AUDITORY SENSITIVITY AFTER PROLONGED VISUAL DEPRIVATION

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ABSTRACT

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Two recent studies at the University of Manitoba have reported the presence of increased cutaneous sensitivity in subjects exposed to a week of visual deprivation. The purpose of this study is to determine whether visual deprivation can produce a similar increase in auditory sensitivity and also to assess the effects on visual sensitivity. Increased sensitivity in both the auditory and cutaneous modalities would strengthen the possibility that a general enhancement of sensory functioning may occur as a result of visual deprivation.

Fifteen male subjects, wearing black masks, were confined in groups of two or three in a small room for a period of seven days. Apart from exposure to constant darkness, their sensory environment was normal. Two auditory and one visual measures were taken before and after the week of darkness, as well as at intervals of 1, 2, 5, and 7 days following termination of 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 were in no way restricted.

Auditory discrimination, as measured binaurally by a flutter fusion method, increased significantly after the week of darkness. This increased auditory sensitivity, which was shown by fourteen of the fifteen experimental subjects, was still present a day after termination of visual deprivation. On the other hand, measures of absolute threshold

of hearing for five different frequencies and the critical flicker frequency (CFF) were not affected by visual deprivation.

The increase in auditory and cutaneous sensitivity following visual deprivation is believed to be mediated by the reticular activating system.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION AND HISTORICAL BACKGROUND

I. Statement of the Problem

Recently, two studies, completed in this laboratory, reported that a pronounced increase in cutaneous sensitivity can be obtained in subjects exposed to a week of visual deprivation. This effect was shown by almost all of the experimental subjects and persisted for several days after termination of visual deprivation. The purpose of this study is to determine (a) what effect prolonged visual deprivation has on the auditory sense modality, (b) the duration of any auditory effects following termination of deprivation and (c) effects on visual sensitivity as measured by a critical flicker frequency technique.

II. Introduction

Since the early 1950's, when the first experimental work on isolation was performed at McGill University (Bexton, Heron, & Scott, 1954), considerable interest has been shown in the behavioral and physiological effects of a severe reduction in the level and variability of sensory and perceptual stimulation. The attempts to achieve such a reduction in environmental stimulation are often referred to by such terms as sensory isolation, stimulus deprivation, sensory deprivation or perceptual deprivation. Although a variety of procedures have been used to reduce sensory stimulation, they fall, in general, into two main categories, viz., sensory deprivation and perceptual deprivation (Kubzansky, 1961). In the first, efforts are made to reduce sensory stimulation to as low a level as possible. Generally this includes the use of a dark, sound-proofed cubicle where subjects, wearing heavy gloves and cardboard cuffs, are instructed to lie quietly on a cot or mattress. In the second category, perceptual deprivation, efforts are made to reduce the variability and organization of sensory stimulation while maintaining its level near normal. This procedure typically has the subject lie on a cot in a cubicle wearing gloves and translucent goggles which permit homogeneous, unpatterned vision. A masking sound, usually white noise, is directed into both ears. The intensity of the light and noise is maintained at a constant level. Under these two types of deprivation conditions, subjects are required to endure anywhere from one-half hour to fourteen days of isolation. The more commonly used deprivation periods are 2, 4, and 7 days.

Regardless of the type of deprivation condition which is employed, a variety of behavioral and physiological effects may be produced, e.g., disturbances in EEG activity, perception, thinking, emotion, motivation and occasionally hallucinatory-like phenomena (see reviews of the literature by Kubzansky, 1961; Fiske, 1961; Zubek, 1964). Facilitation of certain behavioral functions has also been reported, e.g., certain types of verbal learning and immediate memory. Perhaps the most perplexing of these phenomena is an increase in cutaneous sensitivity in terms of tactual acuity and pain sensitivity. These cutaneous effects have been demonstrated in a number of different laboratories in Canada (Doane, Mahatoo, Heron, & Scott, 1959; Zubek, 1964), the United States of America (Vernon & McGill, 1961) and in Japan (Nagatsuka & Maruyama, 1963; Nagatsuka & Süszuki, 1964). Furthermore, the Japanese investigator Nagatsuka (1965) has recently reported an increase in taste sensitivity following a day of perceptual deprivation. Although the mechanism underlying these "supersensitivity" phenomena is not known, it is believed that an overall reduction in the level of visual, auditory, tactile-kinesthetic and social stimulation is essential for their appearance. Recent work at the Manitoba laboratory, however, has demonstrated that such a severe reduction in sensory input is not necessary. Increased cutaneous sensitivity can occur following visual deprivation alone (Zubek, Flye, & Aftanas, 1964; Zubek, Flye & Willows, 1964). This phenomenon was shown by almost all of the experimental subjects, on all skin areas tested, and on all cutaneous measures (two-point threshold, tactual fusion, and pain sensitivity). Furthermore, the effects were still present several days after the termination of visual deprivation.

These results have implications for the general area of sensory interaction. They raise the possibility that a general enhancement of sensory functioning may occur as a result of visual deprivation. The purpose of this thesis is to explore this possibility by determining whether visual deprivation alone can also increase the sensitivity of other sense modalities, for example the auditory modality. This sensory system was selected primarily because of certain reports in the literature indicating that isolated and visually deprived subjects frequently mention certain improvements in their hearing. A measure of visual discrimination, the CFF, was also taken in order to determine the possible effects of visual deprivation upon the visual modality itself.

III. Historical Background

The review of the literature will be presented in three sections beginning with a survey of sensory isolation studies in which auditory observations were made, followed by a review of the auditory sensitivity of the blind, and finally an examination of those studies dealing with sensory interaction or intermodal stimulation.

Sensory Isolation Studies

Although a variety of sensory and perceptual functions have been investigated during a decade of intensive sensory isolation research, only a few of these studies have concerned themselves directly with possible post-isolation changes in auditory sensitivity. Furthermore, many of the reports on auditory phenomena are purely qualitative in nature and, therefore, only suggestive. The relevant sensory isolation studies fall into three categories, namely long term, short-term, and visual deprivation alone, and they will be reviewed in that order.

Long duration studies. Zubek et al. (1961) used 16 subjects who were paid to lie on an air mattress in a dark, sound-proofed chamber for a period of 7 days. Earmuffs were worn to further reduce external sounds and no vocal or physical exercises were permitted. Under this sensory deprivation condition, auditory vigilance (Mackworth type) was not affected. However, during the second half of the two hour vigilance period an improvement in performance, although not significant, occurred. In noting qualitative observations after isolation, the study reports that hyperacuity to sounds in terms of loudness was a very common phenomenon, especially during the first night at home. The slightest sounds could be heard and normally irritating sounds seemed pleasant. The noise of the traffic also seemed particularly loud and was somewhat startling. Myers, Murphy, Smith and Windle (1962), using a 4 day period of darkness and silence, reported a slight but not significant improvement in auditory vigilance. Many of their subjects also reported being hypersensitive to sounds after termination of isolation. In a subsequent 7 day study, employing unpatterned light and white noise rather than darkness and silence, Zubek et al. (1962) reported a significant impairment in auditory vigilance when compared to two matched control (recumbent and ambulatory) groups. This apparent discrepancy in results, as shown by the three studies, may possibly be attributed to differences in experimental conditions imposed during isolation and not to inconsistencies in results. The first two studies used darkness and silence while the third used unpatterned light and white noise. Various studies (reviewed by Zubek, 1964) have shown that these two conditions are not equivalent behaviorally for long isolation intervals and that the effects of light and noise almost always have a greater impairing effect on post-isolation measures.

Vernon et al. (1961) measured auditory effects in subjects exposed to one, two and three days of darkness and silence. They used a delayed auditory feedback technique where subjects were required to read aloud 100 two-syllable words while listening to a delayed feedback (0.75 sec. duration) of their own voice. All experimental subjects, as well as almost all the controls, improved in their ability to overcome the blocking effect on the post-isolation measure as compared to the pre-isolation measure. The authors suggest that the blocking effect was not sufficiently severe to be influenced by sensory deprivation.

