EFFECT OF PROLONGED VISUAL DEPRIVATION ON VARIOUS CUTANEOUS AND AUDITORY MEASURES

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ABSTRACT

Effect of Prolonged Visual Deprivation on Various Cutaneous and Auditory Measures

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Three studies performed recently at the University of Manitoba have reported a significant increase in tactual acuity and in heat and pain sensitivity after a week of visual deprivation. A significant improvement in auditory discrimination but not of the absolute threshold of hearing was also reported. The purpose of the present study was to employ a variety of additional cutaneous and auditory measures to determine how general or limited these facilitatory effects may be.

Fifteen male subjects wearing black masks were confined in a small room for a period of seven days. Apart from constant darkness, their sensory environment was normal. Measures of auditory localization (absolute and differential), tactile localization, and sensitivity to pressure on five skin areas were taken before and after a week of darkness, as well as at intervals of one, two, and five days following termination of visual deprivation. Fifteen male control subjects, unmatched with, but drawn from the same population as the experimental subjects, were tested at the same time intervals but under a condition of normal visual stimulation.

The results indicated that visual deprivation can produce a significant increase in pressure sensitivity of the finger, forearm, neck, and leg, with the after-effects persisting for several days after

the restoration of normal visual stimulation. A trend toward increased sensitivity of the palm was also observed but the change was not statistically significant. Two possible explanations were offered for the negative results on the palm. Measures of tactual and auditory localization, on the other hand, showed no significant changes after visual deprivation, a finding which may be related to the strong dependence of these measures on practise and learning.

The results of this study and of the earlier Manitoba studies provide some experimental support for Schultz's (1965) sensoristatic theory of the nervous system.

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INTRODUCTION AND HISTORICAL BACKGROUND

I. Statement of the Problem

Recently, several studies performed at the University of Manitoba have reported that subjects, exposed to a week of visual deprivation, showed no change in the absolute threshold of hearing for various frequencies but did show a pronounced increase in auditory discrimination, pain sensitivity, heat sensitivity, and tactual acuity. These intersensory facilitatory effects were shown by all or almost all of the experimental subjects and persisted for several days after termination of visual deprivation. The purpose of this study is to employ a variety of other measures of cutaneous and auditory sensitivity in order to determine how general or limited these intersensory facilitatory effects may be.

II. Introduction

The topic of sensory interaction has interested people for a long time. Early investigations employed two general approaches viz., the use of the blind as subjects and the employment of an accessory stimulus. Recently, a third technique, involving various periods of stimulus deprivation, has been developed to study sensory interaction.

The theory of sensory compensation (i.e., when an individual loses one of his senses the remaining senses function vicariously to compensate for the loss) has led to many studies investigating the differences in sensory functioning between blind individuals and those with normal vision. This approach, although important because of its implications for the field of blindness as well as sensory interaction, has not been too fruitful. Uncontrolled variables such as the extent of damage to the nervous system of the blind individual, the length of time the individual has been blind, the age of onset of blindness, and the degree of blindness have, in general, produced contradictory results which are difficult to interpret.

The second general approach (accessory stimulus) to sensory interaction involves studying the response of one sense modality during a very brief stimulation of another. This technique, which has been used extensively in the Soviet Union since the early 1930's, has not been employed in the western world until relatively recently. One advantage of this method is that each subject can be used as his own control whereas in the study of the blind it is impossible to know what the sensitivity of the subject was prior to his blindness. In spite of this advantage, the results of accessory stimulus studies have also been contradictory in nature.

The third general approach to sensory interaction is the reverse of the second approach. In this case, the response of one sense modality is studied following a period of deprivation of another sense modality, a deprivation duration which may range from a few minutes to a week. This technique again possesses the advantage that each subject can be used as his own control. However, unlike the accessory stimulus approach, the deprivation procedure has yielded a consistent pattern of results which will be described in detail in the next section.

III. Historical Background

For organizational purposes, the review of the relevant literature will be presented under the following three headings: studies on the blind, studies employing accessory stimulation, and finally, experiments involving the deprivation of a single modality.

Studies on the Blind

Although in recent years the number of studies based on the theory of sensory compensation in the blind has declined, a voluminous literature, nevertheless, has been accumulated. Because of the vastness of this literature, this review will be limited to measures of cutaneous and auditory sensitivity.

Behavioral Studies

Cutaneous sensitivity (two-point limen). One of the earliest experimental attempts to study sensory compensation was by Griesbach (1899). Using an esthesiometer, he determined thresholds for 37 blind and 56 sighted subjects on the forehead, cheekbone, tip of the nose, lips, thumb, and finger tips. The results indicated that the blind possessed poorer tactual acuity than did the sighted. A similar finding was recently reported by Wilson et al. (1962) who observed poorer tactual acuity of the forearms of the blind. Seashore and Ling (1918), on the other hand, reported no significant differences between blind and sighted subjects in tactual acuity of the inner forearm and tip of the index finger.

Although these three experiments furnish no support for the theory of sensory compensation, some evidence for it is provided by two other studies in which a two-point threshold technique was again employed. One such study was performed by Brown and Stratton (1925) who used a modified form of the two-point threshold. Subjects indicated whether one or two points were felt while moving the fingers over single and double rows of steel points set in a board. The results indicated that the blind were superior to the sighted and that the longer the individual had been blind, the more superior he was likely to be at this task. In the other study, Axelrod (1959) reported that early blind subjects possessed superior tactual acuity but only on the right index finger. Furthermore, Axelrod, who reanalyzed Plata's (1941) data which showed no evidence for sensory compensation, observed a superiority of blind girls over sighted on the two-point threshold. No difference was seen between blind and sighted boys.

Other measures of cutaneous sensitivity. Using von Frey hairs as a measure of light touch sensitivity, Axelrod (1959) reported that early-blind girls possessed poorer sensitivity on the left and right index fingers and on the ring finger of the preferred hand. However, early-blind boys displayed improved touch sensitivity on all fingers, although only the results on the ring finger of the preferred hand were significant. He hypothesizes that differential callous formation characteristic of the manual activities of the two sexes may account for some of the results. Employing a similar technique, Stratton (1903) and Krogius (1907) demonstrated that blind subjects (sex not specified) were superior to sighted subjects in sensitivity to light pressure.

Blind subjects were also found superior to sighted in a study by Hunter (1954) on tactual recognition of straightness. Blind and sighted subjects were compared on their ability to tell when a ruler was bent or straight. The blind judgments of straight were closer to objective straightness than the judgments of sighted subjects.

Axelrod (1959) found the blind somewhat superior and more variable in a task requiring subjects to discriminate whether the second pressure was stronger or weaker than the first. In another section of the same study, blind subjects were found inferior to sighted subjects in their ability to feel a copper wire under varying layers of paper by stroking the area with their fingers.

Auditory localization. Griesbach (1899) compared the ability to distinguish the direction of a sound in 28 blind and 28 sighted subjects. No differences were found between the two groups. Similar results were reported in a recent experiment by Fisher (1964) which employed both differential and absolute measures of auditory localization. Different results, however, were obtained when the subjects were given a whistle in the center, followed by a noise and a touch stimulus, a situation requiring the subject to report whether the noise or touch stimulus was further to the left. In this experimental condition, the blind showed superior auditory localization relative to sighted subjects.

In two separate experiments, one employing Griesbach's method of auditory localization and the other a different method of auditory localization, Krogius (1905, 1907) demonstrated that for both types of localization the blind were superior to the sighted. Seashore and Ling (1918) also found the blind slightly superior and more variable on a measure of the angular displacement of an auditory stimulus in the horizontal plane directly in front of the observer.

Other auditory measures. None of the studies, employing measures of absolute auditory sensitivity, provide any support for the theory of sensory compensation. For example, Griesbach (1899) measured the distance at which sounds could be distinguished by each of 49 sighted and 19 blind subjects. No superiority of blind over sighted subjects was indicated by the results. Using a technique which involved allowing a tuning fork to "ring off," Horter (1913) reached similar conclusions. Kunz (1908), on the other hand, reported the presence of poorer auditory sensitivity in the blind. A similar tendency to poorer sensitivity has also been observed by Waidele (1905) and by Hayes (1933) who reported that the mean distance from the head at which a watch was just audible was 311 cm. for the 38 blind subjects and 374 cm. for the five sighted subjects.

Two other studies, employing more complex measures of auditory functioning, have also yielded negative results. In the first, Seashore and Ling (1918) used an audiometer to measure loudness discrimination in blind and sighted subjects. The results indicated no difference in their ability to perform this task. In the second study, Hayes (1933) required blind and blindfolded sighted subjects to recognize the contents of a box by shaking it and listening to it. Again, the blind showed no superiority.

Physiological Studies

Recently, some physiological evidence for sensory compensation has been found. Grey Walter (1963) reported that in some congenitally blind children, the nonspecific cortical responses evoked by tactile and auditory stimuli were unusually large in relation to those of sighted children of the same age. Further evidence of cortical changes following blindness was reported by Krech et al. (1963). In this study rats were subjected to peripheral blinding at the time of weaning and raised for 80 days in an enriched environment. Examination of the brains revealed a significant increase in the weight and cholinesterase activity of the somesthetic cortex relative to that of sighted controls raised in the same environment. Similar somato-sensory changes were reported by Bennett et al. (1964) in a study on sighted rats raised in darkness for 80 days. However, MacNeill and Zubek (1967), in a replication of the Bennett experiment, obtained no evidence for an increase in the weight of the somesthetic cortex following dark-rearing, a finding which they attributed to possible differences in the complexity of the enriched environments employed in the two experiments.

It is evident from this survey of the literature that no clear relationship appears to exist between the loss of vision in the blind and tactual and auditory sensitivity, with increases, decreases, and no changes in sensitivity being reported in the various studies. There is, however, some evidence indicating that such variables as sex (Axelrod, 1959), intelligence (Ewart & Carp, 1963; Winer, 1962), age of onset of blindness (Axelrod, 1959; Worchel, 1951; Drever, 1955; Hatwell, 1959), and emotional stability (Winer, 1962) could account for some of the discrepancies in results. There are still other variables such as degree of blindness, length of blindness, age, and causes of blindness which have not yet been fully investigated and controlled in experiments on the blind.

Accessory Stimulus Studies

The second general approach to the study of sensory interaction involves the investigation of modifications of response in one sense organ under direct stimulation, where another sense organ has been, or is subject to its own characteristic stimulus. Because of the vastness of the literature, this review will be restricted to studies appraising the interaction between the visual and auditory senses and the visual and skin senses.

Behavioral Studies

Soviet studies. An excellent review of the Soviet research on sensory interaction has been prepared by London (1954). Although this research is extensive in nature, London has criticized most of it on the grounds that the instrumentation and methodology were inadequate, the statistics primitive, and the reports, describing the results, too general in nature for proper evaluation. In view of the weaknesses of these studies, only a brief summary of London's extensive review will be presented in order to demonstrate the general nature of the Soviet results.

Most of the Soviet work involves the effects of various accessory stimuli on measures of visual sensitivity. Both tactual and auditory stimuli were found to influence peripheral visual sensitivity. For example, auditory stimulation produced a decline in peripheral visual sensitivity, while exposure to ultrasonic frequencies, e.g., 32,800 cps., was associated with increased peripheral sensitivity. For touch, a cold accessory stimulus was found to increase peripheral visual sensitivity while a warm stimulus brought about a decrease. A cold accessory stimulus was also reported to accelerate dark adaptation.

The results of studies on absolute sensitivity of central vision indicated that auditory stimulation of moderate intensity heightens central sensitivity to white light for the dark-adapted eye. However, for monochromatic light the effect varied with the wavelength employed. For short wavelengths (blue-green) the sensitivity was raised by auditory stimulation, while for longer wavelengths (orange-red) sensitivity was decreased and for extreme spectral red and violet central sensitivity was unchanged.

Accessory stimuli were also capable of changing the differential sensitivity to brightness discrimination. Another finding was that the brighter the viewed field became the greater was the decrease in differential sensitivity under the effect of simultaneous auditory stimulation.

Investigation of the C.F.F. (critical flicker frequency) under accessory auditory stimulation yielded even more complex interactions than the above. For central vision the C.F.F., using white light, was heightened in the presence of an auditory stimulus while the C.F.F. for peripheral vision was lowered. Furthermore, the C.F.F., using a monochromatic light of short wavelength (520 mu.), was reduced by auditory stimulation (800 cps. at 85 db.) while C.F.F., using a monochromatic light of long wavelength (630 mu.), was increased by auditory stimulation.

Several studies reported that auditory stimulation of medium intensity increased the electrical sensitivity of the eye while high intensity sounds decreased it.

A number of the studies dealt with the effect of accessory stimuli on auditory sensitivity. For example, illumination of the eyes with white light was claimed to have increased auditory sensitivity while the absence of visual stimuli decreased it. Also, different monochromatic stimulation resulted in different auditory changes e.g., green light increased auditory sensitivity while red light decreased sensitivity.

