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TFF: QUANTITATIVE ASPECTS OF THERMAL FLICKER FUSION PHENOMENON

by

CAROL JEANETTE LADAN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled: "TFF: Quantitative Aspects of Thermal Flicker Fusion Phenomenon", submitted by Carol Jeanette Ladan in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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PREFACE

The thesis attempts to cover relevant physiological and psychological literature relating to Thermal Flicker Fusion. Further, it attempts a theoretical extension of the alternation-of-response theory into the area of temporal aspects of thermal response. This theory was chosen as a basis for the study, because it organizes a vast amount of visual data involving intermittent input and it is possible that to the extent that basic neurophysiology is shared, it may organize material in the thermal modality.

Unfortunately, investigators have ignored coding in the thermal modality in favor of investigating the visual and auditory modalities. As a result, very little temporal response data exists in the thermal modality. Collection of this particular data may bear directly on alternation-of-response.

This thesis attempts to produce a thermal study analogous to investigations testing the alternation-of-response in the visual modality. Thermal Flicker Fusion (the analogy to Visual Flicker Fusion) is studied because the largest amount of visual data relating to alternation-of-response is in the area of flicker-fusion.

The purpose is not to justify the alternation-of-response theory. It has been outlined in many places (see Bartley, S.H., in the Freiburg Symposium, 1961; Bartley, S.H. in _J. Gen. Psych._, 1971; and Bartley, S.H. in _Contributions to Sensory Physiology_, 1965).

The alternation-of-response theory also has its opponents (see Throsby, 1962).

However, accepting alternation-of-response without further justification of the theory, an attempt will be made to interpret the present study within an analogous framework.

In regards to cutaneous information, relevant aspects are covered. Thermal regulation and comfort, and related aspects are omitted, as peripheral to a temporal study of the thermal modality. For further information relating to cutaneous sensation and mechanism, the reader is referred to texts such as Corso's *Experimental Psychology of Sensory Behavior*, Bartley's *Principles of Perception*, Sinclair's *Cutaneous Sensation*, and Nafe in Murchison's *Handbook of General Experimental Psychology*.

Abstract

Results from a study of Thermal Flicker-Fusion (TFF) are reported. The study tested the effect of input factors similar to those significant in varying CFF (Critical Flicker-Fusion) thresholds for vision. More specifically, amount of area stimulated, intensity level and PCF (Pulse-to-Cycle Fraction) were tested separately, with other factors held constant.

Thermal Flicker-Fusion (TFF) thresholds were obtained by means of intermittent radiant energy produced by a modified Hardy-Wolff-Goodell dolorimeter. Four trained observers were employed, and were tested under all conditions replicated five times. Stimulation was applied to the two body areas (upper back and volar forearm).

In general, the thermal fusion results show close correspondence to the functions produced by varying similar parameters in the visual modality. In both, curves relating sensory fusion thresholds to PCF increase to a maximum and then decline. Significant curvilinearity is seen. Also, increases in amount of area stimulated produces a corresponding increase in both types of fusion thresholds, i.e., results show a significant linear relation between TFF and the variable of area.

One major discrepancy does occur, however. In the visual modality, fusion curves produced by variation of energy level increase to a maximum and then decline. The thermal fusion curves ascend with increases in intensity, as one might expect, but no decline occurs in the range tested. Results indicate a significant linear relation between intensity and TFF. Even though "ascending" judgments were analyzed separately from "descending" judgments (due to the resulting absolute differences in rate between the two types of judgments), the form of the curves remained similar. Moreover, the form of the functions is also similar for the different body areas tested, although differences in absolute rates at fusion are noted.

Results are compared to previous fusion studies in the thermal and other modalities. Decreases in inter-_O_ variability were seen with increasing practice. Results of the present study were similar to those of Kastorf's investigation, in that the form of the analogous curves tended to correspond. Following this, a theoretical explanation in terms of Alternation-of-Response theory is suggested. The significance of the thermal experiments to von Bekesy's hypothesis relating thresholds and density of innervation are briefly discussed.