Short duration studies. In addition to these experiments on prolonged sensory and perceptual deprivation, two experiments, employing brief isolation periods, have been performed. The first was reported by Batten (1961) who, in a doctoral thesis, analyzed the effects of one hour of perceptual deprivation on auditory and visual sensitivity. Sensitivity was evaluated, in terms of difference thresholds, by a modified method of constant stimuli using a variable tone (pitch threshold) for the auditory stimulus and a variable intensity light (brightness threshold) for the visual stimulus. No changes in auditory or visual sensitivity were reported. Two possible explanations may account for these negative results. First, one hour may not be a sufficient period of deprivation for observing facilitatory effects. Second, the isolation literature indicates that both perceptual deficits and improvements can occur depending upon the particular technique that is employed (Zubek, 1964). Therefore, it is possible that methods other than a difference threshold technique may have shown a facilitatory effect.

In the second study, Cohen et al. (1961) exposed 10 subjects to a two hour period of sensory deprivation. The subjects were placed in a dark, sound-proofed chamber in a seated position and were not allowed to move, speak, or make noises. In post-isolation interviews, the subjects reported that occasionally slight noises, due to some irregularity in the functioning of the ventilating fan, were heard and that these proved very "provocative". Some subjects also reported that the silence exaggerated the effect of these slight noises which at times became anxiety producing. This study suggests that even during a short-term deprivation condition, minimal auditory stimuli may become subjectively elaborated in terms of increased loudness.

Visual deprivation studies. Finally, several experiments will be described in which the auditory effects of visual deprivation alone were investigated. These studies have employed either darkness or homogeneous visual stimulation (Ganzfeld).

Zubek, Flye, and Aftanas (1964), assessing cutaneous sensitivity after 7 days of darkness, report along with quantitatively pronounced increases in cutaneous sensitivity, numerous subjective reports of auditory and olfactory hyperacuity. Several subjects reported spontaneously that on their return home, the radio was unusually loud and that its volume had to be reduced well below its usual level. In a second study, involving a week of unpatterned light, Zubek, Flye, and Willows (1964) again commented on the prevalence of post-deprivation auditory hypersensitivity. It is possible, therefore, that a quantitative increase in absolute auditory sensitivity may occur after prolonged visual deprivation.

Özbaydar (1961) compared the effects of 10 minutes of darkness and 10 minutes of a control condition on various auditory threshold measures. These measures were taken immediately after exposing subjects to either of the two conditions. A small but significant impairment (1.25 db) occurred on both the absolute and masked threshold measures after 10 minutes of darkness. No change was found in differential threshold. These results, however, may be questioned since Özbaydar failed to take both pre-experimental and post-experimental measures.

In a study employing a brief period of visual deprivation, Cohen (1962) also reported an impairment on some auditory measures. Three auditory tests were administered before, during, and after 20 minutes of darkness, uniform visual stimulation (Ganzfeld) and a control condition. On the Seashore loudness discrimination test both dark and Ganzfeld conditions produced more errors than did the control condition. There was, however, no significant difference between the two experimental conditions. On the second task, a discrimination between odd and even numbers, performance in darkness was significantly better than under the Ganzfeld condition. Finally, on the last task, discrimination between one and two tones, the first always loud and the second when present lower, the experimental conditions had no effect. These results, therefore, seem to suggest that a brief period of visual deprivation may increase, decrease, or have no effect on auditory sensitivity depending upon the particular measures that are employed.

In conclusion, it appears that exposure to both prolonged and short-term periods of sensory deprivation (darkness and silence) can produce increases in auditory sensitivity. Unfortunately, some of the observations were purely qualitative in nature and therefore can only be regarded as suggestive. On the other hand, the effects of visual deprivation alone appear to be differential in nature. Both increases and decreases in auditory sensitivity can occur depending upon the particular measures that are employed.

Studies on the Blind

A generalization of long standing is that when an individual loses the use of one of his senses, the remaining senses function vicariously to compensate for the loss. The literature on the blind, however, is replete with contradictory reports which both confirm and refute the notion of sensory compensation.

Early studies. The literature of the 1800's (Kitto, 1852; Levy, 1872; Whalen, 1892) dealing with sensory compensation was anecdotal, conflicting, and none of the reports were based on experimental observations. Early studies of an experimental nature dealing with auditory sensitivity of the blind fall largely into two categories of basic acuity, in terms of intensity, and simple auditory functioning, in terms of localization.

One of the first experimental attempts to study sensory compensation in the blind was by Griesbach (1899) in Germany. He carried out a study on blind and seeing subjects comparing three sense modalities, viz., hearing, smell and touch. Two auditory measures were taken. The first, an early form of localization, involved distinguishing the direction of a sound. Each subject from both blind (N = 28) and sighted (N = 28) groups was given a series of 9 tests: 3 monaural tests for each ear and 3 binaural tests. The results showed no essential differences between blind and sighted groups. The second auditory test measured basic acuity by determining the distance at which sounds could be distinguished by 49 sighted and 19 blind subjects. The stimuli were numbers from one to 100 or monosyllabic words whispered in a long corridor. Again there was no superiority of the blind over the sighted subjects. It is interesting to note that his comparative studies involving touch and smell also gave no evidence of greater sensitivity in the blind.

Krogius (1905), replicating Griesbach's method, reported that 20 blind female subjects could localize sounds more exactly than seeing subjects. In 1907, using a different localization technique, he reported that of 6,000 measures taken, the results showed a clear superiority for the blind as they generally made only about one-half as many mistakes as the seeing.

In terms of basic auditory acuity, Waidele (1905) claimed there were many blind people who did not have superior hearing and further that many were afflicted with ear diseases showing inferior hearing as compared to controls.

Kunz (1908) tested 38 blind and 5 sighted subjects with a watch and found the mean distance at which the watch was audible. The mean distance for the two types of subjects was 311 cm. and 374 cm., respectively, thus indicating poorer auditory sensitivity in the blind.

Horter (1913) using a tuning fork, which was allowed to "ring off", concluded that no auditory differences existed between the blind and the seeing subjects.

Seashore and Ling (1918) carried out a much more precise experimental comparison of the blind and the seeing. They used 16 blind subjects, of ages 16 to 26 years, who were totally blind for 5 years, and 15 sighted subjects, ages 14 to 19 years. Two auditory measures were taken of which the first was sound localization. Discrimination for the direction of sound was measured in terms of the angular displacement in the horizontal plane directly in front of the observer. A click in a phone receiver was the stimulus. The results showed the blind to be slightly superior. However, they varied more than the seeing and the best single record was made by a seeing subject. For the second test a precise audiometer, developed by Seashore, was used to measure loudness discrimination. Two tones were presented successively and the subject was asked to decide whether the second tone was stronger or weaker than the first. The results showed no decided superiority either for the blind or the seeing and no great differences in variability within the groups. Seashore's findings support neither prior claims of poorer auditory sensitivity in the blind nor the notion of sensory compensation.

Hayes (1933) reports a study in which acuity of hearing, of 92 male and 84 female blind subjects and 19 seeing female subjects, was determined by a sensitive audiometer. No sensory compensation was evident when the blind were compared with the seeing. On the whole, blind subjects didn't hear as well. A second study measured the ability of blind and blindfolded seeing subjects to recognize the contents of small boxes via a combination of auditory and muscular cues. Again no clear superiority for the blind was established.

Supa, Cotzin, and Dallenback (1944) report that audition appears to be at the basis of Fernism ("absolute sense") in the blind thus indicating some support for the notion of compensation.

Recent studies. After the early studies, there appears to be a scarcity of relevant literature until the late 1950's. Axelrod (1959), in a study of the early blind, offers some current explantions of previous compensation results. He points out that no complex tasks were used to test possible compensation in either auditory or cutaneous modalities. He states that differences in residual functioning between blind and sighted subjects on simple tasks can be explained on the basis of differential attention, or learning, or both. As for early empirical investigations, sources of confusion are differences in characteristics of blind samples studied (subjects' ages, age of onset of blindness, amount of residual vision, etc.) and in functions tested.