North American studies. Although the Soviet studies have provided a considerable amount of data indicating the presence of a variety of complex intersensory effects, much solider evidence has been provided by North American investigators. In contrast to the Soviet work, these studies were carefully executed and well designed.

Johnson (1920) studied the effect of changes of illumination upon tactual discrimination in card-sorting. Ground-glass goggles were worn throughout the experiments to prevent patterned vision. Out of 16 subjects, six showed reliably better discrimination when the visual field was bright, seven showed unreliable differences in favor of the bright field, and only one of the 16 was reliably more accurate when the field was dark.

A recent study by Symons (1963) demonstrated that thermal stimulation (45° C water) of the right hand resulted in increased visual acuity. In the same study the effect of maintaining a steady muscular contraction of the right arm and hand, using a hand dynamometer, resulted in a significant increase in visual acuity. Symons stated that the more caudal parts of the brain stem reticular formation could be responsible for these interactions.

There have been several studies on the effects of visual stimulation on auditory sensitivity. The possible facilitatory effects of light upon the discrimination of pitch and intensity differences were investigated by Hartmann (1934), using the Seashore test. He found a fairly uniform improvement of three percent under a condition of very strong illumination relative to that shown under very dim illumination. Some exceptions, however, were noted. In a second experiment, he reported that auditory acuity was better during complete darkness than during high illumination.

Sheridan et al. (1966) investigated the effects of darkness, constant illumination, and synchronized photic stimulation on the auditory thresholds of five different frequencies (250, 500, 1000, 2000, and 6000 cps.). The results indicated that the effect of concurrent visual stimulation on auditory sensitivity was dependent on the frequency of the auditory stimulus. Furthermore, a significantly lower auditory threshold was found under the darkness condition than under either of the two experimental conditions for the 6000 cps. tone but not for any of the lower tones.

The influence of illumination upon auditory acuity as a function of the temporal interval between the light and the tone was investigated by Child and Wendt (1938). The facilitatory effects of the illumination were found to be greatest when it occurred from 0.0 to 1.0 seconds prior to the onset of near-threshold tonal stimuli.

Gregg and Brogden (1952) studied auditory thresholds for a 1000 cps. tone as a function of the intensity of the accessory illumination under two conditions of attention. The results showed that, when the subjects were instructed to report the presence of light, a significant decrease in auditory sensitivity occurred as the brightness of the light was increased. However, a significant increase in auditory sensitivity was obtained with increases in brightness of the light when no response to the illumination was required. In a related study by Thomson, Voss, and Brogden (1958) threshold measures of a 1000 cps. tone were taken under eight different levels of light intensity ranging from below to well above threshold. Three groups of subjects were used; one responding verbally to the light, one not responding to the light, and a control group in which all thresholds were made at zero light intensity. The results demonstrated that the subthreshold light inhibited auditory sensitivity for the responding group but had no effect on the nonresponding group. In supra-threshold light conditions both the responding and nonresponding groups showed an increase in auditory sensitivity, with the nonresponding group showing the greater facilitation. The threshold did not vary with increased supra-threshold illumination. These results were not in complete agreement with those of the previous experiment on the effect of responding to the accessory visual stimulus or varying the illumination.

In addition to these experiments, a number of investigators have studied the effects of auditory stimulation on various measures of visual sensitivity. Hartmann (1933) reported that visual acuity, for discriminating either black on white or white on black, could be temporarily increased to a slight but consistent level by simultaneous application of high and low tones. However, Symons (1963), using a 6.5 cm. white line on a black background, found no change in visual acuity during accessory stimulation by a 1000 cps. tone at 60 db. Another study that reported no significant effect of sound was performed by Serrat and Karwoski (1936). They found that neither the illumination threshold at 506 mu. nor the hue threshold at 710 mu. showed any variation because of the presence of sound. Experiments reporting negative results are rare exceptions since the majority of studies have demonstrated some degree of interaction between vision and hearing.

Thorne (1934) reported that the effects of auditory stimulation on absolute visual sensitivity may be either facilitatory or inhibitory depending upon the relationship between the auditory and visual stimulus. If the accessory sound was in the background in relation to the visual stimulus, it facilitated visual sensitivity. On the other hand, if the auditory stimulus was focal and the visual stimulus was in the background, then visual sensitivity was inhibited.

Chapanis, Rouse, and Schachter (1949) investigated the effect of a 1000 cps. tone on dark adaptation, as well as the effect of auditory and tactile accessory stimulation on contrast sensitivity. The results were negative in both aspects of the study and in complete disagreement with two Soviet researchers (Kekcheyev, 1943, 1945; Streltsev, 1944) who claimed enormous effects of accessory stimulation on dark adaptation and night vision.

The C.F.F. has been used as a measure of visual sensitivity by several investigators. Allen and Schwartz (1940) reported that the intensity of an accessory tone resulted in differential effects on the C.F.F. A loud tone produced an enhancement while a weak tone produced a depression of visual sensitivity. It was also reported that stimulation to the left ear evoked an enhanced visual response in the right eye.

Ogilvie (1956) reported that continuous white noise had no effect on the C.F.F. However, in-phase auditory flutter raised the C.F.F. higher than out-of-phase auditory flutter, although out-of-phase auditory flutter raised the C.F.F. higher than continuous noise. Neither brightness of the visual stimulus nor intensity of the auditory stimulus produced a significant change in the C.F.F. Ogilvie considered the effect of the auditory flutter on visual sensitivity to be a clear demonstration of the existence of an hypothesized central mechanism (Sherrington, 1947) for the integration of neural impulses from the two sense organs. Because all auditory flutter subjects received the same absolute amount of auditory stimulation, the phase difference in the results indicates that the intersensory effects cannot be due to changes in "attention" as has often been maintained. In a second experiment, Ogilvie (1956) used a wider range of brightnesses than in the first. He again reported that in-phase C.F.F. was higher than out-of-phase C.F.F. and that stimulus brightness had no effect on this interaction.

Maier, Bevan, and Behar (1961) investigated the influence of auditory stimulation upon monocular and foveal C.F.F. for lights of different wavelengths. Three groups of subjects were tested with one of three dominant wavelengths (490.5, 538.0, and 650.7 mu.). Each group experienced auditory stimulation in all combinations of three loudness levels (0, 40, and 80 phons) and three frequencies (290, 1050, and 3900 cps.). The results indicated the existence of complex intersensory relationships. Auditory stimulation raised the C.F.F. from two to four percent, the loudness-level effects on the C.F.F. for orange, red, and blue were monotonic, and pitch alone had no effect on the C.F.F. unless paired with loudness and color.

Physiological Studies

Two investigators have demonstrated sensory interaction phenomena of a physiological nature. Chang (1952) showed that continuous retinal illumination enhanced the cortical response to electrical stimulation of the medial geniculate body of the auditory system in cats. The primary locus of this interaction between vision and hearing appeared to occur at the subcortical level since the removal of the visual cortex only partially reduced the facilitatory effect of light on the auditory response. Chang (1959) has suggested that the reticular activating system (R.A.S.), which receives convergent afferent impulses from various sensory sources through collateral fibers, may be the neural mechanism mediating this intersensory facilitatory effect. In the second physiological study, Gellhorn et al. (1954) reported that in lightly anesthetized cats, nociceptive stimuli increased the electrical responsiveness of the sensory projection areas to visual and auditory stimulation.

This survey of the literature has indicated that brief periods of stimulation of one modality can enhance, diminish, or in the rare instance, exert no effect on the sensitivity of other modalities. Furthermore, the specific nature of these effects appears to be dependent upon numerous variables e.g., the frequency, wavelength, or intensity of the accessory stimulus, type of response being measured, temporal interval between the accessory stimulus and the measurement of the response, nature of instructions given to the experimental subjects, etc. Thus, although a variety of intersensory effects have been demonstrated with the accessory stimulus technique, the results are of such a complex nature that no satisfactory theoretical explanation has as yet been formulated to account for the results.

Deprivation Studies

This final section of the historical review is concerned with a survey of the relatively few experiments employing the deprivation approach i.e., an appraisal of sensitivity of one modality after various deprivation durations of another sense modality. In contrast to the results of the two earlier approaches, this method has, in general, produced a consistent pattern of intersensory effects, particularly after prolonged periods of stimulus deprivation.

Short Duration Studies

Although short deprivation periods can produce intersensory effects, the results are contradictory in nature. Ozbaydar (1961) compared subjects tested after ten minutes of either darkness or light on the absolute auditory threshold, the difference threshold, and the masked threshold for a 1,200 cps. tone. Although no change was found on the difference threshold, the darkness condition produced a small, but reliable, impairment on both absolute and masked thresholds. The presence of an auditory impairment was also reported by Cohen (1962) who compared subjects who had been exposed to either 20 minutes of darkness, of a Ganzfeld (a uniform textureless field) or of a control condition on three auditory measures viz., the Seashore loudness discrimination test, discrimination between odd and even numbers, and discrimination between one or two tones. Although no significant differences were found on the third task, more errors were produced on the Seashore test by both the Ganzfeld and darkness conditions relative to the control condition. On the odd-even numbers test the Ganzfeld condition resulted in a greater degree of impairment than the darkness condition.

Bakan and Manley (1963), using male subjects, reported an improvement on an auditory vigilance task after 15 minutes of darkness. Female subjects, surprisingly, showed no change.

The Soviet investigator, Kamchatnov (1962), employed a two-point threshold technique to study tactual acuity differences between women working a period of eight hours in the dark and those working the same period in the light. He reported that the subjects working in darkness exhibited poorer tactual acuity on all three skin areas (index finger, thumb, and forearm) tested than did the subjects working in light. However, an inspection of his data reveals that a difference of the same magnitude was present prior to visual deprivation. A statistical treatment involving a "difference of differences" analysis would probably have yielded negative results.

Long Duration Studies

One possible explanation for these contradictory results is the brevity of the deprivation period which ranged from ten minutes to eight hours. These durations are perhaps too short to produce demonstrable and reproduceable results. Some supporting evidence for this hypothesis is provided by four experiments recently conducted at the University of Manitoba, all employing one week of visual deprivation.

In the first study (Zubek, Flye, & Aftanas, 1964), 16 subjects were placed, in groups of two, in a room for a week. Apart from constant darkness the sensory environment was quite normal with no restrictions on movement, conversation, or use of a radio. Measures of tactual acuity were taken from the index finger, palm, and forearm before and immediately after a week of darkness and subsequently at intervals of 1, 2, 5, and 7 days. The acuity of the palm was measured by the two-point limen technique while that of the index finger and forearm was determined by a tactual fusion technique (interrupted bursts of air whose frequency can be increased until a constant sensation of pressure is obtained). In addition to these measures of tactual acuity, heat and pain sensitivity of the forearm was determined by the Hardy, Wolff, and Goodell dolorimeter. For comparative purposes, a group of 16 non-deprived control subjects were given the same measures and at the same time intervals as the experimentals. A significant increase in tactual acuity occurred on all three skin areas with the after-effects persisting for several days: one day for the palm, two days for the index finger, and even longer for the forearm. An examination of the individual data revealed that the increased tactual acuity was shown by all 16 experimental subjects and on all skin areas. The heat and pain threshold measures also showed a significant post-deprivation increase in sensitivity with the after-effects persisting for one day for heat and two days for pain. Again, all experimental subjects showed the effect, on both measures.

The purpose of the second experiment (Zubek, Flye, & Willows, 1964) was to determine whether effects, similar to those of darkness, will result from prolonged exposure to non-varying homogeneous illumination. If this should occur, it will suggest that these cutaneous effects probably resulted from an absence of pattern vision rather than from an absence of visual stimulation per se. The previous procedure, therefore, was repeated with a new group of subjects with the exception of a pair of translucent goggles which were worn at all times. The results revealed a significant increase in heat and pain sensitivity with the after-effects persisting for two days for heat and one day for pain. Similar results were reported for tactual acuity with the after-effects persisting for a day for the finger and no persistence on the forearm. Finally, the palm revealed a slight, though not statistically significant, increase which the authors attributed to a lack of sufficient sensitivity of the two-point limen technique. Uniformity of the individual data was again seen but this was not as striking as under the darkness condition. Thus, significant increases in cutaneous sensitivity can occur after prolonged exposure to either darkness or homogeneous illumination. Furthermore, the somewhat smaller effects produced by the latter condition are attributed by the authors to the presence of random fluctuations in illumination resulting from the opening and closing of the eyes together with movements of the head away from the overhead light source -- a factor not present during the darkness condition. These random fluctuations in level of illumination probably served to alert the neurovisual system periodically and hence diminished the magnitude of the effects.

