whole to partial report. Elithorn, Piercy, and Crosskey (8) also found significant left-right confusions toward the center of each hand. In addition, the data of Saslow (18) may be used to show significant inwardly directed proximal-distal confusions, although Saslow did not test his data for this effect. Another result of our analysis showed that more proximal-distal confusions than left-right confusions were made. Saslow (18) also noted that proximal-distal confusions were significantly larger than left-right confusions for stimuli contained on a single fingertip. In addition, Krohn (13) noted that radial-ulnar localization was superior to proximal-distal localization.

In the analysis discussed thus far, the SC values of the experimental variables (positions per pattern, n, or marker delay, m) were averaged together in order to obtain the spatial information from the data. When, instead, the SC values of the spatial variables (finger and phalanx) are averaged together, the effects of the experimental variables on the data can be investigated. Typical data obtained from this spatial averaging are given in Figure 8, which show the average values of SC plotted as a function of displacement for the four M subjects and separately for Subject JK. These data are from the whole report, with $n = 12$. The presentations of Figure 8 show the average probability of reporting a position correctly, of reporting a position to the left, or of reporting a position with any given displacement. If a subject reports all of the positions of the patterns perfectly, then a SC surface as in Figure 8 would have a central peak of one, and all other displacements zero. However, if a subject guesses at the positions, then all of his SC would be zero. The shape of the SC surface shown in Figure 8 indicates that the subjects most frequently reported the positions correctly and often reported positions next to the actual position. Seldom did they report positions two spaces away. Also, the central peak of Figure 8(a) is higher than that of Figure 8(b), indicating that Subject JK correctly identified more positions of the patterns than did the other subjects. The left- and right-side skirts of Figure 8(b) are smaller than those of Figure 8(a). This indicates that Subject JK made fewer left-right confusions than did the other subjects. The SC of all the subjects in both parts of the experiment are given in Figure 9. The presentations of Figures 8 and 10 for any part of the experiments can be constructed with these data. Figure 9 contains the 5 percent two-sided t-test for testing the difference between two points and the difference between each point and zero.

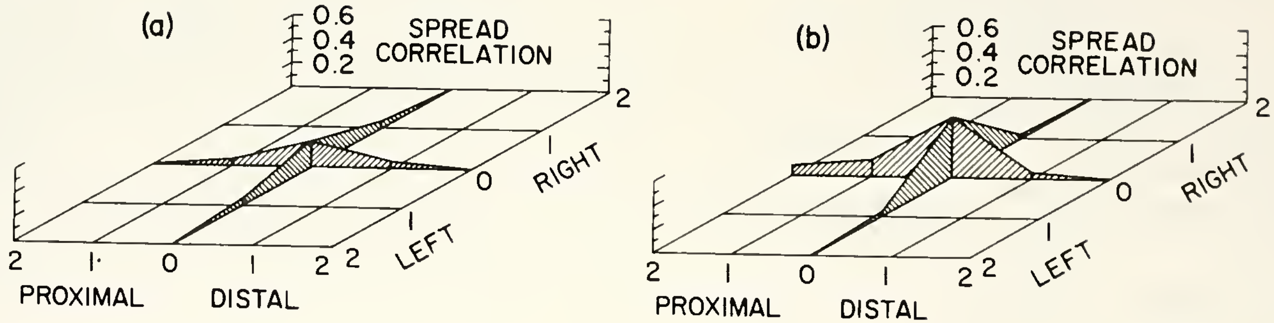

Figure 8. Spread Correlations of (a) the Four M Subjects, and (b) Subject JK, Computed from the Whole-Report Data with n = *12*

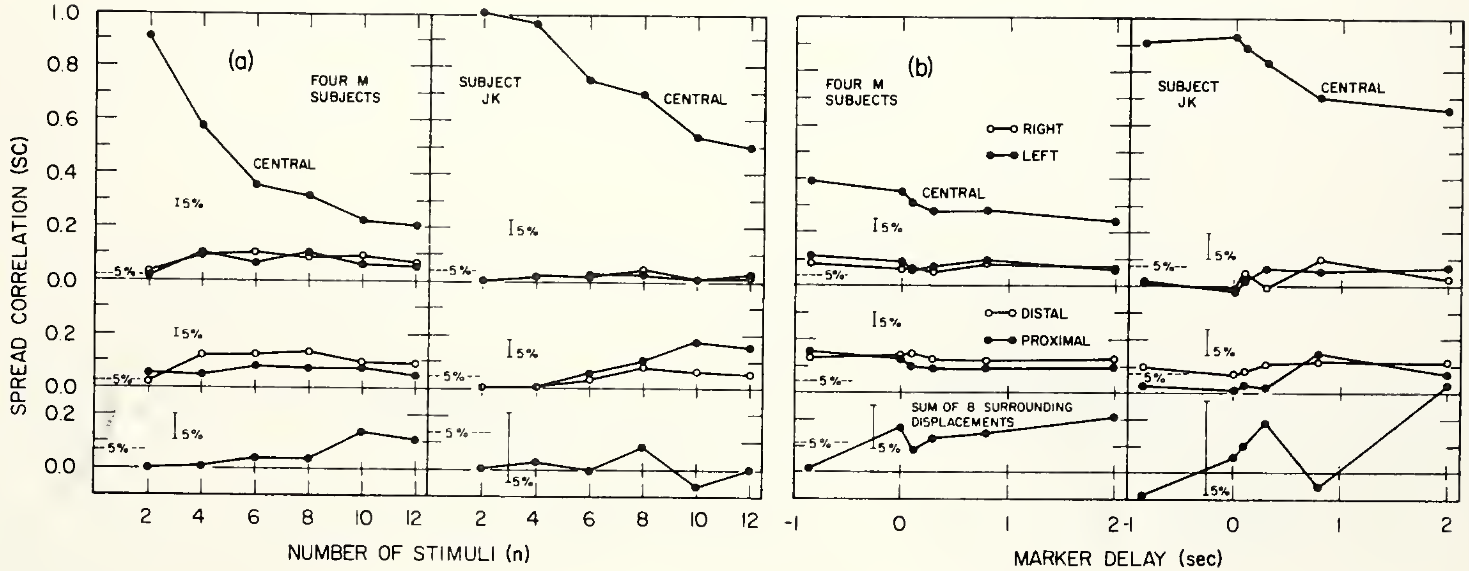

Figure 9. Spread Correlations for the Four M Subjects and Subject JK Computed From the Data of (a) the Whole Report, and (b) the Partial Report, with n = *12*

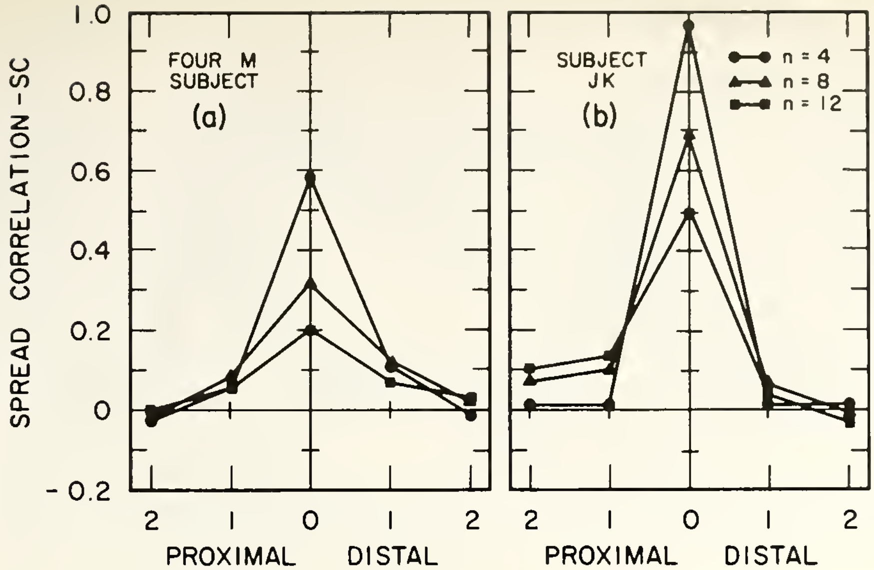

Figure 10. Typical Whole-Report Spread Correlations of (a) the Four M Subjects, and (b) Subject JK, with n *= 4, 8, and 12*

Figure 10 shows the SC of Figure 8 as well as the whole-report SC, with $n = 4$ and $n = 8$ plotted along the proximal-distal axis. Two different effects of the experimental variables can be noted in Figures 9 and 10: *(1)* the *e* general decrease in the sum of all the SCs with *n* in the whole report, and *(2)* the large relative decay of the central SC with respect to the relatively constant surrounding SCs. The first effect (detection) occurs because subjects perceive fewer positions of the patterns with increasing *n* and *m*. The second effect (localization) occurs because subjects do not localize the positions of the patterns as accurately with increasing values of *n* and *m*.

The results of these two independent effects in the data are illustrated by the hypothetical curves in Figure 11. The curves labeled *l* in both parts of Figure 11 are identical. When the detection process acts alone (no localization), the result is a constant attenuation of all the SC values, indicating a decreasing ability to detect positions, but a constant ability to localize them. The sum of the central SC value and the neighboring SC values is the fraction of positions that have been perceived. This sum will be referred to as the *detection factor*.

When the localizations process alone affects Curve *l*, the sum of all the SC values remains constant. The localization curves of Figure 11 indicate a decreasing ability to localize positions correctly, but a constant ability to detect them. In this case, the ratio of the central SC to the sum of all the SC changes, and indicates the fraction of the stimuli detected that are also correctly localized. This ratio will be referred to as the *localization factor*.

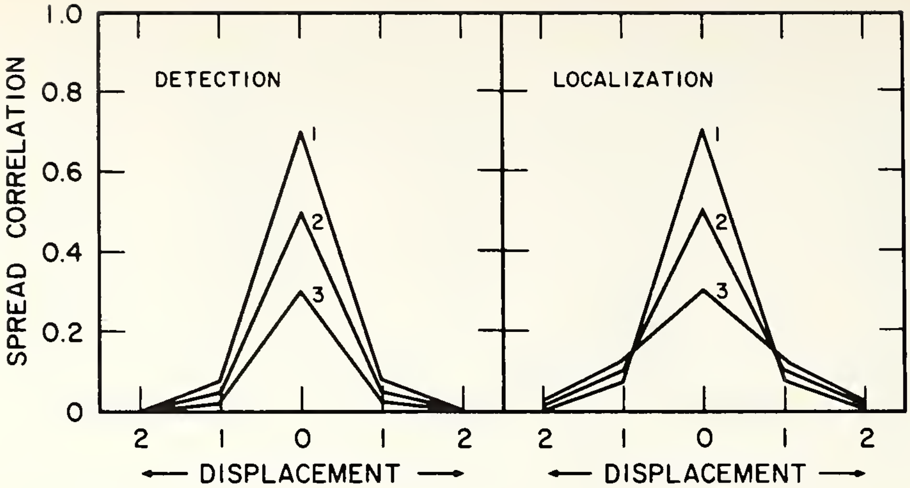

Figure 11. Examples of Purely Decaying and Purely Dispersing SC Plots

The localization and detection factors of the four M subjects and Subject JK were calculated, using the 13 most central SC displacements. Both factors computed from the whole-report data are presented graphically in Figure 12, and the partial report data are similarly given in Figure 13. Both figures contain the 1-percent and 5-percent two-sided t-tests for testing differences between any two points of the data of the four subjects. The t-tests for comparing data points of Subject JK are obtained by doubling the lengths of the lines. The significance of differences between the data points of Subject JK and the four other subjects can be tested by multiplying the line lengths by 1.73.

In general, localization has a more pronounced effect on the results than does detection. Since the localization factor is smaller than the detection factor, localization is the limiting factor in the perception of tactile patterns.

MASKING VS FACILITATION

Two different ways in which stimuli at neighboring locations might affect the perception of a given stimulus position can be described as masking and facilitation. Masking, or inhibition, is a common concept in psychology, usually meaning that the application of one stimulus reduces the strength of the sensation derived from another. Numerous investigators have reported masking with tactile stimuli. For example, Békésy (27, 28, 29) has shown that a model for tactile perception containing inhibition (the "neural unit") can explain a wide variety of tactile phenomena. He calculated the size and shape of the "neural unit" and showed

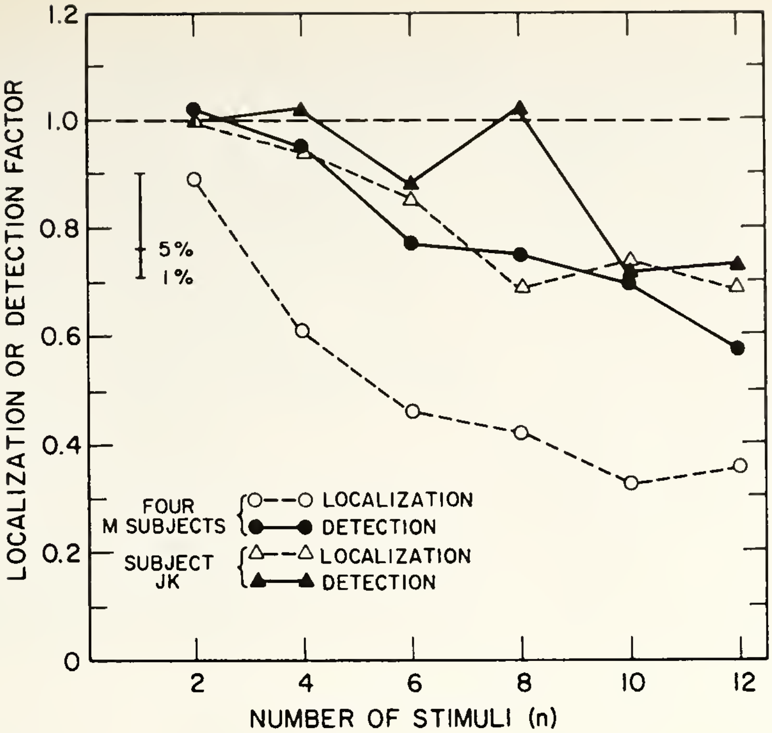

Figure 12. Localization and Detection Factors of the Whole Report

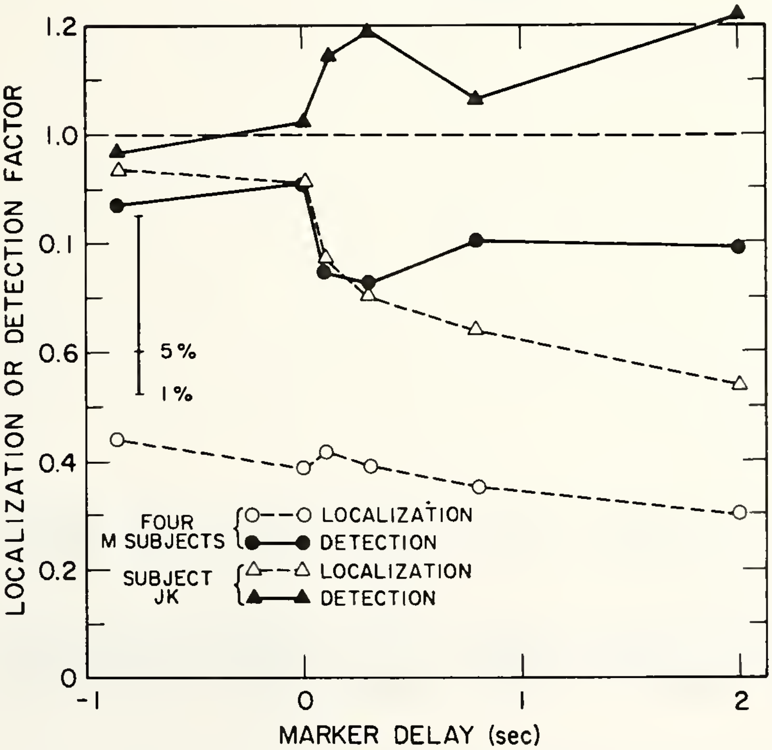

Figure 13. Localization and Detection Factors of the Partial Report with n = *12*

that inhibition extended over distances as great as 3 cm on the palm and lower arm. Uttal (26), using electrically stimulated tactile sensations separated 1 ms in time has shown the presence of masking between each pair of fingertips on the hand. Ethel Schmid (19), also using electrical stimuli, found that the maximum masking effect occurred between neighboring fingers with simultaneous or nearly simultaneous stimuli (interstimulus interval < 10 ms). Sherrick (21), using simultaneous mechanical pulsed stimuli, found that masking was more than 20 dB between the index and little fingers of one hand. Thus, one could reasonably expect masking phenomena to influence the data of our Experiment 2.

Facilitation is also a common concept, but not so widely reported in conjunction with tactile stimuli. We use facilitation here to mean that the application of one stimulus enhances the sensation derived from another.

In order to test whether masking could explain the low middle-phalanx accuracy of Experiment 2, two methods were used to compute the accuracy on the middle phalanges with each of the possible patterns of surrounding stimuli. The first method involved computing the spread correlation, SC, function and the second method involved computing the sensitivity parameter, *d'*, of the signal-detection model (15).

The data for these analyses were obtained by cataloging the stimuli and responses according to the following conditions: *(1)* Which one of the 16 neighboring stimulus patterns shown in Figure 14 was present, *(2)* whether a stimulus was present or not present on the middle phalanx, and *(3)* whether a response was reported or not from the middle phalanx. On the extreme left and right fingers, the pattern was determined by assuming that the outside location was the nonstimulus condition. Using this method, eight data points were obtained from each stimulus pattern. These data points were assembled into sixteen 2-by-2 tables of the form shown in Table 3, each table containing the totaled detection data for only one of the 16 "+" patterns. Using the entries in each table, the probability of a hit (a report given that the signal was presented) and the probability of a false alarm (a report given that a signal was not presented) were calculated. The resultant probabilities, along with a few curves of constant parameter *d'* and SC, are shown in Figure 15.

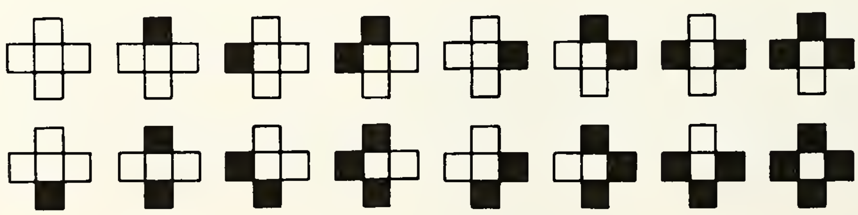

Figure 14. The Set of 16 "+" Patterns for Describing the Local Context of the Tactile Patterns

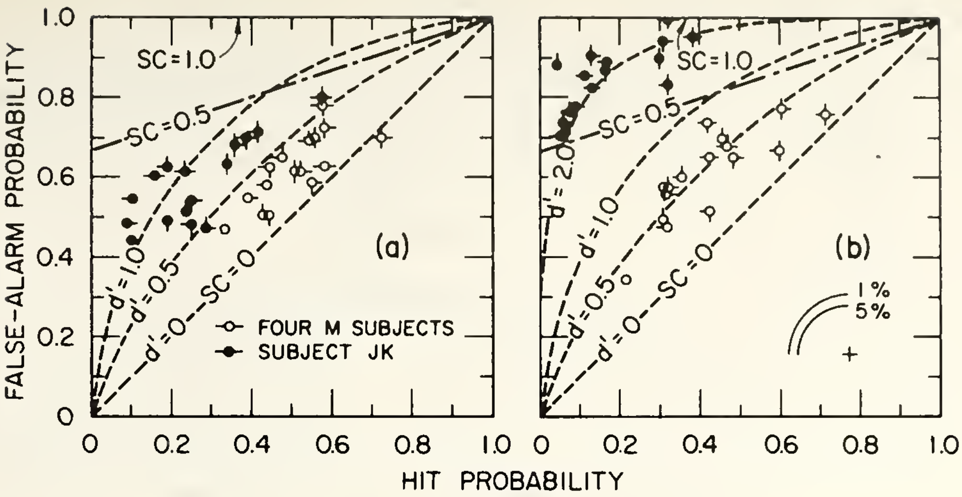

Figure 15. Operating Characteristics of the Four M Subjects and Subject JK Obtained from the Middle Phalanx Data of (a) the Whole Report, and (b) the Partial-Report Experiments Both with n = *12*

Table 3

Detection Data Table for Each Pattern

	Stim.	*No Stim.*
Response	SR	SR
No Response	SR	SR

To determine whether masking accounts for the relationship between the surrounding "+" patterns and the low middle-phalanx accuracy observed in the partial-report analysis, we tested the null hypothesis that accuracy does not depend on the number of neighboring stimuli, using both the SC and signal detectability methods of measuring the accuracy of the middle phalanges. These relationships are shown in Figure 16. The analysis showed that in three of the tests there was not enough evidence to indicate that masking or facilitation explained the results, and in the remaining case there was sufficient evidence to show that facilitation explained the results.

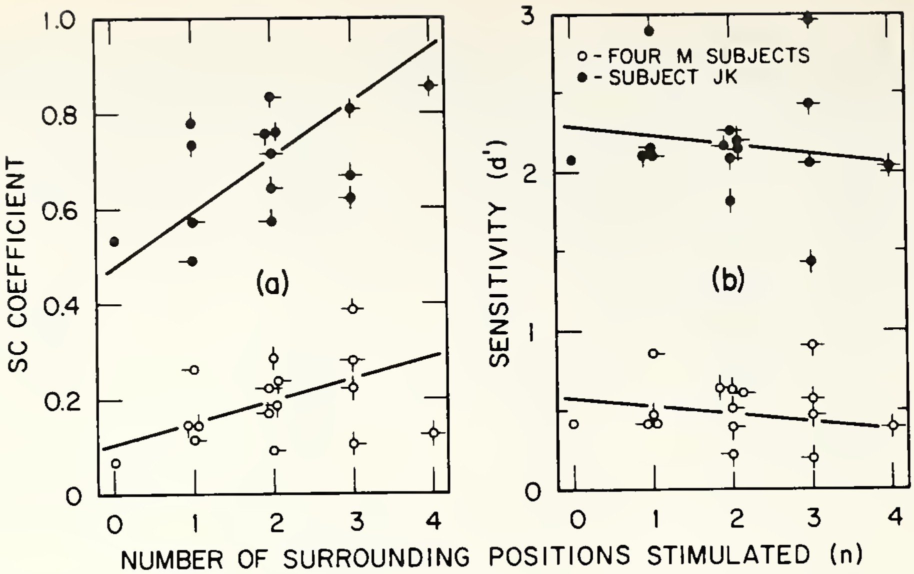

Figure 16. Values of SC and d' *Plotted vs the Number of Surrounding Positions Stimulated in a Given "+" Pattern*

Only the upper left regression line is significant ($p < 0.02$). Flags indicate the "+" pattern for each point. The data are from the partial report with $n = 12$.

A LINEAR SUMMATION MODEL

With the failure of masking to explain the responses in terms of local context in the stimulus patterns, the facilitation concept was investigated further. A linear model for these data was tested in which the presence of a stimulus at each of the five stimulus locations of the "+" patterns is considered to linearly increase the probability of giving a response at an average middle phalanx. In such a model, the reporting probability R is represented as the sum of five terms, plus other effects. That is,

$$R = R_C + R_P + R_D + R_L + R_R + R_{subj} + \varepsilon \qquad (3)$$

where the subscripts C, P, D, L, and R refer, respectively, to the effects of the central, proximal, distal, left, and right cells of the "+" pattern. The last two terms are effects due to different subjects and to errors of measurement.

The hypothesis that Eq. (3) is a proper model for the data (called the spread or facilitation model) was tested for all subjects with an analysis of variance, using the data of both the whole and the partial report. For the four M subjects, the deviation mean square, as well as the error mean square, could be computed.

For all of the subjects, the validity of the linear spread model of Eq. (3) was very significant. The spread model describes the majority of the variance due to the different stimuli present in the "+" patterns. Each of the effects of Eq. (3) as well as the standard deviation of the error, σ_ε, is given in Table 4. The results of this linear model are nearly identical with the spread-correlation analysis.

Table 4

Magnitudes of the Effects of Eq. (1)

	Report	R_C	R_D	R_p	R_L	R_R	σ_ε
Four M subjects	Whole	0.115	0.065	0.075	0.085	0.095	0.085
	Partial	0.179	0.119	0.141	0.077	0.117	0.096
JK	Whole	0.329	0.116	0.129	0.078	0.058	0.061
	Partial	0.677	0.012	0.155	0.031	0.048	0.085

Several features of Table 4 are as follows:

1. The effect of the central locations in the "+" patterns is the largest.
2. For the four M subjects in the whole report, all four surrounding effects are about the same.
3. For all subjects in the partial report the proximal stimuli have the second largest effect.
4. The effect of the proximal and distal locations is generally larger than the effect of the left and right locations.

Although the linear model describes the great majority of the variation in the data, it is not a complete model for the data. For the partial-report data of the four M subjects, the deviation mean square was significant, indicating that the model was not complete in this case. A closer investigation of the analysis showed that the main source of the deviation variance was the interaction between two and three stimuli at different locations of the "+" pattern. The sum predicted by the model when two or three stimuli are presented simultaneously in the "+" pattern is less than the sum actually obtained from the data. This interaction represents a nonlinearity of the model, not the effect of masking. The nonlinearity of the model could be investigated by applying different nonlinear transformations to the data and repeating the analysis summarized in Table 4. Stevens (25) shows that sensation generally increases as a power function of the stimulus. A logarithmic or power-function transformation could linearize the data, allowing a more accurate model to be fit. This refinement was not carried out.

DISCUSSION

A wide range of performance has now been observed on the whole-report task of naming all the interjoint regions of the fingers that were simultaneously stimulated. Figure 17 gives these data for all eight subjects that participated in various versions of the experiment. With the exception of JK, the subjects with more experience performed better. Subject S had the most experience; he was involved continuously on a multiple tactile stimulation task with n = 2 for three months previous to the experiment. Subjects M_1, M_2, M_3, M_4, and JK had only one week of training. Subjects A and K had roughly two weeks of training. If subject JK had obtained relevant tactile experience in his everyday life (for example, by reading Braille and operating his Braille-writer), a learning hypothesis would explain the wide range of performance observed.

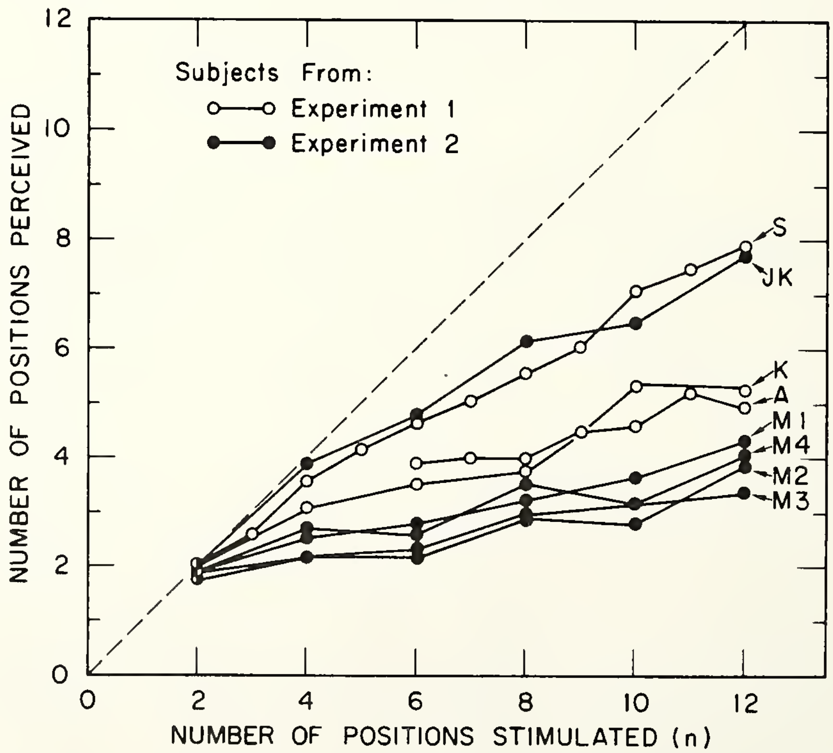

Figure 17. Whole-Report Data of All Eight Subjects Corrected for Guessing with Model II

Previous multiple-tactile-stimulation data have not generally been presented in a form showing the span of immediate memory or sensory register capacities. A survey of multiple-tactile-perception data is shown in Figure 18. Krohn's (13) data were obtained directly from his paper. Alluisi *et al.* (1) and Saslow (18) give only the fraction of erroneous patterns (abbreviated here by FEP). An erroneous pattern is a pattern containing one or more errors. If it is assumed that the frequency of errors at each stimulation site is the same, then it can be shown that the number of positions perceived is

$$\frac{n}{\sqrt[n]{1 - \text{FEP}}}$$

(Alluisi stated that the frequency of errors was constant at different locations.) This equation was used to obtain the corresponding plots in Figure 18. The data from Geldard and Sherrick (11) deserve further explanation. Since subjects in this experiment were given two patterns with which to respond "same" or "different," some model of how the subjects distinguished between the patterns had to be assumed to obtain the plot of Figure 18. Results from two different models are plotted: The first (results plotted with dots in Figure 18) is that some stimulus location

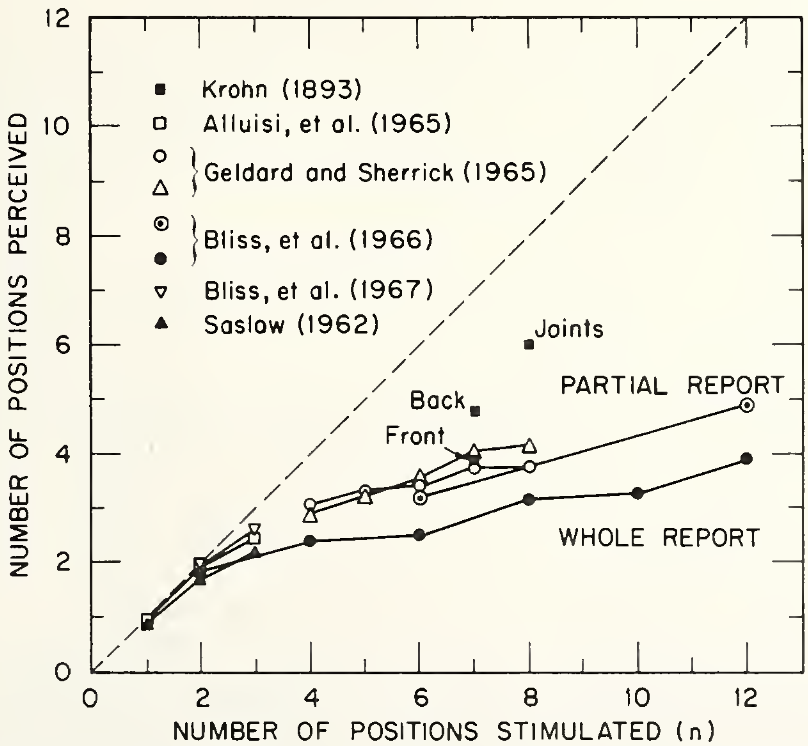

Figure 18. Comparisons of the Number of Positions Perceived, Estimated from the Data of Other Experimenters

read into the sensory register on the first pattern was not read in on the second pattern. With this assumption, the number of positions perceived is

$$n(1 - \%\text{ error with } n - 1 \text{ degree of communality})$$

The second model (results plotted with triangles in Figure 18) is that there is a constant probability of noticing a change at any stimulus location. With this assumption, the number of positions perceived is

$$n\sqrt{1 - \sqrt{\%\text{ error with } n - 1 \text{ degree of communality}}}$$

Since the original data were not available, the adequacy of these models could not be checked and these assumptions must be considered speculations showing what may be obtained from this "same" and "different" data. It should be noted that we have assumed that the pattern comparisons are made in the sensory register and not in the short-term store. Both models give similar sensory-register-capacity estimates that agree well with our partial-report experiment. This agreement, between an experiment involving finger stimulation and an experiment involving stimulation sites on the body separated as widely as possible, suggests a central limitation rather than a peripheral one. This suggestion is also consistent with the observed improvement with training.