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Introduction

Interest in the better explored areas of sensation, such as vision or audition, stem from questions posed centuries ago by philosphers, questions raised prior to the time of Aristotle. Few references to their thought about the skin senses can be found, however, since these chapters are believed to have been deleted by Christian monks who translated these works. Rejection was on grounds of moral principles (von Bekesy, 1959). The continuing lack of psychological literature on the skin senses is more difficult to explain. Hall (1969) notes that

> "it is only recently that some remarkable thermal characteristics of the skin have been discovered. Apparently, the capacity of the skin both to emit and to detect radiant (infrared) heat is extraordinarily high, and one would assume that this capacity, since it is so highly developed, was important to survival in the past and may still have a function."

Certainly the skin senses, which include the thermal senses, provide an important route for making contact with the environment and merit more attention than is received in the literature. Whatever the cause, the result is a large gap in our knowledge.

Touch is the most fully explored, although clearly, the information is far from complete. The thermal senses are much less well understood. They have only lately begun to be investigated. Current interest is primarily due to recent advances in physiology. Psychological research has not kept pace with the physiological inquiry, with the result that there is a dearth of systematically organized sensory information.

The present research deals with one problem that can be approached from a psychological perspective. By comparison of the functional characteristics in vision and audition, an attempt will be made at quantification of similar aspects of the thermal modality. It is hoped that this will aid in advancing psychology parallel to the advances being made in the physiology of sensation.

Physiology and Anatomy Underlying the Thermal Senses:

There is a great quantity of recent information. Only those aspects will be considered which are directly related to sensory psychology, however.

1. Receptor Theory:

The thermal receptors for the sensations of warm and cold have, in this century, received intensive study, but often with contradictory results. Von Frey's "spot" theory suggested that a specialized end-organ could be found under the skin of each sensory spot, responding to a particular type of stimulus. Endings were expected to be anatomically different for each of the four modalities considered (von Frey, 1895).

There is no credible evidence, however, confirming the supposed nature of the warm or cold receptors (Sinclair, 1967). The closest thing is experimental evidence regarding the depth of thermal receptors which has been accumulated by several different methods. The unanimity of the results indicates that the cold receptors may lie more superficially in the skin than the warm receptors. Unfortunately, these results do not take the next obvious step. Neither warm nor cold receptors have been subjected to a detailed analysis of the anatomical type and distribution at various depths. This would need to be done to establish the unique structures required by the theory. However, while the evidence on morphological distinctions is in dispute, the physiological data do seem to suggest that some receptors are more or less selective for temperature change (Hensel and Boman, 1960), i.e., some functional differences in nerve endings might exist.

Although the von Frey or "spot" theory has little experimental support, it is still the best known explanation for the reception of warm and cold. Its value exists in the ability to explain the punctate distribution of touch, pain, and the temperature senses (Mueller, 1965). Implicit in the von Frey theory is the notion that the immediate stimulus for thermal sensation is temperature (as a form of energy transfer), since heat exhange will occur when unequal amounts of heat are contained by the skin and the stimulus object or environment. As long ago as 1690, Locke hypothesized that the sensation of warmth is perceived when energy is transferred to the skin, and cold sensations arise when the skin is cooled (by negative energy transfer). A correlate to this theory suggests that a stimulus that is experienced as warm to a cold skin might feel cool to a warm skin. While some supporting evidence exists, the theory is incomplete, because a cold sensation may persist after the stimulus is withdrawn (when the flow of heat to the skin in interrupted), and even when skin temperature has reached a steady state or is warming up (direction of heat flow is reversed). Perception of a thermal stimulus is, therefore, apparently not a simple matter of energy transfer (Sinclair, 1968).