During the course of these two experiments, several of the subjects reported spontaneously that their sense of hearing seemed to be much better. In view of these remarks, two types of auditory determinations were made in the third study (Duda & Zubek, 1965). These were administered to a group of 15 subjects before and immediately after a week of darkness and subsequently at intervals of 1, 2, 5, and 7 days. The first test involved the measurement of auditory discrimination using an auditory flutter technique (interrupted white noise at a 0.90 on-off ratio) and the second consisted in the determination of the absolute threshold of hearing for five different frequencies viz., 100, 300, 1,000, 5,000, and 9,000 cps. The results revealed a significant improvement on the auditory discrimination task with the after-effects persisting for one day. All experimental subjects but one showed this increased sensitivity. On the other hand, the absolute threshold of hearing for the five frequencies was not affected. Furthermore, no trends were evident. The failure of this second auditory measure to show a facilitatory effect is puzzling. One possible explanation of this finding may be in the nature of the stimuli employed in the two auditory measures. The absolute threshold measures used pure tones whereas the auditory discrimination determinations employed a white noise. Some support for the importance of this variable was recently provided by Galin (1964) who demonstrated that white noise and pure tones produced qualitatively different patterns of evoked activity at different levels of the auditory system. The most notable difference occurred at the inferior colliculus where white noise produced a marked increase in activity while pure tonal stimulation had no such effect. This distinctiveness in physiological response to the two types of auditory stimuli may be an important factor in accounting for the differential effects on the two measures of auditory sensitivity.

The purpose of the fourth experiment (Schutte & Zubek, in press) was to determine whether a week of darkness can produce an increase in gustatory and olfactory sensitivity. If this should occur, it will suggest that prolonged visual deprivation can exert a facilitatory effect on a number of different sense modalities. Olfactory sensitivity (recognition threshold for benzene) was measured by a power-operated, syringe type olfactometer. In the determination of gustatory sensitivity, the stimuli consisted of 21 different concentrations of sucrose (sweet), 20 for NaCl (salt), 22 for HCl (sour), and 23 concentrations for quinine sulphate (bitter).

The results indicated a significant increase in olfactory sensitivity. On the other hand, gustatory sensitivity showed a differential pattern of results. Sensitivity to salty and sweet substances was increased significantly; a strong trend, though not significant, was observed for sour (11 of the 12 experimentals showed an improvement); and no change occurred for bitter. These differential results, it is important to note, appear to be related to the per cent concentration of the four taste solutions. Quinine and HCl, which subjects can normally detect at very low concentrations, produced non-significant results whereas NaCl and sucrose, to which subjects are much less sensitive, produced a significant increase in sensitivity. Further evidence in support of the possible importance of this variable was provided by a rank-ordering of the four taste solutions according to concentration and the magnitude of the post-deprivation change. The greatest sensory change was shown by NaCl, followed by sucrose, HCl, and quinine, in descending order, a rank order corresponding to the descending concentrations of the four taste solutions. In view of this correspondence, it is possible that increased sensitivity to both sour and bitter may have occurred if other taste substances, to which subjects are less sensitive, had been substituted for HCl and quinine.

The results of these four Manitoba experiments, indicating the presence of pronounced intersensory facilitatory effects in a number of modalities, are of considerable theoretical importance since they provide experimental support for the sensoristatic model of the nervous system recently formulated by Schultz (1965). Further details of this theory will be presented in the section on discussion of results.

In conclusion, this review of the literature has indicated the existence of a variety of intersensory effects between vision and hearing, and vision and touch. However, no consistent, meaningful pattern of results has emerged from either the technique of accessory stimulation or the study of the blind. On the other hand, the deprivation procedure, employing durations of a week, has not only provided consistent results but also demonstrated intersensory facilitatory effects which are present in all, or almost all, experimental subjects. The purpose of this thesis, therefore, is to increase our knowledge of sensory interaction by determining the effects of prolonged visual deprivation on some measures of auditory and tactual sensitivity which were not employed in the earlier Manitoba studies. Both absolute and differential measures of auditory localization, as well as measures of absolute pressure sensitivity and tactual localization will be used. The employment of these additional measures will provide some valuable information as to how general or specific the intersensory effects are in the auditory and skin modalities.

CHAPTER II

EXPERIMENTAL METHOD

I. Subjects

The subjects were male university students drawn almost exclusively from the faculty of Arts and Science of the University of Manitoba. The sample consisted of 16 experimental subjects and 15 control subjects, with mean ages of 20.4 and 22.5 years respectively. All subjects were volunteers who received financial remuneration for participating in this experiment.

II. Deprivation Procedure

The experimental subjects, each wearing a black cloth mask, were placed in groups of two in a dimly illuminated room which was equipped with two spring filled mattresses and a radio. The black masks were never removed during the experimental period of seven days. Apart from the condition of constant darkness, the subjects' environment was relatively normal. No tactile, auditory, or motor restrictions were placed on the subjects. The radio was regularly in use. All 16 subjects successfully endured the week of darkness but one subject was rejected because he violated the conditions of the experiment.

III. Auditory and Tactual Measures

Two auditory (absolute and differential localization) and two tactual measures (point localization and pressure sensitivity) were administered before and at the end of one week of visual deprivation and subsequently at intervals of 1, 2, and 5 days after the termination of the experimental condition. A practise session, for purposes of test familiarization and exclusion of any subject with possible sensory deficiencies, was given a day prior to the experiment. Further details of the test procedure are presented below. A copy of the standard set of instructions, administered to all of the subjects, is given in Appendix A.

Absolute Auditory Localization. Auditory localization was measured by means of a sound cage (Marietta Apparatus Company, Catalogue No. 16-1) which consisted of a movable sound boom arranged so as to permit the sound source to be moved in a 90 degree arc. The essential components of this apparatus were: 1) a drafting chair with an adjustable head rest; 2) a rotating ball-bearing unit having an extension to one side which supported the vertical post carrying a degree scale and pivot for the speaker arm; 3) a scale calibrated in degrees positioned under and behind the seat; and 4) a high quality miniature speaker, attached to a movable arm, which produced a low volume click when a button was pressed. The apparatus was placed in the center of a 10 by 15 ft. room containing a rug and sound absorbing material on the walls and ceiling. The subject, seated in the chair and wearing a black mask, was required to keep his head in the same position throughout the test and his eyes directed straight ahead (Goldstein & Rosenthal, 1926). The speaker, attached to a movable arm and placed at the level of the subject's ears, could be moved in a horizontal plane throughout a 90 degree arc from directly in front of the subject to opposite his right ear.

The method of average error was used to measure the subject's ability to localize a sound at 30 degrees and 60 degrees to the right of center in a horizontal plane in front of the subject. The error was the difference in degrees between the location of the sound source and the location of the subject's index finger which he used to point out the direction of the sound by holding it out at arms length at a point approximately an inch below where he estimated the speaker to be. Ten trials were administered of which four were 30 degrees to the right of center, four were 60 degrees to the right of center, and two were at center to prevent the subjects from realizing that only two positions were being tested. The trials were arranged so that the same location was never tested twice in a row and the choice of which stimulus was to be presented first on a test day was decided on a random basis.

Differential Auditory Localization. The sound cage, described in the previous section, was also used to measure differential auditory localization. The method of limits was employed to measure the just perceptible difference in location of the auditory stimulus when the standard was placed at either 30 degrees or 60 degrees to the right of center. Each judgment resulted from two clicks, separated by three seconds. The first was the standard, placed at either 30 or 60 degrees to the right of center, and the second was the comparison stimulus to be judged as either in the "same" place or to the "right" of the first. Two blocks of trials were administered, first the 30 degree determinations which were followed by a five minute rest period, and then the 60 degree determinations. Each block consisted of five descending (one of which was for practise purposes) and four ascending determinations. Beginning well above (descending) or well below (ascending) the expected just perceptible difference, the angular distance between the standard and comparison stimulus was made either smaller or larger in steps of one degree. The setting recorded was the first time the subject said "right" in the ascending series and the last time the subject said "right" in the descending series. Check trials were used in which the two clicks were presented at the standard position in the descending series and far above the subject's just perceptible difference point in the ascending series.

Absolute Pressure Sensitivity. The absolute pressure sensitivity of the skin was determined for five different areas of the body viz., middle of index finger, palm, volar surface of the forearm, back of the neck, and front of the leg below the knee. Sensitivity to pressure was determined by the Semmes-Weinstein Pressure Aesthesiometer (Shaw Laboratories, Inc., New York, N.Y.) which consists of a series of 20 nylon monofilaments, 38 mm. in length and ranging in diameter from .06 to 1.14 mm. Each filament is embedded at one end in a plastic rod handle. The series of filaments were calibrated, by the manufacturer, by pressing the tip of each filament on a chemical balance and determining the force required to bend it maximally. This procedure resulted in a scale of stimuli with roughly equal intervals. The logarithm of the force was used in the computation of the thresholds.

The procedure used was similar to that employed by Semmes et al. (1960) with one modification viz., the employment of a mechanical rather than a manual presentation of the stimuli. The filaments were placed in a metal arm which was lowered automatically toward the skin, at a constant speed, until the filament was bent maximally. The mechanical arm was subsequently withdrawn, again at a constant speed. Each filament was applied for approximately three seconds with intervals of 15 to 20 seconds between individual applications. The method of limits was employed to determine the thresholds. The filaments were applied in serial order, starting from different points below and above the expected threshold. With the exception of the back of the neck which received eight determinations, four determinations were made for each area, two in descending and two in ascending order (DADA). A record was made of the first filament perceived in each ascending determination, and of the last filament perceived in each descending determination. All measures, except those on the back of the neck, were taken while the subject was blindfolded, and lying on his back on a spring filled mattress. While measuring the sensitivity of the neck the subject was lying on his stomach. Prior to testing, all areas with hair were shaven. The order of testing was as follows: left finger, left palm, left arm, neck, right finger, right palm, right arm, left leg, and right leg. A five minute rest period was given following the second, sixth, and the seventh area measured. In analyzing the data, the results for the same area on opposite sides of the body were combined (e.g., right and left finger combined).

Tactual Localization. The error of localization of a single point (point of an aesthesiometer) applied to the volar surface of each forearm was determined for the longitudinal direction. The subject was seated, blindfolded, with his arm on a pad while five points, each five millimeters apart, were marked lengthwise down the center of his forearm. Each of the five points was stimulated twice in a random order with the single point of a two-point aesthesiometer. The stimulus remained on the skin for approximately one second, after which the subject, using the tip of a sharpened pencil, indicated the apparent location of the stimulus. The measure recorded was the distance, measured in millimeters with a flexible plastic ruler, from the point stimulated to the tip of the subject's pencil. In all cases the right arm was tested first, followed after a one minute rest period, by the left arm.

The various measures were always presented in the following order viz., absolute pressure sensitivity, differential auditory localization, absolute auditory localization, and tactual localization. There was a five minute rest period between each measure. Fifteen control subjects, drawn from the same population but unmatched with the experimental subjects, were given the same tactual and auditory measures and at the same time intervals.

CHAPTER III

EXPERIMENTAL FINDINGS AND DISCUSSION OF RESULTS

I. Results

Two-tailed t-tests for independent measures were carried out on the pre-post difference scores of the experimental and control subjects. In addition, trend analyses were performed in certain cases where the t-tests revealed no significant changes.

Figures 1 - 5 summarize the results on absolute pressure sensitivity for the five different areas of the skin surface. It can be seen that on all skin areas the experimental subjects showed heightened sensitivity to pressure immediately after the week of visual deprivation. However, not all of the differences were found to be statistically significant.

The sensitivity to pressure on the forearm (Figure 1), following a week of darkness, was increased significantly ($p < .002$), an effect which was still present five days after termination of visual deprivation ($p < .02$). Changes in pressure sensitivity on the back of the neck (Figure 2) followed the same pattern as the forearm. The difference between the conditions was significant immediately after a week of darkness, and on "post day 1" and "post day 5" (p's $< .05$). The t-test analyses of the "pre-post" differences in pressure sensitivity of the finger (Figure 3) indicated that, although the difference was not significant immediately after the week of visual deprivation, it was significant on "post day 1" and "post day 2" (p's $< .01$). A trend analysis showed that the difference in slope of the curves of the two groups was statistically significant ($p < .01$), thus indicating a reliable increase in sensitivity. Figure 4 shows the results on the palm. Although an increase in pressure sensitivity can be seen (increased in 11 of the 15 experimental subjects) neither the t-test nor the trend analysis revealed any significant changes. Finally, in Figure 5 it can be seen that the experimental subjects show an increase in sensitivity of the leg, relative to the controls, immediately after the week of visual deprivation. Although a t-test analysis of the "pre-post" differences failed to yield significant results, a trend analysis indicated that the difference in slope of the curves of the two groups was statistically significant ($p < .05$). Further evidence in support of the results of the trend analysis is indicated by the fact that 12 out of 15 experimental and only six of the controls showed an increased sensitivity of the leg at the end of the one week period.