All of the data of Figure 18, except for Krohn's were obtained from subjects having only one to two weeks of practice. Since all of these data lay in a relatively narrow band across the figure, and since the data represent widely different spatial separations of the stimuli, the existence of a central spatial-decision mechanism that can be "focused" on different areas of skin surface, and that improves with practice, is further suggested.

The partial-report data show the existence of a tactile sensory register (that is, more information was available than could be reported in a whole report). For all the subjects the sensory register had a capacity *(1)* that was about 50 percent greater than the span of immediate memory, and *(2)* that decayed with a time constant of 1.3 sec. The mechanism for this sensory register may be the same as that for tactile persistence (after-sensations) reported in the literature. The tactile sensory register has considerably less capacity than the visual sensory register determined using letters instead of dots. However, there is little comparable visual dot pattern data.

Spatial properties of the sensory register were determined by two separate analyses. The SC analysis considered the set of locations where a typical stimulus would be reported, and the linear analysis considered the set of stimulus positions that influence a typical report. In comparing the results of these two analyses, a basic similarity is seen. Both results show that a given stimulated position may be reported at a neighboring location as well as at the proper location. We have called this concept the spread model.[4] This spread model, rather than masking, explains the poorer accuracy on the middle phalanges; there are more locations to which stimuli can spread on the middle phalanges than on the distal or proximal phalanges.

The result of applying the spread model to data collected by Bliss (5, p. 51) using double simultaneous tactile-kinesthetic stimulation of six fingers is shown in Figure 19(a), together with the comparable data of Experiment 2. Summarizing his results, Bliss stated that most errors resulted from confusions between adjacent fingers of the same hand. The data of Saslow (18), collected with 1, 2, and 3 simultaneous airjet stimuli on the index fingertip, are shown in Figure 19(b). The spread correlation was estimated from Saslow's data. Figure 19(b) shows that the "localization" process completely describes Saslow's data because the sum of the SC values is one. Thus the spread model seems to describe a range of multiple tactile perception experiments, and perhaps it is a common property of the "central decision maker."

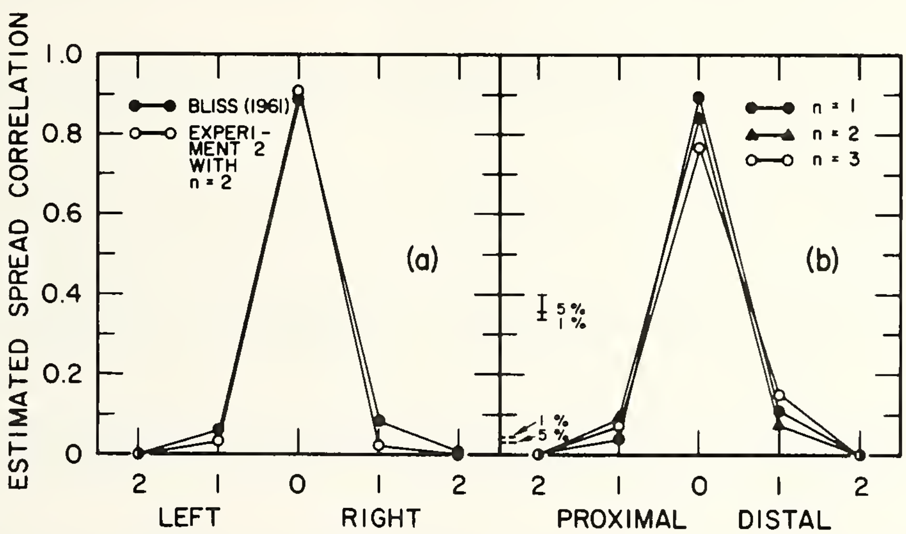

Figure 19. (a) Left-Right Localization Function Computed from Data Given by Bliss (5) Compared with the SC of the Four M Subjects Whole-Report Data with n = *2, and (b) Proximal-Distal Localization Function Computed from Data Given by Saslow (18) for* n = *1, 2, and 3*

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NOTES

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2. In Figure 5(a) it appears that the maximum mutual information $I(S;R)$ occurs at $n = 2$. However, more tactile perception data can be called upon at this point. In Bliss (7) an experiment is described with $n = 2$ and $n = 3$, using the apparatus identical to that in the present experiment. The group of five subjects in this new experiment transmitted an average of 7.30 bits with $n = 2$, and 8.14 with $n = 3$. Thus, the information transmitted by the four subjects shown in Figure 5(a) probably has a maximum value of about 7.3 bits at $n = 3$.

For Subject JK, whose lower bounds are shown in Figure 5(b), it appears that the maximum information is transmitted with $n = 4$ or $n = 5$. No data on this subject were taken with $n = 5$, and it must be assumed that the 12.1 bits transmitted with $n = 4$ is typical of his maximum. In either case, the maximum transmission by Subject JK occurs with a higher value of n than that of the other subjects.

3. A possible explanation for the decreased middle-phalanx accuracy is that there is interference from stimuli on neighboring locations. On the middle phalanges, this interference or masking could come from adjacent locations on all four sides of a stimulus. On the proximal and distal phalanges, this masking could come from only three sides. As shown in the analysis of spatial properties of the sensory register, neither interference or masking appropriately describes the decreased accuracy of the middle phalanges, but a "spread" model does, in which the ability of subjects to localize the positions of the patterns decreases as n increases.

4. The spread model should not be confused with the spread function of the Fourier transformation. Other possible names for the spread model are *(1)* lateral excitation model (in contrast to the lateral inhibition or masking model), *(2)* crosstalk model, and *(3)* linear-distribution model in which a stimulated point can be reported over a set of locations described by a probability distribution.

Appendix A

METHODS FOR ESTIMATING NUMBER OF POSITIONS PERCEIVED

Because of the nature of the stimuli used in these experiments, subjects can guess a significant portion of the stimuli locations correctly even if they were not perceived. For $n = 12$, for example, a subject could just guess 12 locations and, on the average, get 6 correct. In order to estimate memory capacities independently of the guessing behavior of the subjects, one needs to be able to estimate the number of positions actually perceived from the experimentally derived number of positions correctly reported. We have examined several models of the subject's guessing behavior and derived guessing corrections for each. Below is a brief description of these models; more complete descriptions are given by Hill (12).

Model I--Constant Number of Positions Perceived

Out of a set of S possible stimulus positions, n positions are presented on each trial. We assume that the subject perceives a constant, average number of them, P, and makes $n - P$ guesses randomly from the remaining $S - P$ unperceived locations with probability of success $g = (n - P)/(S - P)$ on each guess. The average number of positions correct per trial, C, is then

$$C = P + (n - P)\frac{n - P}{S - P}$$

Solving this equation for P yields

$$P = \frac{SC - n^2}{C + S - 2n} \qquad \text{(A-1)}$$

The values of P can easily be determined from the measured values of C, using this equation.

Model II--Constant Report Probabilities

On a given stimulus pattern, n positions are presented and the subject is required to report n different positions. We assume that the probability of the i^{th} report being a perceived position is a constant probability p_i, $(i = 1, 2, \ldots, n)$, and that the probability of a successful guess when the i^{th} report is an unperceived position is a constant probability g_i, ($i = 1, 2, \ldots, n$). The fraction of time that the ith report is correct, c_i, is then given by n equations of the form

$$c_i = p_i + (1 - p_i)g_i \quad i = 1, 2, \ldots, n \tag{A-2}$$

We need to solve these equations for the p_i, and then sum the p_i to get the total number of positions perceived. In general we wish to allow for unequal values of the g_i. However in equation set (A-2) there are only n equations and we may only solve for n unknowns. Therefore, we cannot solve the equation set (A-2) for both the p_i and g_i simultaneously. We want solutions for the response probabilities, p_i, and hence we must evaluate the g_i in terms of the p_i in order to keep the number of unknowns equal to n. In order to express the values of g_i in terms of the p_i we must postulate a model for the guessing scheme.

One method for evaluating the g_i assumes that the subject guesses uniformly from among the unperceived positions. If j positions are perceived on a trial, then the guessing probability is $(n - j)/(S - j)$. If the probability of perceiving j positions when response i is guessed, is $P(j|\text{response } i \text{ guessed})$, then

$$g_i = \sum_{j=0}^{n} \frac{n - j}{S - j} P(j|\text{response } i \text{ guessed}) \tag{A-3}$$

As an approximation we can replace the average of the function $(n - j)/(S - j)$ by the function of the average value of j. Then Eq. (A-3) reduces to

$$g_i \simeq \frac{n - \bar{j}}{S - \bar{j}}$$

where $\bar{j}$ is the expected value of the number of positions perceived when the i^{th} position is not perceived. If we further assume that the p_i are independent then

$$\bar{j} = \sum_{\substack{k=1 \\ k \neq i}}^{n} p_k$$

Since the function $(n - j)/(S - j)$ is not linear, the average of this function of j is in general unequal to the function of the average value of j (or $\bar{j}$). However, we will show this function is linear enough for small variations of j about $\bar{j}$, so that the resultant approximation is close enough for practical use. If we assume independent values for the p_i, the resultant distribution is wider than those obtained in the experiment and we can put bounds on the accuracy of this approximation.

When all of the p_i are either zero or one, the approximation is exact. The approximation is worst under variations in the p_i, when $p_i = 1/2$ for all p_i, because this gives the broadest distribution of conditional probabilities. The approximation is also exact for $n = 2$, and gets progressively worse as n increases. The highest value of n used in the experiment is $n = 12$. In the worst case, $n = 12$, $p_i = 1/2$. In this case, $\bar{g}_i$ is 1.5 percent higher than the actual value g_i, an amount of error that is tolerable in terms of the accuracy of the measurements made.

Equation set (A-2) with $\bar{g}_i$ instead of g_i can be reduced to a set of n linear equations in n unknowns and solved directly in theory. In practice, difficulties in the solution could easily arise since the equations are nearly singular for higher values of n. A simple and economical iterative solution of these equations is given by Hill (12).

Model III--Constant Position Probabilities

We assume that each position of the array of S positions has associated with it a constant probability p_i, $(i = 1, 2, \ldots, S)$ of perceiving the presence of a stimulus at the position and a constant probability g_i, $(i = 1, 2, \ldots, n)$ of guessing a stimulus. The fraction of correct responses, c_i, at the i^{th} position is then

$$c_i = p_i + (1 - p_i)g_i$$

which may be solved for the S values of p_i,

$$p_i = (c_i - g_i)/(1 - g_i)$$

where

$$c_i = \frac{\text{Number of stimuli with responses}}{\text{Total Number of stimuli presented}}$$

$$g_i = \frac{\text{Number of responses when no stimuli present}}{\text{Total number of times that no stimuli were present}}$$

This model is not a complete model for this stimulus-response situation because there is no restraint on the total number of positions reported per pattern. This restraint would require that of the set of S positions that could produce responses to a stimulus pattern, only n produce responses. Even though this model does not fulfill this requirement, the average number of positions perceived per pattern or some fraction of a pattern (hands, fingers, rows, or individual positions) may be computed from this model. The average number of positions perceived per pattern, P, is n times the average value of p_i:

$$P = n\bar{p}_i = \frac{n}{S} \sum_{i=1}^{S} p_i$$

Comparison of Different Models

In order to compare the three different models, all three were used to compute the average number of positions perceived per stimulus pattern on the whole-report data. In general the number of positions perceived computed from each of the models agreed to within a few percent. Specifically, Model II and Model III agreed to within 1.5 percent of each other on all values of n. Model I gave consistently higher estimates of the number of locations perceived than the other two models. The difference varied directly with n, Model I giving 0.4 percent higher results with $n = 2$, and 4.5 percent higher results with $n = 12$ than Model II. Considering that the standard deviation of the number of positions perceived per pattern is about 7 percent, the differences between guessing corrections are smaller than the standard deviation. Thus, any conclusions drawn from the number of positions perceived, computed by one of the models, should apply to the number computed by the other models too. The three models can be considered equivalent from the point of view that they estimate the same number of positions perceived per stimulus pattern.

Models I and II can also be compared on their ability to explain the variance in the total number of positions correctly reported per pattern, C. The variance of C predicted by Model I is $g^2(S - n)^2/(S - P - 1)$. The variance of C predicted by Model II is the sum of the n probabilities of correct response, c_i, $(i = 1, 2, \ldots, n)$. This variance can be expressed as

$$\sigma_c^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} \sigma_{ij} \tag{A-4}$$

where σ_{ij} is the variance between c_i and c_j, and where $\sigma_{ii} = \sigma_i^2$ is the variance of each c_i.

If the c_i are independent, then $\sigma_{ij} = 0$ if $i \neq j$ and

$$\sigma_c^2 = \sum_{i=1}^{n} \sigma_i^2 = \sum_{i=1}^{n} c_i(1 - c_i) \tag{A-5}$$

In general, the response probabilities, c_i, of Model II are not independent, and the possibility of nonzero values of covariance must be allowed for. The difference between the variance predicted by Eq. (A-5) and the actual measured variance is the sum of the off-diagonal covariance terms of Eq. (A-4). If this variance difference is significantly different from zero, then the difference is an estimate of the sum of these terms.

The variance predicted by Model I and Model II along with the actual variance of C for the three sighted subjects and for the early blind subject (JK) on the different values of n are given in Figures A-1(a) and A-1(b).

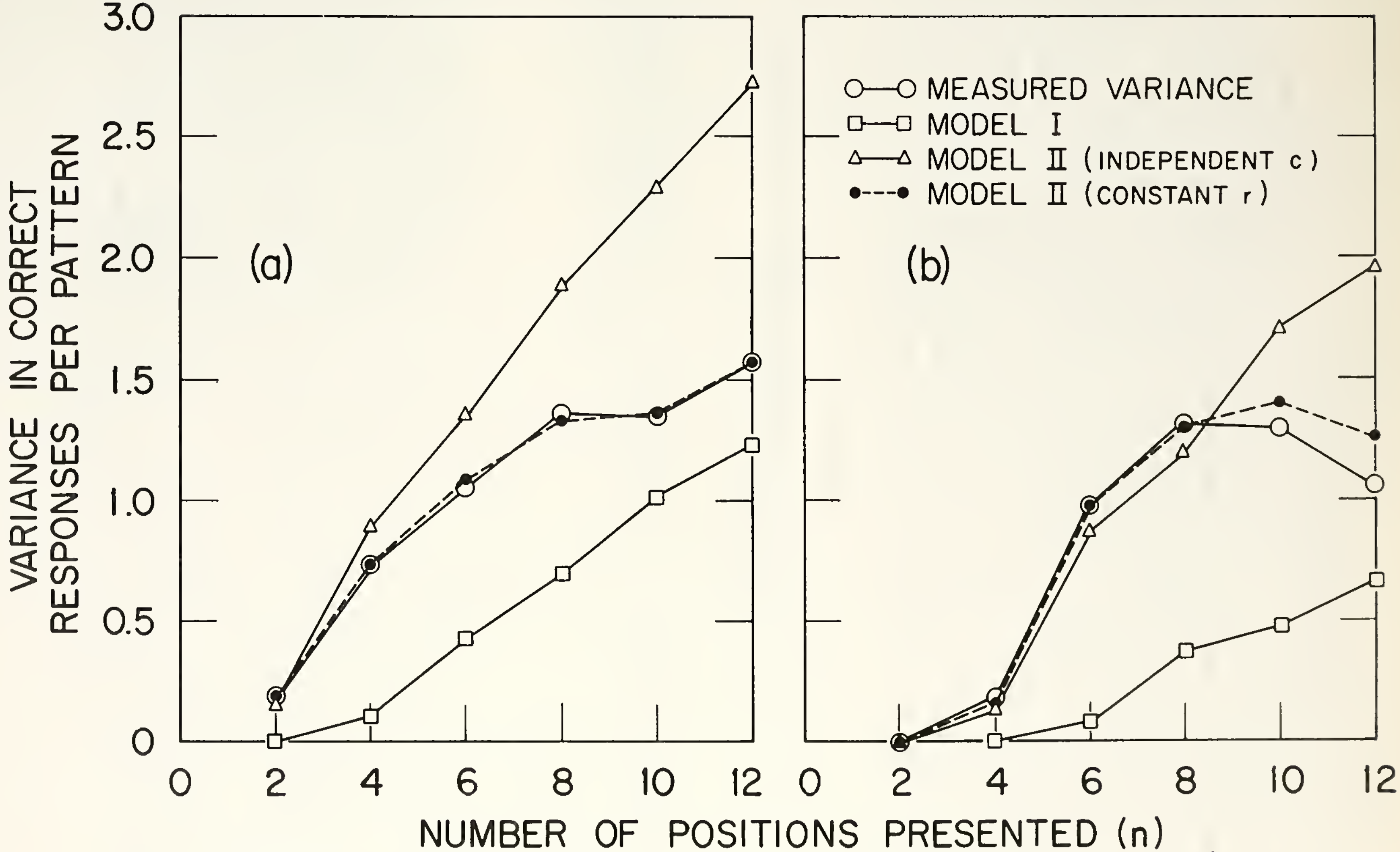

Figure A-1. Measured and Model Variance (a) the Three Sighted Subjects, and (b) Subject JK

It can be seen in the figures that Model II with independent response probabilities explains the variance data with $n = 2$ and $n = 4$ for the sighted subjects, and with $n = 2$ through $n = 8$ for the early blind subject (JK). Model II, with nonindependent response probabilities, c_i, can be made to explain the data for the higher values of n too. In this case there must be negative covariances between the c_i. It was found that the average between-response correlation coefficient, r, computed from the data, was independent of all the experimental parameters except n. With a constant r model for determining the covariance of the c_i a better estimate of the variances can be obtained. The restuls of Model II with a constant-response correlation coefficient have been plotted in Figure A-1 as a dotted line. Model I falls short of explaining the observed variance, and is not flexible enough in nature to permit adjustments that would make it fit. Model II is therefore judged to be the best model of the subjects' performance, as it gives both the number of points perceived and can give the variance of the number of correct responses per pattern.

Appendix B

A FUNCTION FOR MEASURING RESPONSE LOCALIZATION (The Spread Correlation)

$P(S_1 \rightarrow R_2)$ will be defined as the probability that a stimulus at one particular location (Location 1) in the pattern causes a position to be reported in another specific location (Location 2, possibly the same as Location). The conditional response probability, $\Pr(R_2|S_1)$, can be expressed in terms of $P(S_1 \rightarrow R_2)$ by the following equation:

$$P(R_2|S_1) = P(S_1 \rightarrow R_2) + b[1 - P(S_1 \rightarrow R_2)] \qquad \text{(B-1)}$$

where b is a bias parameter that depends on the experimental procedure.

The bias parameter, b, is restricted by the paradigm of Experiment 2. In both the whole and partial reporting schemes used in this experiment, the subjects were informed of the number of stimulus positions occurring in each pattern and gave the same number of responses. Below, we first explain how the parameter b was chosen, and then describe some of the resulting properties of $P(S_1 \rightarrow R_2)$. The variables n and S are defined in Appendix A.

When stimuli and responses at the same location in the patterns are considered, then $b = n/S$. When stimuli and responses at different locations in the patterns are considered then the interdependence of the stimulus locations must be taken into account and

$$b = P(R_2) - A_{12}\,[P(R_2|S_2) - P(R_2)]$$

and

$$A_{12} = \frac{P(S_1|S_2) - P(S_1)}{1 - P(S_1)}$$

In Experiment 2 the expected value of A_{12} is $1/(1 - S)$. In all of the analyses described in this paper the values of $P(R_j|S_i)$, $P(R_j)$, and A_{ij} were computed from the data for every pair of stimulus and response locations. The expected values were not used.

The resulting function $P(S_i \rightarrow R_j)$: *(1)* maintains some of the properties of a probability function, and *(2)* has many of the properties of a correlation function. The first point aids in the interpretation of $P(S_i \rightarrow R_j)$ and the second point aids in the analysis and significance testing of $P(S_i \rightarrow R_j)$.

There are two features of $P(S_i \rightarrow R_j)$ that allow it to be interpreted as a probability. One is that when stimuli and response are independently or directly related, $P(S_i \rightarrow R_j)$ has the intuitively correct values (zero or one). Equation (B-1) may be solved for $P(S_1 \rightarrow R_2)$ to give:

$$P(S_1 \rightarrow R_2) = \frac{P(R_2|S_1) - b}{1 - b} \tag{B-2}$$

The independent and dependent limits of $P(S \rightarrow R)$ may be examined using Eq. (B-2). The definition of pair wise independence takes the form of two conditions

$$P(R_2|S_1S_2) = P(R_2|S_2)$$

$$P(R_2|S_1\bar{S}_2) = P(R_2|\bar{S}_2)$$

When these conditions hold, it can be shown that with the constraints of Experiment 2, $P(S_1 \rightarrow R_2)$ is zero, the desired result. On the other hand, when every stimulus at location 1 is followed by a response at location 2, $P(R_2|S_1)$ is one. From Eq. (B-2) it follows that $P(S_1 \rightarrow R_2)$ is also one, the desired result.

Another feature is that the sum of the $P(S_i \rightarrow R_j)$ over j of Eq. B-2 is a number between zero and one. Specifically with an average S_i

$$\sum_{j=1}^{S} P(S_i \rightarrow R_j) = \frac{E[P(R_i|S_i)] - n/S}{1 - n/S}$$

When stimulus and response patterns are independent (pure guessing) then

$$\sum_j P(S_i \rightarrow R_j)$$

is zero. When the stimulus and response patterns are identical (perfect responses), then the sum is one.

There are several features of $P(S_i \rightarrow R_j)$ that allow it to be interpreted as a correlation coefficient. $P(S_i \rightarrow R_j)$ defined by Eq. (B-3) is a regression coefficient where the regression of stimuli at one location and responses at another location are considered (30, p. 497), $P(S_i \rightarrow R_j)$ is also closely related to the usual correlation coefficient, r. Indeed, when $P(R) = P(S)$, the spread probability and the correlation coefficient are identical. In most of the cases considered in this paper $P(R_j)$ and $P(S_i)$ are approximately equal. When values of $P(S_i \rightarrow R_j)$ are close to zero, it may be shown that $P(S_i \rightarrow R_j)$ is approximately normally distributed, and hence, that $P(S_i \rightarrow R_j)$ may be analyzed using an analysis of variance. As $P(S_i \rightarrow R_j)$ is basically a difference between two random variables estimated from the data, negative as well as positive values can occur. Since negative correlations are more acceptable than negative probabilities, and since $P(S_i \rightarrow R_j)$ has such a close kinship with the correlation coefficient, $P(S_i \rightarrow R_j)$ defined by Eq. (B-2) is referred to as the "spread correlation" (abbreviated SC) in this paper.

COMMUNICATION BY ELECTRICAL STIMULATION OF THE SKIN*

Emerson Foulke

From November 1, 1963 through March 31, 1965, work was continued on the development of a communication system based upon electrical stimulation of the skin. Training on a code composed of signals that combined values in the three stimulus dimensions of locus, intensity, and duration was terminated. It was concluded that the communication rate possible with a code of this sort was seriously limited by the long, and apparently irreducible, reaction times to code signals.

Another code, with patterns of simultaneously stimulated locations used as signals, was tested. Reaction times to signals of this sort were found to be much shorter, and when appropriate restrictions were placed upon the kinds of location patterns to be used in the code, high accuracy was demonstrated. This stimulus alphabet is now felt to be sufficiently developed to justify an attempt to pair its signals with the elements in the Katakana Syllabary, and to teach the resulting ensemble to Japanese subjects who are familiar with the Katakana Syllabary.

Collateral studies were conducted in an effort to learn more about the parameters of the electrocutaneous stimulus. Included were an investigation of the absolute threshold of the electrocutaneous stimulus as a function of several relevant variables, the determination of equal apparent intensity contours for the electrocutaneous stimulus, absolute identifications of the intensity of an electrocutaneous stimulus at two levels of irrelevant information, an exploration of a technique for stimulating with an electric spark with a view to improved multiple stimulus acuity, and finally an effort to transmit Morse Code in which the usual auditory signals were replaced by electrocutaneous signals.

THE DEVELOPMENT OF AN ELECTROCUTANEOUS STIMULUS ALPHABET

Conclusion of training on the three-dimensional electrocutaneous code: During the past two and one-half years a three-dimensional electrocutaneous code has been tested. Two intensities, two durations, and ten locations were employed in the

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formation of code signals. This arrangement produced forty code signals to which letters or other meanings could be assigned. The construction of this code is discussed in greater detail in previous progress reports (4, 5). The letters of the standard English alphabet were assigned to 26 of the signals. Two signals were reserved for punctuation marks. The remaining signals represented frequently recurring letter groups such as "er," "ing," and "and." Code signals were taught to *S* by a paired associates method in which *S* attempted to identify a presented signal and was informed of the correctness of his guess by *E*. When code signals had been mastered, *S* was presented with words, at first singly and later on as connected prose. Short passages of unfamiliar simple prose were presented by means of a modified self-pacing technique. When *S* depressed the "right" foot pedal, signals were presented to him automatically at a constant predetermined rate. Releasing this pedal stopped the flow of signals. When he pressed the "left" foot pedal, the signal experienced last was repeated. With this arrangement, *S* could repeat missed signals and could review sequences of remembered signals.

On trials composed of random permutations of code signals, a record was kept of errors, and of reaction times. For *S*s receiving connected prose, a record was kept of the number of words sent, number of words correctly received, number of words missed, and the time required for the communication of the passage. With this information, it was possible to determine the number of words correctly received per minute.

Ten paid volunteer college students received significant amounts of training over a period of approximately two and one-half years. The number of training sessions on the reception of connected prose ranged from 150 sessions for the most experienced *S* to 35 for the least experienced *S*. There were frequent interruptions in training due to college vacations and more compelling commitments such as examination weeks.

All of the indices of code learning employed revealed a negatively accelerated improvement with practice. The most skilled *S*s attained word rates of around 25 words per minute. However, performance remained quite variable throughout the training and on some days these skilled *S*s could do no better than fifteen words per minute. The frequency of errors was reduced with practice. However, even after prolonged training, *S*s made many errors. When signals and responses made to them were displayed on confusion matrices, persistent error patterns were revealed. The analysis of these matrices has shown the error frequency for each signal and has indicated the kind of confusions to be expected from signals of given composition. A knowledge of these error frequencies and probable confusions may now be used in a rational assignment of meanings to code signals.

Though reaction time, or the time elapsing between the onset of a signal and *S*'s response to it, decreased with practice, it remained quite long. Reaction times were rarely as short as 1 sec, sometimes as long as 3.5 sec, and 1.24 sec on the average. Even in the case of the most practiced *S*s and despite efforts to promote it, subitization of responses to signals did not take place. *S*s continued, in most instances, to analyze the composition of signals and it appears that this analysis time produced the cumbersome reaction time.

The results of our efforts to train people in the use of this code suggests several conclusions: (*1*) Communication by means of a code composed of three-dimensional electrocutaneous signals is possible. However, because of the modest word rate and high error rate, its usefulness is quite limited. (*2*) A response alphabet composed of elements such as those that occur in the standard English alphabet is inefficient and when it is coupled with a stimulus alphabet that must be presented serially, the inefficiency approaches intolerability. This problem was recognized at the outset. However, since the initial aim was only to test the feasibility of communication by electrical stimulation of the skin, the fact that available *S*s were highly practiced in the use of the English alphabet was regarded as sufficient justification for its employment. (*3*) The use of three stimulus dimensions appears to produce perceptually difficult signals. *S*s cannot learn to respond to them rapidly or accurately enough to achieve generally useful communication rates. In order for communication by electrical stimulation of the skin to have practical significance, more research on the composition of an electrical stimulus alphabet is required.

Influence of the number of stimulus dimensions on the identification of electrocutaneous signals:* As indicated in the preceding progress report (5, p. 26), the inability to reduce the time required to respond to code signals led to a search for new ways of composing signals. Verbal reports from *S*s indicated quite clearly that they analyze signals into their three component dimensions before responding. This suggested that the number of stimulus dimensions employed in the formation of signals was an important variable in determining reaction time to signals. Therefore, an experiment was performed in which each of four groups of *S*s was taught a different electrocutaneous code with eight signals. The first code used location cues only, and presented signals to the eight fingertips. The second code combined location and duration cues and presented signals at one of two durations to each of four fingertips. The third resembled the second except that intensity replaced duration as a code cue. The fourth code combined the three stimulus dimensions of location, intensity, and duration. Signals that could be presented at either of two intensities and either of two durations were presented to either of two fingertips. *S*s were

**Work described in this section was performed by Mr. Glynn Coates, a research assistant, under the supervision of the principal investigators.*

given both force-paced and self-paced training. The effectiveness of training was indicated by error scores and by response time, or the time required to respond to a random sequence of 104 self-administered signals.

In general, the results supported our hypothesis. With moderate amounts of training, the location code was best, followed by the location-intensity code, the location-duration code, and finally the location-duration-intensity code. With prolonged practice, a higher communication rate was achieved with the location-intensity code than with the location code. Otherwise, the order remained the same.

The use of location patterns in the composition of code signals: The results of experience and experiments suggest that the number of stimulus dimensions employed in the composition of electrocutaneous signals should be held to a minimum--for example, location or possibly location plus intensity. The experience of many investigators suggests that a large number of absolute identifications of locations is possible. One could probably construct a code with an adequate set of signals for language communication that made use of a different body location for each signal. However, the apparatus needed in order to present signals to a large number of locations would doubtless prove too cumbersome for any purpose but laboratory demonstrations.

A code that made use of a relatively small number of locations would be practical. However, if only a small number of locations, and possibly two intensities are available for the composition of code signals, another way must be found to produce a large enough set of signals for the communication of language. One possibility is the use of patterns of simultaneously stimulated locations. If this approach is taken, the maximum number of patterns available with intensity held constant will always be two raised to a power equal to the number of locations used. For instance, if eight locations were available, 256 discrete patterns could be generated. If each pattern could occur at a low intensity and a high intensity, there would be twice 256, or 512 signals to which meanings could be assigned.

The recognition of patterns of simultaneously applied stimuli is not a perceptually difficult task. Braille readers learn, with moderate training, to identify patterns of dots by touch. People may be able to learn to identify similar patterns of electrically stimulated locations.

In the preceding progress report (5) work then in progress was described in which the principal investigator, who is also a Braille reader, identified patterns of simultaneously stimulated locations that resembled the patterns of dots used in the Braille code.

This work is now completed and the results support two conclusions of relevance for this project: (*1*) Reaction time to signals composed of patterns of simultaneously stimulated locations are considerably shorter than reaction times to three-dimensional signals such as those employed in the original code studied. Reaction times to the patterned signals averaged 1 sec with some shorter than 0.5 sec. In evaluation this finding, it should be remembered that *S* was serving in what amounted to a disjunctive reaction time experiment with 63 stimuli (the number of stimulus patterns in the Braille code) and 63 responses (the number of corresponding meanings in the Braille code). (2) On a set of signals consisting of only those patterns making use of three locations or fewer, near perfect identification is possible.

The results just summarized are supported by an experiment performed by Alluisi, Morgan, and Hawkes (1).* In this experiment, *S*s were stimulated electrically at six locations, three on each side of the body. When a given pattern of locations was stimulated, *S*'s task was to respond by calling out the numbers of the stimulated locations. It was found that when more than three locations were stimulated or when more than two locations on one side of the body were stimulated, error scores became prohibitive.

It is a generally accepted fact that when electrocutaneous stimuli are employed, acuity is poor. Two electrical stimuli applied to the skin must be well separated in order to be distinguished as two. Acuity for punctiform stimuli, such as those employed in the Braille code, is good enough so that six punctiform stimuli may be applied to a single fingertip. In the case of the pilot work reported in this paper in which the principal investigator served as *S*, the six locations employed were six fingertips, three on each hand. In the experiment performed by Alluisi, Morgan, and Hawkes the locations employed were the wrists, elbows, and shoulders. The poor acuity observed in connection with electrical stimulation and the change in such acuity from one body area to another must be taken into account in the development of a successful electrocutaneous code.