In his 1959 study, he presented a complex auditory task to his subjects. This task involved tonality (chime or buzzer), number (1 or 2 tones) and temporal sequence (first, second, or third). In each trial, 3 stimuli were presented with each consisting of 1 or 2 short (0.5 second) notes on either chime or buzzer. The inter-stimulus interval was approximately 1 second. The correct stimulus, where temporal position varied randomly from first to third, was the one identical to the second in number and tone. The results showed that early-blind subjects performed significantly worse than did the sighted controls. Late-blind subjects didn't differ from sighted subjects. His study, therefore, offers little support for auditory sensory compensation.

Winer (1962) studied the relationship of intelligence, emotional stability, and use of auditory cues in 22 totally blind subjects. Significant positive correlations were found between (a) intelligence and use of auditory cures, (b) emotional stability and use of auditory cues and (c) intelligence and emotional stability. This study, therefore, seems to suggest that the degree of auditory compensation in the blind may be dependent on their intelligence and emotional level.

Fisher (1964) measured the ability of blind people to localize stimuli by sound and touch. He also hoped to determine the nature of the information utilized. This localizing ability is often remarkably accurate and one hypothesis put forth is that acuity of hearing is markedly improved. The results of comparing auditory and tactile localizing abilities of 5 blind and 5 sighted subjects gave no support for this hypothesis. This may be due to the fact that spatial contexts were not available to the subjects. In an experiment, where they were reintroduced, it was observed that blind subjects appeared to be able to utilize the additional information provided, particularly in audition. This seems to be the reverse of the tendency of sighted subjects under similar conditions. This study reports little evidence for marked auditory compensation in the blind.

Finally, some physiological evidence exists for the notion of sensory compensation. Grey Walter (1963) reported that in some congenitally blind children, the nonspecific cortical responses evoked by tactile and auditory stimuli are unusually large in relation to those of sighted children of the same age. Krech et al. (1963) have also demonstrated that rats subjected to peripheral blinding at the time of weaning, subsequently show an increase in the weight and cholinesterase activity of the somesthetic cortex. In a further study, Krech (1964) reported similar somatosensory changes in sighted rats living in darkness. It is unfortunate, however, that Krech did not study the auditory cortex as well, for findings of similar anatomical and chemical changes in this cortical area would strengthen the physiological evidence for auditory compensation.

It is evident from this survey that conclusions regarding the abilities of the blind to perform simple and complex auditory tasks are difficult to arrive at. The evidence is both inconclusive and contradictory. Several important considerations are not adequately accounted for in many of the studies, thereby reducing the validity of the results reported. These considerations are the degree of blindness possessed by subjects, the age at onset of blindness, age of the subjects, sex, I.Q., and emotional stability and use of inadequate experimental techniques. Due to these factors, it is difficult to arrive at a clear picture of the relationship between the loss of vision and auditory sensitivity.

Studies of Sensory Interaction

The general area of sensory interaction has been the object of considerable attention in the Soviet Union since the early 1930's but has received only limited attention in the western world until recently. Western neglect of interaction research has been largely attributed by Maier et al. (1961) to a prevalence of conflicting empirical reports, absence of an adequate conceptual framework to accommodate positive findings and the fact that sensory psychology has been marked by peripheralism due to a misinterpretation of the doctrine of specific nerve energies. Most interaction studies involve the study of modification of response in one sense organ under direct stimulation, where another sense organ has been, or is subject to its own characteristic stimulus. This review will be restricted largely to intersensory phenomena associated with vision and hearing.

Early reports. The first report of intersensory phenomena was made in 1669 by a Copenhagen anatomist, Bartholinus (1669) who announced that partially deaf individuals could hear better in the light than in the dark. The next report, over a 100 years later, was published by

Ebermaier (1796) who claimed a beneficial influence of light in cases involving diseases of the ear and recommended that concentration of light rays be directed into the auditory tract by means of a convex lens. This was a claim for intersensory effects at a peripheral level. In 1929, Freund and Hoffman checked Ebermaier's claim and found that in 50 per cent of the cases, a lamp source on a deafened ear improved acuity, the amount of improvement being directly proportional to the intensity of light. Freund (1929) also reported a facilitation of olfactory perception following illumination. Furthermore, he claimed that this facilitatory effect of light was central and not peripheral since the effect disappeared when the nostrils of blindfolded subjects were radiated with light.

Urbantschitsch (1888, 1902) reported a two-way interaction between vision and hearing. He observed that auditory acuity fluctuated with the light or darkness, being greater in the light. Conversely, he noted that auditory stimulation with a tuning fork increased color sensitivity, with binaural stimulation being more effective than monaural and high tones better than low tones. His work is primarily suggestive and considered scientifically unreliable.

Russian studies. A brief summary of the Russian studies will now be presented, as reviewed by London (1954). He points out that while most of the studies are methodologically weak or unacceptable, the large number of studies is indicative of persistent and systematic attention.

The main body of the Russian sensory interaction research is concerned with the effects of auditory stimulation on a variety of visual measures. Pronounced effects on peripheral visual sensitivity have been demonstrated. Peripheral sensitivity generally declines during auditory stimulation of average or above average intensity. On the other hand, exposure to ultrasonic frequencies, e.g., 32,800 c.p.s., has been reported to facilitate peripheral sensitivity.

Studies on absolute sensitivity of central vision indicate that moderate auditory stimulation heightens central sensitivity to white light for the dark-adapted eye. If monochromatic light is used, the effect varies with the wavelength chosen. For example, central sensitivity of the dark-adapted eye to short wavelengths (blue-green) is increased during auditory stimulation whereas to longer wavelengths (orange-red) it is decreased. On the other hand, wavelengths in the middle range and those at the extreme spectral end are not affected. Kravkov (1936) reports that the above effects vary directly with intensity and duration of the auditory stimulus.

Regarding differential sensitivity to brightness, the Russians report that simultaneous auditory stimulation impairs differential sensitivity. The amount of impairment varies directly with increases in brightness of the viewed field.

The effects of auditory stimulation on the CFF is differential depending on whether white or monochromatic light is used. If white light is the primary stimulus, accessory auditory stimulation (800 c.p.s. at 85 db) increases the foveal CFF and decreases peripheral CFF. On the other hand, when monochromatic light of short wavelength, green (520 mu), is employed, the CFF is decreased by auditory stimulation, while for longer wavelengths, orange-red (630 mu), it is increased.

Several studies report that auditory stimulation of medium intensity increases electrical sensitivity, while sounds of high intensity decrease electrical sensitivity.

The color zones of the eye appear to be affected in a complex manner by auditory stimulation, e.g., for green and blue they are enlarged, for orange-red they are diminished, while those for extreme red remain constant.

It is also reported that auditory stimulation affects the course of extinction of afterimages, e.g., a strong auditory stimulus increases the brightness of the afterimage but shortens its temporal duration.

While many of the Russian studies are concerned with the effects of auditory stimulation on various visual measures, only a few are concerned with the auditory effects of visual stimulation. The effects of accessory stimulation have been demonstrated when sound was the primary stimulus. Illumination of the eyes with white light is reported to increase auditory sensitivity, absence of visual stimulation decreases it. When different monochromatic lights are used as accessory stimuli, various effects are obtained. Illumination of a white room with green light increases auditory sensitivity, whereas using red light decreases it. It is further reported that olfactory and gustatory stimulation can improve auditory sensitivity.

North American studies. Several investigators have examined the effects of visual stimulation on auditory sensitivity. Hartmann (1934) examined the possible facilitatory effects of light upon the discrimination of pitch and intensity differences. Using a Seashore test, under very dim and very strong illumination, he reported a fairly uniform improvement of 3 per cent for subjects under the very strong illumination condition. Some exceptions, however, were noted. In a second experiment, he reported that auditory acuity was better during complete darkness than during high illumination.

Cason (1936) reported that when a light stimulus of low intensity coincided with the presentation of an auditory stimulus, the auditory stimulus was judged louder than when presented alone. It was further noted that a sound combined with light made the light appear brighter than when the same light was presented alone.

Child and Wendt (1938) investigated the influence of a light upon auditory acuity as a function of the temporal interval between the light and the tone. They reported that the facilitatory effects of the light on auditory acuity were greatest when it occurred from 0.0 to 1.0 second prior to the onset of near-threshold tonal stimuli.