The experimental subjects, after a week of visual deprivation, showed no significant differences in tactual localization relative to that of the controls. As can be seen in Figure 6, both groups show an almost identical pattern of temporal changes.

Figures 7 - 10 summarize the results on auditory localization. The experimental subjects, after a week of darkness, showed no significant changes in absolute auditory localization at either 30 degrees (Figure 7) or 60 degrees (Figure 8) relative to that of the controls. Although the t-test on "pre-post" differences was not significant, Figures 7 and 8 seem to suggest that the experimental subjects are more accurate in auditory localization than are the controls, after the seven day period.

In the analysis of the data on differential auditory localization,

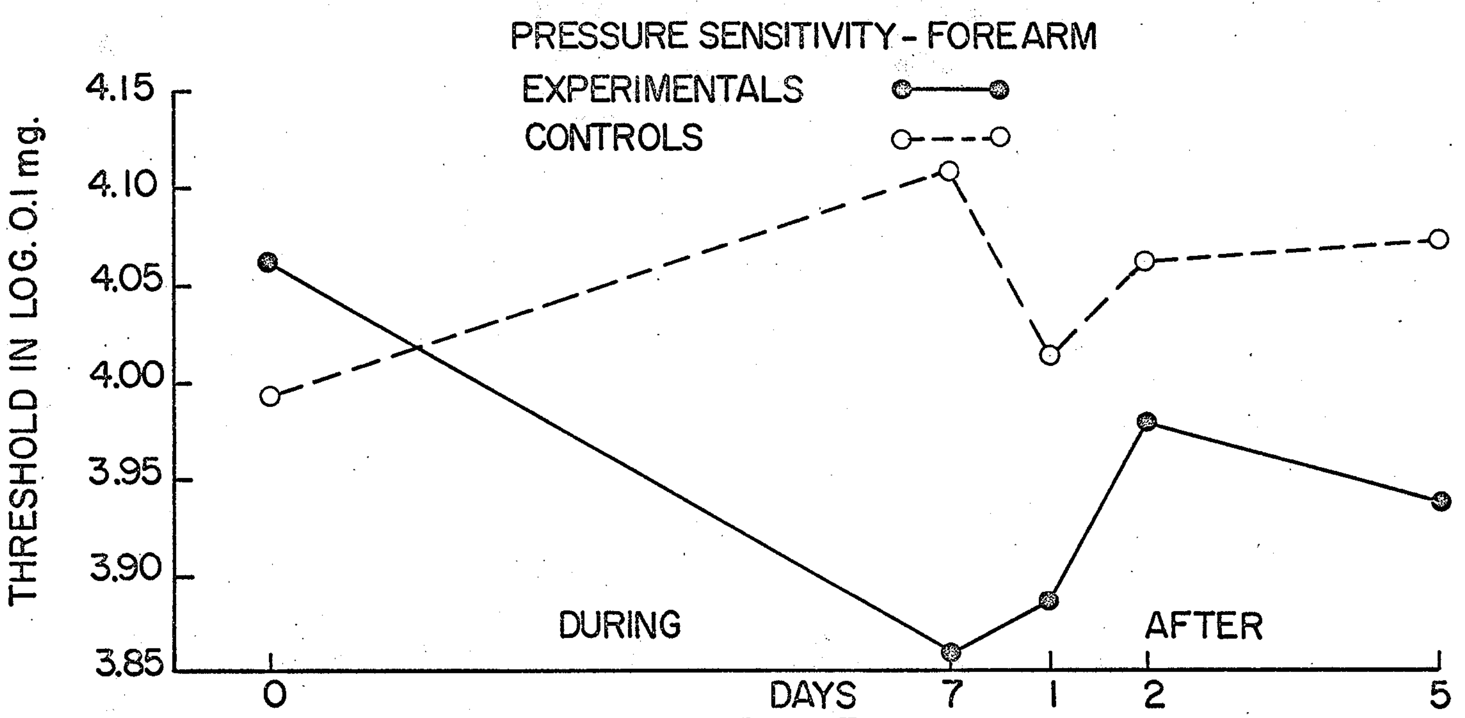

FIGURE 1

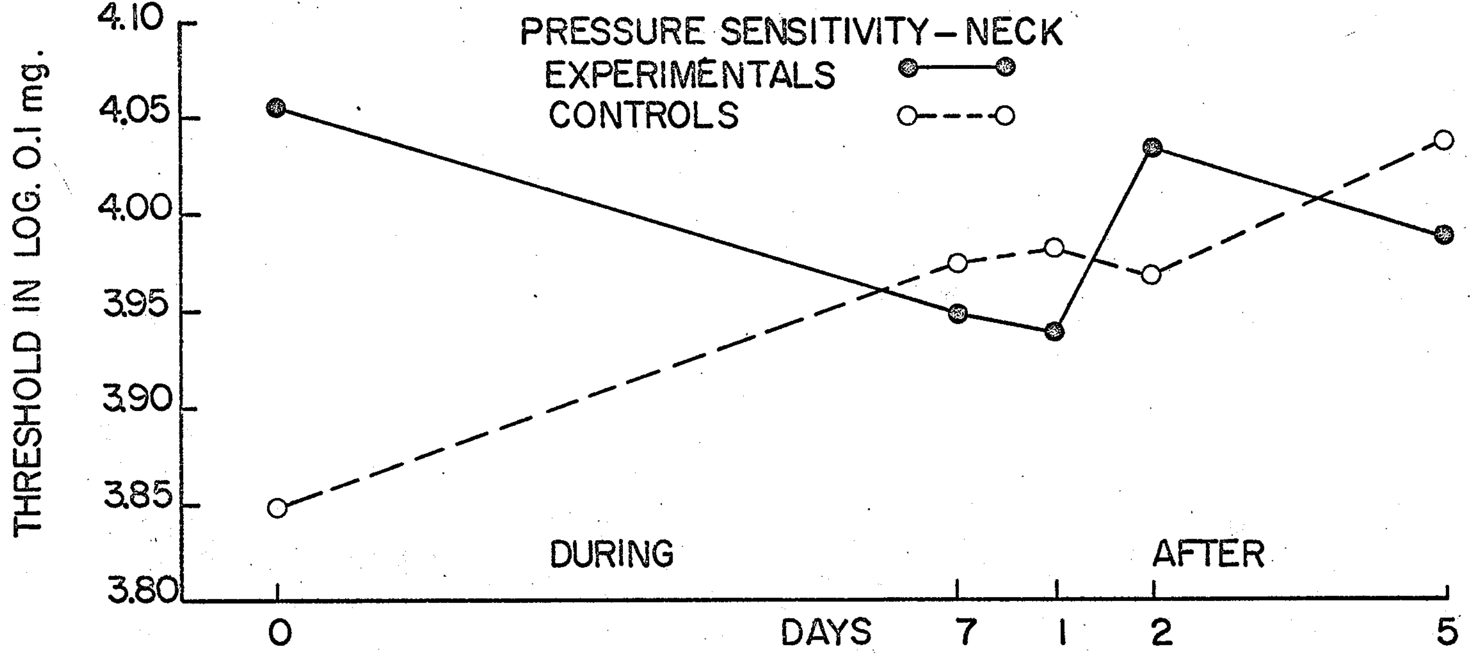

FIGURE 2

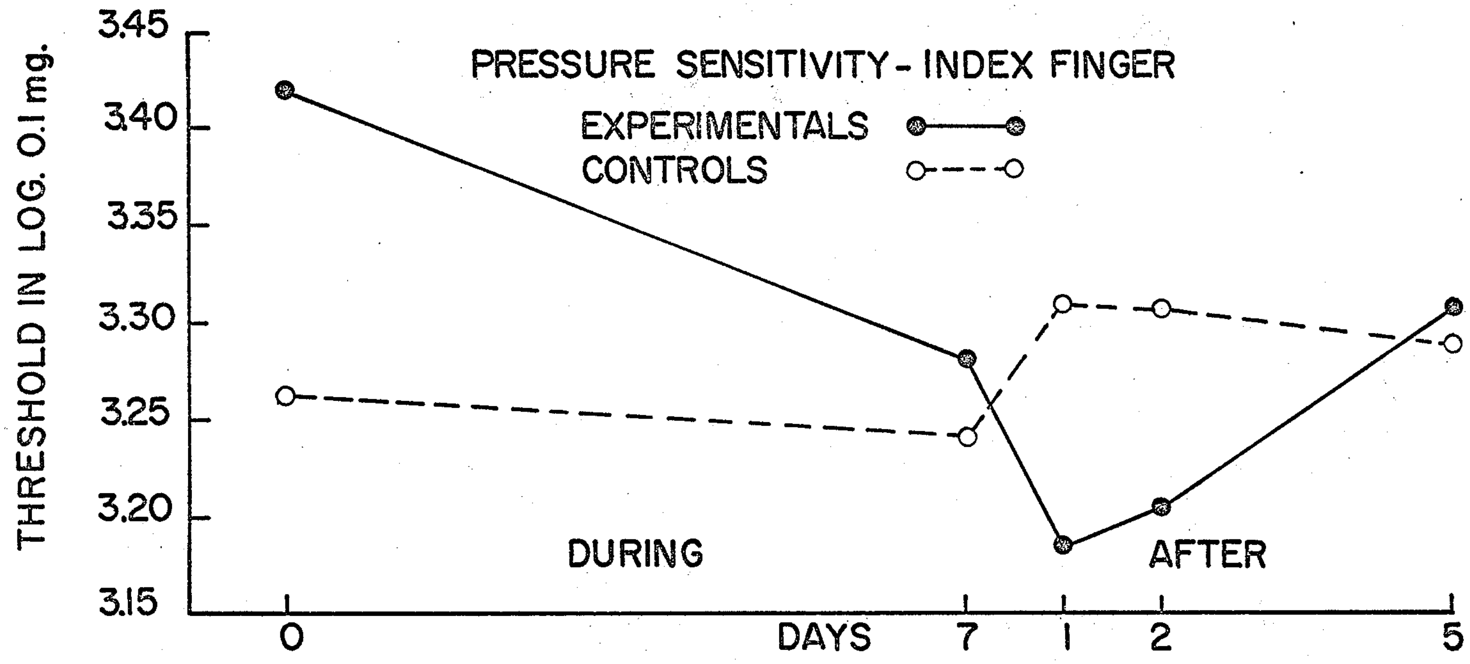

FIGURE 3

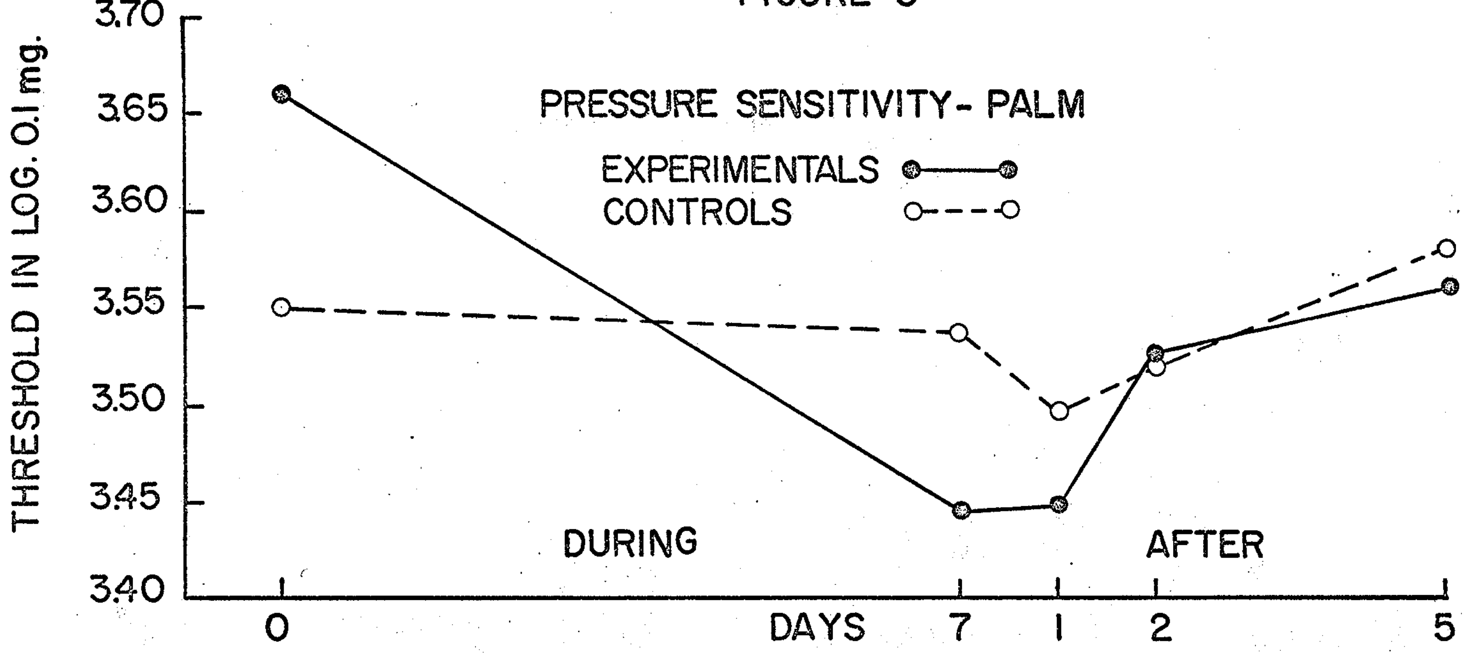

FIGURE 4

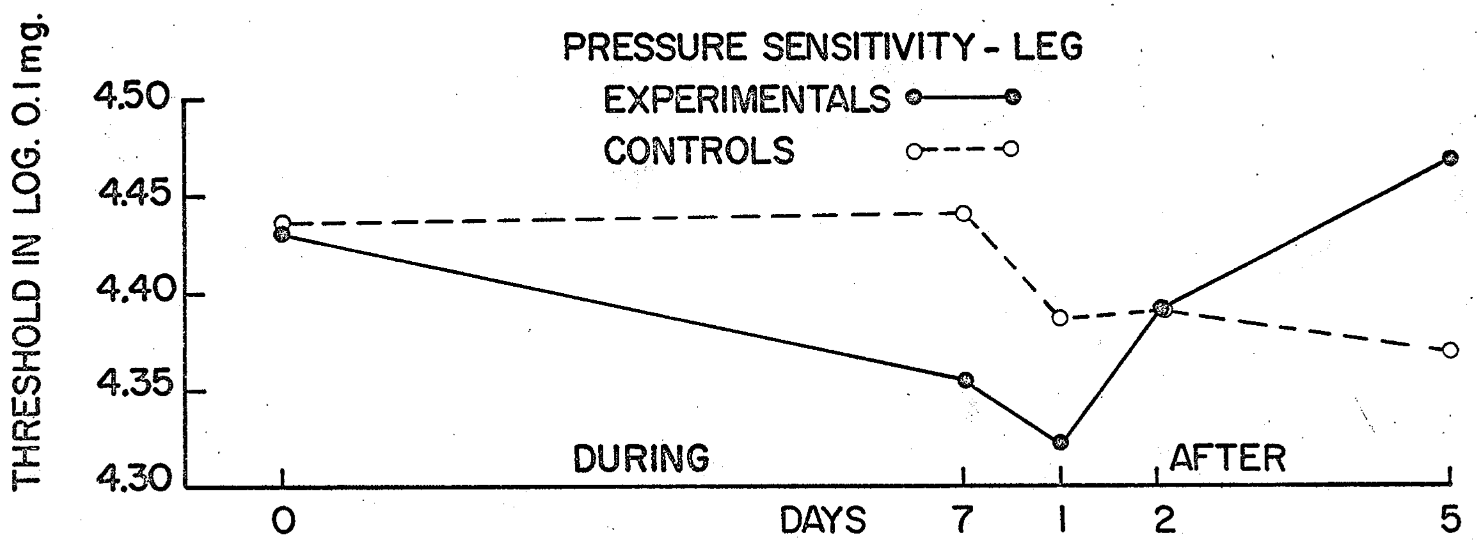

FIGURE 5

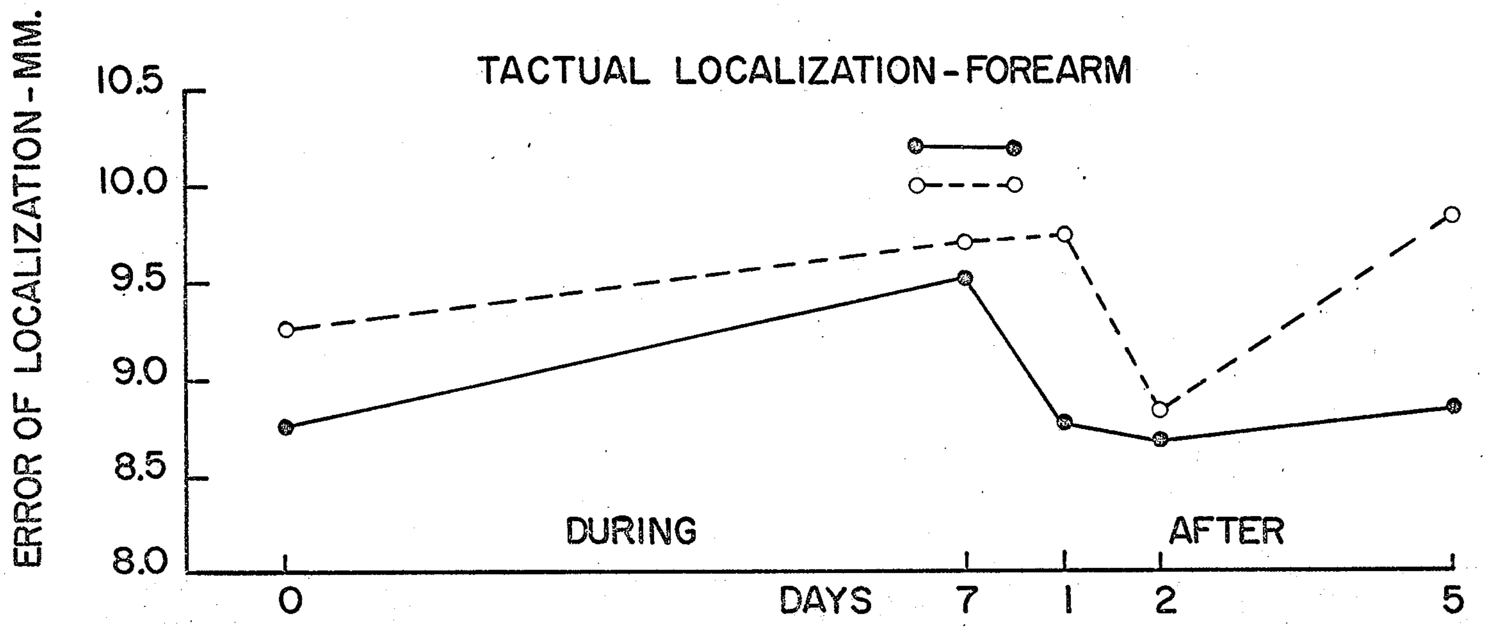

FIGURE 6

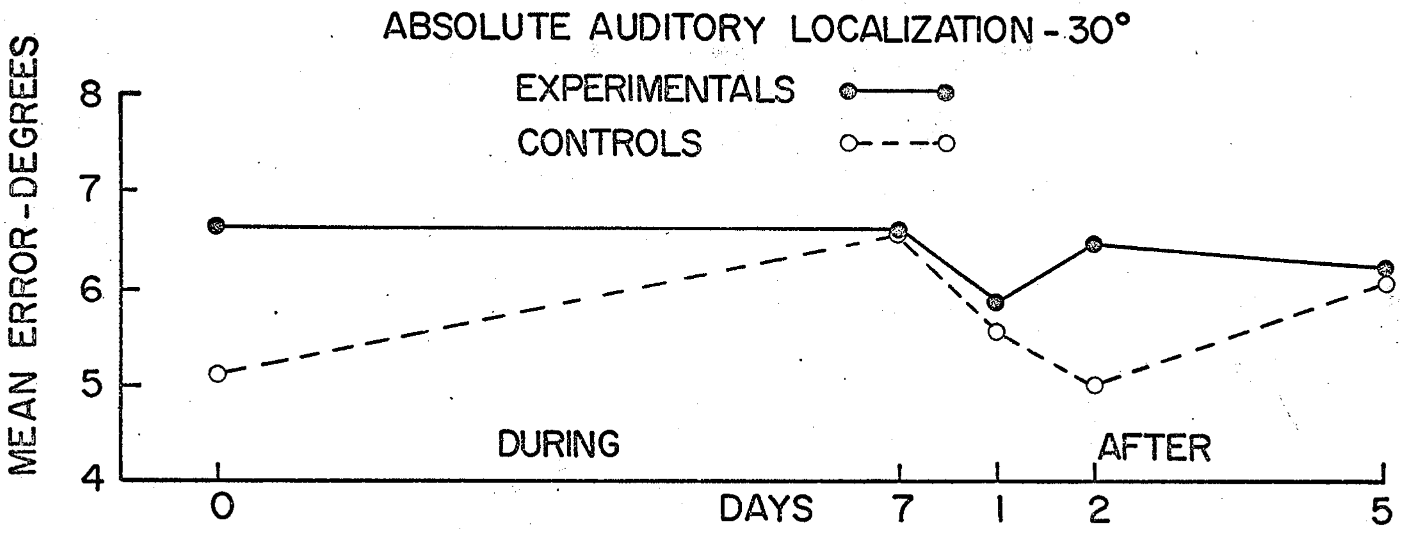

FIGURE 7

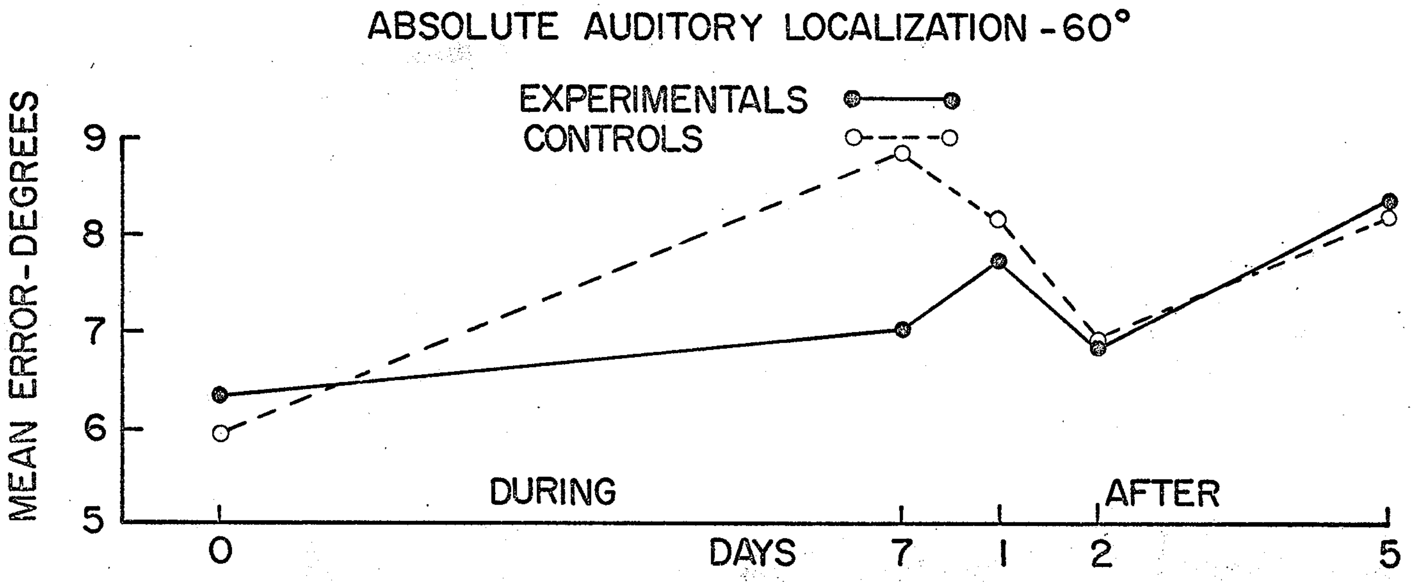

FIGURE 8

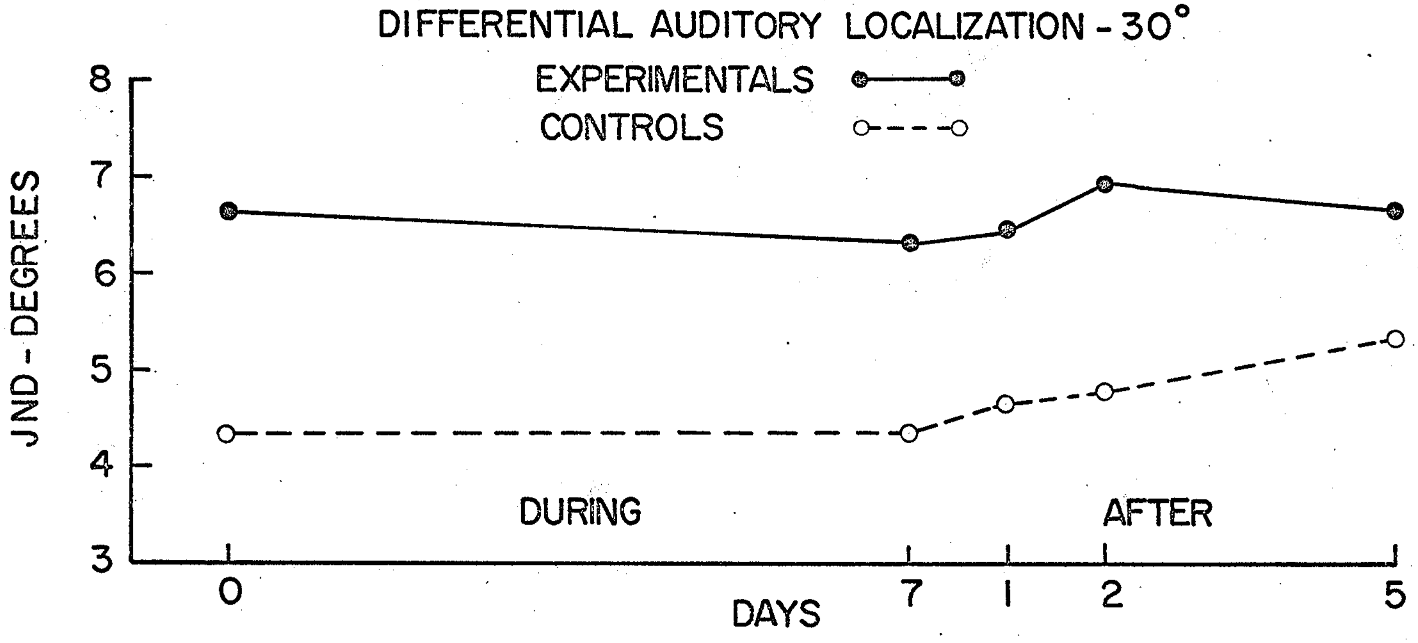

FIGURE 9

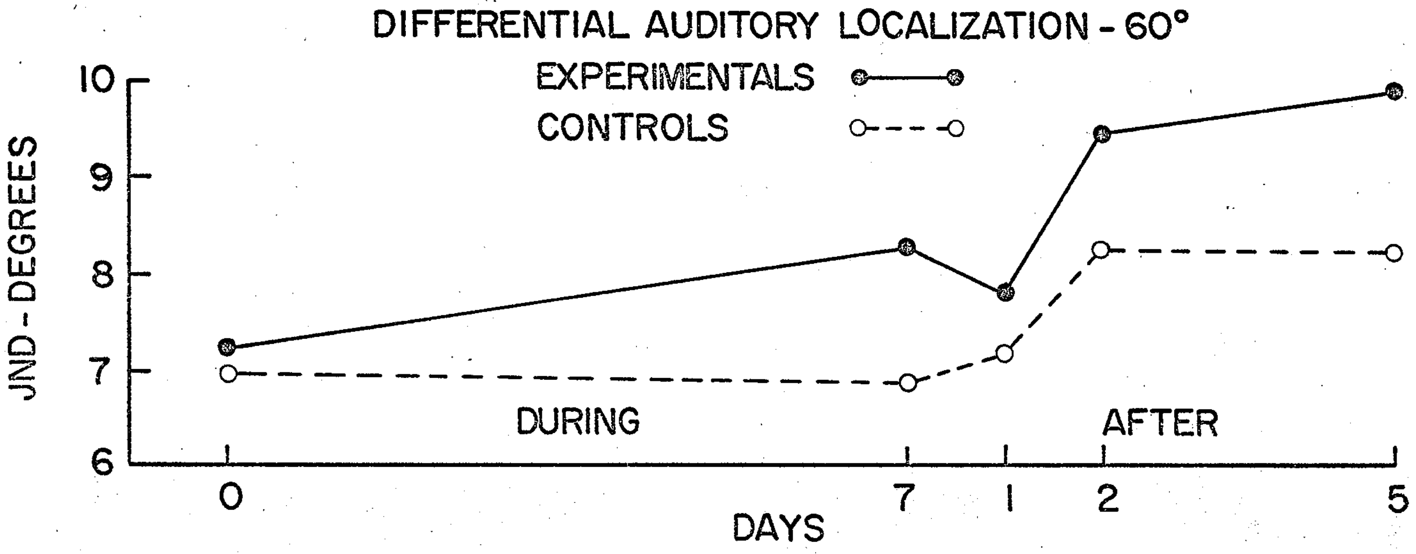

FIGURE 10

a transformation of the scores into logarithms was necessary in order to make the variances for the control group and the experimental group homogeneous. The results revealed that, after a week of visual deprivation, the experimental subjects showed no significant change in differential auditory localization relative to that of the controls. This negative finding occurred for both the 30 degree (Figure 9) and 60 degree (Figure 10) auditory discriminations. As can be seen in Figures 9 and 10, both the experimental and control groups show an almost identical pattern of temporal changes.

II. Discussion of Results

The results of this experiment have indicated that prolonged visual deprivation can produce a significant increase in pressure sensitivity of the finger, forearm, neck, and leg, with the after-effects persisting for several days after the restoration of normal visual stimulation. A trend toward increased sensitivity of the palm was also observed but the change was not statistically significant. Essentially similar results, derived from other cutaneous measures, have been demonstrated at the University of Manitoba laboratory. Zubek et al. (1964), for example, reported that a week of darkness produced not only a pronounced increase in heat and pain sensitivity of the forearm but also an increase in tactual acuity of the index finger, palm, and forearm. Furthermore, the effects persisted for a number of days after the termination of the experiment. Unfortunately, no measures of heat and pain sensitivity of the palm and finger were taken nor was an appraisal made of the cutaneous sensitivity of the leg and neck.

In view of this general increase in cutaneous sensitivity, as indicated by a variety of measures, it is surprising that tactual localization did not show a significant improvement or even a trend toward improvement. One possible explanation of these negative results may be that tactual localization is much more dependent on practise and learning than are the other cutaneous measures which have been employed. Halnan and Wright (1960), in a study exploring both the objective and subjective aspects of tactual localization, stated that "tactile localization in its finer forms is largely a complex, acquired skill." Therefore an increase in cutaneous sensitivity may aid an individual in developing this skill but without reinforced practise at localization no improvement might be expected.

The demonstration of an increase in pressure sensitivity of the finger, forearm, neck, and leg but no change on the palm is puzzling particularly since Zubek et al. (1964) have reported a significant increase in tactual acuity of the palm. Two methodological variables may account for these differential results. First, no attempt was made to match the initial, pre-experimental sensitivity of the visually deprived and control subjects as was done by Zubek et al. (1964). If this had been done, the trend toward improved pressure sensitivity of the palm might have been statistically significant. The possible importance of this variable was recently noted by Zubek (in press) who observed a relationship between the level of initial cutaneous sensitivity