The development of a stimulus alphabet with elements composed of location patterns: The next step was to construct an electrocutaneous stimulus alphabet in terms of the experience just summarized. The signals employed in this alphabet were patterns of stimulated locations, since *S*s can respond more rapidly to stimuli of this sort than to other stimuli tested. No pattern used contained more than three stimulated locations since this restriction makes possible an acceptably accurate level of pattern identification. However, the size of the set of locations from which patterns could be formed was still at issue. The set should be large enough to generate the number of signals required for the communication of general language. However, it was suspected that an increase in the size of the set might be accompanied by an increase in reaction time to signals and a decrease in accuracy of pattern identification.

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To settle these issues, an experiment was performed in which three different codes were evaluated. In all three codes, the locations employed were the fingertips. The first code made use of six locations--the index, middle, and ring fingers on each hand. The second code made use of eight locations, by adding the little fingers on each hand to the locations employed in the first code. The third code made use of all ten fingers. The stimuli were DC pulses of approximately 0.5-msec duration (see 4, paragraph 2, p. 48). Each code contained 39 signals, and the three codes were equated with respect to the number of one-, two-, and three-location patterns employed. Each location to which a stimulus could be applied was numbered, and *S*s were instructed to respond to signals by calling out the numbers of stimulated locations. Since responses to this sort precluded the determination of reaction times to signals, only errors were recorded. For reaction times to be measured, *S*s will have to learn a more elaborate response alphabet in which there is a different specific response, such as a letter of the alphabet, for each signal in the stimulus alphabet.

Each alphabet was taught to a different group of *S*s. The *S*s were volunteers of both sexes, drawn at random from the introductory classes in psychology at the University of Louisville.

Results were in conformity with expectations. That is, the smallest average number of errors was made on the six-location code and the largest average number of errors was made on the ten-location code. However, differences, though significant, were small and performance on all three codes was considered good.

In view of these results, it was decided to perform an additional experiment using an eight-location and a ten-location code. These codes were optimized by using all of the one- and two-location patterns available before using any three-location patterns. This procedure resulted in a ten-location code with a larger number of one- and two-location patterns than the eight-location code. The two optimized codes were evaluated as before and results indicated a slight but significant superiority for the ten-location code.

As a result of this research, we now have available a stimulus alphabet with characteristics that make it a promising candidate for use in the formation of an S-R ensemble adequate for the communication of general language by electrical stimulation of the skin The signals can be identified rapidly and accurately and there are enough of them for use in an ensemble whose response members are the elements in a syllabary. Our next step will be to pair the elements in the Katakana Syllabary with the signals in the location-pattern stimulus alphabet. The resulting code will be taught to a few Japanese speaking individuals who are already learned in the use of Katakana. If this effort is successful, a syllabary will be devised for the English language, and its elements will be paired with the signals in the stimulus alphabet. This new code will be taught to naive English speaking *S*s and its efficiency will be evaluated.

Another kind of response alphabet that may be considered for use in association with our stimulus alphabet is a phonetic alphabet such as the Initial Teaching Alphabet (6).

COLLATERAL INVESTIGATIONS OF ELECTRICAL STIMULATION OF THE SKIN

The major objectives of this project have been the demonstration of the feasibility of communication by electrical stimulation and the development of an improved system of electrocutaneous communication. In support of these objectives, it has seemed desirable to learn more about the basic properties of the electrocutaneous stimulus. Therefore, several experiments intended to reveal the parameters of the electrocutaneous stimulus have been performed.

The absolute threshold for electrocutaneous stimulation:* An experiment was performed to determine the absolute threshold for a sinusoidal AC stimulus under several conditions. Sources of variation represented in the design of the experiment were: variation due to individual differences, variation in individual performance from day to day, variation in individual performance due to time of day, variation associated with the hand stimulated, and variation associated with the finger stimulated. A method of limits was used. The absolute threshold was determined for each *S* on all ten fingertips at three daily times and on three successive days. The results revealed significant variation in the absolute threshold from individual to individual and as a function of the fingertip stimulated. There was also a suggestion of a diurnal effect which was, however, not significant. In view of the importance of such an effect, if real, another experiment is planned in which this effect will be examined specifically. No significant difference was associated with the hand stimulated. The failure to find significant differences in absolute thresholds obtained from one day to the next suggests a stability in performance which should be a welcome finding for those interested in using the electrical stimulus for communicative purposes.

Equal apparent intensity contours for the electrocutaneous stimulus:+ The frequency of the AC stimulus is a dimension that could be exploited in an electrocutaneous communication system. However, the experienced intensity of the AC stimulus changes as the frequency is changed. If discriminated differences in the AC stimulus are to be based on frequency alone, it is necessary to adjust the intensity of the stimulus from frequency to frequency. In order to provide the information necessary for such adjustments,

The research discussed in this section was performed by Mr. James Sheridan under the supervision of the principal investigator and coinvestigator.

+*The research reported in this section was performed by Mr. Kent TeVault, a research assistant, under the supervision of the principal investigator.*

an experiment was performed in which an effort was made to determine equal apparent intensity contours for the sinusoidal AC stimulus. The standard stimulus was set at 120 cps, and contours were determined for standard stimuli at each of two intensities (150 and 250 percent of the threshold). The two contours were similar in shape and, unlike equal loudness contours, the intensity required for a match of CO to ST was not at a minimum in the neighborhood of ST. The intensity required to match CO to ST decreased on the low side of ST as a function of decreasing CO frequency and increased on the high frequency side of ST as a function of increasing CO frequency.

Absolute identifications of the intensity of a sinusoidal AC stimulus as a function of the amount of irrelevant information:* Any code intended for practical use must be effective in environments with varying amounts and kinds of noise. One factor influencing the success of an electrocutaneous code is the ability of a code receiver to filter out concurrent, irrelevant information and/or noise. As an initial step in the investigation of this problem an experiment was performed in which one group of *S*s was required to make two absolute identifications of the intensity of an AC stimulus and a second group was required to make three such identifications. One half of each group made its identifications while hearing concurrent bursts of random noise during each stimulation. The other half of each group experienced the bursts of concurrent random noise on 50 percent of the stimulation, chosen at random. Those *S*s making two absolute identifications of stimulus intensity showed nearly errorless performance regardless of the distribution of irrelevant information. However, those *S*s making three absolute identifications of stimulus intensity with irrelevant information present half of the time, at random, made a significantly greater number of errors in identification than did those who made three absolute identifications of stimulus intensity with irrelevant information always present.

The informal experience of the principal investigator suggests that the learning of an electrocutaneous code is a task easily interfered with by extraneous noise. The contribution of this factor to effective electrocutaneous code reception must be examined more carefully before such a code can be recommended for use.

Single fiber stimulation with brief DC pulses:+ Comment has already been made on the poor acuity generally found with electrical stimuli. This may be a consequence of the manner in which such stimuli are usually applied. Most investigators have applied

**The research reported in this section was performed by Mr. Davis Moore under the supervision of the principal investigator and co-investigator.*

+The research reported in this section was performed by Mr. Kent Tevault and will be reported in his master's thesis. It was supervised by the principal investigator and by Dr. R. P. Smith, a member of the Psychology Department faculty at the University of Louisville.

their stimuli by means of metallic electrodes in contact with the skin. These electrodes are usually large enough to make contact with many fibers sensitive to electrical stimulation and there has probably been an undetermined and uncontrolled spread of stimulation to adjacent fibers resulting in poor acuity. The solution to this problem, when the discrimination of simultaneously administered stimuli is required, has been the placement of electrodes at widely separated points on the body. The necessity of observing this restriction means that large areas must be involved if patterns of simultaneously applied stimuli are to be presented--for example, the location patterns discussed earlier. This state of affairs seriously limits the situations in which a code based upon location patterns might find practical application.

It may be that the acuity problem can be eased by a more precisely controlled and more carefully confined stimulation. Bishop (2) has reported a technique for stimulating an extremely small area of the skin with an electric spark. He suggests that with this technique he may have succeeded in stimulating a single fiber or a group of related fibers branching from a single trunk. He reports that when this manner of stimulation is employed and when the sites of stimulation are carefully chosen, two stimuli are clearly distinguished as two. The required separation of such sites appears to vary from four to twenty millimeters. His work suggests the possibility of delivering legible location patterns to a relatively small area of skin.

In a study now in progress, an effort is being made to determine more precisely the conditions under which two point acuity is realized. If the outcome of this study is positive, an experiment will be performed to discover the number of absolute identifications that are possible when locations are defined and stimulated in this manner.

An electrocutaneous Morse Code:* The communication rate possible with Morse Code is relatively slow. A word rate of 25 words per minute is considered good. Word rates in this neighborhood are, nevertheless, adequate for many situations in which communication is required, and Morse Code has been widely used primarily because of the ease with which it can be transmitted on wire or by radio. The Morse Code operator is ordinarily required to interpret heard signals that are composed by forming sequences of dots and dashes. He usually writes down the meanings of these signals (letters, numbers, and so forth) as he receives them. Some operators become so habituated in this performance that they can receive and record information sent by Morse Code while attending to some other task, such as a conversation with a bystander.

The research described under this heading was performed by Mr. Alvin Brodbeck with the assistance of the principal investigator and was reported in his senior thesis (3).

There are probably situations in which Morse Code could meet communication needs effectively if it were not for a high level of interfering noise. One possibility is the removal of the Morse Code signals from the auditory realm by replacing heard dots and dashes with felt dots and dashes formed by AC pulses of short and long duration.

To test the feasibility of this approach, an experiment was performed in which two radio amateurs served as *S*s. Both of them could receive Morse Code at a rate of twenty words per minute or faster. The use of *S*s already practiced in the reception of Morse Code permitted an immediate test of their ability to receive it electrocutaneously.

The signal recorded on a code practice record energized a relay which was used to key an electronic switch. This switch, in turn, keyed the amplified output of an audiofrequency oscillator which was applied through electrodes to the skin of *S*. Thus, both *S*s received the same sinusoidal AC signal which conformed exactly to the correctly composed signal recorded on the practice record.

One *S*, near the end of training, received ten unfamiliar five-letter words per minute. However, performance was quite variable for both *S*s. They had difficulty in distinguishing the boundaries of dots and dashes. Adjustment of the rise time and the frequency of electrocutaneous signals brought about slight improvements. However, it was possible to arrange for only limited participation on the part of the *S*s and these signal parameters could not be explored systematically. Improvements in the ability to communicate Morse Code by electrical stimulation of the skin will probably depend upon finding the right way to constitute the signals with respect to such variables as rise time, frequency, relative duration of dots and dashes, intensity, electrode placement, and so forth.

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AGE AND SEX DIFFERENCES IN PURE-TONE THRESHOLDS: A SURVEY OF HEARING LEVELS FROM 18 TO 65 YEARS*

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INTRODUCTION

The current interest in the relationship between noise exposure and auditory functions has led to a growing concern about the validity of the American reference level of normal hearing. While Harris (29), Albrite *et al.* (1), Corso (12), and others have published articles which point out certain critical problems inherent in the specification of normal hearing standards, it appears that the data now available may lead to the reestablishment of audiometric 0 for both national and international purposes (20, 30). One of the practical issues in which the reference level of normal hearing is involved is the specification of the amount of permanent hearing impairment which may result from excessive noise exposure. This problem has become increasingly important in recent years for two main reasons: (*1*) the development-production of jet aircraft, rocket engines, and other devices which can generate over-all sound pressure levels of 130 db or more re 0.0002 dynes per square centimeter (33), and (*2*) certain state court rulings which hold that industrial deafness is an occupational disease, thus entitling the affected worker to a schedule award under the Workmen's Compensation Law (43). It is apparent, therefore, that the medicolegal aspects of noise-induced hearing loss encompass serious consequences which can no longer be ignored, either by private industry or by the military services (24).

Since it is now clearly established that prolonged exposure to noises having certain intensity and frequency characteristics can produce permanent shifts in man's auditory thresholds (40), two major issues remain to be solved if the amount of damage due to noise exposure is to be appropriately evaluated: (*1*) the exact method of measuring and specifying the amount of hearing loss--that is, the number of decibels by which the intensity of a pure tone must be raised above a "normal" threshold intensity in order to elicit a response from an observer--and (*2*) the determination of the degree and type of auditory impairment which must be present to be considered of practical significance. Only the first issue, however, will be treated in the present study. It should be pointed

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out, furthermore, that with respect to this issue some writers (21) prefer the term "hearing level" rather than "hearing loss" to indicate "the deviation in decibels of an individual's threshold of hearing from the American Standard value for the reference 0 for audiometers." Nevertheless, the term "hearing loss" will be retained in this paper because it is less likely to lead to confusion due to its historical precedence; also, the term "hearing level" does not convey the immediate impression of a hearing discrepancy between an individual's threshold and that of an appropriate comparison group.

The measurement and specification of hearing loss must consider a wide number of related factors (39). These may be grouped into the following five classes: (*1*) the kind of material on which the individual is to be tested--for example, pure tones, speech, and so on; (*2*) the psychophysical testing procedure to be used--for example, method of limits, method of adjustment, and so on; (*3*) the environmental conditions under which the testing is to be done--for example, ambient noise levels, temperature, time of day, and so on; (*4*) the psychophysical characteristics of the individual to be tested--for example, intelligence, motivation, reaction time, and so on; and (*5*) the training and qualifications of the test administrator. Assuming that these and other factors which influence the accuracy of auditory threshold measurements can be reasonably well controlled in certain situations, a crucial problem arises when the attempt is made to specify an individual's threshold of hearing in terms of hearing loss--that is, relative to a group of individuals with "normal" hearing. As Hirsh has pointed out, "A normal absolute threshold is a concept that must be inferred statistically from a group of individuals measured in an adequate sample of a particular population" (32). This implies that any conclusions about the extent of the effects of noise exposure on hearing sensitivity must be based upon comparisons involving proper normative groups--that is, groups of subjects whose hearing has not been impaired by noise exposure.

One of the primary decisions which must be made in selecting the proper normative group is the choice between the values of "normal" auditory sensitivity obtained from laboratory studies and those obtained from field surveys. The data from these two sources have been shown to differ markedly (1, 12, 29). Of the laboratory studies, specific mention is made of the studies by Munson (36) in 1932, Sivian and White (41) in 1933, Dadson and King (19) in 1952, Wheeler and Dickson (46) in 1952, Harris (29) in 1954, Albrite *et al.* (1) in 1958, and Corso (12) in 1958 and in 1959 (14). Of the field surveys, specific mention is made of the studies by the United States Public Health Service (37) published in 1938, Steinberg, Montgomery, and Gardner (42) in 1940, Webster, Himes, and Lichtenstein (45) in 1950, and Glorig *et al.* (26) in 1956 and in 1957 (27). Since the threshold values from the laboratory studies are consistently lower than those from field surveys, it seems reasonable to conclude that in the laboratory studies, the effects of extraneous factors have been minimized, and hence the results provide a more realistic evaluation of "normal" hearing functions. Numerous professional societies have already recommended the desirability of establishing an international standard reference level for audiometry (20), and Technical Committee No. 43 of the International Standards Organization has developed a set of values for audiometric zero (30) which are from 4.1 to 12.6 db lower (fainter) than the present American Standard (Z 24.5-1951) based upon the United States Public Health Survey, (1935-1936) (29). From these more sensitive values, the magnitude of the effects of those factors directly related to hearing impairment can be assessed more validly, and auditory defects may be identified at an earlier stage of development.

In recent years, in addition to industrial noise exposure, the effects of sex and age on hearing have received increased attention in research. While it is now established that men and women differ in auditory sensitivity (14), the relationship of age to auditory sensitivity is still under consideration, even though several studies (14, 26, 42, 45) have shown that with advancing age there is a steady decline in hearing acuity, particularly at the higher frequencies. This effect--that is, "diminished acuteness of hearing occurring in old age"--is medically termed "presbyacousia" (44) or, more commonly, presbycusis. While the term "presbycusis" does not explicitly refer to causal factors underlying the hearing impairment, some attempts have been made (28) to restrict the meaning of the term to "the amount of hearing loss that results from physiologic changes that occur with age." Such a definition has a certain theoretical appeal but, unfortunately, no data are available which assess this factor directly, nor are they likely to become available. There are two main problems here: (*1*) to determine the physiologic effects per se, human subjects would need to live a lifetime in a sound-isolated environment, and (*2*) much of the information needed would require histological studies derived from subjects killed during the course of the experiment. If measurements were to be made in a primitive society, biological differences would complicate the interpretation of data, and the effects of noise exposure would still not be completely eliminated; even isolated natives are exposed to the sounds of their own society and to the sounds of nature. However, appropriate studies could be easily performed by using laboratory animals and extrapolating from the animal data to man. This is not an unreasonable approach when it is recognized that much of our knowledge regarding the functional aspects of human hearing has already been obtained in this manner (4).

In view of these problems, the best approximation which can be made for the effect of presbycusis is to obtain threshold data for a sample of subjects stratified by age and exposed to minimal levels of environmental noise. By using the data from such a sample, the loss of sensitivity produced by prolonged or excessive noise exposure can be, at least in part, separated from the loss which might be expected to accrue from physiologic and other factors extended over time. This is the approach taken in the present study. It should be understood, however, that in this correction for presbycusis the effects of age are separated from the effects of noise by the simple process of subtraction. This assumes that hearing losses from presbycusis and noise exposure are additive, with no interaction between the two. While this is a reasonable assumption since both factors probably produce permanent damage to sensory cells and their nerve fibers, the possibility exists that the two variables may in fact interact and thus generate multiplicative effects. The lack of adequate information on the possible interaction effects of age and noise has precluded the formulation of a specific rule for making an allowance for presbycusis in the calculation of the percentage of hearing impairment from pure tone audiograms. However, it has been suggested that "in the rules for determining the disability of hearing. . . , an allowance for the hearing loss expected with advancing age should be included" (18).

It should now be clear that the problem of evaluating the effects of occupational noise exposure on hearing acuity involves more than the establishment of a single set of standard sound pressure values for a given earphone-coupler combination. The degree of hearing loss due to noise exposure can be determined validly only when other factors known to affect threshold values, such as the age and sex of the subject, the age of the normative group, the testing procedure, and the ambient noise environment have all been properly considered.

PURPOSE AND GENERAL PLAN OF STUDY

The primary objective of this study was to conduct an extensive laboratory survey designed to yield a comprehensive set of data on the hearing characteristics of a sample of subjects stratified by age and drawn from a population exposed to minimal levels of industrial noise. The study was conducted in State College, Pennsylvania, from 1952 to 1962, and hearing data were collected for men and for women from 18 to 65 years of age. Before beginning the hearing survey, ambient noise levels together with octave band analyses were obtained at 17 different locations within the community on widely different dates and times. While the noise levels in the community were found to be similar to those in the residential districts of larger cities, there were no excessively high noise levels such as those associated with industry or heavy traffic (5).

It was anticipated that the data obtained in this study would contribute new information on the basic issues presented in the Introduction, particularly with respect to the reestablishment of an appropriate reference level for the normal hearing of pure tones. In addition, it was intended by experimental design that the threshold data for stratified age groups sampled from the same geographical location would provide a more adequate basis than had been previously available for evaluating the effects of presbycusis, with relatively little confounding due to high-intensity noise effects.

The hearing survey was accomplished in two main parts: (*1*) a series of basic experiments was performed initially to establish an adequate methodology for the hearing survey (8, 9, 16, 17), and (*2*) a series of hearing studies was then conducted to establish threshold values for speech and for pure tones for the specified population (10-14). The present report is not intended to be a compendium of the numerous studies already published, but will provide new information not previously available on the two oldest age groups and will develop a unified interpretation of the effects of presbycusis based upon the integrated data from 18 to 65 years.

SAMPLING OF SUBJECTS AND SCREENING TECHNIQUES

The subjects tested in the hearing survey (N = 912) were selected from six age categories: (*1*) 18 to 24 years; (*2*) 26 to 32 years; (*3*) 34 to 40 years; (*4*) 43 to 49 years; (*5*) 51 to 57 years; and (*6*) 59 to 65 years. Each age group covered a seven-year period, and the age span between the means of the two extreme groups covered a period of 41 years. The sequence of testing by age groups was Group 1, Group 4, Group 2, Group 3, Group 5, and Group 6.

The subjects in Group 1 (18 to 24 years) were taken from the undergraduate student population at The Pennsylvania State University; the remaining subjects were selected at random from the lists of registered voters for State College, Pennsylvania. For Group 4, the voters' register for 1955 was used; for Groups 2 and 3 the 1956 register was used; and for Groups 5 and 6, the 1960 register was used. This sampling procedure was adopted to restrict the initial (original) sample of subjects in the older age categories to the more-or-less permanent residents of State College, Pennsylvania.

The subjects in the five older age groups were obtained by individual interviewing techniques. The initial preparation of the interviewing team for a given age group included an orientation period in which the general techniques of conducting a good interview were stressed as: (*1*) creating a friendly atmosphere, (*2*) developing appropriate approach and terminal behavior, (*3*) asking questionnaire items in a standardized manner, (*4*) obtaining specific responses, and (*5*) recording the responses exactly as given by the respondent.

Immediately prior to starting the survey for each age group, additional specific and detailed instructions were given to each interviewer. The emphasis at this time was to provide the interviewer with a clear understanding of the procedures which each subject would be expected to follow if he consented to participate in the survey. The three-step process required of each subject included: (*1*) completing a hearing survey questionnaire as administered by the interviewer, (*2*) obtaining an otological examination as scheduled at some later date, and (*3*) taking an audiometric test within 48 hours after the otological examination. All interviews were carried out on an individual face-to-face basis, either at the subject's home or in a private office. The interviewing teams worked on a regular weekly routine as required to maintain a steady program of audiometric testing over a number of years.

After each subject had completed the three steps required in the survey, he was given the results of both his otological examination and audiometric test on a standard form. This form, together with a letter of appreciation for participating in the study, was transmitted by mail. The final step in the survey consisted in mailing a standard form to each individual sampled from the voters' register but who, upon being interviewed, refused to participate in the hearing survey. The form, completed anonymously and returned to the project director, was intended to provide information on subject refusals. An analysis of the refusal forms indicated that the most common reasons for not participating in the study was the lack of time to fulfill the three-step requirement as set up in the study. For the five older age groups, only eight respondents refused to participate for a reason related to hearing ability; these individuals believed their hearing to be "normal."

An examination of the number of individuals sampled in the five older age groups and the number who actually completed the three-step requirement showed that the poorest participation was in the 43-to-49-year-old group. In this group, 46 percent of the men (N = 46) and 55 percent of the women (N = 54) completed the study. For the 26-to-32-year-old group, participation was 62 percent for the men (N = 84) and 64 percent for the women (N = 93). For the 34-to-40-year-old group, participation was 61 percent for the men (N = 84) and 66 percent for the women (N = 92). The best participation was in the 51-to-57-year-old group, with the men at 75 percent (N = 102) and the women at 71 percent (N = 107). For the 59-to-65-year-old group, participation was 56 percent for the men (N = 100) and 62 percent for the women (N = 100). For the five older age groups, men and women combined, the data show that approximately 62 percent of the individuals sampled (862 in 1381) actually participated as subjects in the study and completed the three-step requirement.

Since one of the aims of the present study was to provide pure tone threshold data for a large sample of subjects with no otological abnormalities or pathology and a life history of minimal exposure to high-intensity noise, screening criteria were applied at a particular point in the analysis of data to eliminate certain subjects. The criteria covered three general categories: (*1*) otological examination, (*2*) military service, and (*3*) environmental setting. Those subjects in each age group who passed in all three categories (composite screening) were designated as the screened sample for that age group in the subsequent analysis of data.

As already indicated, all subjects in the study were given an otological examination. The results of the examination for each subject were recorded on a standard form which included sections on the pinna, external auditory canal, mastoid bone, tympanic membrane, middle ear inflammation, ossicles, eustachian tube, and nose and throat. All forms were critically reviewed and evaluated by a consultant in otology. On the basis of the data provided on the examination form, each subject was rated as "pass" or "fail" by the consultant in accordance with his judgment of a negative otological history. Those subjects who failed in this category were excluded from the screened sample. The percentage of failures in each age group was as follows: (*1*) 18-to-24-year-old group, 8 percent (N = 4); (*2*) 26-to-32-year-old group, 10 percent (N = 17); (*3*) 34-to-40-year-old group, 12 percent (N = 21); (*4*) 43-to-49-year-old group, 15 percent (N = 16); (*5*) 51-to-57-year-old group, 14 percent (N = 29); and (*6*) 59-to-65-year-old group, 18 percent (N = 37). This indicates that with advancing age there is a progressive increase in the percentage of subjects who failed due to otological histories or disorders, starting with the youngest age group and reaching a maximal value in the oldest age group. On the average, there is approximately a 2 percent increase in otological failures between successive age groups. It may be of interest to note that of the 577 males between 18 and 23 years of age who reported for the Wheeler and Dickson (46) normative study, 8.2 percent (N = 47) were rejected by the clinical examination.

Examination of the results of the otological examinations indicated that there was no marked systematic tendency for the prevalence of certain disorders to increase with advancing age. Certain disorders, however, did show a slight trend. These included eczema in the External Auditory Canal category and the presence of atrophic scars in the Tympanic Membrane category. While trends were generally absent, certain disorders seemed to occur most frequently in the oldest age groups, for example, the presence of cerumen and nontransparency, retraction, atrophic scars, thickening, and immobility of the tympanic membrane. In the Nose and Throat category, the most noticeable finding was the inverse relationship between age and the percentage of subjects with tonsils removed. The oldest age group had the smallest percentage of removals. This suggests that in recent years there has been a growing tendency in medical practice to perform tonsillectomies. The percentage of adenoidectomies, however, does not parallel this trend.

Information related to the categories of military service and environmental setting was obtained for each subject by administering a standard hearing survey questionnaire. The questionnaire contained three major parts: Part A, Background Data (vocational education, residence, occupational experience, military service, hobbies and recreation, and transportation); Part B, Aural History (familial deafness, illnesses, pathological symptoms, accidents, operations, and medical compensation); and Part C, Present Hearing Status (changes in hearing, effect of noise on hearing, effect of telephone use on hearing, present hearing ability, diagnosis of hearing disorder, tinnitus, and diplacusis). The specific screening criteria applied to the hearing survey questionnaire are presented in Table 1 in terms of the minimal time limit for rejection.

Table 1

Screening Criteria for Hearing Survey Questionnaire

Questionnaire Item	*Minimal Time Limit for Rejection of Subject*
I. Education	Enrolled in Industrial Arts Curriculum 6 mo. or more, or enrolled in trade school or service school 3 mo. or more
II. Residence	Lived within 1 mile of an active commercial or military airport 6 mo. or more, or Lived in an industr. distr. 1 yr. or more
III. Occupation	Worked in environment characterized "fairly noisy" or noisier 6 mo. or more per yr. for total of 3 or more yrs.
IV. Milit. Serv.*	Experienced active milit. service 3 mo. or more, provided weapons were used, or Had flying experience of 30 hrs. or more
V. Hobbies	Participated in hobbies listed (e.g. hunting, home machine shop, motorboating, etc.) 6 weeks or more per yr. for 3 years or more
VI. Transportation	Rode trains, airplanes, or subways weekly or more frequently for 1 yr. or more

*Since most male subjects in the age categories beyond 18 to 24 years would have been rejected on the basis of this item, the military service criterion for these groups was altered to read as follows:

1. Subject received bodily injuries in military service, or
2. Subject received, or is receiving, compensations for service connected hearing loss, or
3. Subject experienced combat conditions for 6 months or more, or
4. Subject had flying experience of 30 hours or more.

Accordingly, each of the six major questionnaire categories listed in Table 1 was scored as "pass" or "fail" for each subject. For screening on the military service criterion, a subject failed that category if at least one of the conditions specified under Item IV was met. For screening on the environmental setting criterion, a subject was failed if three or more of Items I, II, III, V, or VI exceeded the minimal time limit for rejection. Thus, in addition to passing the otological screening criterion, each subject had to pass both the military service criterion and the environmental setting criterion to be included in the screened sample

The results of the screening by the three criterion categories (otological examination, military service, and environmental setting) showed the following percentage of failures in each age group: (*1*) 18-to-24-year-old group, 22 percent (9 percent female, *N* = 2; 33 percent male, *N* = 9); (*2*) 26-to-32-year-old group, 41 percent (21 percent female, *N* = 19; 63 percent male, *N* = 53); (*3*) 34-to-40-year-old group, 36 percent (12 percent female, *N* = 11; 62 percent male, *N* = 52; (*4*) 43-to-49-year-old group, 34 percent (25 percent female, *N* = 14; 44 percent male, *N* = 20); (*5*) 51-to-57-year-old group, 26 percent (19 percent female, *N* = 20; 33 percent male, *N* = 33), and (*6*) 59-to-65-year-old group, 25 percent (23 percent female, *N* = 23; 25 percent male, *N* = 25). Notice that in each age group, more male subjects than female subjects were eliminated from the original sample to produce the screened sample. Also, the large percentage of failures among the various age groups indicates that the screened samples were required to pass a relatively stringent set of composite criteria.

TESTING PROCEDURES

All audiometric tests performed in the conduct of this study were administered in the anechoic chamber of Osmond Laboratory at the Pennsylvania State University. A complete description of the design, construction, and calibration of the chamber has already been reported (6). The ambient noise level per cycle in the chamber has been measured to be no less than 20 db below the minimum audible field curve adopted by the American Standards Association (2) from 50 to 10,000 cycles per second (cps). Thus, it seems reasonable to conclude that over the range of frequencies tested in this study (250 to 8,000 cps) probably little or no masking of threshold sounds occurred due to the presence of ambient noise.

All subjects (whether "pass" or "fail") were tested on a Beltone audiometer, Model 10-A, which was appropriately modified with an impedance matching network. This permitted the use of a set of Permoflux PDR-8 earphones (mounted in MX-41/AR cushions) in place of the earphones supplied with the audiometer. The resistive network also reduced the output voltage over the frequency range tested by approximately 15 to 30 db below the normal values of the United States Public Health Survey as reduced to equivalent PDR-8 pressures by the National Bureau of Standards (26).

The sound pressure output of the audiometer was calibrated periodically in a National Bureau of Standards (NBS) Coupler 9-A in accordance with recommended procedures (3). Periodic checks were also made on the frequency of the signals generated and on the characteristics of the hearing-loss attenuator. For the two oldest age groups (51 to 57 years and 59 to 65 years), an additional stage of amplification was added to the audiometer to provide a fixed gain of approximately 7 db above the maximal value provided by the manufacturer at each frequency from 1,000 to 8,000 cps. Detailed information related to the instrumentation and calibration used in this study may be readily obtained elsewhere (9, 13, 15).

The testing procedure followed the method of limits with 2-db changes in intensity when the signal was near threshold strength. Three tone pulses were presented at each intensity setting near threshold, and the criterion of hearing was set at two responses. The duration of each tone pulse was approximately 1.0 sec; the interpulse interval--that is, the silent time within each group of three pulses, was altered from subject to subject to allow for individual differences in response tendencies. Accordingly, the interpulse intervals ranged from about 0.6 sec to several seconds, with the intervals irregularly varied around the "average" value for each subject to destroy any "set" to respond in a rhythmic manner. At each frequency, the threshold was crossed in a series of two ascending and two descending trials presented in alternation. The absolute threshold was taken as the mean audible intensity for these four trials.