Other peripheral sensory theories regard the nature of the immediate stimulus for warmth and cold as either temporal or spatial gradients in the skin. Neither heat transfer theory nor any modifications of this theory have gained much support (Sinclair, 1968). More specifically, the spatial gradient theory proposes that sensations of warm and cold result either from thermal gradients between blood vessels and tissues near the end-organs, or from temperature changes in the blood (Bazett and McGlone, 1932). The temporal gradient theory considers the effective stimulus to be a difference of temperature between the stem axons and their terminals. This latter theory was first suggested by Lele et al., (1954), who proposed an apparatus similar to a thermopile bolometer, used to measure temperature differences. Evidence against both heat transfer theories has been put forth by Hensel and Zotterman (1951) who found that thermosensitive fibers in the cat's tongue continue to discharge rapidly for long periods at almost constant frequency although the temperature gradient quickly becomes constant.

Another theory explains thermal reception using an intervening physiological variable.[1] This theory suggests that temperature itself does not fire the thermosensitive endings, but does so only through an intermediate process. One type of suggestion has been that thermal energy is first converted to mechanical energy. Dessoir (1892), an early proponent, suggested that thermal stimulation caused a change in the calibre of the blood vessels, providing a cue to higher centers. Nafe (1934) thought that the smooth muscle of the cutaneous vessels acts as a thermomechanical transducer stimulating sensory nerves which it contains by contracting or relaxing. The cue for warmth would be the relaxation of the vascular muscles, whereas contraction would be the cue for cold.

A more recent suggestion has been that of a chemical intermediary. Certain chemicals, when placed on the skin, can produce sensations of cold or warm, and can also affect the discharge from thermosensitive fibers (Hensel and Zotterman, 1952).[2] It is commonly agreed that the possibility of a chemical intermediary requires further research.

2. Transmission of Sensory Cutaneous Information:

Although the structure of the peripheral neural apparatus is far from settled (Geldard, 1953), somewhat more fixed evidence exists for the system for transmission of cutaneous information to higher centers. The nerve fibers involved in thermal transmission are believed to terminate in the grey matter of the spinal cord. The fibers are thought to cross to the contralateral side of the cord and ascend with a group of fibers in their own pathways in the lateral column. The fibers responding to pain and temperature are thought to ascend in the lateral spinothalamic tract, whereas the ventral spinothalamic tract conveys information about touch (Geldard, 1953). The pain and temperature systems are diffuse since they are presumed to be an earlier phylogenetic system than that serving discriminative touch. The lateral spinothalamic tract, dealing with qualitative rather than quantitative aspects of cutaneous sensation, is thought to have evolved earlier since these aspects are thought to have more adaptive value than those dealing with fine and precise discriminations (Mountcastle, 1959). Although the pain and temperature systems are qualitative rather than quantitative on a sensory level (indicating a diffuse, non-specific system), the pain and temperature pathway to the thalamus is direct. This is where the final relay to cortex occurs. The chief projection is upon the primary sensory cortex in the post-central gyrus.

It should be mentioned, however, that although central reception seems inevitable and that some cortical cells have been found in this region which respond to cold stimuli, none have as yet been found responding to warmth (Sinclair, 1968). But, since cells which are responsive to more than one modality exist (Mountcastle, 1959), it may be that warmth is the more subtle or less obvious reaction of these cells, and has, for this reason, received little attention.

Thermal homeostasis, however, implicates central mechanisms. Benzinger (1963) notes that the thermally-sensitive nerve endings of the skin are implicated via the centers of consciousness of the cortex. The body reacts to thermal sensations by use of the effector organs, i.e., an organism seeks to change its environment to alleviate thermal discomfort. Benzinger further notes that the skin thermoreceptors cannot regulate internal temperature with any degree of precision, however. More precise control is achieved by an autonomic mechanism, first described by Ranson (1939) and termed a "warm sensor" by Benzinger (1963). Its location is thought to be a region of the anterior hypothalamus; its function is hypothesized to be a role in temperature regulation. The receptors of this sensor are thought to have a sharply defined threshold and to be highly sensitive.