and the magnitude of the improvement in tactual acuity resulting from a week of tactual deprivation of a circumscribed area of the skin. Schutte and Zubek (in press) have also reported that the presence or absence of an improvement in gustatory sensitivity, after visual deprivation, was related to the initial, pre-experimental concentrations of the four taste solutions. In this study, quinine and HCl, which subjects can normally detect at very low concentrations, produced non-significant results, whereas NaCl and sucrose, to which subjects are much less sensitive, produced a significant increase in sensitivity. In view of these two sets of results, particular attention must be paid in future research to the initial level of sensitivity shown by subjects prior to experimental treatment.

The second methodological variable which may account for these differential results on pressure sensitivity pertains to the time of test administration. In both this experiment and in the earlier ones conducted at the University of Manitoba, the sensory measurements were taken before and after a week of visual deprivation; none were taken during the one week period. In view of this, it is possible that a significant increase in sensitivity of the palm may have occurred if the measure had been administered some time prior to the termination of the experiment. Some evidence for the importance of the time of test administration has been provided by Doane et al. (1959) who observed a greater increase in tactual acuity after two days than after three days of perceptual deprivation (unpatterned light and constant noise). Vernon et al. (1961) also reported that two days of sensory deprivation (darkness and silence) produced a greater deficit than did three days on color perception, mirror drawing, and on a rotary-pursuit task. Since in both of these studies a recovery of function, with increasing durations, is indicated it is possible that a significant increase in sensitivity might have been demonstrated in the present experiment if the measure had been taken after one or two days rather than at the end of the one week period when most of the effect on the palm may have dissipated.

In view of the importance of the time of test administration, it is clear that future research in this area should be directed at the temporal course of sensory changes occurring at various intervals of a prolonged duration. If this were to be done, it is possible that the pressure sensitivity of the various skin areas might exhibit a differential pattern of temporal gradients with some skin areas showing peak sensitivity much earlier than others. Furthermore, this type of research would be important not only in determining the minimum duration of visual deprivation required to produce these intersensory facilitatory effects but also in helping to reconcile some of the apparently contradictory results derived from long-term and short-term deprivation studies (described in historical section).

The results on the two auditory measures indicated that visual deprivation had no significant effect on either absolute or differential auditory localization, a finding similar to that obtained for tactual localization. There was, however, a slight tendency for the visually deprived subjects to be somewhat more accurate in absolute auditory localization than the controls. No such trend was evident for differential auditory localization. One possible explanation of these negative results may be because the tests were administered at the end of the one week period when most of the effects may have dissipated as a result of the adaptation of the subject to visual deprivation. If they had been administered earlier, a significant improvement may have been demonstrated particularly for absolute auditory localization which showed a definite trend. Although this remains a distinct possibility, the negative results probably can be attributed to the fact that these two auditory measures, like tactual localization, are strongly dependent on practise and learning. The importance of practise in auditory localization has been clearly demonstrated in three separate studies. Held (1955), for example, showed that experience in localizing a sound from a changed axis resulted in ability to change the point of localization by ten degrees in one hour. This indicates that an individual is constantly checking his apparent localization against the real source of sound. Elfner and Carlson (1965) also demonstrated a change in lateralization, regardless of the frequency of the auditory stimulus, as a result of several hours experience with a hearing aid to one ear only, causing a binaural intensity imbalance. This occurred even though no differences in the sensitivity of the ears resulted from this experience for three of the frequencies employed. Finally, in a study on teaching the blind to localize objects by auditory means in an outdoors setting, Worchel and Mauney (1951) found that practise resulted in a very significant improvement in auditory localization.