All threshold tests were administered individually in the anechoic chamber which was provided with a two-way voice communication system and a closed-loop television system. Nine test frequencies were used and were presented to all subjects in the following order: 1,000, 500, 250, 1,000, 1,500, 2,000, 3,000, 4,000, 6,000, and 8,000 cps. The initial 1,000-cps test for each ear was always considered to be a practice trial, and the data were discarded in subsequent computations. The frequencies given for the audiometer are nominal values only. The calibrated frequencies as measured by a Hewlett-Packard electronic counter, Model 522-B, were 255, 505, 1,000, 1,530, 2,010, 3,010, 4,050, 6,100, and 8,000 cps for all age groups except 51 to 57 years and 59 to 65 years. For the 51-to 57-year-old group, the calibrated frequencies were 253, 499, 1,006, 1,521, 2,028, 3,095, 4,096, 6,081, and 7,976 cps. For the 59-to-65-year-old group, the calibrated frequencies were 249, 490, 1,000, 1,542, 2,052, 3,115, 4,086, 6,061, and 7,925 cps. To simplify the presentation, the data in this report are presented in terms of the conventional audiometric frequencies. The sequence of testing right and left ears was alternated between subjects, and a five-minute rest period was provided between the tests for each ear. The total testing time per subject was approximately 50 minutes.

RESULTS

The basic data of this study consisted of individual threshold values for right and left ears expressed in terms of sound pressure level (SPL)--that is, decibels re 0.0002 dynes per square centimeter, at each of nine frequencies. From these data, derived measures of central tendency and variability were computed at each frequency for the six groups of subjects tested. The derived measures were analyzed at each frequency by age groups, by ears, and by sex in terms of three types of distributions: (*1*) original distributions which contained the data for all subjects selected for the study; (*2*) screened distributions which contained the data for only those subjects who passed the rigid screening criteria related to otological disorders and extent of noise exposure; and (*3*) truncated distributions which contained only data ±15 db from the mode of the screened distributions. Thus, the analyses yielded successive estimates of hearing sensitivity, proceeding from the large unscreened sample to a smaller, highly restricted sample. Since an exhaustive presentation of the statistical treatment and the corresponding results are available in a separate source (15), the present report is restricted to the more critical findings regarding the effects of presbycusis. The entire methodology of this study, including the testing procedures, screening techniques, and data analysis, followed in detail the recommendations made by the Committee on Hearing and Bio-Acoustics of the Armed Forces-National Research Council (47).

The first step in the treatment of data concerned the mean threshold SPL values for the original sample of subjects, with the values for men and women computed separately. The data for right and left ears of the subjects in the original sample are summarized in Table 2. The combined mean thresholds (for right and left ears) of Group 1 (18 to 24 years) next served as a baseline and, by subtracting these values from the obtained mean thresholds (combined ears) at each frequency for each of the five remaining age groups, estimates of presbycusis were obtained for the men and women in the original sample. These data are presented in Figures 1 and 2 and show, respectively, a comparison of the curves obtained for men and for women and those published by the American Standards Association (23). For the men (Figure 1), there is a general similarity in the two sets of curves but, except for 4,000 cps, the data of the present study indicate that the major "break" in the curves occurs at about 32 years of age, with less than 2 db hearing loss for any frequency below this point. The 4,000 cps threshold is depressed starting with the 26-to-32-year-old group, and the curve is consistently lower than that of the American Standards Association up to approximately 54 years of age. In general, there is a trend for the magnitude of the discrepancies between the two sets of data to decrease as a function of increasing age. For the 59-to-65-year-old group (plotted at 62 years), the maximal discrepancy is approximately 2 db (at 4,000 cps).

The data for women shown in Figure 2 would seem to support the contention of the American Standards Association that the break in the curves occurs at about 37 years of age. At ages younger than this, there is less than 5 db hearing loss; beyond this, there are differential frequency effects but not as marked as for men. Notice also that the differences between frequencies for women are not as great as those for men. In general, except for 500 and 1,000 cps in the 43-to-49-year-old group (plotted at 46 years), the data of the present study beyond about 37 years differ from those of the American Standards Association in three ways: (*1*) the present data show greater hearing losses as a function of age; (*2*) the differences between frequencies are smaller than those shown by the curves of the American Standards Association; and (*3*) while all the curves of the American Standards Association appear to "level off" beyond 60 years, the present curves for 2,000, 3,000, and 4,000 cps have a marked negative slope in this region.

Table 2

Threshold Data by Age Groups, Sex, and Ears for Original Samples

Age Groups		*18-24 Yr*			*26-32 Yr*			*34-40 Yr*		
Freq.[a]	Ear[b]	*N*[c]	Mean[d]	SD[e]	*N*	Mean	SD	*N*	Mean	SD
					Male Subjects					
250	R	27	27.5	7.5	84	25.9	8.0	84	24.6	6.4
	L	27	27.6	7.6	84	26.6	6.2	84	27.4	9.7
500	R	27	12.0	8.5	84	13.2	7.5	84	12.8	6.8
	L	26	11.5	5.5	84	12.6	5.1	84	14.0	10.4
1,000	R	27	7.7	8.0	84	7.2	6.7	84	9.6	5.7
	L	26	5.5	5.1	84	6.5	5.0	84	9.1	9.4
1,500	R	27	9.2	8.5	84	7.2	7.2	84	9.5	7.8
	L	26	6.0	4.8	84	7.0	7.9	84	9.8	10.8
2,000	R	27	8.7	6.9	84	8.9	9.4	84	10.9	9.5
	L	27	7.7	11.5	84	7.7	8.0	84	11.9	11.7
3,000	R	26	13.6	8.3	84	12.4	13.8	84	15.8	14.6
	L	24	14.0	11.5	84	14.1	16.1	84	18.4	15.1
4,000	R	25	12.6	8.4	84	20.0	22.1	84	24.1	19.1
	L	26	14.8	11.6	84	21.7	19.7	84	25.2	18.8
6,000	R	27	27.1	12.3	84	36.4	23.3	84	38.2	21.5
	L	23	32.9	12.2	84	42.1	21.1	84	44.8	17.6
8,000	R	27	26.3	14.4	84	34.1	20.5	82[f]	35.7	19.5
	L	26	27.9	11.8	83[f]	32.5	19.6	81[f]	39.7	19.0
					Female Subjects					
250	R	23	24.3	4.2	92	25.8	8.7	90	25.1	6.2
	L	23	24.5	4.5	92	26.4	6.5	90	26.9	6.7
500	R	23	11.0	4.2	92	14.0	13.6	90	11.2	6.5
	L	23	9.1	6.4	82	13.4	7.9	90	12.6	6.1
1,000	R	23	5.7	4.3	92	7.9	9.9	90	7.7	5.5
	L	23	4.2	4.6	92	6.9	7.3	90	11.1	5.8
1,500	R	22	5.3	5.0	92	8.5	9.3	90	8.6	7.6
	L	22	4.5	4.3	92	6.6	6.3	90	7.1	6.9
2,000	R	21	5.5	5.4	92	8.5	9.4	90	9.5	7.4
	L	21	4.4	4.3	92	6.7	6.6	90	8.5	7.7
3,000	R	21	7.5	6.3	92	8.0	8.8	90	9.3	7.9
	L	18	7.3	4.3	92	5.7	6.7	90	8.6	7.9
4,000	R	23	11.1	5.8	92	10.3	9.6	90	12.9	9.7
	L	21	9.5	4.3	92	8.4	6.2	90	12.8	8.9
6,000	R	22	21.4	6.9	92	21.8	12.5	90	24.1	11.1
	L	21	21.1	5.5	92	24.3	10.6	90	29.0	10.9
8,000	R	23	17.1	6.0	92	25.7	14.7	90	26.9	11.9
	L	22	22.3	10.0	92	23.9	11.8	89[f]	28.3	11.9

[a]For exact frequencies, see Testing Procedures.

[b]Right and left ears are denoted by R and L.

[c]The *N* is not constant for all frequencies as equipment difficultie or deviations from standardized testing procedures indicated that certain data should be discarded.

43-49 Yr			51-57 Yr			59-65 Yr		
N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
45	28.4	15.6	99	28.5	10.2	100	34.5	8.8
45	28.7	16.2	99	31.0	10.4	100	35.1	10.7
45	12.5	14.0	99	17.0	11.7	100	19.3	8.8
45	11.2	16.5	99	18.6	11.5	100	18.9	10.3
45	10.1	13.4	99	15.7	13.5	100	16.0	9.9
45	11.4	15.3	99	15.4	14.9	100	16.4	12.2
45	14.3	12.8	99	18.1	16.6	100	20.8	11.9
45	16.4	13.8	99	18.9	17.1	100	21.9	14.7
45	14.4	11.5	99	20.8	16.2	100	26.1	16.0
45	18.9	14.6	99	23.4	18.1	100	29.1	17.8
45	26.9	18.5	99	29.7	20.6	100	40.0	21.8
45	30.5	17.7	99	33.0	20.8	100	44.2	21.1
45	34.9	18.0	99	36.9	22.7	100	48.7	20.3
45	37.6	18.8	99	39.7	21.8	100	51.7	20.2
45	42.2	21.4	99	49.5	23.4	100	60.3	21.5
45	49.6	20.0	99	52.3	22.3	100	65.6	22.2
45	35.1	20.5	99	48.0	23.5	100	56.2	23.1
45	42.0	19.2	99	50.3	21.4	100	59.1	22.4
55	26.3	12.3	106	31.0	11.1	100	37.2	10.9
55	24.4	11.9	106	34.6	12.8	100	37.5	10.7
55	12.2	12.3	106	18.8	10.7	100	21.7	12.6
55	11.0	10.7	106	21.5	12.9	100	21.6	13.0
55	8.3	10.6	106	15.2	11.0	100	17.0	14.4
55	8.1	11.1	106	16.7	13.4	100	15.8	14.5
55	14.2	11.7	106	16.2	12.0	100	20.2	14.0
55	12.3	8.5	106	17.0	13.5	100	19.1	15.7
55	13.9	12.1	106	19.2	11.1	100	22.4	14.3
55	11.5	9.0	106	19.8	13.3	100	22.3	16.7
55	13.7	13.5	106	20.7	12.7	100	25.7	16.2
55	13.8	13.5	106	23.0	15.1	100	26.5	16.0
55	19.1	11.5	106	25.2	14.0	100	30.2	18.1
55	18.7	12.4	106	27.2	17.5	100	30.8	17.0
55	35.7	12.9	106	38.0	14.8	100	48.0	21.7
55	34.3	12.7	106	41.4	16.0	100	47.6	18.3
55	31.0	16.5	106	39.3	17.9	100	47.1	23.3
55	29.6	14.5	106	41.5	17.7	100	45.1	20.6

[d]The mean threshold value is expressed in db re 0.0002 d/cm^2 as measured in NBS Coupler 9-A.

[e]The standard deviation (SD) is expressed in db.

[f]The 8,000 cps threshold value for several ears could not be determined since the thresholds were above 100 db hearing loss on the audiometer.

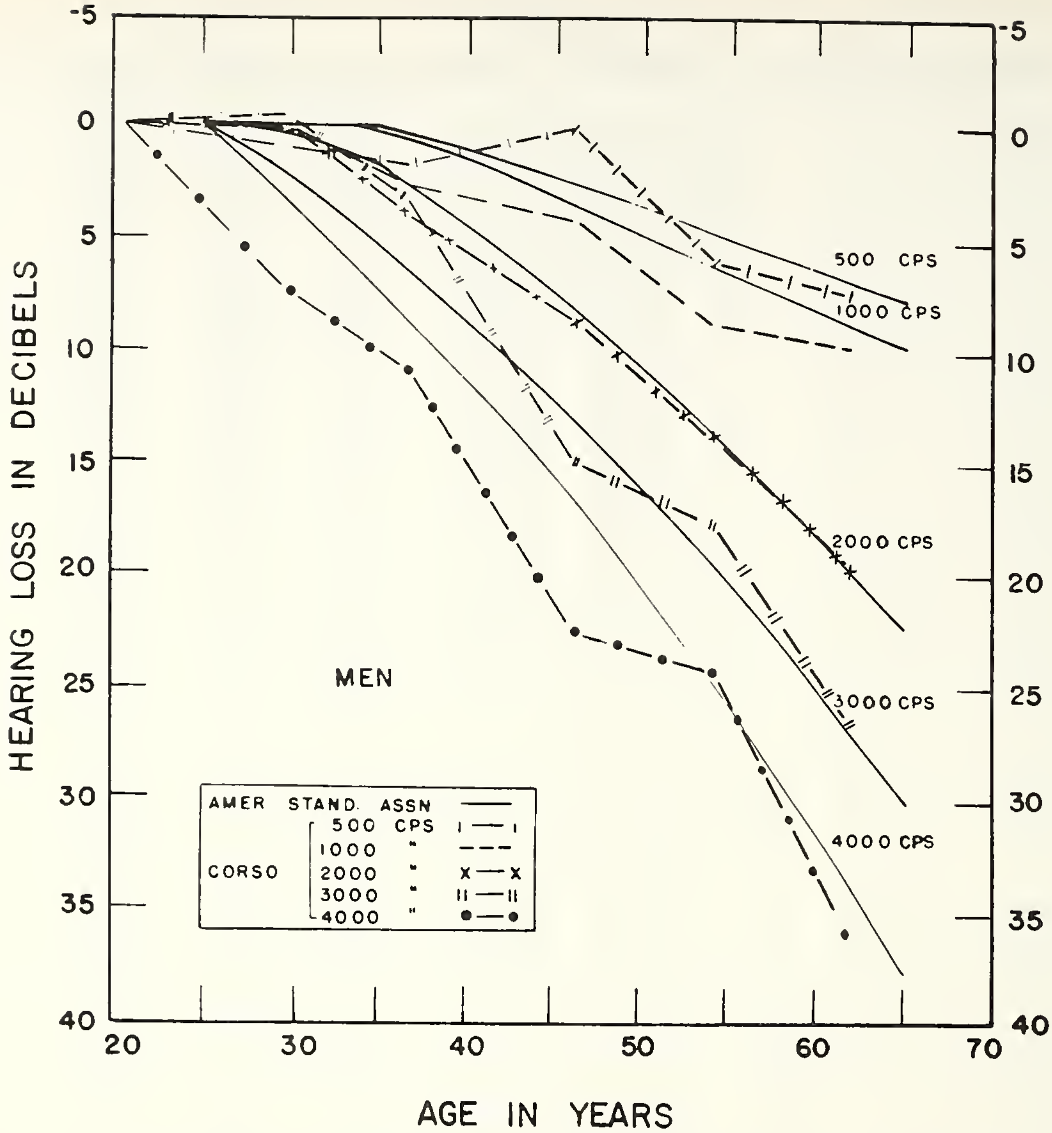

Figure 1. Comparison of Presbycusis Curves for Men of American Standards Association and Corso Mean Hearing Loss Relative to the Original Distribution of Threshold SPL Values for Male Subjects 18 to 24 Years of Age

Although the data for the original sample tend to conform in some degree to the curves of the American Standards Association, the original samples were known to contain subjects with otologically abnormal ears, as well as subjects exposed to high levels of noise. Consequently, the effects of these extraneous factors probably served to inflate the derived values of Figures 1 and 2. In order to obtain more valid estimates of presbycusis, the rigid screening criteria of Table 1 and the otological screening procedure were introduced to eliminate those subjects who showed a history of excessive noise exposure and/or had otological abnormalities.

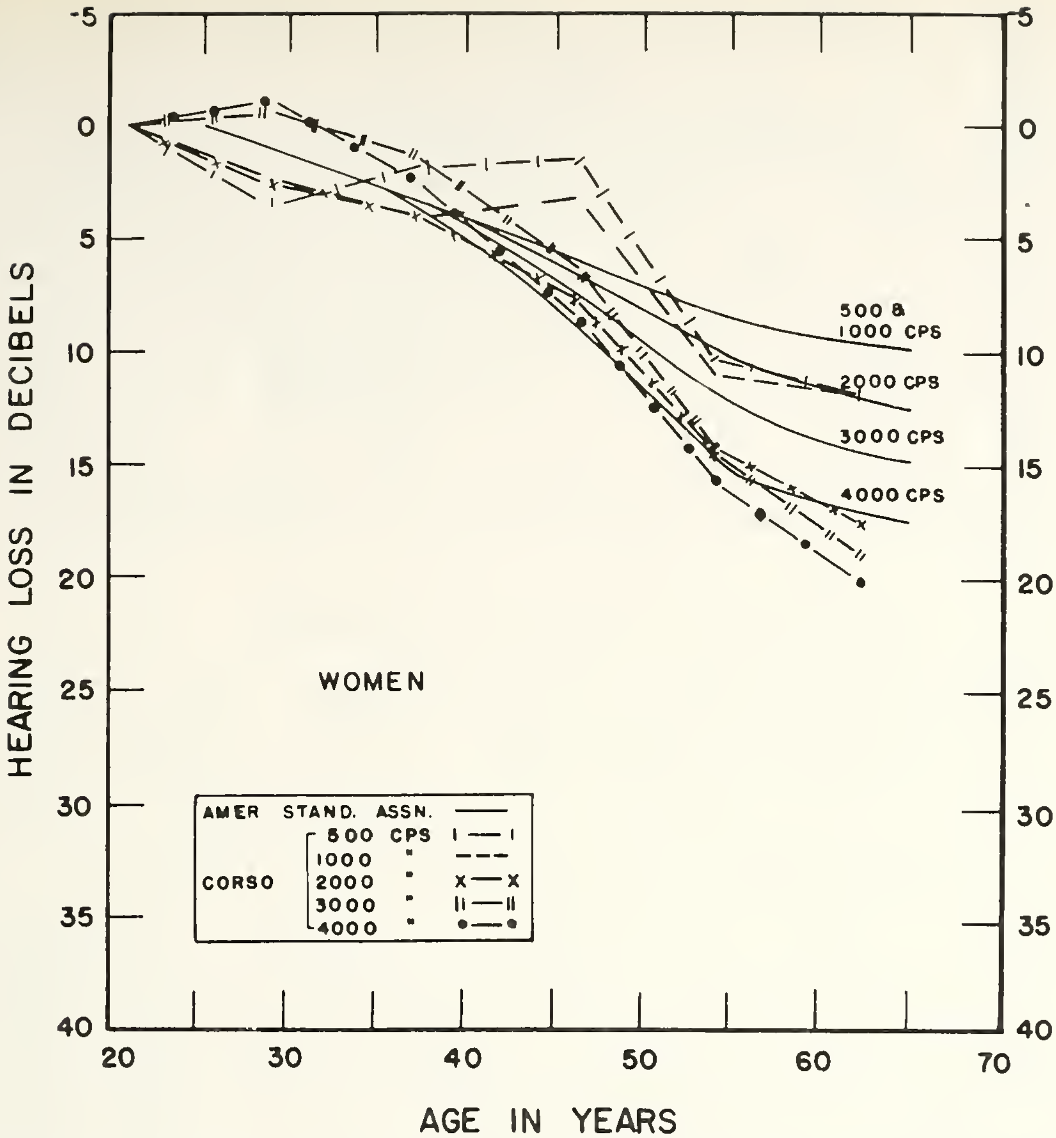

Figure 2. Comparison of Presbycusis Curves for Women of American Standards Association and Corso Mean Hearing Loss Relative to the Original Distribution of Threshold SPL Values for Female Subjects 18 to 24 Years of Age

The relation between sex and hearing was determined by performing certain statistical analyses on the threshold SPL data of the screened sample. Tests of significance of the differences between male and female means (t-ratios) and between variances (F-ratios) were computed at each frequency, ear held constant, for each age group (7, 22). Of the 108 mean differences tested (6 age groups × 9 frequencies × 2 ears), 51 were statistically significant; of 108 variance comparisons, 65 were statistically different. In general, where significant differences existed, the mean threshold

SPL values for women were lower than those for men. These differences occurred approximately in the region of 3,000 cps and above, except for Group 4 (43 to 49 years) in which a significant difference occurs as low as 500 cps. Likewise, in general, significant differences in variability are associated with lower values for women, particularly above 3,000 cps. Below this frequency, there are some instances in which the variability for men is significantly less than that for women. This is especially apparent in the 51-to-57-year-old group; here the women not only show greater variability than the men at the lower frequencies, but are also characterized by higher thresholds (poorer hearing) below 3,000 cps, with significant differences at 250 and 500 cps. In the 59-to-65-year-old group, the women also show significantly greater variability at some frequencies below 3,000 cps (at 250, 500, and 1,000 cps), but except for 2,000 cps on the left ear, there are no significant differences in means at these frequencies. The results of these statistical tests indicate conclusively that real differences exist between men and women in auditory sensitivity and threshold variability.

The next step in the analysis was to determine whether the screened threshold values for right and left ears could be combined for men and for women in each age group. Tests of significance were therefore computed at each frequency for differences in means and in variances for both men and women. To obtain the appropriate error term for testing the significance of these differences, product-moment correlation coefficients (22) were computed for the threshold values (SPL) of right and left ears. Of the 108 mean differences, 23 were statistically significant; of 108 variance comparisons, 27 were statistically significant; of 108 correlation coefficients, 97 were significantly greater than 0. Of the 11 correlation coefficients which failed to reach statistical significance 10 occurred in Group 1 (18 to 24 years). Where significant mean differences did occur, the maximal difference between ears was approximately 9 db, but nearly all remaining differences were 5 db or less. Thus, it was concluded that for *practical* purposes, the threshold data of the screened distribution for right and left ears could be combined, and that no appreciable biasing effect would be introduced by this procedure.

The means and standard deviations combined for right and left ears for the men and for the women in the screened samples are presented in Table 3 for each of the 6 age groups. Notice that in nearly every instance, the mean threshold SPL value and corresponding standard deviation are greater for men than for women, with the exception of the values for the 51-to-57 and 59-to-65-year-old groups where this trend is suddenly reversed for all frequencies below about 2,000 cps and 1,000 cps, respectively.

The threshold data of Table 3 were next converted to hearing loss values with the mean thresholds of Group 1 (18 to 24 years) serving as the baseline. This transformation provided a set of values for each of the five remaining age groups which are shown as curves of presbycusis for men and for women in Figures 3 and 4,

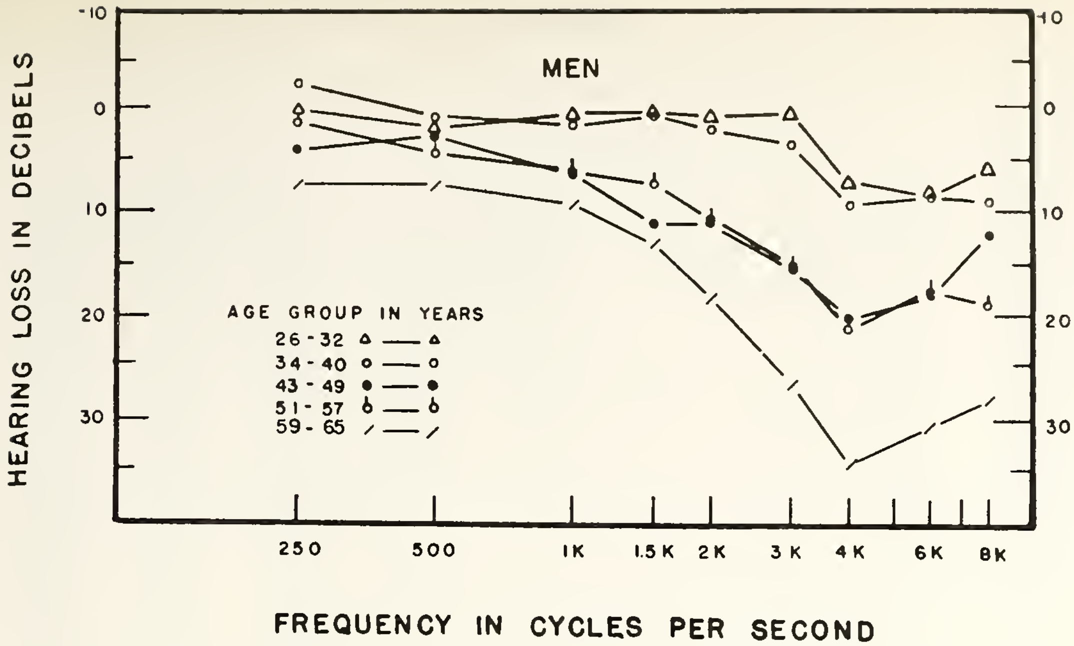

Figure 3. Mean Hearing Loss for Men in Screened Distributions of 26-to-32, 34-to-40, 43-to-49, 51-to-57, and 59-to-65-Year-Old Age Groups Relative to the Mean Threshold SPL for the Men in Screened 18-to-24-Year-Old Group

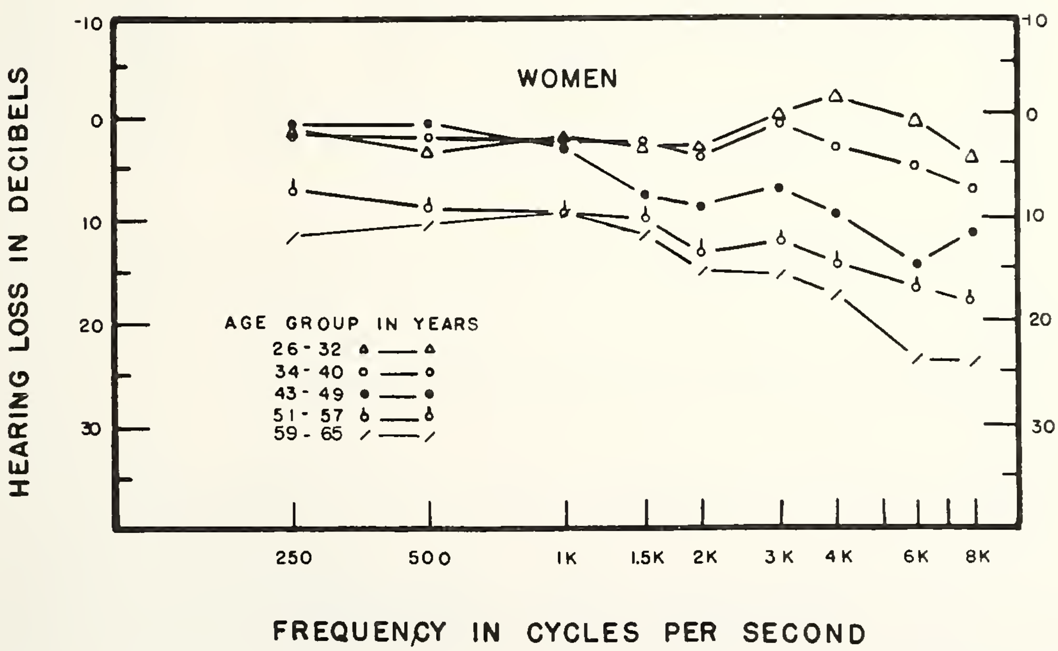

Figure 4. Mean Hearing Loss for Women in Screened Distributions of 26-to-32, 34-to-40, 43-to-49, 51-to-57, and 59-to-65-Year-Old Age Groups Relative to the Mean Threshold SPL for the Women in Screened 18-to-24-Year-Old Group

Table 3

Means and Standard Deviations Combined for Right and Left Ears of

Freq.[a]	Sex[b]	*N*[c]	*18-24 Yr* Mean	SD	*N*	*26-32 Yr* Mean	SD	*N*	*34-40 Yr* Mean	SD
250	M	36	26.8	4.6	62	27.2	6.2	64	24.5	6.7
	F	42	24.3	4.3	146	25.6	7.1	158	26.1	6.2
500	M	36	11.1	5.8	62	13.3	6.0	64	12.1	6.7
	F	42	9.6	5.0	146	13.1	10.8	158	11.9	6.1
1,000	M	36	5.9	4.4	62	6.7	4.9	64	7.8	4.1
	F	42	4.8	4.5	146	7.1	8.1	158	7.3	5.5
1,500	M	36	7.2	5.2	62	7.8	8.4	64	8.2	7.8
	F	40	5.2	4.9	146	8.0	7.6	158	7.8	7.2
2,000	M	36	7.7	6.2	62	8.8	9.5	64	10.0	10.2
	F	38	4.7	4.6	146	7.8	8.0	158	8.8	7.2
3,000	M	33	12.8	7.2	62	13.6	14.8	64	16.3	13.9
	F	36	7.7	5.8	146	7.7	7.7	158	8.9	7.8
4,000	M	35	14.0	8.6	62	21.5	19.3	64	23.7	17.5
	F	40	10.1	5.4	146	8.3	6.6	158	13.2	9.0
6,000	M	35	30.0	13.1	62	38.8	19.0	64	38.9	18.4
	F	40	21.1	6.3	146	21.7	10.4	158	26.4	11.4
8,000	M	35	27.6	14.0	62	33.6	16.9	64	36.8	19.4
	F	42	19.4	8.4	146	23.9	12.1	157	26.7	10.5

[a]For an explanation of the column headings see footnotes in Table 2.

[b]Male and female subjects are designated by M and F respectively.

[c]*N* indicates the total number of ears, both right and left.

[d]Although there were 75 male subjects in the screened sample of this age group, the combined *N* for right and left ears is only 149 due to computer malfunctioning. At each frequency one punched data card was rejected at random.

Male and Female Subjects in the Screened Sample

43-49 Yr			*51-57 Yr*			*59-65 Yr*		
N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
50	31.0	19.4	132	28.3	7.9	149[d]	34.3	9.4
82	25.3	10.8	172	31.7	10.6	154	36.5	10.8
50	14.0	18.5	132	15.8	7.9	149	18.6	8.7
82	10.6	10.8	172	18.8	10.2	154	20.4	12.4
50	12.5	17.1	132	12.4	9.0	149	15.5	10.5
82	8.0	10.6	172	14.4	10.8	154	14.5	13.2
50	18.6	15.4	132	14.9	11.4	149	20.1	12.9
82	13.2	8.7	172	15.4	10.7	154	17.2	13.0
50	19.1	15.5	132	18.7	12.6	149	25.9	16.3
82	13.8	10.3	172	18.2	10.4	154	20.0	13.7
50	28.6	17.1	132	28.4	16.8	149	39.8	20.9
82	15.0	13.2	172	20.1	11.0	154	23.7	13.7
50	34.6	14.7	132	35.3	19.6	149	48.8	20.8
82	19.6	12.1	172	24.7	13.7	154	27.6	14.7
50	48.2	18.4	132	47.7	21.0	149	61.3	22.6
82	35.9	13.6	172	38.0	13.6	154	45.2	17.8
50	40.1	19.7	132	46.6	20.7	149	55.3	22.6
82	30.9	15.9	172	37.7	16.5	154	43.7	20.5

respectively. These curves, unlike those of Figures 1 and 2, are influenced minimally by the effects of noise exposure and otological abnormalities. Consequently, they represent "purer" or unbiased estimates of presbycusis.

There are six points which should be noted in referring to Figures 3 and 4: (*1*) Except for 250 cps in the female group 59 to 65 years, all losses at and below 1,000 cps do not exceed 10 db regardless of age. (*2*) Over the frequency range tested (250 to 8,000 cps) and up to 40 years of age, there is no loss greater than 10 db for either men or women. (*3*) For both men and women within each of the five age groups, there is a consistent trend for the greatest hearing losses to occur at the higher frequencies. (*4*) For men in the four oldest age groups, the greatest loss occurs at 4,000 cps; for women, the hearing loss curves fall gradually from approximately 1,000 to 8,000 cps, particularly in the three oldest groups. (*5*) For comparable age groups, the hearing loss for men and women is approximately the same at 1,000 cps; however, for frequencies above this point, the hearing loss for men is generally greater than that for women, while below this point the hearing loss for women is generally greater than that for men. (*6*) In general, there is a trend for hearing loss to increase with advancing age; for women, the decline appears to occur fairly regularly from age group to age group, but for men the decline seems to occur in distinctive stages.

The final analysis of data involved the elimination of extreme thresholds from the screened distributions of Table 3. This was accomplished by omitting all values which fell beyond ±15 db from the mode of the screened distributions at each test frequency for both men and women in each age group. If the threshold values at a given frequency formed a distribution with more than one modal value, the truncation was made from the mode which eliminated the minimal number of subjects. In case of a tie, the modal value was randomly chosen. After the extreme values were eliminated from each screened distribution, a mean was computed for the remaining truncated distribution. Table 4 presents a summary of the screened modes for both men and women at the nine test frequencies, together with the number of cases (*N*) in the screened distributions. To provide a more complete description of the screened distribution, median values have also been included.