Ranson (1939) further noted that the hypothalamus is the chief center for integration of homeostatic regulation by the central nervous system. Removal of the brain in front of the hypothalamus does not abolish temperature regulation, as does removal of the hypothalamus. Further, temperature regulation is impaired by transsection of the cervical spinal cord. This interrupts descending paths from the hypothalamus to the sympathetic system which controls piloerection, vasoconstriction and sweating. In this way, the hypothalamus is thought to control heat production and loss.

Benzinger's studies indicate that warm receptors are located in the central nervous system and are sensitive to internal indicators of temperature, e.g., blood. Peripheral (cold) receptors project into the hypothalamus, as indicated by Ranson (1939) who hypothesized a cold-sensitive region located in the posterior hypothalamus. Benzinger's studies have led him to conclude that in temperature regulation of man, central reception of warmth and peripheral reception of cold are dominant, in that conscious sensations of warmth correspond to internal measures while cold sensations correspond to peripheral measures. Differing projections for warm and cold fibers may be implied.

Psycho-physiological Aspects of Warmth:

It is difficult, of course, to draw a firm dividing line between the psychological and physiological aspects of the thermal modality. Physiological study of the thermal modality not only attempts to relate an isolated stimulus with the restricted event it produces, but also considers the possible significance of the stimulus for the animal. For example, warmth is often allocated to a stimulus having a temperature above 37° C. or containing a certain number of calories. It should be realized that this is a physical designation and clear only in light of the sensation "warmth" as perceived by the observer. The interests of the psychological and physiological disciplines are closely interrelated.

As mentioned previously, that aspect of exploration of the thermal senses that is for the most part psychological has lagged behind physiology.

However, psychology has attacked the problem of the exploration of the thermal senses from the aspect of adaptation and changing thresholds. One result has been delineation of the "zone of thermal indifference" (Geldard, 1953).

Several behavioral phenomena have been observed that have relevance for both physiology and psychology. One is adaptation, which simultaneously affects both cold and warm. Prolonged stimulation with either hot or cold produces a shift in the sensory threshold for both modalities, and also changes the point of thermal indifference. The course of thermal adaptation has been plotted by Hahn (1929) and can be found in Geldard (1953). An improved technique for determining the temporal course of thermal adaptation was developed by Kenshalo and Scott (1966). Their technique required subjects to adjust the temperature of the stimulator to maintain a just-detectable sensation, and resulted in a more precise plot of the course of thermal adaptation.

The Cutaneous System in Alternation-of-Response Theory Perspectives:

The present study will consider the thermal senses in terms of alternation-of-response theory. This theory was originally proposed by Bartley (1938). It was designed to describe how the visual system reacts to intermittent light stimulation and alters sensory experience of brightness and affects flicker-fusion thresholds.

The basic concept of the theory is that all neural units react to stimulation with a burst of activity and then require a recovery interval before they can be reactivated (Bartley and Nelson, 1963). Nelson and Bartley (1964) state that:

> "the alternation-of-response theory provides a time-intensity picture of the central end of the optic pathway. It consists of a set of statements regarding the way the optic pathway responds in relation to the quantitative (intensive, durational, and distributional) aspects of photic input. It predicts what is to be expected in cortical response and sensory end-results when various features of the pathway activity are altered by known forms of input."

The alternation theory suggests that flicker and fusion and brightness vary because factors throughout the optic pathway work in certain temporal patterns and combinations (Nelson and Bartley, 1965).

Flicker and fusion thresholds are related to uniformity of discharge density. Density refers to the discharge activity per unit time and is defined as the reciprocal of separations between channel discharges within central portions of the pathways (Nelson and Bartley, 1965). Nelson and Bartley have put forth the hypothesis that flicker persists so long as critical values in irregularities of density persist. They suggest that presenting photic stimuli at low rates produces a very dense average channel activity for a brief period. However, this is followed by a period in which average density is very low, producing the effect of a highly variable density. As rate of stimulation is increased, the proportion of channels in synchrony gradually decrease, producing an increasingly uniform pattern of discharge. Near CFF, channels are firing uniformly at their instrinic maximum rate and differences between recycling characteristics lead to minimally structured temporal sequences of activity.