Since the practise variable may be the main factor in accounting for these negative results, it might be fruitful, in future research, to employ a variety of other auditory measures which are only minimally dependent upon practise and learning, for example, frequency and intensity discrimination. The use of such measures may produce significant changes particularly since Duda and Zubek (1965) reported a significant improvement in auditory discrimination as measured by an auditory flutter technique. If this was to be done, the research might indicate that visual deprivation can produce auditory facilitatory effects of a much more general nature than appears to be the case at present.

Since the present experiment can be considered to involve an environmental or laboratory production of "blindness," although of a temporary nature, one might expect some degree of correspondence between the results of this study and those derived from the studies of the blind. Although no data are available on tactual localization in the blind, the results on pressure sensitivity are similar in nature. For example, Axelrod (1959) demonstrated that blind boys were more sensitive to pressure on the ring finger of the preferred hand than sighted boys. Stratton (1903) and Krogius (1907) also found that blind subjects were superior to the sighted in sensitivity to pressure.

The results on auditory localization, unfortunately, show no such correspondence. Supporting the present findings, both Griesbach (1899) and Fisher (1964) observed no differences between blind and sighted subjects in auditory localization. On the other hand, contrary results were obtained by Seashore and Ling (1918) who reported that the blind were superior in auditory localization. Krogius (1905, 1907) also observed a superiority of the blind on two different measures of auditory localization. This lack of correspondence is perhaps not too surprising in view of the many methodological differences between these two approaches to sensory interaction. Furthermore, the studies of the blind are, in general, characterized by insufficient control over a host of confounding variables such as sex, age of subjects, duration, degree, and causes of blindness, etc., which make the results difficult to interpret.

In conclusion, some consideration will be given to the possible neural mechanism or mechanisms which may account for not only the increase in pressure sensitivity but also for the other sensory facilitatory effects which are known to occur after a prolonged period of visual deprivation. Three lines of evidence suggest that these intersensory effects are probably mediated by the reticular activating system (RAS). First, this neural system receives afferent impulses from various sensory sources via collaterals of ascending tract fibers and transmits them diffusely to various regions of the cerebral cortex, including the primary sensory areas. Thus, a mechanism for intersensory effects is present. Second, an improvement in sensory discrimination can occur following electrical stimulation of the RAS. For example, Fuster (1958) has shown that stimulation of the brain-stem reticular formation of monkeys, while they were engaged in the performance of visual discrimination tasks, increased their speed of reaction, improved their discriminatory accuracy, and lowered their tachistoscopic threshold of recognition (i.e., they were more sensitive). Lindsley (1961) has also reported that stimulation of the RAS "improved the resolving power of efficiency" in the visual cortex to two brief flashes of light. Third, Chang (1952) has shown that continuous retinal illumination can enhance the cortical response to electrical stimulation of the auditory system (medial geniculate body) of cats. Since this phenomenon was only partially reduced by excision of the visual cortex, Chang (1959) concluded that the RAS was the logical mediator for this intersensory facilitatory effect.