A comparison of the screened means of Table 3 and the screened medians of Table 4 indicates that these values are more nearly alike for the 18-to-24-year-old group than for the older age groups. In general, the screened means are larger than the screened medians with the largest discrepancies occurring in the oldest age groups. This effect is present for both men and women, but is more marked for men; also it is most noticeable for men at the higher frequencies up to 40 years of age. In the three oldest groups, the differences between mean and median values are fairly large for all test frequencies, but there is no apparent trend for the differences to increase over the span of years. The discrepancy between means and medians indicates that hearing thresholds are essentially

Table 4

Summary of Threshold (SPL) Data Showing the Medians and Modes by Age Groups and by Sex for the Screened Samples

Age Groups		*18-24 Yr*			*26-32 Yr*			*34-40 Yr*			*43-49 Yr*			*51-57 Yr*			*59-65 Yr*		
Freq.[a]	Sex[b]	*N*[c]	MDN[d]	Mo[e]	*N*	MDN	Mo	*N*	MDN	Mo	*N*	MDN	Mo	*N*	MDN	Mo	*N*	MDN	Mo
250	M	36	25.8	25	62	25.0	23	64	23.2	27	50	23.8	23	132	26.5	28	149	32.6	30
	F	42	24.2	25	146	24.4	25	158	24.5	23	82	24.2	21	172	29.0	20	154	34.9	30
500	M	36	11.2	11	62	11.9	11	64	11.1	11	50	7.6	5	132	14.9	15	149	16.9	15
	F	42	10.0	9	146	11.9	11	158	11.0	7	82	8.9	9	172	16.8	17	154	19.0	14
1,000	M	36	6.0	5	62	6.7	7	64	6.9	7	50	5.5	5	132	10.9	9	149	13.6	13
	F	42	6.3	7	146	6.2	7	158	6.2	5	82	5.9	5	172	12.7	8	154	11.8	6
1,500	M	36	6.6	5	62	6.0	7	64	7.0	5	50	14.5	9	132	11.6	7	149	16.8	18
	F	40	5.7	7	146	6.9	7	158	7.4	7	82	11.3	9	172	12.5	10	154	14.6	21
2,000	M	36	6.7	5	62	7.0	9	64	8.4	9	50	14.0	5	132	14.6	9	149	22.9	28
	F	38	4.8	7	146	7.3	11	158	8.3	13	82	11.4	9	172	17.5	14	154	17.7	10
3,000	M	33	11.3	9	62	11.7	7	64	13.3	13	50	25.1	25	132	24.4	20	149	36.1	20
	F	36	7.3	5	146	6.7	5	158	8.2	5	82	11.3	17	172	18.3	20	154	20.7	20
4,000	M	35	11.0	9	62	13.1	7	64	19.4	9	50	32.0	35	132	26.8	24	149	48.8	66
	F	40	9.7	9	146	8.4	7	158	11.6	3	82	15.8	15	172	21.7	17	154	25.9	26
6,000	M	35	28.8	31	62	34.0	25	64	35.4	37	50	45.5	47	132	41.7	31	149	60.3	43
	F	40	21.0	23	146	21.7	19	158	25.5	27	82	33.4	29	172	35.2	35	154	42.5	27
8,000	M	35	23.0	19	62	30.0	25	64	34.3	35	50	36.0	29	132	42.0	40	149	57.2	72
	F	42	17.8	17	146	21.6	17	157	26.0	19	82	25.8	21	172	34.0	34	154	41.8	23

[a]For exact frequencies, see Testing Procedure.

[b]Male and female subjects are designated by M and F, respectively.

[c]*N* is the total number of ears (both right and left) in the screened distribution.

[d]MDN is the median threshold SPL in db re 0.0002 dyne/sq cm.

[e]Mo is the modal threshold SPL in db re 0.0002 dyne/sq cm. If a given screened distribution contained more than one modal value, the truncation was made from the mode which eliminated the minimal number of threshold values. In cases of a tie, a random choice was made.

symmetrically distributed in the youngest age group, but tend to be positively skewed in the older age groups, beginning first at the higher frequencies and gradually spreading to all frequencies. It should be especially noted, however, that of the 108 differences between screened means and screened medians, only eight differences exceed 5 db, with five of these occurring in the 43-to-49-year-old group.

Table 5 presents a summary of the means computed for the truncated distribution of each of the six age groups. Inspection of the screened means of Table 4 and the truncated means of Table 5 shows that, as expected, the elimination of extreme threshold values by the truncation process results in smaller means at most frequencies. This reduction in the mean value is a further indication of asymmetry and, therefore, nonnormality of the screened distributions. Such a finding, however, does not invalidate the preceding statistical analyses, since the F-distribution is practically unaffected by lack of symmetry in the distributions of criterion measures provides the same form is common to all groups (35). The mean threshold SPL values for the truncated distributions for men and women represent the lowest (best) thresholds which can be expected in a large group of otologically normal subjects selected at random from a population exposed to minimal levels of industrial noise.

COMMENT

The comparison of the curves of presbycusis based on the original sample of subjects in the present study with those of the American Standards Association (Figures 1 and 2) shows limited agreement between the two sets of curves. At only one point, however, is the discrepancy for either men or women greater than 5 db. This occurs for men at mean age 46.5 years where the discrepancy is about 6 db for 4,000 cps. Although the magnitude of the differences is not excessive, the slopes of the two sets of curves are not consistently similar. These differences may be attributed in part to basic differences in the testing procedures and situations of the field studies represented in the curves of the American Standards Association and the more highly controlled laboratory conditions of the present study. There are also certain differences in the specific age groupings of subjects. In the present study, the curves of presbycusis were derived from smaller class intervals for age (7 years *vs* 10 years) and a younger base-line group (18 to 24 years *vs* 20 to 29 years).

A more serious limitation of the curves of the American Standards Association is that in some cases the loss due to presbycusis was computed from mean threshold values, while in other cases it was computed from a value halfway between the median of the men and the median of the women. This procedure involves two untenable assumptions: (*1*) that no differences exist between threshold means and medians, and (*2*) that no differences exist between threshold values for men and women. While

Table 5

Summary of Mean Threshold (SPL) Data by Age Groups and by Sex for the Truncated Samples

Age Groups:		18-24 Yr		26-32 Yr		34-40 Yr		43-49 Yr		51-57 Yr		59-65 Yr	
Freq.[a]	Sex[b]	N[c]	Mean[d]	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
250	M	36	26.8	59	26.4	62	24.3	42	23.2	124	27.2	132	32.2
	F	42	24.3	141	24.7	147	24.9	79	23.6	157	29.2	127	32.8
500	M	35	10.6	59	12.5	63	11.5	41	6.1	123	14.4	130	16.1
	F	41	9.9	139	11.1	146	10.6	79	9.0	155	16.3	132	16.8
1,000	M	36	5.9	62	6.7	63	7.5	39	4.6	117	9.9	133	12.8
	F	41	4.6	140	5.9	153	6.6	77	6.2	140	10.7	125	9.9
1,500	M	35	6.7	59	6.5	60	6.7	35	10.1	104	10.0	130	16.2
	F	40	5.2	140	6.8	150	6.8	74	11.2	141	12.1	128	17.0
2,000	M	34	6.8	54	6.4	59	8.1	32	9.5	94	12.2	98	25.4
	F	38	4.7	138	7.1	153	8.5	72	11.2	153	15.9	113	13.9
3,000	M	30	10.4	51	8.2	57	12.2	34	23.6	89	18.6	70	22.5
	F	40	5.9	141	6.5	145	7.7	72	12.1	151	17.3	130	20.0
4,000	M	30	11.2	41	10.3	42	13.6	31	39.7	82	23.0	57	64.3
	F	40	10.1	143	7.9	118	8.8	68	15.6	132	18.8	126	24.6
6,000	M	25	26.8	38	28.6	45	34.5	28	44.3	73	33.0	66	43.3
	F	39	20.0	134	20.6	123	24.9	60	30.3	141	34.3	74	31.2
8,000	M	26	19.5	43	26.0	42	33.0	29	28.0	75	39.8	63	70.8
	F	40	18.2	119	20.4	117	22.1	54	23.2	121	32.6	65	25.1

[a]For exact frequencies, see Testing Procedure.

[b]Male and female subjects are designated by M and F, respectively.

[c]N is the total number of ears (both right and left) in the truncated distribution.

[d]Mean threshold values are expressed in db re 0.0002 dyne/sq cm.

these assumptions may not introduce serious errors at the lower frequencies for the younger groups up to 40 years of age, the results of the present study indicate that sizeable errors will be introduced at the higher frequencies for these groups. For the older age groups, and especially for men, errors may be introduced throughout the entire range of frequencies. It appears, therefore, that a more stringent specification of the zero reference level for hearing should be adopted which, in turn, will yield a more valid estimate of the effects of presbycusis.

The curves of presbycusis based on the threshold data for the screened sample of subjects in the present study (Figures 3 and 4) tend to overcome the shortcomings indicated for the original sample. These curves have been prepared separately for men and for women, with hearing loss in each case computed from an appropriate zero reference. Furthermore, the calculation of hearing loss for screened subjects tends to minimize the extraneous influence of noise exposure and otological abnormalities. As indicated in the Introduction, the curves of presbycusis are intended to show the degree of hearing loss which is associated with advancing age as computed from threshold values for young adults 18 to 24 years of age. It is recognized that there may be a number of factors responsible for these losses, such as physiologic aging of the auditory system, ambient noise in the environment, systemic disease, toxicity due to infection, and the effects of certain drugs; but, since no data are currently available which establish the effects of each of these factors in isolation, no attempt has been made to partition the obtained losses into segments related to specific causal factors. Unfortunately, any study of hearing loss as a function of age will always yield results confounded by the effects of extraneous factors related to the subjects' past history. The screening techniques in the present hearing survey were designed to minimize the effects of the most cogent factors, and the curves of presbycusis represent, therefore, the extent of hearing loss which is associated with advancing age for a sample of otologically normal subjects selected from a population exposed to minimal levels of industrial noise. It would appear that in medico-legal cases involving noise-induced hearing loss, a correction factor for presbycusis based on the curves of Figures 3 and 4 would be a more valid estimate than that previously recommended (23).

Several of the more unusual findings on presbycusis in the present study are in substantial agreement with recently reported results of other investigators. Goetzinger *et al.* (25) found that in three age groups (60-69, 70-79, and 80-89 years) men had better hearing than women for the lower frequencies (ear held constant) but the converse was true at the higher frequencies. Although the cross-over point varied among groups, it appeared to be in the region of 500 to 1,000 cps. In the present study, the women in the 51-to-57-year-old group had significantly poorer hearing than men at 250 and 500 cps; in the 59-to-65-year-old group the same trend was present, although the differences were not statistically significant. When the curves of Figure 3 are superimposed on those of Figure 4, visual inspection shows the cross-over point to be at about 1,000 cps.

Since at no frequency did the women in the 43-to-49-year-old group have a lower threshold than men, as opposed to the 51-to-57-year-old group, it may be hypothesized that the curves for men and for women cross at approximately 54 years of age rather than at "ninety" (27).

In the section of Results, it was pointed out that for men, differential frequency effects started at about 32 years of age; for women, at about 37 years of age. Combining this observation with the data of Figures 3 and 4, it may be concluded that: (*1*) the onset of hearing loss as a function of age is more gradual for women than for men; (*2*) once started, loss of hearing proceeds at a faster average rate for women than for men, so that by the common age of 51 to 57 years, the relative hearing loss for women exceeds that for men at the lower frequencies; and (*3*) the rate of deterioration of hearing in women is fairly uniform as a function of age; but, for men, the rate varies with age in a somewhat discontinuous manner. From 26 to 40 years (mean age 33.5 years), there is relatively little change in the hearing sensitivity of men; then there is a marked drop in sensitivity but no further pronounced changes from 43 to 57 years (mean age 50.5 years); this is followed by a second major drop in the 59-to-65-year-old group (mean age 62.5 years). It appears, therefore, that marked changes in the hearing of men occur on the average in steps of about 15 years.

One other fact remains to be mentioned; specifically, the finding that the earliest detectable hearing losses for men and for women occur at the higher frequencies, 4,000 cps and above. With advancing age, these losses become more pronounced, and the effects gradually spread into the lower frequencies, eventually reaching 250 cps. Riley *et al.* (38) have collected data showing a similar trend.

A comparison of the presbycusis data (based on the screened sample means) of the present study with those of Riley *et al.* (38) shows that for male subjects the largest absolute discrepancy in each age group is 4.2 db for 26-32 years (3,000 cps), 5.5 db for 34-40 years (3,000 cps), 3.9 db for 43-49 years (2,000 cps), 9.3 db for 51-57 years (6,000 cps), and 6.7 db for 59-65 years (6,000 cps). Thus, except for the three highest frequencies in the 51-57-year age group and the 6,000 cps value in the 59-65-year age group, all discrepancies between the two sets of male data lie within about ±5 db. The female data show even better agreement, with the maximal absolute difference being only 4.8 db (26-32 years, 4,000 cps). Hence the two studies are in fairly good agreement even though the Riley *et al.* (38) data were obtained on more than 5,000 subjects in an *industrial* setting over a ten-year period. It should be noted, however, that of the 70 comparisons (7 frequencies × 5 age groups × 2 sexes), 42 values (20 male and 22 female) in Riley *et al.* (38) showed a greater degree of hearing loss, especially in the higher frequencies. This probably reflects differences in the two samples attributable to differences in screening criteria.

A comparison of the presbycusis data (based on the screened sample medians) of the present study with those of Hinchcliffe (31) shows the maximal absolute discrepancy to be 5.7 db (51-57 years, 2,000 cps), but all other differences are less than 4.4 db (43-49 years, 1,000 cps). In the 59-65-year age group, the maximal difference is only 3.6 db (at 8,000 cps). It should be pointed out that this agreement was obtained despite differences in earphones (Corso: PDR-8; Hinchcliffe: TDH-39), in calibration couplers (Corso: 6 cc; Hinchcliffe: 3 cc), and in the reference baseline: (Corso: screened medians for female subjects; Hinchcliffe: screened median for male and female subjects where no significant sex differences were obtained). Except for the 18-24-year age base line group, the present study had a greater number of subjects, with about twice as many in each age category. Thus, the findings of the present study may be considered to be somewhat more reliable.

The presbycusis data (screened sample) of the present study were also compared with the laboratory data of Konig (34). Unfortunately, in that study only ten subjects (total male and female) were used in each age category, and the data were not reported for each sex separately. Nevertheless, the maximal absolute discrepancy was 7.0 db (59-65 years, 4,000 cps). With the exception of this value and a value of 6.0 db (43-49 years, 2,000 cps), all other differences were less than 4.4 db (51-57 years, 2,000 cps). All comparisons were based on combined male and female means in the screened sample of each age group.

In general, since the data of the present study are in substantial agreement with the findings of other investigators and no marked systematic tendencies have been noted in the direction of the observed differences in hearing loss, it appears that the obtained curves represent an adequate basis for evaluating the threshold of hearing as a function of age for men and women selected from a population exposed to minimal levels of industrial noise.

Finally, it should be recognized that the problem of specifying normal thresholds of hearing for different age groups involves two major factors: (*1*) the selection of a specific distribution of threshold values (original, screened, or truncated) and (*2*) the choice of a specific measure of central tendency (mean, median, or mode) to represent the values within this distribution. In the present study, the normal values used to specify audiometric zero and to indicate the effects of presbycusis were taken as the means of the screened distributions for men and for women. Depending upon (*1*) the arbitrary definition of the "normal" population--that is, whether it refers to subjects in the original, screened, or truncated distributions, and (*2*) the intended application of the threshold data, other selections might more appropriately be made. Nevertheless, the data of the present study suggest conclusively that in the specification of future standards for normal hearing, separate values should be given for men and for women in prescribed age categories in order that the established effects of age and sex on pure tone thresholds may be properly recognized.

SUMMARY AND CONCLUSIONS

The present study was performed to determine the normal thresholds of hearing for pure tones on an age-stratified sample of subjects drawn from a population exposed to minimal levels of industrial noise. The data of the study were intended to be of theoretical significance in the field of hearing and of practical significance in assessing the degree of hearing loss which, in medicolegal cases of deafness involving noise exposure, might normally be expected to accrue as a function of age.

The subjects of the study were selected from students and faculty of the Pennsylvania State University and residents of State College, Pennsylvania. Six age groups were studied: 18 to 24, 26 to 32, 34 to 40, 43 to 49, 51 to 57, and 59 to 65 years, inclusive. Prior to audiometric testing, all subjects were required to take an otological examination; in addition, all subjects were required to complete a comprehensive life-history questionnaire. Threshold determinations were made at nine frequencies from 250 to 8,000 cps on a Beltone audiometer provided with PDR-8 earphones calibrated in a National Bureau of Standards Coupler 9-A. Measurements were made on both right and left ears, and all subjects were individually tested in an anechoic chamber.

The threshold data were analyzed in terms of three types of distribution: (*1*) original distributions which contained the data for all subjects selected for the study; (*2*) screened distributions which contained the data only for subjects who passed rigid screening criteria related to otological disorders and extent of noise exposure; and (*3*) truncated distributions which contained only the data ±15 db from the mode of the screened distributions. For the three types of distributions, appropriate measures of central tendency and variability were computed, and, where necessary, appropriate tests of statistical significance were performed.

The results of the present study provide data which should be of considerable importance in the proposed revision of the present American standards of normal hearing. It was determined from the screened distributions that, in general, there are only minor differences (less than 5 db) between the average sensitivity of right and left ears. However, the hearing of women is, on the average, more acute than that of men and shows less intersubject variability, except in the 51-to-57 and 59-to-65-year age groups. In these groups, the women have poorer hearing and greater variability at the lower frequencies--that is, at least below 1,000 cps, while the men have significantly poorer hearing and greater variability at least from 3,000 cps and above. The differences between sexes are most marked at the higher frequencies, with the cross-over point in the region of 1,000 cps. For both men and women, there is a decrease in hearing sensitivity with increasing age and a progressive spreading of the loss from the higher to the lower frequencies.

Men are more affected than the women, with the hearing loss occurring at an earlier age by at least five years (32 years *vs* 37 years) and producing a greater degree of auditory impairment at the higher frequencies. Although the onset of presbycusis is later in women than in men, it proceeds at a faster rate after onset, so that by 51 to 57 years of age the loss of hearing for women exceeds that of men for the lower frequencies. Furthermore, the rate of deterioration of hearing in women is fairly uniform as a function of age, while the rate for men seems to vary in a discrete manner with major drops in sensitivity occurring in steps of approximately 15 years, on the average.

Consideration was given to the curves of presbycusis proposed by the American Standards Association, and it was concluded that the curves of the present study derived from the screened distributions are probably a more valid estimate of the "pure" effects of age on hearing. The truncated data of this study represent the most sensitive thresholds that can be expected in a large group of otologically normal subjects selected from a population exposed to minimal levels of industrial noise.

The findings of the present study in terms of monaural minimum audible pressure are offered for consideration as proposed normal standards of hearing for pure tones under laboratory testing conditions. It is suggested that the earlier technique of using a single set of threshold values for denoting normal hearing is no longer an adequate procedure and should be abandoned. The recommendation is made that future audiometric standards be specified independently for men and for women according to particular age levels.

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EVALUATION OF AN AUDIBLE MOBILITY AID FOR THE BLIND*

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INTRODUCTION

A large number of guidance devices for the blind have been designed to utilize the echo-sounding principle. In Volume IV of the *Proceedings of the International Congress on Technology and Blindness* (1963) forty such devices are described; half were discontinued at the prototype stage, and the other half are at the prototype stage. To our knowledge only one, that designed by Dr. Leslie Kay of the University of Birmingham, England, has reached limited production (2) and has been evaluated (4). Many of the more sophisticated devices, including Kay's, use ultrasonics/ should they be marketed, their cost would likely be beyond the means of many blind persons. With this factor in mind, a preliminary attempt was made to develop a low-cost, simple, audio echo-sounding unit in this laboratory. Twenty-eight units were manufactured in two styles of case, belt worn and hand held. No special receiving equipment was used/ echoes were recognized by normal hearing. The units were tested on totally blind children from the Jericho Hill School for the Blind, Vancouver, B.C., Canada. Design is described and results of the evaluation test, which used a specially prepared obstacle course, are given. Conclusions drawn from the test results are discussed and a summary of the subjects' comments about the units is included.

The Audio Transmitter

The audio transmitter consisted of a transistor pulse generator which was powered by two 9V transistor radio batteries and connected to a small standard speaker. To produce a sharp enough

*This project was supported by a grant from the Canadian National Institute for the Blind and by a Fight for Sight Grant-in-Aid of the National Council to Combat Blindness, Inc., New York, N.Y. We are grateful to Mr. G. W. Carson of the Jericho Hill School, Vancouver, for his interest and cooperation; and to our colleagues Mrs. Y. Heap, Misses L. Desautels and J. Dryburgh, and Messrs. K. Hyslop and D. York for their assistance.

click, we had to stiffen the speaker cone by impregnating it with plastic. The units were mounted in two types of case: (a) a flashlight and (b) a metal case worn on the belt. The speaker cones were protected with an expanded metal grill. In the prototype version of the unit the pulse repetition rate was variable by means of a knob, but this feature was not included in the models used in the tests described here. The pulse repetition frequencies were approximately 10 pps, stable with time but with a variation from unit to unit. Both types of unit weighed 240 gms, complete with batteries. Current drain in normal use was low enough that during the project, from May to September, no batteries had to be replaced; in fact the batteries showed no signs of fading at the end of the four-month period.

The Test Course

The test course was built inside a gymnasium of sufficient size that echoes from the roof and walls probably did not contribute to any great extent. It was designed as four successively adjacent rooms joined with doorways. The rooms had no ceilings and their ends were joined by a rope; each was approximately 36 by 20 feet. The walls, which were 12 feet high, were parallel; the doorways were staggered. Obstacles were placed in each room in a random fashion and the positions noted.

The course was so designed that a number of combinations of door positions and obstacle positions could be obtained by changing the order of the rooms without appreciably changing the over-all course length. This feature was necessary to eliminate learning without causing an additional variable due to variation in course length.

Experimental Evaluation

Twenty-six totally blind ten-to-fourteen-year-old children were brought to the test course and sent through it as a control. The course was explained to each child immediately before he started. The marking procedure was as follows: collision with or stopping and feeling a wall, obstacle, or rope was noted appropriately; and the total time required to navigate the course was recorded. After the control run, each child was given one of the navigational aids and instructed in its use, and an explanatory letter was sent to his parents. The units were supplied immediately before the school summer vacation so that the period of use would be in the child's normal home environment and not in the artificial environment of the Blind School.

The children were tested again immediately after they returned from vacation on the same course, but with the order of the rooms changed.

Results

Using the total number of collisions and "stops" in the control run as a criterion, the children were divided into two groups, those who navigated well (Group A) and those who navigated poorly

(Group B). The total number of collisions and "stops" for each child in the control and test runs were tabulated, together with the times required to traverse the course. This tabulation is shown in Table 1 and 2, which contain the results from Groups A and B, respectively. Totals and average for each group are shown: Group A children, who were already able to navigate well, did not improve; in fact the use of the device probably hindered their performance. Group B showed a considerable improvement; the number of collisions and "stops" was reduced to almost one half. Improvement in time averaged 16 percent.

The results were analyzed to determine where the improvement in Group B occurred. Table 3 shows the total collisions and "stops" for walls, obstacles, and ropes for both groups for the control and test runs. Even in Group A ability to detect walls was enhanced through use of the device; ability on the other test aspects was impaired.

In Group B there was an improvement in all phases of navigation; it was most marked in ability to detect walls. Group B also was better able to avoid the ropes; we interpret this as an enhanced ability to detect the *lack* of an echo in this direction (there were no side walls to the rooms). It is not thought that the ropes themselves were being detected, as it can be seen from Table 3 that obstacle detection was not commensurately improved.

Subjects' Comments

During the question session with each child at the end of the tests, we attempted to determine his personal evaluation of the navigational aid.

Unexpectedly, in view of the comments we had received from blind adults, the children expressed concern over the fact that the audible clicking drew attention to them. Because of this many used the devices only when alone. Many believed that the pulse repetition frequency was too slow and were confused by multiple echoes indoors. A number found the unit useful out-of-doors, but reported that it was too quiet. Some suggested that both the frequency and volume should be variable. The belt-type device was definitely preferred: if they wished the children kept the units, and all the belt-type ones were retained. None kept their "flashlight" type; two or three did take them to try in place of their belt-type. It was generally agreed that a hand-held device is a nuisance.

Apparently, the children were unable to judge whether their ability to navigate had been changed through use of the device. Thus even those in Group B whose ability to detect walls had been most strikingly improved were unaware of their improvement. It is doubtful if the childrens' own evaluations of their ability are valid.

Table 1

Group A: 14 Subjects with Lowest Control Score

Subject No.	Total Errors (collisions and "stops") Control	Total Errors (collisions and "stops") Run	Control Time (sec)	Run Time (sec)	Sex
1	7	8	155	167	M
2	8	8	67	166	M
8	11	11	300	317	F
9	12	10	235	182	F
10	11	4	85	99	M
13	13	10	80	70	F
17	13	7	150	144	M
18	7	8	95	115	F
19	9	7	90	99	M
20	13	15	195	284	M
21	4	11	133	234	F
23	4	6	195	233	F
26	8	15	150	408	F
28	10	7	69	87	F
Total	130	127	1,999	2,605	(6M)
Average	9.3	9.1	143	186	(8F)

Table 2

Group B: 12 Subjects with Highest Control Score

Subject No.	Total Errors (collisions and "stops") Control	Run	Control Time (sec)	Run Time (sec)	Sex
3	15	4	215	155	F
4	26	10	375	130	F
6	19	13	275	232	F
7	14	8	100	250	M
11	17	6	165	76	F
12	15	11	175	123	F
14	16	22	140	280	M
15	16	11	105	92	M
16	25	15	230	128	F
22	22	11	150	194	M
24	14	7	175	172	M
25	24	8	270	157	M
Total	223	126	2,375	1,989	(6M)
Average	18.6	10.5	198	166	(6F)

Table 3

Total Collisions and "Stops" for Walls, Obstacles, and Ropes

	Collisions			*"Stops"*		
	Wall	Obstacles	Rope	Wall	Obstacles	Rope
Group B						
Control run	35	30	17	31	3	14
Test run	12	36	14	32	9	24
Group A						
Control run	51	48	43	45	7	29
Test run	23	39	17	27	3	17

DISCUSSION

One purpose of this project was to establish whether an unsophisticated audible-echo device would provide the subjects with sufficient additional information about their surroundings to improve their ability to navigate. There can be no doubt from these results that children who have not developed an efficient method of obtaining this information are helped to a considerable extent by a device of this type. In fact the scores of the poor group (Group B) on the test run were improved to be comparable with those of the good group (Group A). An analagous conclusion, to the effect that a navigational aid was of benefit to adults who had not developed an ability but was either of no use or was detrimental to those who had, was reached by Deatherage (1).

Another purpose of this project was to determine whether the advantage of low cost and simplicity of design would outweigh the disadvantage of an audible signal. It certainly appeared from the childrens' personal evaluations that the audible type of device would not be accepted because of the embarrassment it caused. It was established by the evaluators that the majority of the children did in fact use the device only when they thought nobody was near them. This factor has been remarked upon for all methods of assistance, including the use of dog guides (3).

The majority of the subjects expressed the opinion that the unit was of little use indoors but that it did help out-of-doors, but not in traffic. The additional comments that there was too much echo inside ties in with the general opinion that a volume and frequency control were required. These controls were deliberately left off the test models to try to establish whether they were in fact necessary, and it seems that they might have improved the device to some extent. Obviously, the unit was too quiet for use in a noisy outdoor environment.

CONCLUSIONS

1. The units improved the navigational ability of children who had not developed an efficient navigational system of their own.
2. No improvement in the ability of children already adept at navigating was found, and in fact the units appeared to interfere with this natural ability.
3. It is doubtful if children in this age group would use an audible navigational aid of the type described, because of the embarrassment factor. No tests with adults were made.
4. It was obvious from the tests that a hand-held device will not be acceptable to children in this age group, because of its nuisance value.
5. It is the investigators' opinion that a good training program which teaches blind children with poor navigating ability how to make use of their natural navigating talents would be worthwhile and would produce an improvement superior to that obtained using audible devices such as those described above. Regular testing of blind children over an obstacle course, similar to that described here, could provide information on which children most need training of this type.

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EVALUATION OF THE SONIC MOBILITY AID*

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INTRODUCTION

Recent years have witnessed an upsurge of interest in electronically sophisticated "mobility devices" by researchers and workers with the visually handicapped. This interest is in part due to the multiplication of devices of all kinds from various research settings throughout the world. It has little to do with the actual market availability of most of these devices and even less to do with the demonstrated utility of these devices from the point of view of travel mobility. With very few exceptions (3) there have been no published reports of experimental evaluations of these "aids" and little in the numerous "field testing" reports would indicate careful assessment procedures.

One reason for this situation is that research on mobility devices presents certain problems regarding learning and training criteria within the range of potential usefulness of the instrument. As Dupress has suggested, the blind traveler requires many different types of information for safe mobility (4). A "safe" mobility device must generate information regarding the presence of a safe terrain in terms of area and surface strength; and it must also indicate step-up and step-down conditions in terrain level changes. If one adds to these requirements the additional demand that the mobility device generate this information on an early-warning basis, it is easily seen that mobility device assessment involves the sorting out of a complex interaction between coded information and human decoding skills. Obviously this assessment can be interpreted more easily (although less precisely) in a global "field-testing" situation. The risk involved in this type of assessment is that one loses contact with the hypothetical components of the learning process. However, it should be noted that the

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+A division of Boston's Catholic Guild for All the Blind.

learning component assumption underlying experimental laboratory assessment may reflect an untenable position with regard to training parameters. In other words the optimal conditions for training mobility skills may not prove to be the optimal conditions for assessment procedures. Our attempts to unravel the learning process through an atomistic assessment may lead to inferior recommendations.

This dilemma becomes particularly acute in connection with evaluation research on mobility devices having no specific training philosophy or validated methodology. Assessment in this context is inextricably linked with the development of training methods, and it is here that the assumptions and biases of the investigator become most visible and important. Given the existing state of the art of mobility devices, it is probably no accident that assessment efforts are typically structured on the "field-testing" model. Our existing electronic knowledge, while still relatively primitive, is well ahead of our understanding of efficient training parameters and other aspects of the man-machine system.

Within this context of training and assessment this report describes an experimental evaluation of a mobility device that is presently marketed[a] and has shown promise in limited field testing situations (6, 13).

The Kay Ultrasonic Aid

Experimental work on the feasibility of a frequency modulation ultrasonic mobility aid was first described by Dr. Leslie Kay in 1961. Based at least in part on the analogy of a bat orientation system (8, 9), the Kay device soon received wide scientific recognition and a degree of popular attention through the International Congress on Technology and Blindness, New York, 1962. In its present form the Kay device consists of three components: a torch, a power supply, and a receiver. The receiver is like that commonly used in transistor radios, a little plastic hook keeping it in place near the opening of the ear. The power supply of the device is an external 9-V radio-type battery connected to the main torch by cable. The torch, or transmitter-transducer unit, is shaped like a small flashlight, approximately 7 in. long and weighing approximately 9 oz. This unit contains 18 transistors correlated components, and the ultrasonic transducers protected by an external wire-mesh. In operation the aid sends out a beam of ultrasonic energy. Upon striking an object a portion of this energy is reflected back to the unit, being picked up by the detection transducer.[b] Upon entering the torch this energy is modulated

[a] *Ultra Electronics, Ltd., Western Ave., London W3, England.*

[b] *A mean transmission frequency of 60 kc/sec is used, producing a mean beam width of 15 deg. The rate of change of frequency of transmission is arranged to produce an audible echo note of 3 kc/sec when the echoing object is at 20 ft or 7 ft (according to the*

into the audible range of the listener and heard as signals having a definite loudness, pitch, texture, and tonal pattern. The interpretation of these signals by the listener constitutes a "language" of sound and necessitates learning. The training and evaluation program reported here is based on this aspect of encoding the audible information.