Although the alternation theory originally described visual response, it has also been considered in discussion of other modalities, including the skin senses (Bartley, 1959). It is known that the visual system functions similarly in some respects to the cutaneous senses as well as the auditory modality. The chief qualification here is that due to the very nature of the skin (its thermal mass and the amount of tissue between surface and receptors), the skin senses might be expected to yield a slower response.

Peripheral reception of the cutaneous senses is a variable of major significance. Granit (1955) regards the skin as the prototype of all sense organs and has noted that:

> "the sentient skin surface...illustrates a number of elementary principles in the organization of the sensory message. The stimuli called touch, pressure, and pain deliver both general and localized messages. The general piece of information is based on very large receptive fields, the localized on smaller receptive fields down to punctiform ones. There is considerable overlap of receptive fields. These principles will recur in other organs, such as the eye and ear, which are built up as sentient surfaces."

However, the overlapping receptive fields of vision are more complex than those of the skin, where inhibitory processes are presumed not to act until the level of the spinal cord.

Although the thermal modality is to receive primary attention, a comparison of touch and vision is pertinent. Rose and Mountcastle's (1959) summary of experiments on the tactile system (touch) indicates several parallels between the visual and cutaneous inputs, having relevance for the alternation-of-response theory. Rose and Mountcastle note that in both modalities, and at all levels of the nervous system, the response to brief stimuli is a short train of spikes. The number of spikes in the response train decreases as stimulus rate increases until finally a single spike follows each stimulus. At higher rates, single fibers respond at their intrinsic frequencies, but not to every stimulus. Instead, a redistribution has occurred, with some neurons responding to one stimulus, and others to succeeding stimuli, allowing the first fibers to recover. Also, as in the visual system, the tactile response to repeated brief stimuli consists initially of a synchronous response followed by a reorganization period during which the stimuli produce an irregular response. If the train is of sufficient length, a more regular response is achieved. During the condition of alternation, the overall response per unit time is less than that of all units responding in synchrony, which is, again, like the description of the visual response.

While touch shares the mammalian integument with other modalities including warmth and cold, it is uncertain how far knowledge of tactile activity may be generalized to the thermal modality. The properties of the peripheral receptors of the tactile and thermal modalities seem to be similar in some respects. However, as mentioned previously, channels differ for the central transmission of thermal and tactile information.

1. Similarities Between the Visual and Cutaneous Systems:

According to the alternation-of-response theory, the visual system consists of several independent channels which carry information from the periphery to higher levels. Likewise, in the cutaneous (including thermal) modality stimulation of a large area of the trunk activates several overlapping fibers, the result being a condition in which a distribution of channel discharges might occur.

Another parallel between systems concerns the phenomenon of funnelling. Von Bekesy (1959) describes this phenomenon as the inhibition or complete suppression of a surround sensation which contributes to increasing the magnitude of the central sensation. Mach's Law of Contrast in vision is the best known example of funnelling action according to von Bekesy (1958). This phenomenon occurs when light density is distributed along the retina with two changes in the slope. The sensation density differs from the light density in that the sensation magnitude of the physically brighter area is accentuated whereas the effect of the less bright area is inhibited or suppressed. Von Bekesy has also demonstrated a cutaneous analogy to Mach's Rings, thereby illustrating that sensory funnelling occurs in the cutaneous systems as well as in the visual system. Thermal funnelling has also been successfully demonstrated (Vendrik and Eijkman, 1968). These funnelling properties have been shown to be related to the inhibitory aspects of antagonistic surround fields in the visual and touch modalities, and therefore, it is likely that a similar mechanism may operate in the thermal system.