Recently, Schultz (1965) has incorporated much of the research on the RAS in the formulation of a sensoristatic theory of the nervous system, a theory which appears to account for most of the intersensory facilitatory effects. According to Schultz, sensoristasis is a condition in which the organism strives to maintain an optimal range of sensory variation, a range which is capable of changing to some degree as a function of several variables. The monitor serving to maintain the sensoristatic balance is the RAS which Lindsley (1961) conceives of as serving as a type of "homeostat" or regulator adjusting "input-output" relations. One of the predictions which Schultz derives from his theory is that "when stimulus variation is restricted, central regulation of threshold sensitivities will function to lower sensory thresholds. Thus, the organism becomes increasingly sensitized to stimulation in an attempt to restore the balance" (p. 32). The demonstration of an increase in pressure sensitivity together with increases in tactual acuity, pain sensitivity, auditory discrimination, and olfactory and gustatory sensitivity, reported in earlier studies from the Manitoba laboratory, appear to provide experimental support for this theoretical prediction. Furthermore, according to this theory, an improvement in tactual and auditory localization would not be expected since these performance measures largely involve learning rather than threshold determination of sensitivity.

This sensoristatic theory possesses the virtue of not only accounting for intersensory facilitatory effects but also of generating hypotheses for future research. For example, it would predict that auditory deprivation alone should also produce lower thresholds in the non-auditory modalities. An experimental test of this and other predictions will shortly be undertaken at the Manitoba laboratory.

CHAPTER IV

SUMMARY AND CONCLUSIONS

A series of four studies performed recently at the University of Manitoba have reported a significant improvement on several measures of tactual, auditory, gustatory, and olfactory sensitivity after a week of visual deprivation. This increased sensitivity generally lasted for several days after termination of the experimental condition. The purpose of the present study was to employ a variety of additional cutaneous and auditory measures in order to determine how general or limited these facilitatory effects may be.

Fifteen male university students were placed in a small room for seven days. Black masks were worn throughout the prescribed period. No other restrictions, either of an auditory, tactual-kinesthetic, or social nature were imposed. Measures of auditory localization (absolute and differential), tactile localization and sensitivity to pressure on five skin areas were taken before and after a week of darkness, as well as at intervals of one, two, and five days following termination of visual deprivation. Fifteen male control subjects, unmatched with, but drawn from the same population as the experimental subjects, were tested at the same time intervals but under a condition of normal visual stimulation.

The results indicated that prolonged visual deprivation can produce a significant increase in pressure sensitivity of the finger, forearm, neck, and leg, with the after-effects persisting for several days after restoration of normal visual stimulation. A trend toward increased sensitivity of the palm was also observed but the change was not statistically significant. The negative results on the palm may have occurred because the experimental and control subjects were not matched on the basis of their initial, pre-experimental level of sensitivity. Another possible explanation is related to the time of test administration. A significant improvement may have occurred if the measure had been taken early in the deprivation period rather than at the end of seven days when the subjects may have adapted to the impoverished environment. Measures of tactual and auditory localization, on the other hand, showed no significant changes after visual deprivation, a finding which may be related to the strong dependence of these measures on practise and learning.

Several conclusions may be drawn from these results. First, although prolonged visual deprivation appears to be followed by a general increase in cutaneous sensitivity, this does not appear to be true of auditory sensitivity. Further studies, employing a variety of auditory measures which are only minimally dependent upon practise and learning, are required. Also, in view of the differential results found on pressure sensitivity, a study of the temporal course of sensory changes during visual deprivation would be useful.

Second, the method of single modality deprivation appears to be a more satisfactory method of studying intersensory effects than either the accessory sensory stimulus technique or the method employing blind subjects.

The increase in pressure sensitivity following prolonged visual deprivation has also been reported in the studies on the blind. No such similarity, however, is evident on auditory measures. This lack of correspondence is not surprising in view of the large methodological differences in the two techniques and the insufficient control of confounding variables in the blind studies.

The results of this study and of the earlier Manitoba studies on intersensory effects provide some experimental support for Schultz's (1965) sensoristatic theory of the nervous system.

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APPENDIX A

APPENDIX A - TEST INSTRUCTIONS

Absolute Auditory Localization

"In this test I will place the speaker in a certain position and when it clicks I want you to point in the direction of the click in such a way that your index finger is about one inch under the speaker. For instance, if it clicks in this position, you would raise your hand and place your index finger there (demonstrate using the subject's hand). That's right, now try this one (example). Now put the mask on and let us begin. Be sure to keep your eyes open and look ahead at all times."

Differential Auditory Localization

"Sit down in this chair and place your head against the head holder. I will adjust it so that it is right behind your ears. This is a speaker that may be moved around your head like this (demonstrate). When I press this button you will hear a click (demonstrate). In this test you will hear two clicks. The first one will always be at this position (demonstrate) which is 30° to the right of center. The second click, which follows the first by about three seconds, will be either in the same place or to the right. If both clicks are in the same place say "same" but if the second click is to the right say "right". Only say "right" when the second click is clearly to the right of the first click. If you are in doubt say "same". The click you hear may sound slightly different each time you hear it. Do not say the sound is to the right just because the second sound is different from the first. Make sure that you are responding according to the position of the sound and not the changes in the sound itself. I want you to keep your eyes open and to look straight ahead even though you are wearing a mask. Now put the mask on and let us begin.

This time the procedure will be the same but we will use a different position. The first click will always be in this position (demonstrate) which is 60° to the right of center. If the second click is in the same place or if you are not sure say "same." If the second click is clearly to the right say "right." Now put on your mask and let us begin."

Absolute Pressure Sensitivity

"I am going to touch you with these hairs. When you feel pressure at the spot I am testing say "now." Only say "now" when the pressure is clear, i.e., when you are sure that you have been touched. If there is any doubt as to whether or not you felt pressure, do not say anything. As we proceed with this test I am going to shave a small patch of hair from each arm, each leg, and the back of your neck. I want you to lie down on the mattress for this test and to put on the blindfold.

Let us start with the index finger of your left hand.

Now we will do your left palm.

Now your left arm.

Now, will you turn over and lie on your stomach so that we may do your neck.

Now let us do your right index finger.

Now your right palm.

Now we will do your left leg.

Now will you move your right leg closer to me and then we will do your right leg."

Tactual Localization

"I am going to touch your forearm with the tip of this instrument. After you are touched I want you to find the spot and to place the tip of this pencil on it. Now put the blindfold on and we will start this test."

APPENDIX B

APPENDIX B - RAW DATA

Mean scores on pressure sensitivity of the arm in log. 0.1 mg.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	3.985	3.963	4.091	4.125	4.066
2	4.043	4.080	4.061	4.553	4.313
3	4.396	3.571	3.776	3.931	3.818
4	4.061	3.913	4.091	4.014	4.114
5	3.971	4.114	3.930	4.030	3.826
6	4.215	4.071	3.764	4.030	3.903
7	4.309	3.941	4.076	3.865	3.805
8	3.813	3.718	3.785	3.914	3.866
9	3.884	3.804	3.754	3.824	3.925
10	4.203	3.990	3.764	3.894	3.995
11	4.340	3.854	4.013	4.114	3.911
12	3.813	3.765	3.628	3.783	3.864
13	3.676	3.376	3.815	3.656	3.791
14	4.143	3.971	3.994	4.030	3.971
15	4.090	3.756	3.746	3.926	3.884
Mean	4.063	3.859	3.886	3.979	3.938

Control Group

Subjects	Pre.	Post.	1	2	5
1	4.021	4.103	3.974	4.061	4.091
2	4.080	4.091	4.033	3.943	4.080
3	4.203	4.330	4.526	4.274	4.351
4	4.084	4.060	3.873	4.061	4.074
5	3.736	4.136	3.941	4.061	4.074
6	3.903	3.843	3.648	3.735	3.854
7	3.900	3.941	3.895	3.930	3.843
8	4.468	4.669	4.688	4.665	4.589
9	4.278	4.638	4.488	4.274	4.258
10	4.024	3.941	3.825	4.001	4.073
11	3.541	4.286	3.826	4.214	3.953
12	3.824	3.854	3.783	4.013	4.173
13	3.493	3.825	3.728	3.813	3.854
14	4.101	3.943	4.014	3.843	3.931
15	4.250	3.954	3.955	4.035	3.906
Mean	3.994	4.108	4.013	4.061	4.073

Mean scores on pressure sensitivity of the back of the neck in log. 0.1 mg.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	4.080	4.091	3.874	4.050	4.125
2	4.258	4.143	4.163	4.334	4.474
3	4.476	4.080	3.961	4.080	4.091
4	4.278	4.091	4.073	4.285	4.143
5	4.261	4.435	4.001	4.480	4.369
6	4.386	4.106	4.050	4.253	3.840
7	4.511	4.306	4.163	4.295	4.161
8	3.811	3.960	3.783	3.814	3.678
9	4.053	4.065	3.900	3.925	3.784
10	3.599	3.754	3.676	3.784	3.503
11	3.843	3.813	3.813	3.855	3.825
12	3.931	3.871	3.725	3.725	3.755
13	2.859	3.004	3.840	3.775	3.929
14	4.405	3.941	4.170	3.994	4.278
15	4.074	3.560	3.901	3.853	3.873
Mean	4.055	3.948	3.939	4.033	3.988

Control Group

Subjects	Pre.	Post.	1	2	5
1	4.080	4.080	4.050	3.963	3.974
2	4.080	4.080	4.050	4.103	4.114
3	4.083	4.246	4.131	4.155	4.480
4	4.054	3.811	3.853	3.968	4.036
5	3.813	3.931	3.883	3.968	4.036
6	3.315	3.840	3.734	3.639	3.610
7	3.384	4.020	3.871	3.811	3.778
8	4.095	4.383	4.431	4.435	4.674
9	4.108	3.941	4.123	3.894	3.840
10	3.785	3.619	3.783	3.814	4.013
11	3.678	4.111	4.230	4.300	4.106
12	4.031	3.901	3.843	3.911	3.994
13	3.015	3.668	3.793	3.669	3.911
14	4.071	4.000	3.930	3.913	3.901
15	4.140	3.964	4.011	3.965	4.078
Mean	3.849	3.973	3.981	3.967	4.036

Mean scores on pressure sensitivity of the finger in log. 0.1 mg.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	3.706	3.748	3.915	3.620	3.806
2	3.991	3.786	3.904	3.904	3.991
3	3.366	3.249	2.586	2.684	2.928
4	2.586	2.840	2.928	2.830	3.269
5	3.590	3.123	3.025	2.976	2.819
6	3.811	3.415	3.444	3.668	3.444
7	3.840	3.619	3.696	3.599	3.696
8	3.249	3.025	2.928	2.976	3.171
9	3.200	3.123	2.976	2.859	2.781
10	3.755	3.550	3.269	3.123	3.318
11	2.928	3.025	2.879	3.318	3.318
12	3.054	3.025	2.586	3.074	2.830
13	3.025	3.074	3.269	2.928	3.346
14	3.668	3.464	3.269	3.464	3.541
15	3.521	3.171	3.123	3.074	3.366
Mean	3.419	3.282	3.186	3.206	3.308

Control Group

Subjects	Pre.	Post.	1	2	5
1	3.728	3.590	3.620	3.513	3.728
2	3.571	3.561	3.415	3.318	3.815
3	3.541	3.668	3.639	3.725	3.755
4	2.976	2.928	3.123	3.309	3.290
5	2.830	3.249	2.928	3.309	3.290
6	3.366	3.269	3.639	3.171	2.879
7	2.976	3.025	3.171	3.025	3.074
8	3.561	3.530	3.783	3.609	3.705
9	3.278	3.278	3.375	3.395	3.318
10	2.976	2.733	2.586	2.879	3.074
11	3.424	3.755	3.318	3.464	3.220
12	2.928	2.733	3.269	3.025	3.025
13	3.220	2.830	3.444	3.346	3.123
14	3.346	3.298	3.171	3.171	2.928
15	3.220	3.171	3.171	3.366	3.123
Mean	3.264	3.241	3.310	3.308	3.290

Mean scores on pressure sensitivity of the palm in log. 0.1 mg.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	3.991	3.815	3.884	3.659	3.974
2	3.963	3.581	4.001	4.140	4.050
3	3.800	2.566	2.625	2.879	3.631
4	3.728	3.561	3.484	3.758	3.904
5	3.843	3.844	3.755	3.696	3.813
6	3.871	3.229	3.649	3.818	3.425
7	3.811	3.570	3.530	3.784	3.656
8	2.918	3.084	3.171	3.074	2.928
9	3.074	3.346	3.269	3.444	3.269
10	3.676	3.870	3.444	3.501	3.473
11	3.843	3.766	3.493	3.784	3.541
12	3.686	3.658	3.579	3.395	3.570
13	3.151	2.859	3.376	2.928	3.385
14	3.784	3.318	3.220	3.659	3.366
15	3.756	3.648	3.259	3.375	3.453
Mean	3.660	3.446	3.449	3.526	3.562

Control Group

Subjects	Pre.	Post.	1	2	5
1	3.825	3.815	3.494	3.405	3.845
2	4.050	4.136	4.080	3.904	4.033
3	3.955	3.884	3.814	3.813	3.783
4	3.229	3.269	3.220	3.521	3.580
5	3.123	3.171	3.074	3.521	3.580
6	3.366	3.755	3.668	3.668	3.269
7	3.501	3.131	3.434	3.531	3.171
8	3.705	4.003	3.994	4.070	4.090
9	3.298	3.550	3.629	3.789	3.501
10	3.424	3.171	3.123	2.976	3.151
11	4.084	4.071	3.180	3.241	3.599
12	3.219	3.074	3.366	3.220	3.725
13	2.928	3.464	3.464	3.249	3.326
14	3.756	3.415	3.425	3.424	3.444
15	3.784	3.171	3.493	3.481	3.599
Mean	3.550	3.539	3.497	3.521	3.580

Mean scores on pressure sensitivity of the leg in log. 0.1 mg.