Gregg and Brogden (1952) attempted to differentiate conditions under which an accessory light stimulus facilitates or inhibits sensitivity to auditory stimuli. Auditory thresholds for a 1000 c.p.s. tone were measured under accessory light stimulation whose brightness was fixed at three levels of 0, .015, and .055 ml. The results showed that a significant decrease in auditory sensitivity occurred as the brightness of the light was increased, when subjects were required to give a specific verbal response to the light stimulus. On the other hand, a significant increase in auditory sensitivity was obtained with increases in brightness of the light when no response to the light stimulus was required.

Thompson, Voss, and Brogden (1958) expanded the above study in an attempt to clarify the results. Threshold measurements of the 1000 c.p.s. tone were taken under eight different levels of light intensity ranging from below to well above threshold. Two experimental groups, one responding to the light and the other not responding, were again used. A control group, in which all threshold determinations were made at zero light intensity, was also employed. The results showed that the sub-threshold light inhibited auditory sensitivity for the responding experimental group and had no effect on the non-responding group. When supra-threshold light stimulation was used, both experimental groups showed an increase in auditory sensitivity with the non-responding subjects showing greater facilitation in hearing. The results did not appear to be due to practise effects.

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, in terms of discriminating black-on-white or white-on-black, can be temporarily increased to a slight but consistent level by simultaneous application of high and low tones. 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 stimuli. If the accessory auditory stimulus 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. Serrat and Karwoski (1936) reported no significant effect of sound on the light threshold at 506 mu or on the hue threshold at 710 mu. This study, incidentally, is one of the rare experiments contradicting the large body of positive evidence indicating an interaction between vision and hearing.

Chapanis, Rouse, and Schacter (1949) conducted a study to determine whether a 1000 c.p.s. tone has any effect on dark adaptation. They also determined whether auditory or tactile stimulation have any effect on contrast sensitivity. Their results were negative on both aspects of the study and in complete disagreement with two Russian investigators (Kekcheyev, 1943, 1945; Streltsov, 1944) who claimed enormous effects of intersensory stimulation on dark adaptation and night vision.

Various investigators have used the CFF as a measure of visual sensitivity in sensory interaction research. Allen and Schwartz (1940) reported positive influences of sound upon the CFF, with the particular effect depending upon the intensity of the auditory stimulus. A loud tone produced an enhancement while a weak tone produced a depression of visual sensitivity. They also reported that stimulation of the left ear evoked an enhanced visual response in the right eye.

Ogilvie (1956) tested the effects of auditory flutter on the CFF. He reports that in-phase flutter raises CFF higher than out-of-phase flutter. Furthermore, while auditory flutter increases the CFF, a continuous white noise has no effect. These phase differences are considered by Ogilvie to provide a clear demonstration of the existence of an hypothesized central mechanism (Sherrington, 1947) for the integration of neural impulses from the two sense organs. The phase differences also suggest that the intersensory effects cannot be due to changes in "attention" as some investigators have maintained. In a second study, Ogilvie (1956) reported that the effect of auditory flutter on the CFF is not influenced by changes in the brightness of the CFF.

Maier, Bevan, and Behar (1961) studied the influence of auditory stimulation upon monocular and foveal CFF for lights of different color. 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 c.p.s.). The results revealed complex intersensory relationships. Auditory stimulation raised the CFF from two to four per cent, the loudness-level effects on the CFF for orange-red and blue were monotonic, and pitch alone had no effect unless paired with loudness and color.

Physiological studies. Sensory interaction phenomena of a physiological nature have been demonstrated by two investigators. Chang (1952) reported some preliminary observations on cats showing that continuous retinal illumination enhances the cortical response to electrical stimulation of the medial geniculate body of the auditory system. The primary locus of this interaction between vision and hearing appears to occur at the subcortical level since the removal of the visual cortex only partially reduces the facilitatory effect of light on the auditory response. Chang (1959) has suggested that the reticular activating system (RAS), which receives convergent afferent impulses from various sensory sources through collateral fibers, may be the neural mechanism mediating this intersensory facilitatory effect.

Gelhorn et al. (1954) reported that in lightly anesthetized cats, nociceptive stimuli increase the electrical responsiveness of the sensory projection areas to visual and auditory stimulation.

Finally, it should be mentioned that the many positive reports in the sensory interaction literature have little common basis in terms of a broad theoretical model. In his excellent review of intersensory phenomena, Ryan (1940) points out the primary problem in trying to apply a comprehensive theoretical model to explain these phenomena. He states that the facts of intersensory relations show only that, under very special conditions, one sensory system can influence the specific qualities or limits of function of another sensory system. The effects are by no means general to the extent that they occur whenever two modalities are simultaneously stimulated.

It is clear from this review of the literature that a variety of intersensory effects, often of a very complex nature, are possible between vision and hearing. The literature on prolonged and short-term sensory deprivation (darkness and silence) has indicated several instances of increased auditory sensitivity. Similar increases have also been reported in some studies involving visual deprivation alone. Unfortunately, many of these observations were purely qualitative in nature and, therefore, can only be regarded as suggestive. Precise quantitative measures of auditory sensitivity are required. The purpose of this thesis is to determine quantitatively the effects of prolonged visual deprivation on two measures of auditory sensitivity viz., auditory flutter fusion threshold and the absolute threshold of hearing for five frequencies. If facilitatory effects should occur, the results will indicate that prolonged visual deprivation can increase not only cutaneous sensitivity, which has already been demonstrated, but also auditory sensitivity.

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 15 experimental subjects and 15 control subjects ranging in age from 16 to 38 years, with mean ages of 19.5 and 21.3 years respectively. All subjects were volunteers who received financial remuneration for participating in this experiment.

II. Deprivation Procedure

The 15 experimental subjects, each wearing a black mask, were placed in groups of 2 or 3 in a dimly illuminated room, 10 ft. x 15 ft., which was equipped with three spring filled mattresses and a radio. The black masks were never removed during the experimental period of 7 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 15 subjects successfully endured the week of darkness.

III. Auditory and Visual Measures

Two auditory measures viz., auditory discrimination and absolute threshold of hearing were taken before and after a week of darkness, as well as at intervals of 1, 2, 5, and 7 days after termination of visual deprivation. In addition, a measure of visual sensitivity, the CFF, was taken at the same time intervals as the auditory measures.

Auditory discrimination was determined by a fusion or "flutter" method. This measure, which is considered to be an auditory analogue of visual flicker (Miller & Taylor, 1948), involves the production of an interrupted white noise, at a specific intensity, whose frequency can be systematically increased until the subject reports a constant sensation of noise. The interrupted white noise, at an on-off ratio of 0.90 and an intensity of approximately 70 db re 0.0002 dynes/cm.^{2}, was presented binaurally by a noise audiometer (Grason-Stadler, Model 830-52). The rate of interruptions was initially set at a sufficiently high frequency to produce a sensation of continuous white noise. The frequency was then systematically decreased until the subject reported the first sign of "flutter" or interruptions in the white noise. Subsequently, the interruption rate was increased well above fusion and the procedure was repeated. The critical frequency, at which the first interruptions became clearly discriminable from the continuous pattern, is referred to as the auditory flutter fusion theshold (AFF). The method of limits, with descending series only, was used to measure the fusion threshold since it has been shown (Symmes, Chapman, & Halstead, 1955) "that a minimal flutter stands out as a figure in a ground of repeated continuous noise bursts more distinctly than the reverse". Five practise and five experimental trial blocks separated by a one minute rest period, were administered at each testing session. The difficulty of making this discrimination, due to the 'roughness' of continuous white noise itself, required that practise trials be given at each session so that a consistent set of responses from session to session could be established by the subjects.

The second auditory measure involved the determination of the absolute threshold of hearing for five pure tones whose frequencies were 100, 300, 1000, 5000, and 9000 cycles per second (c.p.s). These frequencies were chosen because they may be considered as representative of the ranges extending from approximately 100 to 10,000 c.p.s. where standard absolute auditory thresholds, based on a minimum audible pressure (M.A.P.) technique, are generally determined (Licklider, 1951). The tones were generated by an audio-oscillator (Grason-Stadler, Model 950-D) and presented binaurally through Phillips earphones (Model HA-10) whose maximum acoustical output is 138 db (SPL). The maximum output obtained from the oscillator was 1.732 V with a 1000 c.p.s. signal. This yielded a total acoustic output, binaurally, of 118.75 db SPL re 0.0002 dynes/cm^2.