More detailed electronic specifications of the device are described by Kay (10).

OBJECTIVES OF THE RESEARCH

Previous research on the Kay device suggested certain guidelines for training and evaluation. In general it has been proposed that the basic utility of the device considered simply as an obstacle detector lies in its ability to answer the question: "Is my travel path clear?" (6). Assuming that this question represents the most basic mobility skill, our training program attempted to build greater skill sophistication to the point of considering the possible utility of the Kay device also as an environmental sensor and navigational aid. Consequently, one objective of this research was:

> *What kind of mobility information can be conveyed reliably and validly by the Kay devices and under what conditions can this be done?*

Another dimension of interest in the Kay device lies in the relationship of personality factors, motivational dynamics, and personal abilities to training readiness and skill acquisition. In this connection we asked ourselves the following question:

> *What background factors can best predict success in training with the Kay device?*

If, for example, a certain constellation of personality factors is closely related to performance in training, this information could be quite useful in the design of subsequent training programs or field trials with this device. Considered in a more general way,

range selected by a push button control). For a single reflecting surface such as a smooth cylindrical post or a smooth wall, the echo is almost a pure note. The pitch of the note is proportional to the distance and is interrupted periodically during the interval when the transmission frequency rapidly reverts to the beginning of the frequency sweep. Although an interruption in the echo occurs naturally in the system, transient clicks are also heard if they are not gated out. This has been arranged with the result that the aid is almost silent when pointing into free space. Therefore, any note or sound heard indicates an object (12).

the relationship of personality factors and training parameters is of interest to mobility training in the widest sense.

Perhaps the most important issue concerning the Kay device is the problem of training itself. Here we are concerned with the components of the learning process and the trainer's ability to communicate these skills effectively. What kind of training regimens are most appropriate in this instance? Is there a similarity between the acquisition of mobility skills with a cane or dog and those of the Kay device? Should Kay device training be done in conjunction with existing mobility aids such as the cane or dog or should it be done separately?

Questions of this kind become crucial in light of the increasing tendency toward acceptance of electronic mobility devices such as the Kay device. The individual or institutional purchaser of a device must be given some consistent guidelines for training purposes, and we felt under an obligation to provide the outlines of training techniques having some demonstrated value. In this connection our question was:

> *What type of training methods are best suited to rapid learning of mobility skills with the Kay device?*

Finally, we attempted to determine certain factors in the man-device system which did not lend themselves easily to quantification and statistical presentation. Questions involving the degree of enjoyment in the use of the ultrasonic system; the relative risk experienced when the Kay device is inevitably compared with the habitual travel aid; the amount of concern with personal appearance when in public with the device; these questions were answered through extensive interviews with our trainees and trainers.

> *For a potential "user" population, what personal factors are important in optimum daily involvement with the Kay device?*

Many difficulties of operations-type research such as the Kay device evaluation can be alleviated by a careful specification of research objectives. As far as this research is concerned, these four questions constitute our research objectives. In the remainder of this report we will explore these objectives in terms of both skill-training-evaluation procedures and background information variables. Our findings as they specifically relate to these objectives will be presented and discussed in the last section.

DESCRIPTION OF TRAINING AND EVALUATION METHODS

We initially determined that our evaluation procedures would be extensions of the training regimen. The first step was, therefore, the determination of the skill parameters associated with the ultrasonic system. We were guided in this by some field testing data reported by Gissoni in a privately circulated tape recording (5), and also by the advice of Dr. Leslie Kay (12). After a period of familiarization with the Kay device in a variety of settings and tasks, we determined that the evaluation would include the following skills:

a. Determination of object in travel path.
b. Accurate estimate of distance from stationary object.
c. Accurate estimate of distance from moving object.
d. Accurate estimate of distance from stationary object while moving.
e. Location of single object in a simple field.
f. Location of multiple objects in complex field.
g. Location of multiple objects in a fixed pattern.
h. Location of multiple objects in a fixed pattern in an outdoor area.
i. Navigational ability in a semifamiliar field (includes step-ups, step-downs, object identification, doorway passage, and so on).
j. Navigation of a standardized obstacle course.

In addition to these specific skills we attempted to evaluate the effectiveness of the man/machine system under a variety of environmental conditions, including rain and snow, and a variety of psychological conditions including self-controlled home use.

Types of Information Conveyed

In order to understand the meaning of these skills it is necessary to describe the kind of information conveyed by the device. It has been noted that when the aid is pointed into free space there is little or no informational feedback to the user. The existence of any note or sound then indicates an object in the path of the ultrasound beam. Therefore, the most basic skill associated with this system is the simple determination of an object within the range of the instrument.[c] However, a series of graduated skills must be built on this simple base and these skills are related to the following kinds of information:

Pitch. The further the aid is from an object it is sensing, the higher the pitch of the signal in the receiver. Similarly, the closer the object the lower the pitch. A change of distance of the sensed object will immediately be reflected in a change of pitch. In this respect the aid is sensitive to distance changes of approximately 1 in.

Texture. The sound of the note produced upon reflection will vary with the nature of the reflecting surface. A hard and smooth surface such as a plate glass or an even wall will produce

[c] *See note on The Kay Ultrasonic Aid for a description of the range control.*

a distinctly different texture in the sound from a rough or uneven surface such as a decorative paneling or fence. Although the pitch remains constant, the clarity of the sound will change. Using this information it is possible to discriminate certain classes of objects by their surface characteristics.

Tonal pattern. Certain types of objects produce characteristic tonal patterns in the received signal. This is due to surface features such as the degree of smoothness and other features such as the regularity of the "design." For example, using the aid it is possible to discriminate a bush or shrub from a wall, the received signal varying subtly with the variations in the leaf patterns. Slight rises and falls of pitch may serve as additional information in this case.

These three types of information constitute the basic "language" of the Kay ultrasonic aid. Through the use of various techniques, such as horizontal and vertical scanning, the user can, with this information, determine both the height and width of objects as well as locate himself in relation to a set of external reference points. For example, it is possible to discriminate a tree from a stoplight by the use of horizontal and vertical scanning; the information in this case would indicate a different surface texture (smooth pole versus a rough tree trunk) and the presence of a "bush" type sound achieved through vertical scanning of the branches of the tree.

Similarly, it is possible to discriminate a flight of stairs through the use of vertical scanning. Standing at the bottom of a staircase, a vertical scanning movement will produce a series of notes each one slightly higher in pitch than the preceding one. It is possible to "play" a pseudo-musical scale in this way (6) and often it is possible to count the stairs by determining the exact number of pitch changes. This same principle is useful in determining step-ups and step-downs such as curbs, although this is a subtle and difficult discrimination.

Evaluation Methods

Evaluation of all skills was in each case tied closely to the training methods. In almost all cases the specific evaluation consisted of an error and/or time analysis of the subject's performance in a training technique. The only exception to this was the evaluation based on the use of an obstacle course prior to training and at the end of the training program. However, in all cases the trainees were instructed when evaluation was taking place.

Obstacle course training and evaluation.[d] Prior to training with the Kay device, all subjects were tested on an obstacle course in order to evaluate their existing mobility skills. With one

[d]*We wish to thank J. Mickunas, Jr., for his assistance in helping us reconstruct the obstacle course used in his research on cane mobility (14).*

exception, a dog-guide user, all of the subjects used a cane on this course. An effort was made to make the course representative of the important aspects of the environment which the blind traveler must face. In this regard we included bounded and open spaces, step-ups and step-downs, different types of obstacles in the travel path, and the selective availability of auditory cues. Figure 1 illustrates this course.

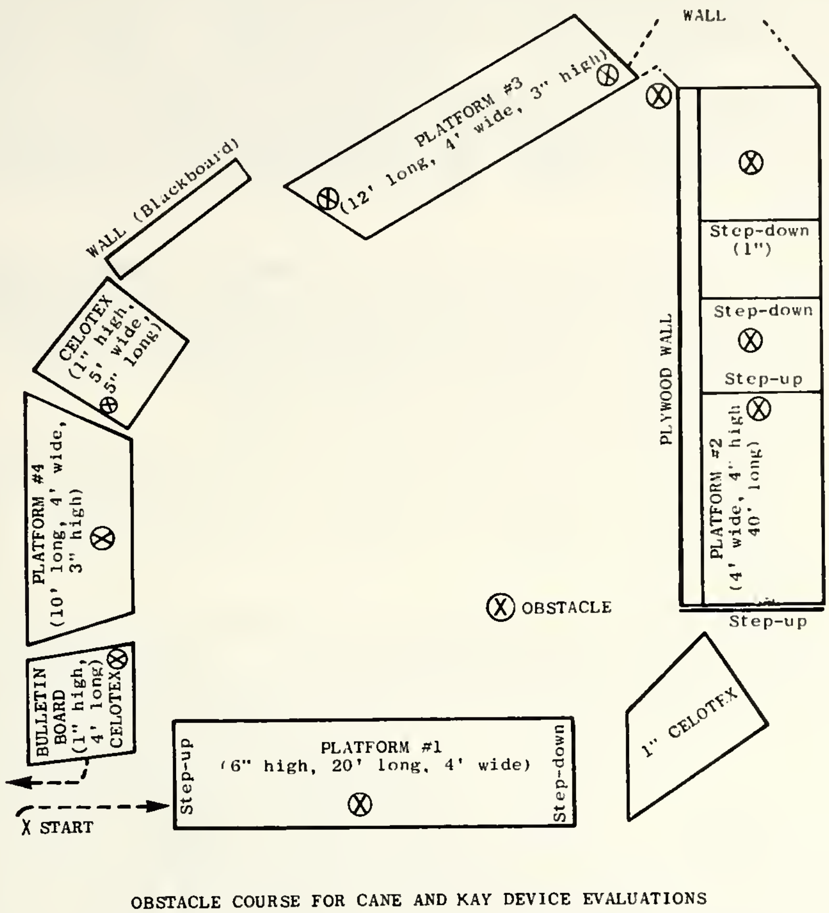

Figure 1. Circular Course of Four Major Wooden Platforms with Celotex Surfaces Between Platforms, and Ten Obstacles As Indicated

The trainees were also evaluated at the end of the training program but this time using the Kay device in negotiating the course. Performance on both occasions was defined in terms of traverse time and "harm events" such as bumping into an object, tripping on an object, sticking the cane in a crevice, and stepping off the course.

The course was set up in a large empty room in the training site. This room was used exclusively for the obstacle course evaluation. The course was approximately 150 ft long and divided into eight sections (see Fig. 1).

Upon entering the room the trainee was given a brief description of the course through the following instructions:

"This is the beginning of the obstacle course. There is a step-up to start and a platform. To your right there is a wooden wall. Walk until you reach the end of the platform. Then, turn a gradual left and continue. You will find a long walkway with a step-up and down in the middle. Cross over this and continue. As you walk through this course your turns will always be to the left. The course is roughly circular and you will end it quite near the beginning. Be on the alert for obstacles along your way and various step-ups and downs. Walk until I ask you to stop. O.K.? Any questions?"

Each trainee walked the course twice. The subject's traverse time and "harm events" were recorded by the trainer who followed him over the course. This same procedure was repeated at the end of the training program with the exception that the subject used the Kay device instead of the cane or dog.

Ranging training and evaluation. A primary emphasis of the training program was on the acquisition of ranging skills. Approximately 20 hours of training were devoted to these skills. Four separate types of ranging skills were trained and evaluated in the following sequence:

1. Stationary ranging #1. Our subjects were instructed to stand while the trainer moved within a line of perception of the device in either a backwards or forwards direction. A 10-foot range was employed and the floor marked with 5 intervals of 2 ft each. Subjects were first familiarized with different intervals of the total range presented in random sequences and then asked to estimate the distance from the trainer based on the pitch information. The subject then stated the interval he thought the trainer was on (numbered one through five). Approximately 5 hours of training time were devoted to this skill.

Evaluation of the stationary ranging followed the same pattern: familiarization with intervals of the range followed by subject estimates of his distance from the trainer in terms of the interval mark. Twenty-five estimates were made by each trainee of intervals of 2 to 8 ft from the trainer. These intervals were presented in random sequences over all subjects.

2. Stationary ranging #2. In this ranging exercise our subjects continued to remain stationary. The trainer moved in and out of the line of perception from side to side, each time appearing at different interval points in the 10-ft range. Subjects were trained to estimate their distance in this manner without the benefit of an anchoring of judgment based on a continuous moving scale as in stationary ranging #1. The same

interval locations were employed for training and evaluation. Approximately 5 hours of training were spent on this skill and the evaluation followed the same format as in #1.

3. Moving ranging #1. Another aspect of ranging involves the ability to estimate distance from a fixed target while moving. In this case the same intervals were used with a wooden wall as the target. Subjects were familiarized with the interval and taken to various interval points by the trainer. After placing themselves at an interval, they were asked to estimate the distance to the wall in terms of the interval points. Approximately 5 hours of training were spent on this task.

Evaluation of this ranging component was based on 15 trials or estimates of various intervals presented in a randomized order across all subjects. The intervals ranged from 2 to 10 ft and a subject could score a possible "right" 15 times. A subject scored "right" if his estimate was within 3 in. of the correct interval.

4. Moving ranging #2. The final ranging skill attempted to train the subject to maintain a constant distance between himself and another moving person. This skill was considered a test of the ability to use distance cues from a moving target while moving at the same time, a somewhat more difficult task than passively estimating the distance of a moving object. A skill of this kind could easily relate to the use of the Kay device in a ticket counter line or a supermarket line. The training for this skill attempted to instruct the subject to maintain a common distance between himself and the trainer on a series of different trials using different constants. On individual trials the trainer would move either forward or backward after establishing a fixed distance between the subject and himself. The trainee would then attempt to increase or close the gap to the established distance, depending upon the movement of the trainer. This phase of training ran approximately 5 training hours.

Evaluation of this skill was structured so that the subject had to maintain a constant distance at three ranges: 4, 6, and 8 ft. The trainer would move forward or backward and the subject would try to maintain the constant distance on the respective trial. Three trials at the three different distances were run and scored for a possible 9 points (the trainer moving 9 times) reflecting a total of 27 points over all trials. Any estimate over 6 in. from the established distance for the trial was considered an error. The sequences of the distances were randomized over the total sample.

Scanning and locating training and evaluation. Following the training and evaluation of the ranging skills, we turned to skills which emphasized object location. In this regard we developed three measures of this skill, staged in terms of relative difficulty:

1. Simple location. In this exercise our subjects stood at the center of a series of 5 concentric circles each 2 ft apart. The trainer would enter the short range of the aid at different points, first within a 180 deg arc and then within a 360 deg arc. The subject would turn and scan with his aid slowly and attempt to locate the trainer. After locating the trainer he would estimate his distance and walk over to him. Approximately 5 hours of training were spent on this skill.

Evaluation consisted of specifying five separate points throughout the 360 deg on different circles, and asking the subject to locate the trainer at these points. These points were at various distances from the center (see Fig. 2). A subject could score a total of 10 points (two over each trial; one for location, and the other for correct estimate and reaching the trainer). There were five trials.

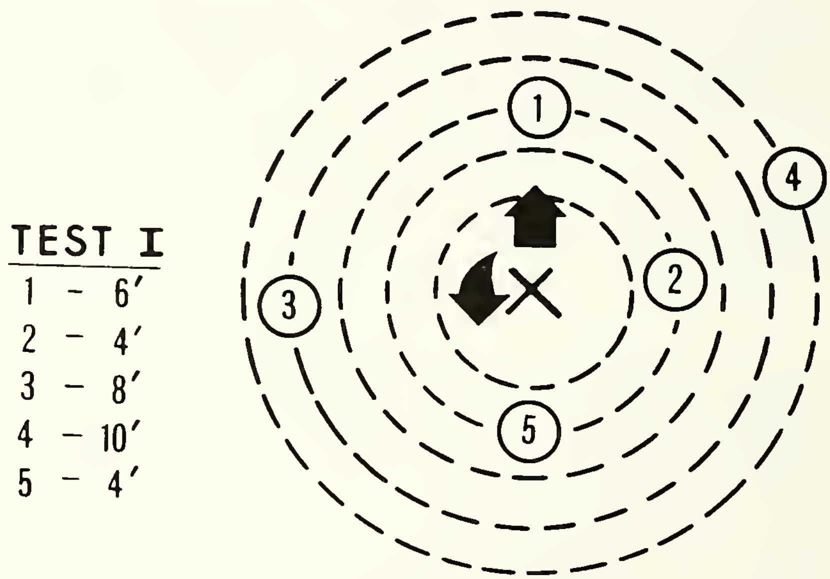

Figure 2. Simple Location

2. Multiple object location. The same concentric circles were used in this training and evaluation. However, in this case different objects were placed at varying distances from the center and over the 360 deg. The subject was asked to scan over the total circle and locate and identify these objects (the objects could be identified by horizontal and vertical scanning after a brief period of familiarization).

Evaluation consisted of locating and identifying four objects (a small 3-ft metal can, a 3-ft piece of upright cardboard, a 1.5-ft wooden basket, and a 4-ft metal can). The subject would slowly scan in a clockwise direction and attempt to locate and identify these objects. Four trials were run. A subject could score a total of 8 points, two points per trial for correct location and identification. The order of the objects was changed over trials although the distance from the center remained the same (see Fig. 3). Performance on this skill was also timed.

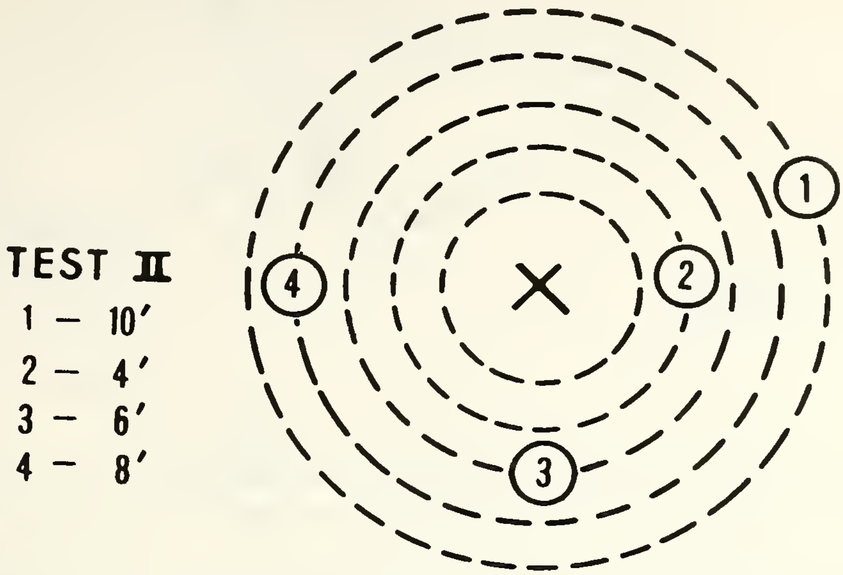

Figure 3. Multiple Object Location

3. Moving, scanning, and locating. This skill involved the ability to locate objects while moving through an area. Different objects were placed in varying sequences and the subject was instructed on how to scan in order to create an "auditory map" of his immediate environment. The subject was told how many objects were in his environment and what they were. He was instructed to find them in sequence before returning to the object he detected first. This skill involved both horizontal and vertical scanning in order to correctly identify and locate the objects.

Evaluation consisted of the same placement of the same objects as used in multiple object location. Standing in the center of the circle (see Fig. 4) the subject was instructed to walk a rough circle (counterclockwise) and attempt to locate and identify each object in turn before returning to his initial object. The subject was told that there were four objects and was briefly familiarized with each of them before evaluation. A subject could score a possible 8 points over 4 trials minus any points for returning to any object which was not his original one. The order of the objects was randomized over all trials and for all subjects.

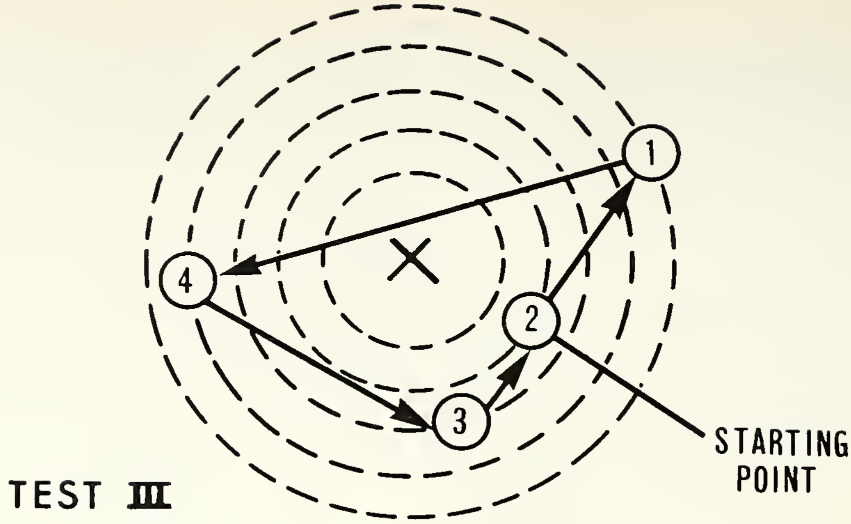

Figure 4. Multiple Object Location

Outdoor training and evaluation. Building on the development of indoor ranging and scanning techniques, the training program next emphasized outdoor performance. In this regard we continued our emphasis on ranging and scanning techniques (including long ranging) using natural objects and obstacles such as trees and bushes. We also developed certain navigational skills such as recognizing pathways, grass borders, curbs, doorways, steps, and driveways. Approximately 40 hours of training time were spent in this phase of the program. Evaluation of this phase involved two components:

1. Tree location. This skill was quite similar to the indoor moving, scanning, and locating. Trees were used as targets and subjects were asked to find each tree in turn before returning to the starting tree. The course was approximately 50 yards in length (see Fig. 5) with the trees separated by approximately 10 yards. Each subject was given two trials on this course and his performance timed. A point could be earned for each correct tree identification. A point was subtracted if the subject returned to a tree previously identified. It should be noted that this was also a long-range use of the aid.

2. Outdoor mobility course. This course was designed to assess the generalized skills considered necessary in order to use the Kay device as a navigational aid. The course selected was a moderately difficult travel area (see Fig. 6). Subjects were familiarzed with the course by walking through it once with the trainer before evaluation. All "harm events" were counted equally, such as bumping a curb, failing to follow a wall, missing a step-up or step-down, losing a grass-gravel border, and failing to find a doorway. Performance was timed and a point was given for each "harm event" committed (scored in a negative direction).

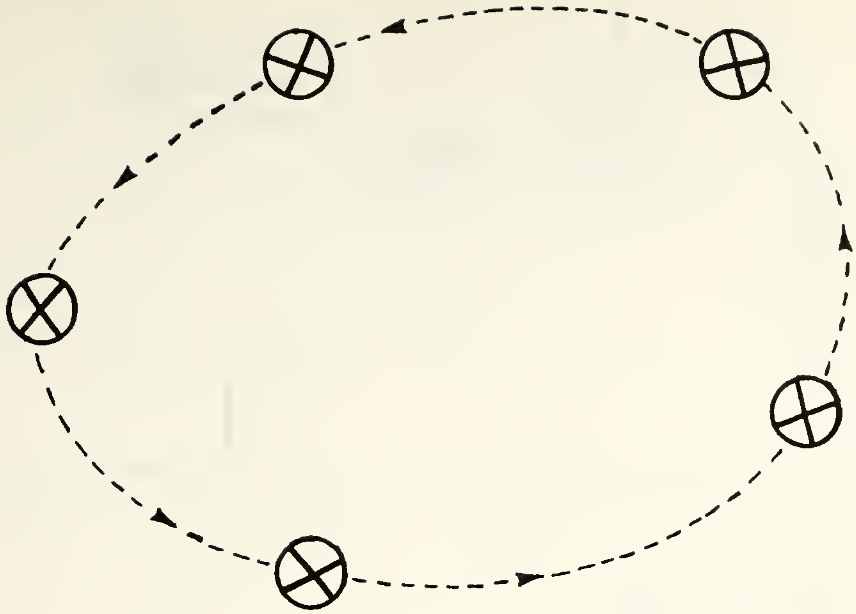

Figure 5. Evaluation of Five Trees

In addition to the formal training given at ACRIBAR, four subjects used the aid in their home or work environment for varying periods of time. This time was logged by the subjects and notes were kept by them on their personal use. All time logged outside of formal training was included in the quantitative estimate of total training time (see results section).

Additional notes on training and evaluation. A number of technical developments were introduced at various points in the training program. These included:

1. The substitution of mercury cells for the carbon-zinc batteries in order to maximize battery output and control diminishing instrument pulse-rate and volume. The mercury cells delivered longer battery life and proved to be a more reliable power source.
2. The testing of a radio-link procedure designed to allow the trainer to hear the feedback from the subject's aid. This link proved to be valuable in outdoor work, giving the trainer better understanding of subject error and helping to shape the direction of supportive instructions.

   A two-way citizens' band transceiver was used in this linkage, the transmitter connected by leads to the Kay device receiver. This transmitter picked up the same signal received by the subject, transmitting it within a range of 50 yards to the trainer's receiver.

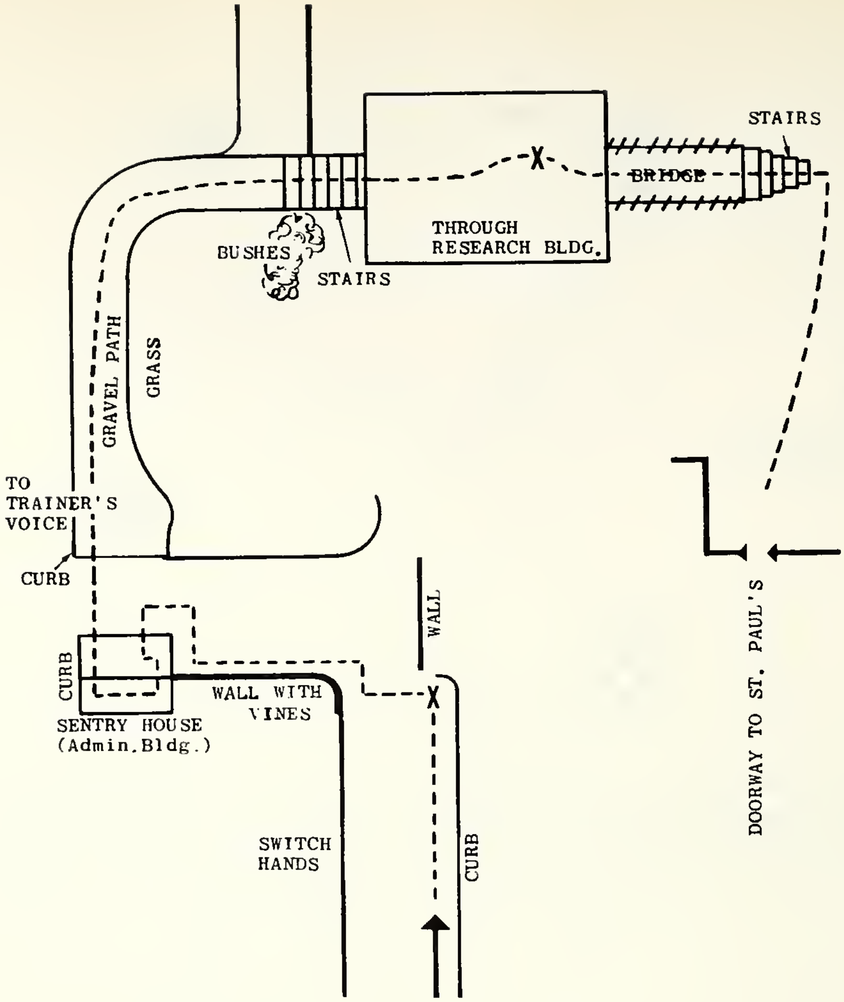

Figure 6. Outdoor Mobility Course

BACKGROUND VARIABLES

Description of Subjects

A total of 19 subjects participated in the training program over a 20-week period. However, the final sample on which complete data exist is 14. Five subjects were excluded from the final sample because of early termination (illness, job relocation, or, in one case, death).

Initial screening was based on a sample recruited by mail from a list of approximately 150 selected blind males living in the Boston area. Subjects were screened first in order to produce a sample representative of an anticipated United States blinded veteran population for the years 1965-1975. A sample of 42 was then invited to ACRIBAR for preliminary interviews. Twenty-seven potential trainees were then selected from this sample. Selection at this stage was guided by the interviewer's estimate of the subject's ability and willingness to participate in a lengthy training program. Following this, intensive interviews and testing were conducted by a clinical psychologist on this sample of prospective trainees. Two subjects were dropped from this sample for reasons of incipient psychosis.

Four subjects were then randomly selected from this sample of 25 for a preliminary 1-month training period during which the project trainers received intensive teaching experience. During this time training methods were tested and developed to the form utilized in the formal training program.

Following this 1-month pretraining period, these four subjects were dropped from the final sample. Shortly before formal training began, 2 subjects dropped from the final pretraining sample reducing it to 19.

Age and IQ. The age range for the sample of 14 subjects completing training was 21 and 57 years. The mean age was 33.9 years and the median for the total distribution was 31.5.

The IQ range for the final sample was 100 to 144, based on projections of verbal sub-scale scores on *Comprehension and Similarities* from the WAIS. The mean IQ was 124.5 and the median was 125.5.

Vision and hearing. All subjects were examined by a physician in order to determine the degree of remaining vision. With the exception of four subjects (who were subsequently blindfolded for all training and evaluation, Table 1) all subjects were judged totally blind.

Table 1

Subject Number	*Degree of Remaining Vision* Right Eye	Left Eye
01	Light projection and very gross objects against light background (L > R). No color vision.	anophthalmos with prosthesis
02	Central acuity 1/160. Gross objects in all quadrants. No color vision.	Same as right eye
07	Light projection only in all quadrants.	Same as right eye
14	Central acuity almost 2/160. Light projection only in all quadrants. All colors good.	Light projection only in all quadrants

Pure tone hearing tests were also conducted for all subjects using a standardized audiometric technique. On the basis of this test all subjects were judged to have normal hearing in at least one ear.[e] In addition to the audiometric testing, all trainees were given the Seashore Audio Perception Test. Scores on the timber scale, the pitch discrimination, and the tonal memory section were derived, as well as a composite score for all three subscales. The composite score for the Seashore ranged from 7 to 41 out of a possible range of 3 to 42. The mean composite score was 22.9 and the median of the total distribution was 27.5. Table 2 gives the range, mean, and median for the Seashore subscales.

Table 2

Range, Mean, and Median for Seashore Subtests

	Range	*Mean*	*Median*
Timber	31-50 (0-50 possible)	41.8	41.0
Pitch	32-48 (0-50 possible)	43.3	44.5
Tonal memory	5-30 (0-30 possible)	22.5	27.5

Existing mobility skills. With the exception of two subjects (one using a guide dog and the other no mobility device) all subjects were cane users. Based on interview data, an estimate was made on the extent of previous mobility training (formal dog or cane training), and this figure was expressed in terms of weeks of training. The range for the final sample was 0-24 weeks with a mean of 10.8 weeks and a median of 11.0 weeks.

Age of blindness. This represents the age at which the subject became legally blind. A score of zero represents congenital blindness. The range for the final sample was 0-44 years with a mean of 16.3 years and a median of 13.0 years. Although these figures are lower than what would be expected from a representative blinded veteran population, they represent the best sample obtainable for the present study.

[e]*This normal ear was subsequently employed for all Kay device training.*

Previous education. This represents the previous formal education of the subject expressed by the number of completed grades. A higher score indicates more education. The range for the final sample was 9 to 16 with a mean of 12.6 and a median of 12.0.