Experimental Group

Subjects	Pre.	Post	1	2	5
1	4.400	4.399	4.101	4.443	4.351
2	4.498	4.598	4.624	4.696	4.589
3	4.505	4.394	4.201	4.418	4.260
4	4.338	4.203	4.386	4.534	4.404
5	4.525	4.655	4.358	4.611	4.801
6	4.856	4.488	4.374	4.525	4.541
7	4.229	4.191	4.449	4.440	4.340
8	4.013	4.201	3.961	3.995	4.171
9	4.449	4.281	4.189	4.341	4.471
10	4.790	4.579	4.320	4.345	4.504
11	4.569	4.449	4.595	4.370	4.429
12	4.269	4.170	4.131	3.930	4.233
13	3.971	3.829	4.219	4.025	4.963
14	4.520	4.480	4.651	4.674	4.626
15	4.540	4.431	4.291	4.504	4.363
Mean	4.431	4.356	4.323	4.390	4.470

Control Group

Subjects	Pre.	Post.	1	2	5
1	4.209	4.383	4.189	4.374	4.340
2	4.211	4.240	4.218	4.148	4.206
3	4.503	4.675	4.566	4.641	4.814
4	4.878	4.643	4.594	4.391	4.370
5	4.494	4.558	4.269	4.391	4.370
6	4.185	4.160	4.083	4.119	4.024
7	4.166	4.023	4.035	4.113	3.931
8	4.793	4.883	5.008	5.121	5.258
9	4.813	5.025	4.923	4.849	4.745
10	4.409	4.418	4.225	4.201	4.190
11	4.421	4.811	4.326	4.539	4.231
12	4.445	4.084	4.221	4.211	4.170
13	4.014	4.070	4.113	4.231	4.236
14	4.440	4.431	4.471	4.299	4.213
15	4.528	4.238	4.576	4.240	4.446
Mean	4.434	4.443	4.388	4.391	4.370

Mean error in tactual localization on the forearm.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	7.60	11.55	6.85	6.40	5.35
2	10.05	11.85	8.65	9.45	9.35
3	10.65	14.60	19.20	12.85	11.90
4	9.20	9.05	6.30	10.20	9.85
5	8.05	6.95	7.90	7.95	6.70
6	9.95	10.65	8.30	7.95	7.90
7	11.75	12.10	9.00	9.70	9.15
8	8.05	7.30	7.80	5.05	7.60
9	5.30	7.80	11.50	9.30	10.10
10	6.15	11.05	5.60	7.35	5.30
11	7.40	6.35	6.55	7.30	8.50
12	8.30	7.80	7.55	9.40	11.45
13	5.65	9.10	8.15	8.25	6.10
14	9.55	7.20	8.95	9.45	9.55
15	13.65	9.75	9.20	9.90	14.05
Mean	8.753	9.540	8.767	8.700	8.857

Control Group

Subjects	Pre.	Post.	1	2	5
1	9.70	6.80	8.05	4.90	6.90
2	9.80	6.50	7.90	8.35	9.10
3	12.80	9.50	7.55	6.70	8.55
4	6.90	6.65	9.95	8.838	9.85
5	11.55	11.45	11.95	8.838	9.85
6	5.85	8.60	8.30	6.00	7.20
7	11.35	15.45	8.10	8.80	13.20
8	7.50	12.55	7.00	12.60	7.00
9	6.40	6.15	7.00	7.60	7.25
10	7.80	11.25	9.10	5.40	7.85
11	1.70	1.60	2.10	2.15	2.60
12	15.20	9.75	18.65	12.50	14.05
13	12.95	11.05	10.10	9.70	14.15
14	9.75	11.35	12.05	8.15	14.35
15	9.30	17.00	18.60	22.05	15.85
Mean	9.270	9.710	9.760	8.838	9.850

Mean error in absolute localization of an auditory stimulus 30° to the right of center.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	7.00	3.50	2.75	4.25	10.25
2	10.00	5.00	11.50	12.50	4.25
3	8.25	4.50	3.25	6.00	2.75
4	2.25	3.75	3.75	9.00	7.25
5	3.50	8.25	5.50	5.75	11.75
6	14.75	9.50	10.50	8.25	7.75
7	8.50	4.75	3.75	2.75	4.00
8	3.25	5.75	4.75	4.00	2.00
9	8.75	6.75	5.25	8.25	4.50
10	5.25	9.00	5.25	7.50	2.00
11	4.50	9.75	3.50	3.50	8.50
12	4.75	4.25	2.75	4.00	5.00
13	5.50	9.75	6.00	4.50	8.75
14	10.00	11.50	15.00	12.25	12.75
15	3.25	3.00	4.50	4.75	1.75
Mean	6.633	6.600	5.867	6.483	6.217

Control Group

Subjects	Pre.	Post.	1	2	5
1	1.75	3.50	4.25	3.75	5.00
2	2.75	10.25	3.75	5.75	4.00
3	5.75	6.75	20.50	12.50	9.25
4	2.75	5.75	3.00	5.00	6.039
5	10.00	10.75	10.00	5.00	6.039
6	3.25	8.25	3.50	4.75	4.25
7	3.00	4.00	2.75	8.50	8.75
8	4.25	3.00	1.50	6.50	13.25
9	7.75	3.00	3.00	1.00	2.75
10	1.25	3.50	3.75	2.25	3.50
11	.50	1.25	1.75	1.50	1.25
12	2.25	5.50	4.50	3.00	3.00
13	14.75	16.75	15.75	9.50	13.50
14	12.50	9.75	4.25	3.00	6.00
15	4.00	6.25	1.50	3.00	4.00
Mean	5.100	6.550	5.583	5.000	6.039

Mean Error in absolute localization of an auditory stimulus 60° to the right of center.

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	5.50	3.25	6.50	8.25	4.75
2	4.50	2.75	5.50	3.75	2.75
3	6.50	6.50	10.25	2.50	6.50
4	6.25	6.50	9.75	11.75	10.50
5	2.00	10.00	9.25	3.50	16.25
6	2.00	6.25	5.00	6.75	9.50
7	26.50	20.75	13.00	16.00	12.25
8	2.50	4.75	3.50	2.50	8.00
9	6.25	3.75	8.00	6.75	7.75
10	2.25	3.75	2.00	3.25	2.75
11	1.75	3.00	4.50	7.00	9.50
12	9.25	19.75	15.00	16.50	7.75
13	3.25	6.50	12.25	8.50	14.75
14	5.00	5.00	6.75	3.25	8.75
15	11.25	2.50	4.50	2.25	3.25
Mean	6.317	7.000	7.717	6.833	8.333

Control Group

Subjects	Pre.	Post.	1	2	5
1	12.25	11.75	12.50	1.00	10.75
2	6.50	11.75	3.25	5.00	7.25
3	1.75	22.25	20.75	24.00	20.25
4	7.50	6.00	9.00	6.904	8.192
5	3.75	4.75	1.50	6.904	8.192
6	2.75	6.00	3.00	2.50	3.00
7	11.50	18.50	10.25	10.00	10.50
8	2.75	2.50	5.25	8.25	10.50
9	3.75	6.00	6.25	4.50	3.00
10	3.50	6.25	6.25	3.25	3.00
11	4.00	6.00	4.50	4.25	4.50
12	6.25	7.25	15.25	7.00	11.75
13	8.75	7.25	7.50	3.50	6.25
14	7.00	4.75	7.25	5.75	10.25
15	7.25	11.50	9.25	10.75	5.50
Mean	5.950	8.833	8.117	6.904	8.192

Mean just noticeable difference in location of an auditory stimulus 30° to the right of center (Differential auditory localization).

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	8.500	11.750	13.250	14.000	16.125
2	16.500	13.625	13.000	11.375	7.375
3	11.500	5.375	8.125	9.375	8.500
4	6.375	8.000	4.125	5.250	4.000
5	5.125	2.750	6.875	4.500	7.375
6	8.250	7.375	9.500	9.000	10.500
7	2.500	4.250	3.750	4.250	4.750
8	2.750	3.875	2.375	4.125	4.625
9	2.625	2.875	3.750	4.250	2.875
10	6.125	5.875	5.875	3.875	4.250
11	2.625	2.250	3.125	3.250	2.875
12	4.125	5.000	3.375	2.375	3.250
13	4.125	4.125	5.500	8.375	6.625
14	10.375	9.875	5.625	10.250	7.000
15	8.250	7.500	8.125	9.750	9.750
Mean	6.650	6.300	6.425	6.933	6.658

Control Group

Subjects	Pre.	Post.	1	2	5
1	3.500	2.500	3.375	3.500	2.625
2	5.125	4.375	5.000	5.125	3.500
3	3.750	5.375	5.250	7.500	8.500
4	4.000	3.375	4.375	4.779	5.317
5	5.250	4.375	4.375	4.779	5.317
6	3.375	4.125	5.625	5.000	5.125
7	5.250	4.000	5.625	6.375	6.125
8	5.750	6.375	5.750	6.125	6.375
9	3.375	4.500	3.875	5.125	6.000
10	5.375	6.000	4.500	6.125	6.625
11	1.875	2.000	1.500	8.250	1.625
12	4.625	3.375	3.125	4.125	4.125
13	4.500	5.250	6.500	5.250	7.500
14	4.500	6.375	5.000	4.250	5.625
15	4.500	2.875	4.875	2.375	5.375
Mean	4.317	4.325	4.650	4.779	5.317

Mean just noticeable differences in location of an auditory stimulus 60° to the right of center (Differential auditory localization).

Experimental Group

Subjects	Pre.	Post.	1	2	5
1	7.375	16.000	17.125	22.375	21.625
2	14.625	10.375	8.625	11.000	9.375
3	10.625	8.875	9.500	14.125	9.500
4	9.000	7.250	3.375	4.375	7.625
5	5.750	7.750	6.000	6.125	7.000
6	10.125	9.125	11.000	13.250	14.250
7	4.250	6.375	5.125	6.875	7.250
8	5.500	4.875	4.375	5.500	4.250
9	1.750	5.500	3.875	3.375	2.000
10	7.125	10.500	10.750	11.625	12.375
11	4.375	4.375	7.000	5.000	6.875
12	3.375	3.875	3.250	5.625	4.875
13	5.500	6.000	7.250	10.625	11.500
14	9.625	13.625	9.375	12.500	15.125
15	9.250	9.625	10.375	9.000	14.750
Mean	7.217	8.275	7.800	9.425	9.892

Control Group

Subjects	Pre.	Post.	1	2	5
1	1.500	4.000	4.625	4.000	4.500
2	5.000	6.250	4.500	5.875	4.500
3	7.625	7.125	7.875	12.125	12.500
4	6.125	4.500	5.250	8.260	8.231
5	7.250	5.750	5.750	8.260	8.231
6	7.250	8.625	7.750	7.875	9.000
7	10.250	6.125	9.125	13.375	10.250
8	14.375	15.375	16.625	13.375	15.125
9	5.500	8.750	4.875	5.750	5.375
10	9.125	11.250	11.250	11.250	14.875
11	2.250	2.125	1.000	1.500	1.500
12	5.125	6.500	5.750	7.000	5.000
13	6.750	4.625	9.375	7.625	6.375
14	9.875	5.375	5.500	9.000	8.250
15	6.750	6.250	8.250	8.625	9.750
Mean	6.983	6.842	7.167	8.260	8.231