The descending method of limits was used. The tones were presented initially well above threshold and reduced systematically in steps of two db until the subject could no longer hear the tone. Four blocks of trials were administered, each block separated by a one minute rest period. The trial blocks contained the five test frequencies whose order of presentation was randomized. Each frequency was thus tested four times in a session, once in each block. Practise trials were given at the initial testing session only. Both the auditory threshold and auditory flutter determinations were made in a sound-proofed room.

In addition to determining the effects of prolonged visual deprivation on the auditory modality, a measure of visual discrimination, the CFF (critical flicker frequency) was employed to study the effect on the visual modality itself. The light stimulus was presented monocularly through a cold cathode modulating lamp (Sylvania Type R 113 1C, Crater Diameter 0.093 in.). The electronic device, used as a control mechanism (Grason-Stadler, Model E622) for turning the glow modulator on and off, was set at a constant position with respect to light intensity (11.3 milliamperes) and at a light-dark ratio of 0.50. The flicker rate was varied systematically by a continuously variable control in steps of one c.p.s. The descending method of limits was used with the subject being asked to report the first indication of flicker. Five experimental trials were given per session. Practise trials were given at the initial testing session only. A 15 minute period of dark adaptation was employed at all test sessions except at the end of the week of darkness when the subjects were already dark adapted.

The three measures of auditory and visual sensitivity were given in random order at each testing session and the subjects were given five minute rest periods between each measure to minimize fatigue effects. They were always read standard sets of instructions preceding each measure over all the testing sessions. The instructions were worded so that the subject was always urged to attend with the fullest concentration on the task at hand. All subjects were required to keep their eyes closed during the auditory measures.

Fifteen control subjects, drawn from the same population but unmatched with the experimental subjects, were given the same auditory and visual measures and at the same time intervals. They were, however, never visually deprived.

CHAPTER III

EXPERIMENTAL FINDINGS AND DISCUSSION OF RESULTS

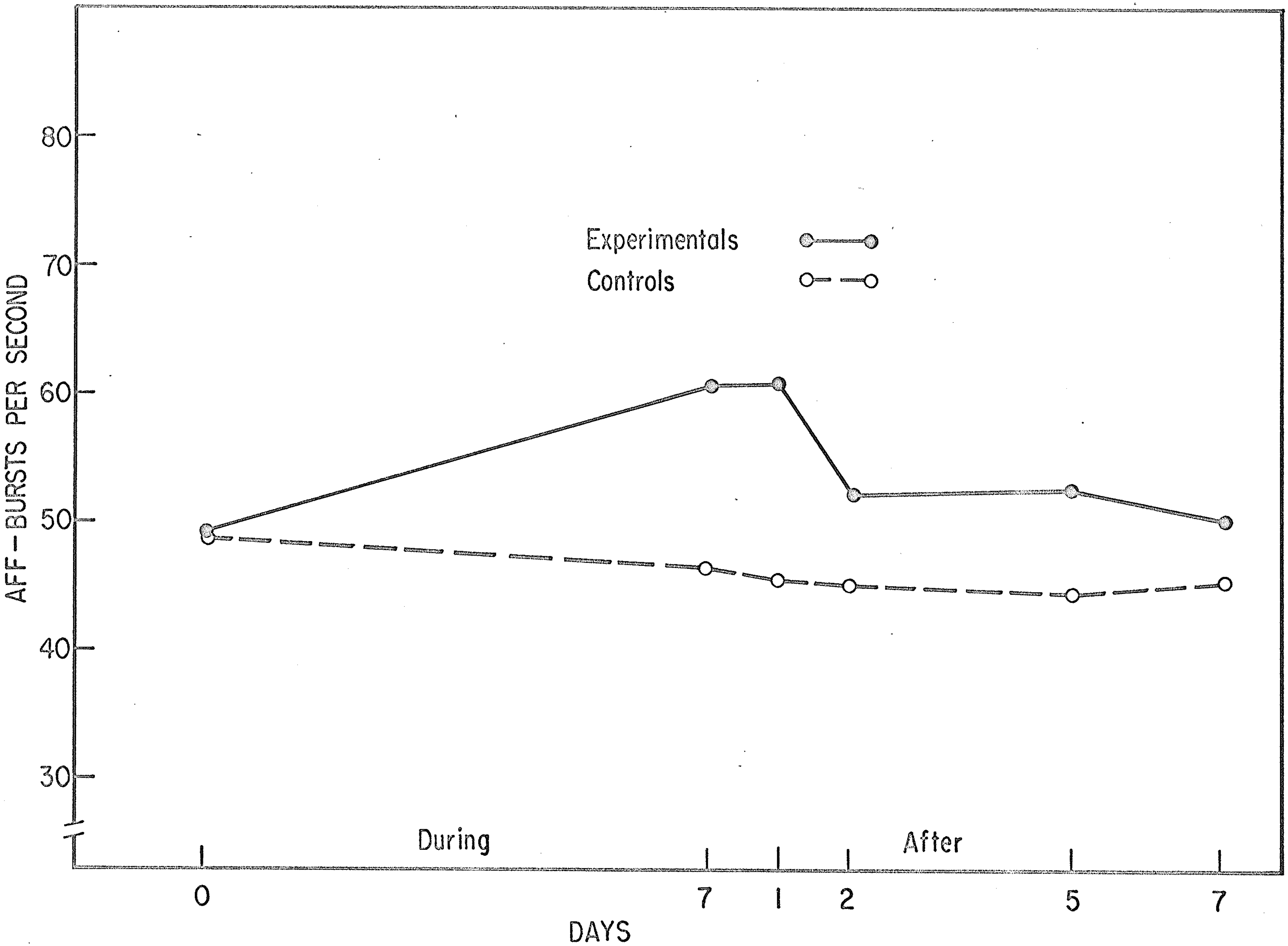
I. Results

Two tailed t-tests for independent measures were used to test the significance of the differences between the amounts of change shown by the experimental and control groups. The statistical analysis was made in terms of difference scores, obtained by subtracting the pre-isolation from the post-isolation test scores for each subject.