Hours in Kay device training. The number of hours spent in training were tabulated. These figures include hours spent in home practice as described in the Description of Training and Evaluation Methods. The hours for the final sample ranged from 26 to 99 with a mean of 61.1 and a median of 60.5.

Trainee favorability[f] *toward device.* This represents rank estimates by the trainers regarding the subject's attitude toward Kay device training. Subjects were rated in the middle of the training program. All subjects were rated independently by the two trainers, their ratings having an interrater reliability of .85 (Kendall rank-order correlation). Higher scores represent greater estimated favorability.

Personality ratings. It was decided to include ratings of subject characteristics by the project staff in the experimental and quantitative analyses. Three characteristics (motivation, anxiety, and concentration) thought to be potentially related to eventual task performance comprised these "personality ratings":

1. Motivation. This estimate was based on the psychologist's rating after the subjects had been accepted into final training. The main criteria were the subject's enthusiasm for the project and the motives behind that enthusiasm. For example, subjects mainly interested in financial remuneration were given a lower ranking even though their apparent enthusiasm level was similar. In all, 20 subjects were ranked; however, for the purposes of the statistical analysis, only 14 subjects were used. Fourteen was used as the highest rank (or highest motivation), one the lowest.

2. Anxiety. In previous psychological literature, anxiety has consistently been cited as one of the primary blocks to effective learning. In the present study, it was decided that any anxiety rating should be closely related to the learning experience of the subjects. Thus, the two trainers were asked to rate subjects' general level of anxiety in the training situation, anxiety being clinically defined as signs of nervousness, upset, uncertainty, and so forth. Subjects were ranked from 1 to 14. The higher ranks represented higher anxiety. Interrater reliability was .58 (Kendall).

[f]*Favorability is used as a synonym for favorableness.*

3. Concentration. It was decided to ask the trainers to rate a more cognitive characteristic which seemed appropriately linked to Kay device learning ability--that is, concentration, or the ability to attend effectively to the training situation and to the training stimuli. Higher ranks on concentration represented higher concentration and vice versa. Interrater reliability was .82 (Kendall).

Personality test scales. Objective paper and pencil testing, though severely limited by the fact of the subjects' blindness, was nevertheless included as a possible source of prediction of success in training and performance.[g] Three tests were selected for their relative brevity, previous validity, and conceptual relationship to the possible learning skills required in the project:

1. The Marlowe-Crowne Social Desirability Scale. This test is composed of 33 true-false items. It was originally developed as a nonpathological test of social desirability (to replace the Edwards Scale). While it was very successful in the empirical literature, the construct changed such that it was considered a scale for "need for social approval." As research has continued [cf. (2)], the construct of "defensiveness" has seemed increasingly appropriate. The scale has related to measures of repression against hostility, defensive behavior on projective tests, and defensiveness in interview behavior. Of more interest to the present study, it has been increasingly associated with cognitive and perceptual styles [cf. (1), for review of literature]. Cohen (1) found that high Marlowe-Crowne (M-C SDS) scorers had a greater intolerance of ambiguity and preferred more structured perceptual stimuli. He also found that M-C "defensiveness" was inversely related to openness to new and unusual experiences. The M-C SDS is scored as high defensiveness equaling higher scores.

2. The California Personality Inventory Flexibility Scale. The California Personality Inventory (CPI) is a widely used true-false personality test, also designed for relatively normal populations. One of its scales, Flexibility (Fx.), consisting of 22 items, was selected for the present study. The scale is designed to tap "the degree of flexibility and adaptability of a person's thinking and social behavior" (7, p. 13). High scorers tend to be seen as "insightful, informal, adventurous, confident, humorous, rebellious, idealistic, assertive." Low scorers tend to be seen as "deliberate, cautious, worrying, industrious, guarded, mannerly, methodical, and rigid" (7, p. 13). Gough quotes three investigations which argue for the scale's validity: "(a) In an

[g]*Test items were read aloud to the subjects. The responses were indicated by hand gestures.*

assessment sample of 40 University of California graduate students, Fx. correlated -.48 with staff's rating of 'rigidity.' (b) In an assessment study of 40 University of California medical school seniors, Fx. correlated -.36 with staff's rating of 'rigidity.' (c) In a college class of 180 students, Fx. correlated -.58 with the California F (authoritarian personality) scale" (7, p. 27). It was expected that greater flexibility might aid in learning Kay device skills, since the stimuli were probably quite new and different from anything the subject had previously experienced.

3. The Intolerance of Ambiguity Scale. Cohen (1) developed a six item intolerance of ambiguity scale which was derived from the best items of three previous scales. In a recent study, ambiguity intolerance correlated with defensiveness, preference for structured perceptual stimuli, and closedness to new experience. In this project, the audio stimuli and extensive perceptual information which demand coding are likely to be experienced as very ambiguous, at least in the early phases of the project. Thus, ambiguity intolerance as a personality and cognitive trait might well obstruct ease of learning in the present project.

These three personality scales, being conceptually related, were pooled into a Personality Composite, which gave equal weight (from ranks) to each personality test.

All variables reported and summarized in this section are described in detail in the Appendix, "Code Book of Kay Device Variables." This appendix includes a listing and description of the variables' numbers, the scoring direction for all variables, and a brief description of the measures employed in this study.

RESULTS

This section presents a synopsis of the quantitative and qualitative analyses of major experimental variables. Part One includes a comprehensive description of the quantitative relationships among 36 operational measures, including variables representing performance and non-intellective factors: Special emphasis is given to the non-intellective correlates of Kay device skill competence. Part Two incorporates the implications of the quantitative data and adds qualitative and anecdotal material in presenting an objective evaluation of the Kay device as a potential navigational aid. In this attempt at evaluation, all relevant information from technical and electronic factors to subjects' reports, is considered salient for the purposes of a comprehensive conclusion.

Relationships Among Operational Measures

Introduction. In the present study, 36 experimental variables were statistically analyzed, each of which represented a performance, background, intellective, or non-intellective measure. Fourteen subjects met the criteria for inclusion in the statistical analysis; that is, they could be assigned scores on all the operational measures.

A complete description of each experimental variable, its numerical parameters, and its mode and direction of scoring are presented in the Appendix. Appropriate abbreviations for these variables will be used in the text. Statistical tests were generated through the computing and programming facilities of the Harvard University Laboratory of Social Relations and the Harvard University Computation Center. Program submissions were run on IBM 7090 Computers. The statistical analyses carried out on the data included the Kendall Tau Correlation, the Mann-Whitney U Test, the Chi-square transformation, the Wald-Wolfowitz Runs Test, and various frequency tabulations. All analyses were based on nonparametric techniques. Many of the experimental variables did not meet all the criteria for parametric data, and in the interests of standardization and conservatism, only ordinal data characteristics were assumed. Since most of the data easily met the criteria of ordinality, the Kendall correlation coefficient (Tau) was used as the principal statistic. Unless otherwise mentioned, it may be assumed that the other nonparametric tests substantiated the implications of the correlation coefficient. It is appropriate to note that correlations are reported for a relatively small sample ($N = 14$). Although this is a relevant consideration invoking caution regarding generalizability, it does not change the interpretation of statistical significance. Table 3 lists the values of Tau representing significance levels for an N of 14.

Table 3

Tau	*Significance Level*	*Tau*	*Significance Level*
.33	.10	.56	.005
.39	.05	.66	.001
.45	.025	.70	.0005
.51	.01	.78	.0001

In the following discussion, mention of a significance level will imply that results are significant at or beyond that level. When the word "significant" is used by itself, it assumes a significance level of .05 or beyond.

Relationships among performance measures. Of the 36 experimental variables, 15 involved specific evaluation measures of a subject's skill with the Kay device. The general performance areas tapped included indoor and outdoor obstacle course traversal, ranging competence, and scanning and locating skills. Each major area was comprised of subtests as well as being represented by composite scores. If the intuitive and deductive assumptions behind the choice of evaluation measures were optimal, two empirical characteristics should be evident: *(1)* a reliable and consistent relationship among the subtests of each major area and among the composites of all areas, and *(2)* the subsequent existence of enough remaining variance to imply that the various skills, though related, are still distinct aspects of programatic learning. The following data supply evidence of such characteristics.[h]

Relationships Among Area Subtests

1. Indoor obstacle performance. The subtests of this evaluation procedure, Time and Errors correlated .54 with each other ($p < .01$). They correlated with the Composite score--.81 and .78 respectively ($p < .001$ and $p = .001$).

2. Ranging performance. The three subtests and ranging composite related as shown in Table 4. All correlations are in the expected direction and are significant with one exception.

Table 4

Intercorrelations of Ranging Subtests

Subtest	*R: Stat.*	*R: Mov.*	*R: 4-6-8*	*R: Comp.*
R: Stat.	X	.43	.44	-.75
R: Mov.	.43	X	.28	-.64
R: 4-6-8	.44	.28	X	-.64
R: Comp.	-.75	-.64	-.64	X

[h]*A word is necessary regarding the interpretation of many of the negative correlations in this study. Since scores were transformed into ordinal data, it was often convenient to rank subjects. Often, highest scores were given a rank of one, lowest a rank of 14. Thus, there is an apparent reversal in the sign of correlations with such variables. Where the direction of the correlations is not specifically mentioned, the common sense or contextual (expected) interpretation should be inferred. If there is any remaining doubt, Appendix gives the scoring direction for each variable.*

3. Scanning-locating performance. The two subtests for scanning-locating correlate -.73 ($p < .0005$). They relate to the composite score -.88 and .85 respectively, as expected ($p < .0001$).

4. Outdoor performance. Relationships of the performance on outdoor tasks are as shown in Table 5. Although the subtests' correlations with the composite are all highly significant, the Trees measure correlation with the outdoor obstacle course variables does not reach significance. It seems reasonable to guess that the inherent similarity of the skills demonstrated on the tree-finding task and the obstacle course traversal is not as great as the inherent level of similarity in the other evaluation areas. However, the comparable high correlation of Trees to the outdoor composite score may justify its inclusion in this subscale.

Table 5

Intercorrelations of Outdoor Subtests

Subtest	*Trees*	*M-Skill: Time*	*M-Skill: Err.*	*Outdoor Comp.*
Trees	X	.28	.27	-.56
M-Skill: Time	.28	X	.39	-.57
M-Skill: Err.	.27	.39	X	-.66
Outdoor comp.	-.56	-.57	-.66	X

Relationships among area composite scores. An obvious question to ask is whether the skill areas are related to each other and to the Overall Performance Composite. (The Overall Performance Composite--or OPC--is the single most important variable for the purposes of this investigation.)

The relevant data are as shown in Table 6. It is noted that all the relationships are statistically significant, and that none of the correlations between the four skill areas and the Overall Performance Composite (OPC) drops below the .005 level. However, the variance unexplained still implies that each skill area is conceptually and empirically distinct as well as justifying the use of the OPC as an accurate representation of each subject's performance with the Kay device.

All the variables included involved skills involving the Kay device. However, measures were also obtained for the traversal of the indoor course with the existing mobility devices. Interestingly, performance with existing device correlated +.40 with subsequent performance on the same course with the Kay device. In addition, it correlated +.46 with the Overall Kay Performance Composite (OPC). This would imply that a generalized skill (involving learning with mobility devices in general) is present in this subject population, reflecting a more general learning competence.

Table 6

Intercorrelations of Performance Task Composite Scores

Task Composite	*Indoor Obs.Comp.*	*Ranging Comp.*	*Sc.-Locat. Comp.*	*Outdoor Comp.*	*Overall Comp.*
Indoor obs. comp.	X	-.61	-.45	.66	.64
Ranging comp.	-.61	X	.41	-.40	-.66
Scan locat. comp.	-.45	.41	X	-.40	-.71
Outdoor comp.	.66	-.40	-.40	X	.69
Overall comp.	.64	-.66	-.71	.69	X

Relationships among non-performance factors. The rationale behind the inclusion of 19 background, intellective, and non-intellective characteristics lies in the possibility that these variables are antecedents, predictors, or meaningful correlates of the ability to learn skills necessary for adequate utilization of the Kay device. Most of the nonperformance variables are single items and will be discussed in the following section. However, there are three clusters of variables which incorporate several items. It is appropriate to examine the interrelationships within these clusters before relating them to performance measures.

1. The Seashore Test. This measure includes three subtests which all represent some facet of the skill in audio discrimination, comprising the elements of timbre discrimination, pitch perception, and tonal memory. It is also possible to tabulate a composite score which gives equal weight to the subscales. The relationships among the subscales and composite are as shown in Table 7. All the Tau values are significant at the .02 level at least. There is clearly a generalized factor representing audio discrimination, but again, each subtest does seem to represent a unique audio sensitivity. Unless noted to the contrary, it will be assumed that the Seashore Composite Score reflects the same direction as each of its subscales at the same general level of significance.

2. Personality ratings by staff. Certain personality and learning attributes were rated by staff members; that is, motivation (by the psychologist previous to training) and anxiety and concentration (by trainers at the midpoint of training). The interrelationships among these variables are as shown in Table 8.

Table 7

Intercorrelations of Seashore Subtests

Task	*Timber*	*Pitch*	*Tonal Memory*	*Seashore Composite*
Timber	X	.49	.55	-.77
Pitch	.49	X	.55	-.63
Tonal memory	.55	.55	X	-.75
Seashore comp.	-.77	-.63	-.75	X

Table 8

Intercorrelations of Staff Rating of Personality

Rating Rating	*Est.:Psych.*	*Anxiety:Tr.*	*Concentration: Tr.*
Motiv.Est.:Psych.	X	.03	.49
Anxiety:Tr.	.03	X	-.03
Concentration:Tr.	.49	-.03	X

While the correlation between motivation and concentration is significant at the .02 level, the other Tau values are totally nonsignificant. This is apparently due to the low discriminating power of the anxiety rating. It would not be surprising if the trainers' anxiety ratings were relatively invalid, anxiety being such a difficult construct to operationalize even under the most sophisticated experimental conditions. In any event, there is no empirical justification for the creation of a personality rating composite score.

3. Personality scales. The rationale behind the inclusion of the three personality scales was based on the hypothesis that the psychodynamic and resultant cognitive dimensions tapped would have a helpful or detrimental effect on learning a new skill. It seemed reasonable to expect that relatively defensive, inflexible, and ambiguity-intolerant individuals would find it more difficult to perceive and integrate complex cognitive information. Training for the Kay device would seem to demand openness to new experience, a suspension of massive self-criticism, and a tolerance for cognitive ambiguity. Thus, there was some expectation that the three personality measures might form a meaningful cluster. The relevant data are shown in Table 9.

Table 9

Intercorrelations of Personality Test Measures

Test	*M-C SDS*	*CPI:Fx*	*IOA*	*Pers. comp.*
M-C SDS	X	-.46	.32	-.66
CPI:Fx.	-.46	X	-.27	.63
IOA	.32	-.27	X	-.55
Pers. comp.	-.66	.63	-.55	X

Generally, the expectation holds up, results showing highly significant relationships among the scales and composites with the exception of the Intolerance of Ambiguity Measures' correlation with the other two scales. (Despite sign direction differences, all results are in the expected direction.) The relative weakness of the IOA scale might be explained by the fact that it calls for five discriminations by the subject and for a visual or cognitive memory organization by the subject (since the item had to be read aloud). Some confusion in responses was noted during testing, and it is probable that a five point response is less valid than a true-false choice given the same item. However, the correlations are strong enough to justify the inclusion of the IOA in the Personality Composite (PC), which does seem representative of a syndrome. For labeling purposes, the Personality Composite dimension is called "defensive inflexibility."

Correlates of Kay Device performance. Second in importance to the question of the potential utility of the Kay device is the question of the antecedents and correlates of effective learning in training. Obviously, in possible future populations, universal training with electronic navigational aids would be unlikely. It would be extremely helpful to have predictive instruments which could assist in subject selection. In this section, this question is squarely faced. What characteristics make for good Kay device performers? Are physical, sociological, or personality characteristics more influential? Or are such nonperformance factors overshadowed by experiential training factors, such as the number of hours the device was used? These questions are answerable in the present study.

1. Age. The correlation between the subjects' age and their overall performance (OPC) was -.25. This is not significant but represents a tendency for the younger subjects to be better learners. Another possible relevant aspect of age is that age at which the subject was blinded. The relationship between age at legal blindness and overall performance was -.20, again nonsignificant but suggesting that the younger subjects

perform better. (If age at blindness, as a linear measure, was more important than sheer age, the correlation should have been higher than the age correlation. This was not the case.) Although it is interesting to note that of the five subjects who might be considered congenitally blind (3 years or under), four were in the high performing group, no firm conclusions can be made because of the fact that all five were relatively young men at the time of the study.

2. IQ and previous education. The notion of IQ scores as representing "general intelligence" has rapidly become antiquated, especially if that notion assumes an inherent capacity which pervades all skills. However, IQ test scores do occasionally have high predictive power when the tasks are relatively generalizable in terms of learning skills. In the present study, verbal intelligence, as approximated by scores on the comprehension and similarities subtests of the WAIS, were correlated with performance measures. The correlation of IQ with Overall Performance was +.25, nonsignificant, but suggesting a slight positive relationship.

One can ask whether experience in formal education might reflect a familiarity with training and proclivity towards intellectual competence--and thus relate to facility in learning Kay device rules. The correlation of previous education in grades and OPC is +.32 higher than IQ, but still not statistically significant. However, this variable is significantly related to three of the performance subtests and also correlates very highly ($p < .005$) with the Seashore Pitch measure (+.65).

3. Previous mobility training. Moving from more generalized to more specific potential predictors, previous mobility training is considered. It might have been expected that subjects who received more training with other modes might be more amenable to Kay training and thus perform better. However, the -.17 correlation with Overall Performance is not only insignificant, but in the wrong direction. Throughout the correlation matrix, the number of weeks of previous training was consistently unrelated to the performance and nonperformance variables.

4. Hours of training. The actual number of hours each subject trained with the Kay Device varied, first because of attendance and scheduling deviations, secondly because of the provision for exploratory field testing at home. Surprisingly perhaps, the relationship between number of hours of training and OPC was -.19, an inverse relationship. Clearly, sheer quantity of experience using the device is not an overwhelming predictive factor, given the variance and the size of the present sample.

5. Audio discrimination ability. The interpretation of sound signals is the sole basis on which the subject learns to utilize his device for environmental sensing. As might be

expected, competence on the Seashore test is positively related to Overall Performance with the Kay Device (.29). While this correlation with the Seashore Composite is not significant, the pitch subtest correlates +.42 with OPC, and between .33 and .40 with the four major performance subcategories. This makes great sense since pitch perception is the way in which the subject learns to determine distance with the Kay Device. So far, the Seashore measures have provided the most powerful predictions of final performance.

6. Subject favorability toward device. Trainers made estimates of each subject's attitude toward (like or dislike) the device at a time three quarters of the way through training. Again, somewhat surprisingly, the relationship between favorability and OPC was only .15, in the expected direction, but certainly not significant. This is surprising in that the favorability ratings can claim some evidence of concurrent validity because of the correlation with the psychologist's estimate of their motivation (+.65).

7. Personality ratings. In predicting performance measures, the anxiety measure was weakest (.07 with OPC). This corroborates the possible weakness of the rating implied above. The psychologist's rating of initial motivation correlated +.35 with OPC. While this figure is significant at only the .10 level, it does suggest what might have been expected; that is, subjects who are more enthusiastic about the project learn more easily. A highly significant correlation was found between the trainers' rating of subject's concentration and OPC--+.69 ($p < .001$). It predicted most strongly for the Ranging (.63) and Indoor Obstacle (.54) tasks. In this rating, concentration was closely allied to estimates of attention-span. It does seem reasonable that subjects who could attend to the audio information and the instructions of the trainers would best learn the most important device discriminations and thus be able to perform better. It must be cautioned, however, that the rating was made in the midst of training, and there is no justification for claiming it as an antecedent variable. In any event, the ability of the subject to concentrate on his learning techniques is positively related to his eventual performance on evaluation measures.

8. Personality test scales. Perhaps the most intriguing and exciting results of this study is the finding that "defensive inflexibility" as a personality trait is consistently predictive for Kay device performance. The M-C SDS (defensiveness), CPI (flexibility) and Personality Composite all show clear relationships to the performance measures. The exception is the IOA scale, which, for example, correlates -.10 with Overall Performance, and which does not relate significantly with any of the 17 performance variables. It is doubtful that

intolerance of ambiguity is unrelated to Kay performance, but it is likely that problems in the administration mentioned earlier, make the IOA scale unreliable in the present study.

The three other measures, however, show a wealth of significant results. Of the 17 correlations with performance measures, 8 M-C SDS Taus are statistically significant. The respective CPI figure is 7 of 17, and the Personality Composite has a striking 11 of 17 possible correlations statistically significant. (By chance, only one of 17 correlations could be significant at the .05 level or better.) Table 10 shows the correlations of these personality scales with the major performance areas.

Table 10

Intercorrelations of Personality Scales and Major Performance Task Composites

Scale or Task	*M-C SDS*	*CPI:Fx*	*Personality Composite*
Indoor course (exist. mob. aid)	-.39	.52	.46
Indoor course (Kay device)	-.33	.41	.44
Ranging composite	.47	-.50	-.49
Scanning location comp.	.49	-.30	-.42
Outdoor comp.	-.18	.27	.26
Overall performance comp.	-.41	.38	.39

Despite the differences in signs, all these figures are in the expected direction. The Personality Composite correlates at the .05 level or better with all the performance composites with the exception of the Outdoor Composite. (Recall that the internal correlations of the Outdoor Composite were the weakest of the performance categories.) The best correlations are among the personality scales and the Ranging Composite, ranging being perhaps the most central skill involved in Kay device navigational competence. It is important to note the comparable high relationships of the personality measures with the obstacle course performance (with existing mobility aid). This implies that "defensive inflexibility" as a personality and cognitive characteristic is a relevant correlate of learning and competence with any navigational aid.

It is important to analyze further the possible influence of the personality cluster on Kay performance. When, for example, one notes that the Personality Composite predicts Kay device performance on the indoor obstacle course better than does performance on that same course with existing mobility aid (.46 vs. .40), we owe it a closer look. There always exists the statistical possibility that a third variable, related both to personality and performance, is responsible for much of the variance. But the evidence for this in the data is scant. In the first place, the personality measures are consistently more significantly correlated with performance than any of the other background variables. Secondly, previous research has shown that such personality characteristics are relatively long-standing and are not influenced tremendously by situational factors. Thus, it is unlikely that previous navigational competence, for example, would create "non-defensive flexibility."

It is interesting to note that the Personality Composite correlates +.54 with the IQ estimate and -.31 with Age. Since the comparable figure for IQ and Kay Performance was only .25, it is unlikely that general intelligence is the primary antecedent factor; in fact, it seems more reasonable to assert that the personality characteristics influence learning and performance measured both on IQ tests and on mobility aid evaluations. From the same line of reasoning, Age cannot be the prime determining variable since its correlation with OPC is -.25 (*lower* than its correlation with the Personality Composite).

Considering other background variables, one can dismiss the following variables as being more influential than the personality tests because of their relatively low correlations with performance measures: previous mobility training, hours of Kay device training, favorability toward device, and personality ratings (with the exception of concentration). The only other hypothesis, though conceptually unlikely, is that audio discrimination ability is responsible for much of the variance explained by the personality tests. The comparison, shown in Table 11, helps us to test this idea.

Table 11

Comparison of Correlations with Seashore Test (With Personality and Performance Measures)

Test	*Seashore Pitch*	*Seashore Composite*
CPI: Fx	.47	-.41
Ranging composite	-.38	.34
Personality comp.	.53	-.46
OPC	.42	-.29

In each case, the personality measure is a better predictor of Seashore performance than Seashore performance is of Kay device performance. If audio discrimination ability was responsible for the high correlations between the personality measures and Kay performance, these findings should have been exactly the reverse. In sum, there is no statistical evidence of a third variable or variables accounting for the personality-performance intercorrelations. Indeed, there is evidence to show that the personality scales correlate more highly with other background variables than do performance measures.

Discussion. The finding of highest prediction with the personality measures deserves some further comment. The most probable explanation for these relationships is to be found in the growing body of empirical research showing that personality characteristics are inseparably linked with cognitive styles. Defensive inflexibility, as measured in the present study, has been empirically related to cognitive characteristics such as "intolerance of cognitive ambiguity," preference for structured perceptual field, "openness to new perceptual and cognitive experience," and so on [cf. Cohen (1) for a review of such finding.) Furthermore, Cohen found that repressive defensiveness (associated empirically with defensive inflexibility), was a deeply embedded personality dimension which had great influence on emotional, psychodynamic, and cognitive variables. Thus, it is not unreasonable that defensive inflexibility, resultant in ambiguity-intolerance and closedness to new experience, is inversely related to the ability to perceive, categorize, and decode a plethora of new audio information, by its very nature ambiguous.

In a theoretical sense, it might be most profitable to view defensive inflexibility as part of a syndrome involving cognitive characteristics and learning facility as well. It is not necessary nor particularly meaningful to demand an interpretation that personality characteristics were antecedent to navigational aid learning facility. Since such learning involved complex perceptual and cognitive transformations, it might be more useful to think of the defensive inflexibility dimension and the learning dimension as interpenetrating. From an empirical perspective, however, these personality measures may offer a more economical predictive technique than performance measures.

Summary. This section presents results obtained from statistical analyses of the interrelationships among experimental variables, both performance and nonperformance variables, as well as their interaction. Intercorrelations among subtests of the major performance categories (training and evaluation) showed high internal consistency. The major performance composites also related highly to each other and to the overall composite for Kay device performance. Among nonperformance measures, the Seashore Test measures and the Personality Scales were internally consistent, while the Personality Ratings were not.

Several possible nonperformance correlates were examined for their predictive or concurrent relationships to performance with the Kay device. Age and age at blindness showed a slight, nonsignificant inverse relationship with performance. IQ and previous education showed a tendency to be related to higher performance, but again not significantly. Previous mobility training was inversely related to performance, at a very low level of significance. Hours of training with the Kay device had *no* significant relationship with performance--the very slight relationship was an inverse one. Performance on the Seashore Test was positively related to Kay performance, the pitch subtest reaching statistical significance with OPC.[i] Subjects' favorability toward the device was not significantly related to Kay performance. Trainers' ratings of subject anxiety were unrelated to performance. The psychologist's rating of prestudy motivation was positively related to OPC, approaching significance. Trainers' ratings of subject concentrative ability at the midpoint of training were highly significantly related to overall performance. The most striking relationships were the personality scales' consistent significant relationships with performance measures.

It is suggested that a Personality Composite dimension labeled "defensive inflexibility" is one of the most important antecedent correlates of eventual mobility and learning ability. The Personality Composite Score measures defensive cognitive styles. It included the Marlowe-Crowne Social Desirability Scale Score, the Flexibility Scale Score (from the California Personality Inventory) and the Intolerance of Ambiguity Scale Score (from the Cohen Composite Scales).[j] Statistical analyses showed that personality measures seemed to be contributing independent variance in the correlational matrix and were also highly related to some of the other background variables. Finally, it is suggested that certain personality, cognitive, and learning characteristics composed a syndrome which was relevant to the acquisition of skills pertinent to utilizing an ultrasonic aid.

Observations on the Kay Device Evaluation

Device reliability. A major problem of the training program described in this report lay in technical failures with the ultrasonic device. Repeated device failures and difficulties under laboratory conditions raised certain questions regarding the

[i]*Overall Performance Composite.*

[j]*See Appendix: Code Book of Kay Device Variables, Variable 6.*

adequate functioning of the Kay device under real-world-stress conditions. Our own field experimentation was too limited to give us data in this regard, but an extrapolation from our laboratory work would lead us to suggest that many problems could arise. In addition to minor repairs made by ourselves, a total of 24 defective aids was returned to the manufacturer during the course of our training program, an average of approximately two breakdowns per aid used in the program.[k]

As to reliability, three major problems arose: *(1)* lead breakage in the power supply cable, *(2)* switch failure, and *(3)* transducer breakdown. While these problems represented great inconveniences they could be adequately controlled in production units in the future.

A continuing problem with the Kay device was the unreliability of the pulse-rate. Upon testing it was found that there was great variance among devices along this dimension, while sometimes, due to losses of battery strength, there seemed to be independent variation between devices. In the course of training we rotated our devices among our trainees; the inconsistency of the signals in this respect often proved confusing and required a period of special adjustment.

Another difficulty was the fluctuation in volume across the devices used in our program. This seemed to be a factor also somewhat independent of battery strength but clearly related at the extremes of full power and exhaustion. Many of our trainees found the inconsistencies in volume control to be an annoying factor in their training.

Even before training began, when we realized that the devices had no internal provision for voltage regulation, we planned to use Mercury batteries instead of the original Carbon-Zinc batteries, but we rejected the idea because the voltage of the Mercury batteries would fall in cold weather. The performance of the Carbon-Zinc batteries, however, left so much to be desired that shortly after the beginning of the training program, we chanced to Mercury batteries which were carried in the subject's shirt pocket to keep the batteries at a favorable temperature.

Personality and training. Our statistical data indicate a very close and significant relationship between Kay device performance and a personality dimension we have summarized as "defensive inflexibility." Our qualitative data lend strong support to this relationship. We noted that the influence of personality factors became most pronounced during evaluation sessions and particularly during the later part of the training

[k]*We wish to thank Ultra Electronics for their quick and conscientious replacement of aids with technical failures.*

program when the skills became more difficult. Many subjects whose early opinion of the Kay device was quite favorable lost interest later in the program when our work moved outside.

One reason for this may have been that our navigational training required more concentration than the simpler indoor exercises. With an increase in outdoor ambient noise the trainee was forced to pay closer attention to the device feedback. An inability to concentrate at this point in training could easily manifest itself in performance measures on our outdoor evaluation.

We also noted a tendency for the continued use of the device in outdoor settings to cause a certain degree of annoyance in our trainees. One of our subjects stated:

"It seems to me that this instrument requires for its successful use a degree of concentration unmatched by any travel aid now used, and this takes some getting used to. Sometimes I get pretty annoyed with it when I try to use it in a busy area. All the noise makes it hard to keep my attention on the sound of the signal."

This trainee was one of our best subjects throughout the course of the training program. His observation was based in part on his experiences with the aid in a semifamiliar home environment.

Another trainee, one scoring quite high on the flexibility scale, reported:

"I find that my performance with the Kay device does seem to vary somewhat from day to day. While there does seem to be a basic norm to which I return from one direction or another, I think it is important to notice that performance does vary. My strong feeling is, incidentally, that this inconsistency is, at least in my case, in the user and not in the instrument."

This report reflects an important aspect of the interaction of concentration and training performance. Specifically, this subject recognizes the inevitable fluctuations in his own performance and is cautious not to attribute his own fluctuations to problems with the device. This is in contrast to a number of subjects who would attribute their own fluctuations in mood and concentrative ability to difficulties with the device itself. However, it should be noted that device reliability is sufficiently suspect to warrant a measure of support to these claims. It is difficult to unravel the complex interaction between device reliability and subject reliability in this regard. Our observations suggest that our better subjects recognize their own fluctuations, become less anxious with these performance fluctuations (whatever their genesis), and generally level out these fluctuations over time. It may also be noted that our data indicate a correlation approaching significance between concentration and flexibility as measured by the CPI (Tau = .34; $p < .10$).

Device limitations. A consistent observation of our training staff was that the Kay device was ineffective in locating ill-defined step-downs such as sloping curbs or low steps. The majority of the trainees were not able to pick up the signal of a step-down. This proved to be a source of major anxiety to almost all the trainees, especially when outdoor work was emphasized. It was inevitable that our trainees would compare this aspect of the Kay aid with the information given by the cane:

"I find that I have little trouble in detecting and avoiding relatively high objects but low objects and step-downs remain quite a problem. These can be detected if specifically being sought but if not expected they are often missed, and in the case of stepdowns, usually missed. Probably the biggest cause of this is the necessity of moving the instrument in an arc occasionally to determine the environment on either side. This is enough to allow many low objects to escape detection. You have to use the cane this way also but the cane more easily tells you if a step-down exists."