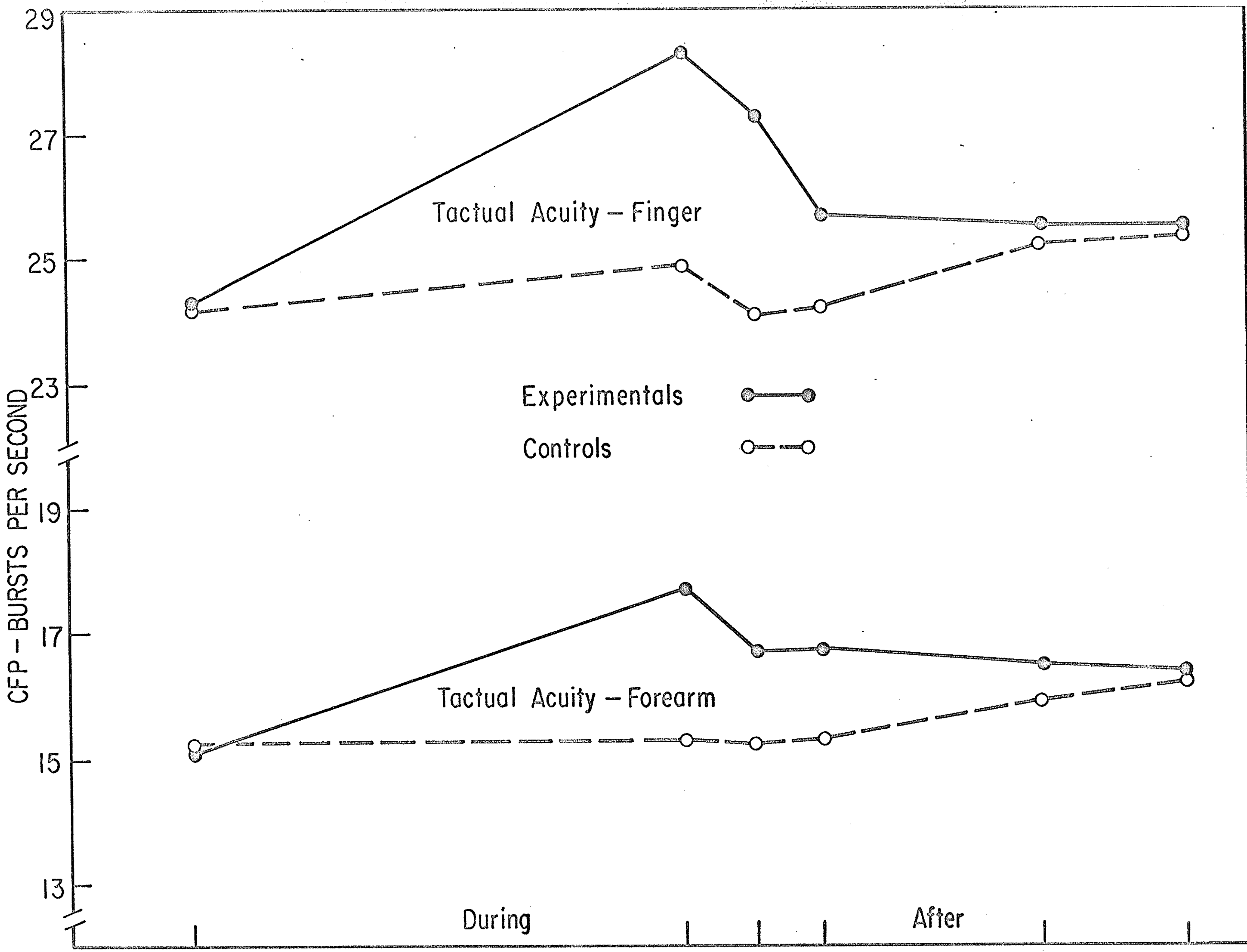
Figure 1 indicates that the experimental subjects, after a week of visual deprivation, show a considerable increase in auditory flutter fusion frequency (greater resolving power) in relation to that of the control subjects ($p < .001$). Fourteen of the 15 experimental subjects showed this increase. On the other hand, the control subjects exhibited a chance distribution of increases and decreases. Figure 1 also indicates that the effect was still present one day after termination of visual deprivation ($p < .01$). The results on post-isolation days 2, 5, and 7 were not statistically significant.

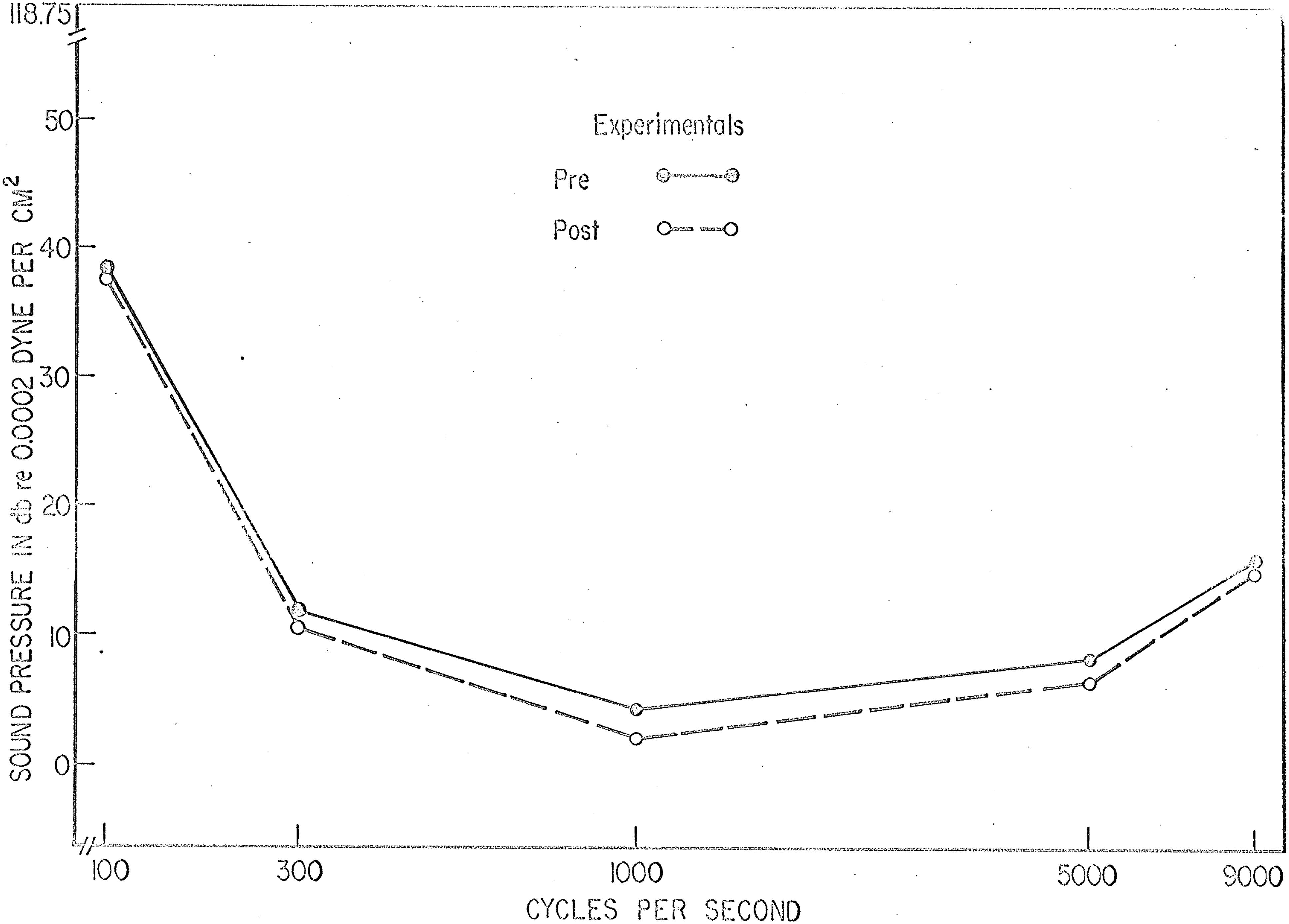
Figure 2 shows, for comparative purposes, the increase in tactual acuity of the index finger and forearm following a week of visual deprivation. All experimental subjects showed the increase and on both skin areas (Zubek, Flye, & Aftanas, 1964). Measurements were taken by a tactual fusion method (interrupted bursts of air) analogous to the flutter fusion method employed in this study. Note the striking similarity between the auditory and cutaneous effects.

Figures3 and 4 show the absolute threshold of hearing curves,

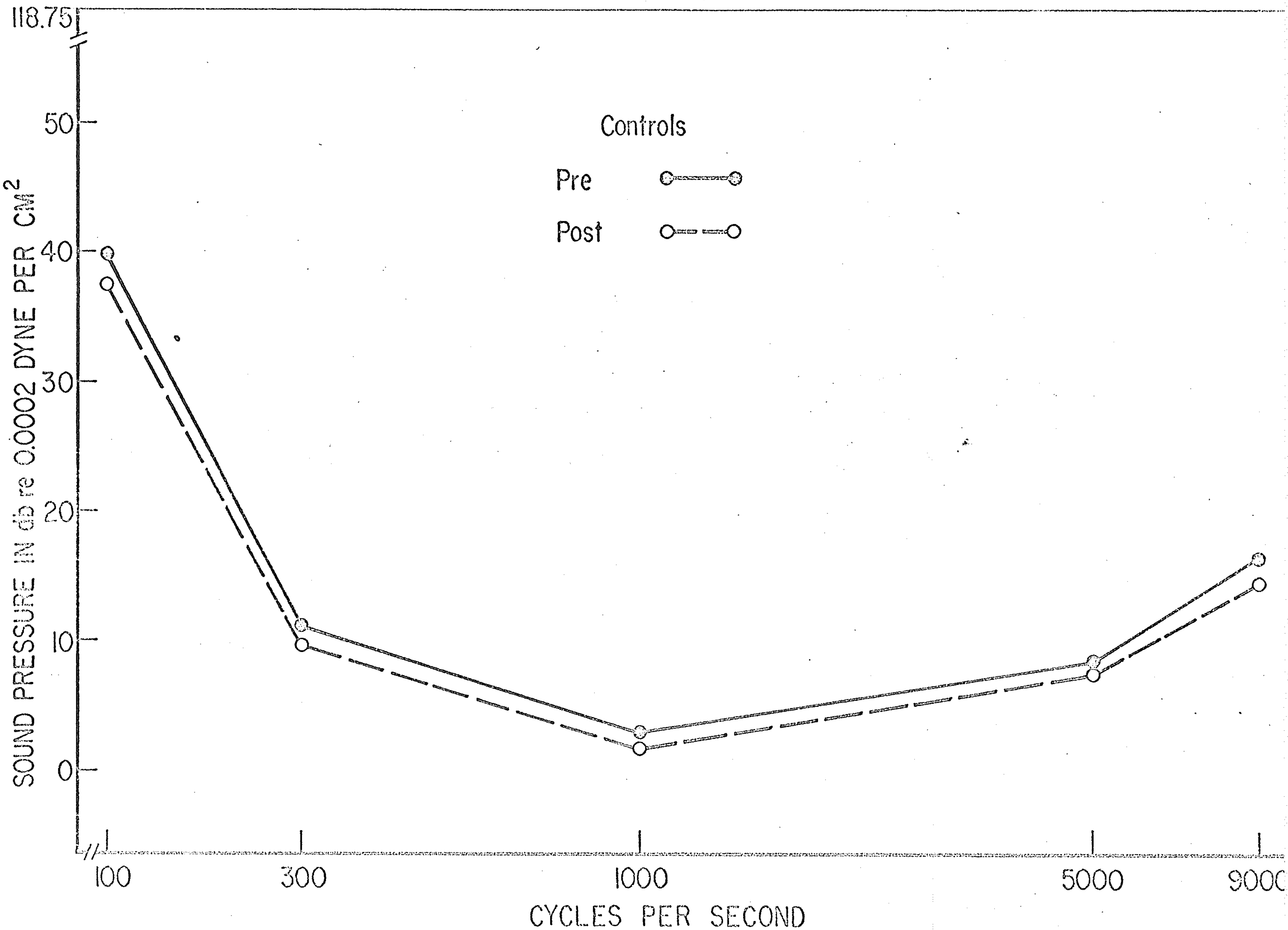


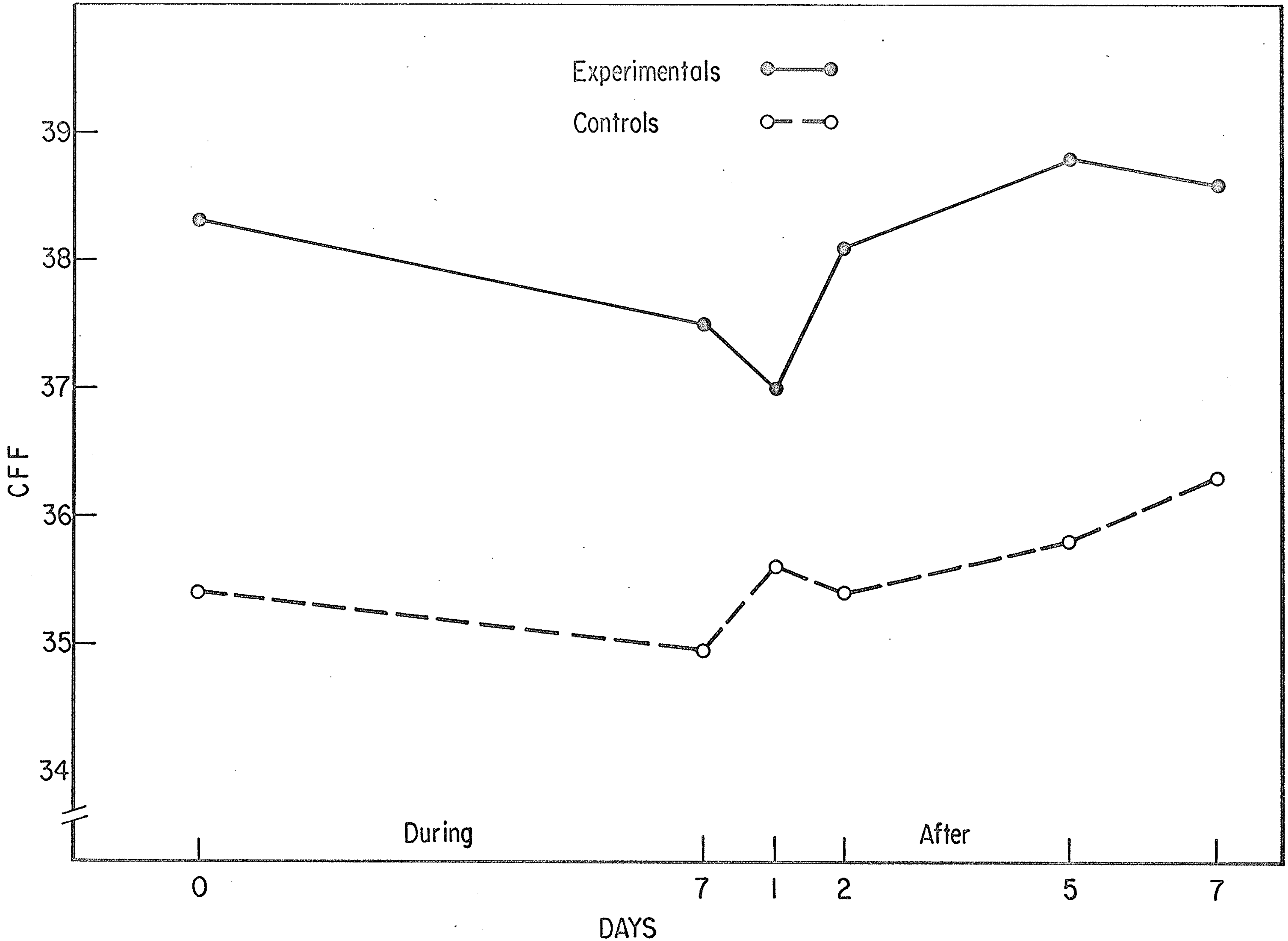
Experimentals
Controls
AFF - BURSTS PER SECOND
80
70
60
50
40
30
During
After
0
7
1
2
5
7
DAYS


CFP - BURSTS PER SECOND
29
27
25
23
19
17
15
13
Tactual Acuity - Finger
Experimentals
Controls
Tactual Acuity - Forearm
During
After



118.75
50
40
30
20
10
0
SOUND PRESSURE IN db re 0.0002 DYNE PER CM²
Experimentals
Pre
Post
100
300
1000
5000
9000
CYCLES PER SECOND


118.75
50
40
30
20
10
0
SOUND PRESSURE IN db re 0.0002 DYNE PER CM²
Controls
Pre
Post
100
300
1000
5000
9000
CYCLES PER SECOND


Experimentals
Controls
CFF
39
38
37
36
35
34
During
After
0
7
1
2
5
7
DAYS

before and after the one week period, for the experimental and control groups, respectively. It can be seen that both groups show a slight increase in sensitivity, on all five frequencies, after the one week interval. None of the differences, however, are statistically significant.

Figure 5 indicates that the performance on the CFF is essentially the same for both the experimental and control groups at the various time intervals. None of the pre-post differences between the two groups are statistically significant.