Another subject reported:

"In comparison to the cane I have no faith in my ability to locate small step-ups or any step-downs. The device seems to detect a drop of under a foot only when it is too late to react. This is because you have to hold the device at an angle favoring the ground and in doing this you give up everything else."

It is interesting to note that it is much easier to pick up a step-up than a step-down with the Kay device. A flight of stairs, for example, is easily detectible from the bottom through a simple vertical scanning technique. Approaching the same flight of stairs from the top is a much more difficult and dangerous matter. In this case, the aid will suggest a drop-off, but not easily or clearly the nature of the drop-off.

Similar to the step-down and drop-off problem is the difficulty of locating small objects on the ground such as toys; for example, roller skates, potentially dangerous obstacles in a travel path. In this case, a forward sweeping motion of the Kay device will usually reveal higher objects but will usually not reveal low-to-the-ground objects with the same scanning motions. The difficulty here is that these objects "come in under the radar" for the most part and will not be detected unless specifically looked for. The economy of motion in scanning with the device suggests the maximum information feedback a few feet above the ground in a line approximately 30 deg to the ground ahead of the traveler. This angle will usually miss these low objects. However, again it must be stressed that the device is capable of registering the existence of an object such as this; the question for training purposes is whether the human can register this information and what types of information trade-offs are necessary in scanning.

In indoor training exercises our subjects could detect objects such as small baskets when they were specifically looking for them (cf. *scanning* and *locating*). Outside, however, in real-life situations, the complexity of the informational input made this kind of discrimination quite unlikely for a majority of our subjects.

Navigational capability. In sum, most of our subjects spoke favorably of the Kay device in the context of using the device as an obstacle detector rather than a navigational aid. This feeling may reflect to a large extent our own training emphasis on a controlled laboratory setting and a piecemeal learning process. Other writers (Gissoni, (6)) see the utility of this device extending to full field navigation, but there is little in our own data which suggests an immediate extrapolation to this application. A few of our subjects felt that with continued training such a use of the device might become possible; however, this was a cautioned optimism and probably reflected many of the difficulties such as step-down discrimination and low object detection. Commenting on the use of the device as a navigational aid under snow conditions one of our trainees reported:

"I found the instrument to be at its maximum usefulness when there was snow on the ground. I was able to use snow banks as guides in walking a straight line when the sidewalks were well shoveled, and when they were not the device was excellent at finding the piled snow so that I could go around it or over it. It may be a great help in finding paths through snow banks also."

Some of our trainees suggested that continued intensive training might help to develop great proficiency in discrimination and that their hesitancy to use the aid as a navigational device reflected more on their present level of competence than on inherent difficulties with the device itself. It should be remembered that our training program had a maximum of 100 hours, a training period too small to develop adequate navigational skills. One of our trainees, quite high in measured flexibility and considered the best subject by our training staff, reported:

"I think that with more time and careful study I could eventually develop great proficiency with this device. I think that it takes a long while to adapt to this novel system of stimuli and it takes a hell of a lot of practice."

This same subject suggested that the best use of the Kay device might be in combination with another mobility aid like the cane, the Kay device giving "long-range" information and the cane giving reliable information on low objects and step-ups and step-downs. The problem with this suggestion lies in the simple fact that with the currently available model, the user must employ both hands for this purpose. This subject suggested some design improvements which would attempt to build an ultrasonic sensing device into the cane itself.

Four of our trainees used the device in home settings approximating navigational use of the aid. Some of their comments lend support to our observation that continued and specialized navigational training is necessary in order more fully to evaluate the utility of the Kay device for this purpose:

"When you are walking down the street the cane gives the necessary and immediate contact; with the device you receive a lot of irrelevant information as well. I slowly began to be able to distinguish the sounds I needed from those that were not important to my travel path. I guess that with more practice I could get better at this."

"I would say that I spend about one to two hours a week at home with the device. Though I do take the device with me almost everywhere I go, it is often not in use since I find myself relying on the white cane when time is a factor. Walking with the device is a slow business and I feel I have to be more on the alert and more careful with it. Maybe with more work I could rely on it more comfortably."

"For the past two weeks I have used the device most of the time in traveling to and from work; about a half-hour a day. I found that my confidence in my ability to detect objects in my path slowly increased and at this point I feel quite assured in this aspect of the device."

"Most of the time I am just confused by all the jumble of sounds I hear when I am in the street. The sounds I usually depend on are more difficult to hear when the device is on; although this gets better the more used to it I get. I really would be afraid to depend on this alone."

Given the amount of emphasis to navigational training in this program, our obstacle course data provide an initial estimate of the relative effectiveness of the Kay device as a navigational aid.

An obvious comparison is the difference between each subject's performance on the indoor obstacle course with his existing mobility device before training was initiated and his performance with the Kay device after training ended.

Thus subjects took about twice as long to traverse the course with the Kay device. The difference in performance is statistically significant ($p < .01$, t-test). Much more striking however, is the difference in number of errors made. Kay subjects made, on the average, 6 times as many errors. The difference is significant beyond the .0005 level (t-test). Certainly, it is no surprise that subjects perform better with the technique they may have been using for years. However, if the Kay device were a comparable navigational aid, one might have expected the differences to manifest themselves in the time taken rather than in the number of errors made. It is clear that the subjects' level of proficiency for detecting and navigating around obstacles with the Kay device is clearly inferior.

Table 12

Performance on Indoor Obstacle Course with Existing Aid and Kay Device

Measure	*Existing Aid*		*Kay Device*	
	Mean	Median	Mean	Median
Total time (two trials)	4.7 min.	4.5 min.	9.1 min.	9.8 min.
Number of errors (two trials)	5.4	5.0	31.5	32.0

Training Recommendations. It is our opinion that future research on the Kay device should emphasize the following points:

1. Subjects should be selected who demonstrate the personality dispositions conducive to training programs of this kind. Specifically, subject screening should emphasize the selection of individuals who are flexible and tolerant of ambiguity. Training regimens should be more easily learned by this group and they should more easily acquire the skills relevant to using an ultrasonic aid.

2. Training for navigation should be a special program of field work with intensive use of the aid the primary goal of training. We would recommend at least two hours per day of training in this respect.

3. Training for navigation should emphasize particularly recognition of step-ups and step-downs and the detection of low objects in the travel path. Training should be conducted initially in semifamiliar territory moving quickly to training in unfamiliar territory.

4. Special evaluation methods should be developed to measure the acquisition of navigational skills. The imposition of laboratory measures may not tap the same skill dimensions as those required for navigation.

5. Particular attention should be paid to the redesign of the ultrasonic aid so that it could be used in conjunction with a cane. Evaluation of the cane device system could compare performance with the Kay device alone and the cane alone under field conditions.[1]

[1] *An adaptation of the Kay system to a head-worn "spectacles" unit is now in research by Dr. Leslie Kay.*

SUMMARY

This report describes a training and evaluation program for the Kay ultrasonic mobility device. The rationale for laboratory testing and field testing is discussed against the background of the requirements for careful assessment procedures. Some of the information requirements for any mobility device are examined and the Kay aid is discussed in this context. The research objectives of this study are examined in light of background variables and training evaluation procedures.

Fourteen trainees completed a 20-week training and evaluation program with the Kay aid. Skill parameters were determined and training procedures were designed around these skills. Evaluation followed closely the training procedures in almost all cases. Evaluation included obstacle course performances before and after Kay training, and specific skills such as ranging and locating objects. Outdoor work emphasized navigational skills and evaluation was based on mobility course using "harm events" and time as measures of skill.

Background data including age, IQ, hearing and vision, age of blindness, previous education, hours spent in training, trainee favorability toward training, anxiety, concentration, and personality test data were taken on all subjects and these measures were related to performance.

Data from this study indicate that the major performance composites related highly to each other and to the personality scale composite scores. It is suggested that "defensive inflexibility" was one of the most important correlates of mobility aid learning. The data strongly suggest that certain personality dimensions, cognitive and hearing abilities such as pitch discrimination compose a syndrome which is extremely relevant to the acquisition of skills relevant to using an ultrasonic aid.

However, many difficulties in navigational use of the Kay device could not be approached directly in this study. Our subject reports and data suggest certain training recommendations for full field research on the Kay device which appears to be promising if certain trainee selection and training methods are established. Our research suggests certain recommendations to this effect.

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A MATHEMATICAL MODEL OF BLIND MOBILITY*

Alan Krigman

ABSTRACT

An analytical model of the mobility process is hypothesized on the basis of a balance between the information expended in traversing a path, and the information acquired by probing the environment. The purpose of the model is to help identify and relate the variables associated with mobility, more adequately define the mobility problem, and thereby help to establish criteria for the design of mobility aids for the blind. The variables considered include the range of the probe, the width and sweeping rate of the scanned path, the complexity of the path, the uncertainties due to memory decay and loss of orientation, and the speed of the traveler.

A number of experiments that were conducted are described. These involved both sighted and blind subjects in path traversal tasks, and sighted subjects operating an instrumented tracking machine. The research program is a continuing effort, but preliminary results show some encouraging correlations with the predictions of the model.

INTRODUCTION

Incomplete understanding of the mobility process, perhaps more than technological limitations, has hampered the development of satisfactory mobility aids for the blind. It has been noted (5), for example, that engineering problems associated with probing the environment for information, while by no means solved for the blind traveler, are within the realm of present electronic capability. It is the display and assimilation of the information that remains the crucial problem. Mann states: "Part of the display problem (and difficult of segregation from the art of beholding) is the discrimination in the field of view of objects of especial and timely interest for the blind man, i.e., the obstacles he must avoid or comply with."

Further, a hierarchy of decision rules may exist to guide the traveler through the dual mazes of objects and signals about objects (3). If such a set of rules existed and were understood, the traveler could be presented with processed rather than raw environmental data.

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In an effort to gain more understanding of the process of mobility, whether of a blind or of a sighted navigator, on foot or at the controls of a vehicle, a mathematical model of the mobility process has been proposed and investigated. It is hoped that such a model may lead to isolation of significant variables associated with mobility, and to comprehension of the interactions among these variables. Such comprehension in turn may lead to methods and devices which present the blind traveler with information he can use to maneuver himself in a world shaped by the sighted.

ANALYTICAL MODEL

The Traveler as an Information Processor

The model proposed treats a traveler as a processor of information. Information is gathered with a probe (eye, cane, radar, and so forth), is "used" in path traversal, and is "lost" in the uncertainties of memory decay and disorientation. The basis for the model is an equation which balances information gains and losses.

The following assumptions and idealizations are made:

a. the probe has a fixed range R

b. the path scanned has width L

c. the path may be characterized by a constant information density n bits/area

d. the traveler maintains a constant velocity V

e. there is a uniform weighting of the information received by the probe from various distances

f. uncertainty due to memory and orientation increase exponentially with time, and may be combined into a single term with time constant $1/K$.

Reaction time and stopping distance undoubtedly have an effect on performance. These have not been considered in the present model in order that the information variables may stand out more clearly. In all the experimental investigations with walking subjects, the reaction and dynamics were assumed uniform and therefore would not introduce spurious data. The form of the probe assumed for the model has an effect on the relationships evolved. Two types of probes have been considered. In the *scanning probe*, a narrow beam searches the path by moving transverse to the direction of travel. A *full-field probe*, on the other hand, covers the entire path width.

Scanning Probe

This probe will be idealized as a beam of width $d\ell$, scanning with speed S normal to the direction of travel. As he moves along the path, in the time T required for a single probe sweep, the traveler traverses an area equal to LVT. In doing so, he "uses" H^* bits of information, where

$$H^* = nLVT \tag{1}$$

The information, H, available to the traveler at the *end of each sweep*, assuming no carry-over from previous sweeps, is found by integrating

$$dH = nRd\ell e^{-K(T-t)} \tag{2}$$

over the cycle. Since $\ell = St$, this yields

$$H = nRSe^{-KT}\int_0^T e^{Kt}dt$$

$$H = \frac{nRS}{K}(1 - e^{-KT}) \tag{3}$$

If the use of information is limited by the amount available, the condition for travel is $H^* \leq H$. Using the equality as a limit,

$$V = \frac{RS^2}{KL^2}[1 - e^{-(KL/S)}] \tag{4}$$

or

$$V = \frac{R}{KT^2}[1 - e^{-KT}] \tag{5}$$

The following limiting cases are of interest.

a. $\lim_{K \to \infty} V = 0$	memory and orientation uncertainties are preponderant, traveler goes very slowly
b. $\lim_{K \to 0} V = R/T$	no uncertainties are present, velocity is limited only by probing ability
c. $\lim_{T \to \infty} V = 0$	slowness of the probing allows finite memory and orientation uncertainty to dominate
d. $\lim_{T \to 0} V = \infty$	fast sweep yields such large information transmission that velocity is not limited by lack of information.

Full-Field Probes

This probe will be idealized as a beam of width L which has a sampling cycle consisting of t active time units followed by τ nonactive time units. During the active portion of the cycle, the information collected is

$$H = nLR + nLVt \text{ bits} \tag{6}$$

The information used during the entire cycle is

$$H^* = nLV(t + \tau) \tag{7}$$

The amount of information lost to decay during the nonactive portion of the cycle is

$$H_L = (nLR + nLVt)[1 - e^{-K\tau}] \tag{8}$$

Therefore, the information available at the end of a cycle is $H - H_L$. For travel $(H - H_L) \leq H^*$. If the equality is taken as a limit,

$$V = \frac{Re^{-K\tau}}{\tau + t(1 + e^{-K\tau}} \tag{9}$$

The following limiting cases are of interest.

a. $\lim_{K \to \infty} V = 0$ memory and orientation uncertainties are preponderant, traveler goes very slowly

b. $\lim_{K \to 0} V = R/(t+\tau)$ no uncertainties are present, velocity is limited only by probe range and cycle time

c. $\lim_{\tau \to \infty} V \to 0$ if probe is always inactive, velocity is zero because no information reaches traveler

d. $\lim_{\tau \to 0} V \to \infty$ if probe is always active, information is unlimited and velocity is not bounded by lack of information.

Discussion of Analytical Results

The equations resulting from the analyses above are different for the two types of probes--but they have the following similarities:

1. The limiting velocities for the memory-orientation time constant, K, approaching both zero and infinity are the same for the two probes, as are the limiting velocities for both zero and infinite probe search periods.

2. For both probes, $\alpha V/\alpha R$ = constant.

3. For the scanning probe,

$$\lim_{K \to 0} \frac{\alpha V}{\alpha K} = R$$

while for the full field probe,

$$\lim_{K \to 0} \frac{\alpha V}{\alpha K} = R(1 + \frac{t}{\tau})$$

--which results are, at least, comparable.

4. Velocity is independent of information density in both equations.

EXPERIMENTAL INVESTIGATION

Four sets of experiments have been conducted to examine the predictions of the information model. For one of these sets, an optical tracking device, on which further work is anticipated, has been built.

The experiments are summarized for reference in Table 1.

Experiment 1

The first set of experiments was performed at MIT in May, 1965. The purpose was to test the prediction that velocity was not a function of information density, and to investigate the effects of memory and orientation on performance.

The experiment was run in two series, consisting of four and six tasks each, as indicated in Table 1. In every case, a normally sighted subject walked along a 120-ft straight-line course with his eyes closed. Lightweight plastic chairs were placed as objects along the course. The assumption was made that the number of chairs was a measure of path information density. Subjects were told that their performance would be measured by their speed, their accuracy, and their behavior at object encounter; in actuality, only speed was used. A description of tasks, by series, is given in Table 2.

Six subjects were used in Series 1, and three in Series 2. A single object density was used for each subject, but this was varied from subject to subject.

The average velocity for each subject was tabulated as a function of the number of objects in his path. The Pearson product-moment coefficient of correlation (1) between object density and velocity may be found to be $r = 0.160$. This is a low enough coefficient to support belief in the independence of velocity from object density.

Table 1

Summary of Experiments

Experiment Set	*Series*	*Effects or Relations Investigated*
I	1. Four course negotiation tasks, normal subjects, eyes closed 2. Six course negotiation tasks, normal subjects, eyes closed. Auditory cues suppressed in three of the tasks.	Independence of velocity from information density; presence of memory and orientation effects in measured performance.
II	1. Course negotiation with objects as travel guides. Normal subjects, blindfolded.	Effect of object density on travel.
	2. Course negotiation with auditory signal to warn of obstacles within range. Normal subjects, blindfolded.	Effect of probe range and warning signal duration.
	3. Goal attainment, with circumnavigation of large objects. Normal subjects, blindfolded.	Relation of orientation to travel.
III	1. Course negotiation with auditory signal to warn of obstacles within range. Congenitally blind subjects.	Effect of probe range and warning signal duration.
	2. Goal attainment with circumnavigation of large objects. Congenitally blind subjects.	Relation of orientation to travel.
IV	Use of travel simulator, the self-paced tracker.	Effect of path complexity, probe range, and scan duration.

Table 2

Summary of Tasks in Experiment I

Series	*Task*	*Conditions*
1	1-a	Unobstructed course
	1-b	Objects viewed prior to course negotiation
	1-c	Objects not viewed prior to course negotiation
	1-d	Orientation aided by string at chest height stretched above straight line along course.
2	2-a	Unobstructed course (same as 1-a)
	2-b	Unobstructed course, with ear protectors used on subjects to suppress auditory cues
	2-c	Objects viewed prior to course negotiation (same as 1-b)
	2-d	Objects viewed prior to course negotiation. Ear protectors used to suppress auditory cues.
	2-e	Objects not viewed prior to course negotiation (same as 1-c)
	2-f	Objects not viewed prior to course negotiation. Ear protectors used to suppress auditory cues.

A tabulation of the average velocity of each subject by task was also made. An analysis of the variance of this data by task, using the Snedecor F test, shows that the differences in Series 1 are significant at the 0.001 level. This indicates that memory and orientation effects may be significant--but the nature of this experiment does not allow a quantitative estimate to be made of the time constant in the model.

A similar analysis of the differences in Series 2 indicates a much lower level of significance (0.25), which may be due to the lack of significance of the use of auditory cues.

Experiment II

The second set of experiments was performed at Clarkson College in April, 1966.* This set consisted of three basic

**The second and third sets of experiments were conducted in conjunction with a course entitled* Human Factors in Engineering, *given by the author at Clarkson College in the spring semester, 1966.*

experimental series, principally concerned with object density, probe range, and orientation, respectively, as indicated in Table 1.

The first series was designed to test the effect of object density on travel. Normally sighted subjects walked blindfolded along a course following the corridors of a building from the ground floor, through the first, to the second story. Objects were placed along the intended path to serve as travel guides. For example, the arms of students chairs indicated the intended direction of travel, tables warned of stairways down, stools of stairways up. Each object was placed at the vertex of a triangular paper taped to the floor, the purpose of which was to signal the presence of the object.

A minimum set of objects consisted of chairs at the origin of each turn, plus tables and stools at the stairways.

Each of three subjects was tested at three distinct object densities. The principal data recorded were in the form of marks on a map of the course showing the position of the subject at 5 second intervals. From the maps, average velocities for the course, and corrected average velocities--compensating for the time devoted to object negotiation--could be calculated.

A Friedman two-way analysis of variance (7) in the traversal times, both total and compensated, indicated that no significant differences in velocities existed among the three object densities.

The data were further investigated to study the effect of object density on traveler confidence. Velocity was considered one measure of confidence--but, in addition, the time spent investigating an object and the time spent in hesitation during the run also were assumed to be confidence measures. A two way analysis of variance on these data also indicated that the differences due to varying object densities were not significant.

This series of experiments yields results that agree with the predictions of the model. It is possible, however, that the object density was too high to achieve significant results. Longer distance between objects--that is, a lower information density--might have revealed an information threshold level.

The second series in the experiment set was designed to investigate the effect of probe range and warning-signal duration on travel. Subjects walked blindfolded along a 9-ft-wide, 120-ft-long, section of building corridor. Chairs were arranged in lines normal to the direction of travel. A portable electric bell was used as the warning device and sounded by the experimenters when the subject came to the appropriate distance from an object. Warnings were given for two "probe" ranges--namely 4 ft and 8 ft--and were of two durations--a short pulse sounded as the subject entered the "collision zone," or a continuous signal that lasted as long as the subject remained in range of the object. Four subjects had four runs each which correspond to the 2 x 2 matrix of the above conditions as summarized in Table 3.

Table 3

Experimental Conditions, Experiment Set II, Series 2

Four-ft probe range Short warning pulse	Four-ft probe range Continuous warning signal
Eight-ft probe range Short warning pulse	Eight-ft probe range Continuous warning signal

The data taken were the times at which the subject left an object, reached a warning line, and reached an object.

A Friedman two-way analysis of variance by ranks, performed on average velocities, indicates that there are no significant differences among the four experimental conditions, and that velocity is not dependent on probe range in the ranges investigated.

If the data are recast into two categories rather than four, that is, 4-ft vs. 8-ft probes, regardless of the type of warning, the differences become more significant, as the greater warning distances give rise to higher velocities. This is especially marked in the collision zone velocities, and it might be a manifestation of measuring an inherent weighting factor in object encounter over different distances.

An interesting result is the fact that when data is cast into a form distinguishing between the short pulse and continuous warning, analysis yields no indication of significant difference. This suggests that an object-detecting aid need not necessarily give a sustained warning, as many present models and proposals do. This can lead to a saving of power and to less possibility of masking the audial channel to other signals.

The third series of experiments was designed to study the relationship between orientation and travel. As an electric buzzer was sounded at one end of a gymnasium, blindfolded subjects were started at various points along the opposite end and were told to walk toward the sound source. On the floor were "islands" of wrestling mats on which the subjects were not to walk. Subjects were to try to reach the buzzer in spite of innate disorienting effects and those introduced by circumnavigation of large objects. In the "machine paced" trials, the buzzer sounded periodically for orientation purposes; in the "self-paced" trials, the subject could ask for a signal by raising his arm.

Time was recorded for interobject travel and for obstacle negotiation, and the travel path was marked on a map of the test area. The speed, travel distance divided by travel time, could be found and used as a measure of confidence. Actual distances traveled were considered to be measures of accuracy; the more circuitous routes were less accurate.

An analysis of the data reveals that the differences in velocity achieved due to different signal rates were not significant, nor were the differences in accuracy. The subjects' levels of achievement, furthermore, were substantially the same in the self-paced trials as in the machine paced.

The subjects' measurable performances were, therefore, relatively insensitive to the amount of information supplied to them from the signaling device. This may be due to a better sense of orientation than we had anticipated, or to the use of other cues. In either case, there is an indication that visually deprived individuals may need only minor aid to their normal orientation.

It might be noted that one subject, who was able to navigate the course with no signals following the initial sound in three self-paced runs, became disoriented in her fourth trial and asked for three additional signals. No other subject required more than one plus two signals. This suggests that a subject, once disoriented, requires considerable assistance.

Experiment III

The third set of experiments was conducted in May, 1966, at the Montreal Association School for the Blind in Montreal, Quebec. Subjects were four totally blind children between the ages of 8 and 11 years. This set of experiments was similar to the set described directly above. It was designed to investigate the effects of probe range and of orientation on the travel process and to test the hypothesis that the performance of the blind children would not be significantly different from that of the sighted subjects previously used.

In the first experiment, obstacles, made of chairs, playboxes, and so on were arranged on an outdoor course 242 ft long and 13 ft wide. The course ran north and south, with a sidewalk as the west and a string as the east boundary. A warning bell was sounded, to simulate a probe, as the subject came into range of the object. Two ranges were selected for each subject, namely three and nine feet. Because of the results of the previous experiment, the warning signal was given for one second--as the subject entered the collision zone.

In their practice sessions the subjects were familiarized with the boundaries and were instructed to move back toward the center in the event of an encounter. If a subject missed an obstacle, after having been given the warning signal, he was told that he had passed it.

The average velocities, both in and out of the collision zone, were higher for the 9-ft warning than for the 3-ft warning, but the "t" test of significance between two sample means did not demonstrate differences significant at the .05 level.

In the second experiment, an outdoor course 200 ft by 45 ft was laid out. A series of large obstacles was spread about the course. The subjects were instructed to attempt to reach a goal--again, an electric bell--building themselves around the obstacles. Information was presented at three rates: six, three, and two signals per minute, and in a self-paced mode, a signal was elicited by a raised hand. Times and paths were recorded.

A Friedman two-way analysis of variance did not show any significance in travel-time differences due to different information rates.

Experiment IV

The fourth set of experiments was performed during the summer of 1966 at MIT. These experiments were run on the self-paced tracking device designed by the author and Mr. Stefan Malek of Clarkson College.

The self-paced tracker is a mobility simulator in which the target, usually a path image drawn on blank 35-mm photographic film, is projected onto a photosensitive target. The film is fed through a motorized strip-film projector at a speed controlled by the subject. The left and right position of the target relative to the path is also controlled by the subject--by means of a Selsyn-controlled mirror. The present version of the device has a single control lever--with forward and back positions controlling fast and slow, and left and right determining sidewise motion of the path-target system. The device also has a relay-operated shutter in front of the lens to cut off the subject's view. The shutter is controlled by a push-button.

Tests were run on paths with three different levels of complexity. This was accomplished by designing the paths to have identical angle-turn characteristics, but to be of different widths. The widths were one half, one fourth, and one eighth of the view field--corresponding to one, two, and three units of information. Three "probe range" values were used. The "probe range" corresponded to the length of path the subject saw in front of the target. Additionally, four shutter rates plus a self-paced shutter control mode were used. These were: shutter open; open one second, closed one second; open two seconds, closed one second; and open two seconds, closed two seconds. In the self-paced mode, the subject opened the shutter when he wanted to view the target.

It should be noted that the position control of the system acted approximately as a proportional controller, while the velocity exhibited a first order response--with a lower time constant on acceleration than deceleration.

In this experiment, the subjects' input signals to the controller were monitored as were signals indicating whether the path was on or off target, and whether the shutter was open or closed.

None of the differences in velocity due to the various experimental conditions appear to be significant. In the open shutter run, the tracking accuracy decreased with path complexity, but speed remained effectively uniform. In the self-paced trials, the subject tended to keep the shutter open most of the time--and again let his accuracy vary in favor of a uniform velocity. In the machine-paced shutter trials, all trackers eventually adopted the tactic of pulsing the speed--on during the view, off during the non-view part of the cycle. The average velocity still was relatively fixed. Accuracy during the nonview portion of the cycle was low--but because of the instrumentation, was not measured.

One factor that was not included in the analysis and not compensated for in the system design is the refractory period inherent in the human response. The system could be modified to allow for this through a longer preview distance or a shorter time constant on the speed controller.

CONCLUSION

Points deduced from the experimental data and from observations made during the performance of the experiments are summarized in Table 4. Note that the deductions mentioned in Table 4 apply only to the particular experiments cited, and to the conditions under which the experiments were performed. No claims of generalization are made except as specifically discussed below.

The experiments tend to verify the prediction that velocity is independent of path complexity, but they do not substantiate the predicted relations between probe range and velocity or between orientation-memory decay and velocity. Instead, they tend to indicate that velocity is relatively independent of these factors. Some correlation between range and velocity was noted in the second and third experimental sets--but observation of subject performance on the self-paced tracker leads to a suspicion that reaction time, coupled with the traveler's stopping dynamics, may be a controlling factor in mobility.

The orientation series in the first three experiment sets lead to the idea that visually deprived travelers are able to maintain a high degree of orientation, and that this need not become a limiting factor in the travel process. It remains to be ascertained how much conscious effort is devoted to maintaining orientation, and whether the effort required for satisfactory travel is excessive. In the experiments, of course, subjects were able to concentrate on their orientation. Experimentation similar in form to the above, but using the auxiliary task technique to measure expended mental effort, might answer this question.

It also appears from observing the experiments that when the actual cost of inaccuracy is not too high (for example, bumping into an object without incurring excessive pain, embarrassment, or damage; driving onto the shoulder of a road without damaging the car, the driver, or the driver's pride),

Table 4

Summary of Deductions from Experiments

Experiment Set	*Series*	*Deductions*
I		
Sighted subjects, eyes closed	1. Straight-line course	Velocity independent of object density; memory and orientation effects showed significance
	2. Straight-line course, auditory cues suppressed	Auditory cues were not significant
II		
Sighted subjects, blindfolded	1. Objects as travel guides	Velocity independent of object density
	2. Auditory warning of approaching objects	Velocity independent of probe range; continuous and pulse warnings had equivalent effects
	3. Orientation toward fixed goal	Subjects displayed excellent innate sense of orientations
III		
Blind subjects	1. Auditory warning of approaching objects	Velocity independent of probe range
	2. Orientation toward fixed goal	Subjects displayed excellent innate sense of orientation
IV	Self-paced tracking system	Accuracy sacrificed for speed

travelers are willing to sacrifice accuracy for speed. In an independent experiment at an earlier stage of development of the self-paced tracker, it was found (4) that a bell arranged to ring while the subject was off track produced anxiety and embarrassment--and decidedly lower speed. An innate cost function (6) may therefore exist with several discrete values--triggered by the danger level of the stimuli.

Experiment II, Series 1, involved the traveler's *use of objects* as opposed to his *encounter with obstacles*. The results of this experiment reflect favorably on the information concept of travel, in that the minimum set of objects led to performance not exceeded with a larger number. Some confusion, in fact, was exhibited by the subjects on encountering the additional objects. The traveler may have been faced with the decision of whether the object contained new information or was redundant. A sighted traveler may unconsciously extract information from the environment as desired; a traveler who receives information in discrete portions may have to evaluate each message as it is presented.

Somewhat in accord with findings (2) regarding veer from a straight line path, we found that in control runs in which subjects walked a 48-ft straight line, blindfolded, veer could be significant. Of four subjects tested, two walked 48 ft with 0 deviations, one with 2-ft deviation; and one with 8-ft deviation.

In Cratty's work, substantially longer courses--200 yards--were used, and all subjects veered appreciable distances. There is little doubt that some orientation assistance is needed by a blind traveler, but, as stated above, this may be a small amount.

It is interesting to note that there was consistency in the accuracy of subjects in the control runs and in the actual experiment. The subject with the 8-ft deviation had the worst accuracy record in the orientation runs, with an actual path-length average of 147 ft. This may be compared with 137 ft for the subject with the 2-ft deviation, and 128 and 136 ft for those with 0 deviation. It should be noted that the subjects with 0 deviation during the control run and the best accuracy during the actual runs were both females. One of the experimenters advanced the observation that the young ladies both walked by placing one foot in front of the other, while the male subjects walked by placing each foot in front of its own previous position. Whether this has any implications for training of the blind traveler remains to be seen, but it appears as an interesting possibility. A final observation was that in Experiment II, Series 2, a warning pulse, sounded when the subject reached "probe range" of an obstacle, had the same effect as a continuous signal, given from the moment that the subject entered the range until he had passed out of a zone in which he would encounter the object (either by changing path or by going around it). This indicates, as discussed in the experimental sections, that warning devices for the blind might be designed to give only a warning pulse in normal travel, thereby not keeping the attention of the traveler distracted from other potential cues.

In conclusion, it should be emphasized that the experiments conducted were designed to test various facets of the proposed information model of the mobility process. To some extent, this has been done. For example, there is reasonable evidence to support the independence of velocity on path complexity. While other aspects of the testing program have brought out interesting points, they have, as could be anticipated, raised more questions than they have answered. Detailed study of the results, moreover, has shown that, while the model was proposed for the general mobility process, more careful study of the sighted and partially sighted, congenitally and adventitiously blind is needed. The tests conducted in Montreal, with the kind support of the Montreal Association School for the Blind, were an attempt to show that the information usage of one group of blind children was not significantly different from that of the normally sighted college students used in the other tests. This was verified at a superficial level, but, as with the majority of the points investigated, a great deal of detailed and specific work remains to be done.

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