II. Discussion of Results

The results of this experiment indicate that prolonged visual deprivation has a facilitatory effect on a task of auditory discrimination, an effect which persists for at least a day after restoration of normal visual stimulation. The failure of the absolute auditory threshold to show an improvement is puzzling. It may, however, simply indicate that the facilitatory effects following visual deprivation apply only to sensory tests involving a temporal discrimination. Measures of absolute threshold may not be affected. This apparent discrepancy in results may also be due to differences in auditory stimuli employed in the two tests. The absolute threshold measures used pure tonal stimulation, whereas flutter fusion determinations employed a white noise. Some support for this hypothesis was recently provided by two electrophysiological studies on unanesthetized cats showing that the nature of the sound stimulus used is critical in studies of the auditory system. Starr and Livingston (1963) reported profound differences in distribution of activity between auditory clicks or other transient stimuli and sustained white noise at subcortical levels of the auditory system. An even more relevant study was performed by Galin (1964) who demonstrated that white noise and pure tones produced qualitatively different patterns of evoked activity in the cochlear nucleus, inferior colliculus, and the medial geniculate body. The most notable difference occurred at the inferior colliculus where white noise produced a marked increase in activity while pure tonal stimulation produced no such effect. This distinctiveness of the response pattern of the auditory nuclei to different forms of auditory stimulation may be an important factor in accounting for the differential effects on the two types of auditory measures.

The finding that the CFF was not affected by visual deprivation is supported by two experiments on prolonged perceptual deprivation. Doane, Mahatoo, Heron, and Scott (1959) reported no effect on the CFF following two and three days of perceptual deprivation. Zubek (1964) also observed no effect on the CFF even after a 14 day period. Whatever trend existed, it was toward a lowering of the CFF rather than an increase. Recently, however, the Japanese investigator Nagatsuka (1965) reported a significant decrease in the CFF after one day of perceptual deprivation. He interprets these results as indicating a disturbance of the organizing processes of visual perception and a lowering of the level of arousal as a result of reduced sensory stimulation. Since the above studies on the CFF used similar perceptual deprivation techniques, it is possible that the discrepancy in results may have resulted from differences in isolation duration. It may be that after 24 hours of perceptual deprivation, certain chemical processes of decomposition and regeneration in vision are affected adversely. These effects, however, may diminish with time thereby producing no effect on the CFF several days later.

The results of this experiment, together with the earlier research on cutaneous sensitivity, suggest that prolonged visual deprivation may produce a general enhancement of sensory functioning involving not only the cutaneous and auditory modalities, but also smell, taste, and kinesthesis. Some support for this suggestion was recently provided by Nagatsuka (1965) who reported a 35 per cent increase in taste sensitivity (sweet and bitter) after only one day of visual and auditory deprivation. Although two modalities were deprived, it is probable that a similar effect would result from visual deprivation alone.

This pronounced increase in taste sensitivity, reported by Nagatsuka, is surprising since it is greater than any of the cutaneous and auditory facilitatory effects (approximately 20 per cent in magnitude) reported at the Manitoba laboratory during a one week period. Two possible explanations for this unusually large effect may be offered. First, visual and auditory deprivation together may have additive effects, i.e., each individually may produce a facilitatory effect of approximately 15 or 20 per cent, a magnitude similar to that reported at the University of Manitoba. Second, these Japanese results may indicate that the facilitatory effects perhaps attain a maximum early in the one week period and subsequently begin to decline. Some support for the importance of duration was provided by Vernon et al. (1961) who observed a greater deficit on color perception after two than after three days of sensory deprivation. They also reported that depth perception was worse after a day than after either two or three days of deprivation. In view of these results, it is possible that sensory facilitatory phenomena may show a similar time course. Further research on the duration variable seems to be indicated.

Various lines of evidence suggest that these intersensory facilitatory effects may be mediated by the reticular activating system (RAS). First, this neural system receives afferent impulses from various sensory sources via collaterals of ascending tract fibres and transmits them diffusely to the cerebral cortex. Thus, a mechansim for intersensory effects is present. Second, it has been suggested (Lindsely, 1961) that the RAS may act "as a sort of homeostat regulating or adjusting input-output relations... Its changes and adjustments depend upon the ebb and flow of activity in the afferent or efferent systems and when these are restricted, compensatory adjustments are made". One of these compensatory adjustments may be a facilitation of certain sensory processes. Third, facilitation of sensory discrimination can occur following electrical stimulation of the RAS. For example, Fuster (1958) has shown that stimulation of the brain-stem reticular system 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 recognition thresholds. 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.

In conclusion, it would appear that a deprivation procedure is a better technique for studying the interrelationships existing among various sense modalities than the classical method of stimulating one modality for a short interval and testing the sensitivity of another. The effects of the deprivation procedure are quite pronounced and, furthermore, they occur in all or almost all experimental subjects.

Finally, since the present study deals with experimentally produced "blindness", its results should have implications with regard to the sensory capacities of the blind. Since performance on an auditory discrimination task increased after a week of darkness, it would be expected that similar or even greater increases would occur in blind subjects, particularly in those afflicted with the condition for many years. This, however, does not appear to be the case. Whatever literature is available is contradictory in nature with both increases and decreases in auditory sensitivity being reported. Although the reasons for this discrepancy in results between the functionally and organically blind are not known, two suggestions may be offered. First, the measures used to assess auditory sensitivity in the blind have usually been auditory tasks of too simple a nature. No study in the literature has employed a complex auditory measure of a temporal nature such as auditory flutter. Future research on the blind with measures of this type may produce results of a more positive nature. Second, it is possible that increased auditory sensitivity in the blind may only occur shortly after their affliction, when they are expected to be most reliant on their remaining senses in adjusting to the environment. Although no literature on the blind is available to support this hypothesis, there is some animal data which indicates that some of the after-effects of surgical deafferentation diminish with time. For example, the Russian investigators Beteleva and Novikova (1959) reported an increase in activity of the reticular system following olfactory deafferentation in the rabbit. However, several months later this change in reticular activity returned to its normal pre-operative level. It is possible that similar effects may follow visual deafferentation. Villablanca (1962) has also reported that massive deafferentation produced by complete midbrain transection (the "cerveau isole" preparation) resulted in high voltage, slow wave activity similar to one of the stages of sleep in the normal cat. After ten days, however, both high frequency, low voltage waking patterns and slow, high voltage sleep rhythms began to appear. This return to normal EEG activity was attributed to the "re-establishment of homeostasis and in the lessening of shock like factors in the long-term preparation". In the light of this physiological data, together with the auditory and cutaneous facilitatory effects following prolonged visual deprivation, perhaps a "new look" at the centuries old controversy over sensory compensation in the blind may be justified.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Two recent studies at the University of Manitoba have reported a pronounced increase in tactual acuity and pain sensitivity following a week of visual deprivation (darkness). Furthermore, these effects were still present several days after termination of the experimental condition. The purpose of this study was to determine whether visual deprivation can produce a similar increase in auditory sensitivity. If this should occur, it will suggest that prolonged visual deprivation may produce a general enhancement of sensory functioning.

Fifteen male university students were placed, in groups of two or three, in a small room for a period of 7 days. Black masks were worn throughout the prescribed period. No other restrictions, either of an auditory, tactual-kinesthetic or social nature were imposed. Two auditory measures, absolute threshold of hearing and auditory flutter, and one visual measure, the CFF, were taken before and after a week of darkness, as well as at intervals of 1, 2, 5, and 7 days after termination of visual deprivation. A group of 15 control subjects were given the same tests and the same time intervals as the experimentals.

A significant improvement in auditory flutter fusion threshold was observed following visual deprivation. This effect was shown by 14 of the 15 experimental subjects and was still in evidence one day after termination of visual deprivation. Measures of the absolute threshold of hearing and of the CFF were not affected by visual deprivation.

Several conclusions may be drawn from this study. First, the differential results seem to suggest that only auditory tasks involving temporal discrimination are affected. Measures of absolute threshold do not appear to be changed. Second, the negative results on the CFF measure indicate that the visual modality itself is not affected. However, it is possible that other measures of visual sensitivity may be affected. Third, the fact that cutaneous sensitivity and one of the auditory measures is facilitated seems to suggest that prolonged visual deprivation may produce a general sensory enhancement involving not only these two modalities but also taste, smell, and kinesthesis. Fourth, these results suggest that the method of prolonged deprivation of one modality may prove useful in the study of intersensory relationships. Finally, the results suggest the advisability of a new look at the centuries old controversy over sensory compensation in the blind. A clarification of the nature of the auditory processes in the blind may be obtained if more complex auditory measures were to be taken and under more controlled conditions.

Several lines of evidence suggest that these intersensory facilitatory effects, following visual deprivation, may be mediated by the reticular activating system.

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