The function of the skin as a sense organ is also similar to that of the retina in that the latter is stimulated directly by quanta which impinge on the receptor. The skin also requires direct stimulation in the case of touch and pain. Likewise, the hair cells in the ear are activated by bending. All sense organs are contact organs.

However, the skin is more flexible, in that it can be stimulated thermally be contact stimuli and also by impingements from a source removed from _O_. A psychological distinction exists between the senses, in that the eye and ear are classed as distance receptors and the skin as a contact receptor. However, the difference may depend more on the method of presentation of stimuli rather than on any intrinsic differences.

2. Differences Between the Visual and Cutaneous Systems:

A comparison of the receptor densities (number of receptors/unit area) of the retina and the skin is possible. Granit (1955) mentions that prior estimation of the number of human optic nerve fibers (Bruesch and Arey, 1942) exceeds one million, and further notes that the average convergence of the receptors on the optic nerve fibers is approximately 100:1. The human retina would, therefore, contain approximately one hundred million receptors. The skin surface, on the other hand, contains approximately five million receptors excluding the touch receptors (Steen and Montagu, 1959). The number of touch receptors, estimated by ratio from knowledge of the average number of spots per square centimeter for touch and pain (Woodworth, 1938), and the approximate number of pain points in the skin (Steen and Montagu, 1959) is approximately two million, bringing the total number of skin receptors to approximately seven million. The ratio of visual receptors to skin receptors is therefore 100:7, or approximately 14:1. Further, the number of thermal points in the skin are as follows: cold: 150,000; warm: 16,000 (Steen and Montagu, 1959).

The density ratio of visual receptors compared to thermal receptors would therefore be much larger.

The skin also differs from the retina in that it is a continuous surface in three dimensions, a sensory sac as it were, presenting a large, potentially stimulatable area to the environment. The retina, on the other hand, is a single, slightly curved area, receiving stimulation from an angle scarcely greater than 180°, requiring movement of other body parts in order to receive stimulation from other than a frontal plane.

The integument is more than a sensory surface - it is also a protective shield from the environment. Further, portions of the skin are covered and receive tactile stimulation from clothing, a sensation which quickly adapts. The skin is necessarily a more durable, thicker surface than the retina, as the skin is almost continuously being stretched, crushed and compressed. The skin can withstand these harsh conditions and return to shape without loss of function, whereas the retina, a more delicate and protected apparatus, could not. The retina is primarily a receptor surface, whereas the skin incorporates more functions than one. The skin is, therefore, much less specialized than the eye on this account alone, and can be expected to be considerably limited as a sensor.

Vision: Specific Relations Between CFF and the Stimulus Parameters of Intensity, Area and PCF:

1. CFF (Critical Flicker Frequency) as a Function of Intensity (Luminance):

A direct relation between CFF and luminance of the stimulus has been suggested. This is known as the Ferry-Porter Law, and states that CFF increases as a direct function of the logarithm of the stimulus luminance. (As an equation, $F = a \log L + b$, where F is CFF, L is luminance and "a" and "b" are constants.) As with many visual laws, the Ferry-Porter Law is a generalization which holds only for an intermediate range, and for rather restricted conditions. At low levels of luminance, the increase in CFF is slower than predicted by the function. At higher luminance levels, the curve increases to a point, and then begins to fall. Nelson and Bartley (1965) note that:

> "intensity is effective in increasing CFF in so far as it puts more channels into activation; hence, increases the likelihood of residual synchrony being maintained at higher rates of repetition. At extreme intensity, however, the peripheral elements continue activity after the pulse has terminated. And this is reflected both in a more random activation of the central end of this pathway and by reduction in CFF. When intensity conditions are optimal, the peripheral (retinal) response corresponds to stimulation rate, and almost all central portions of the visual system (channels) likewise approach correspondence with peripheral rate".

Wavelength also alters the Ferry-Porter relation, as does the retinal location of the stimulus. The values of the constants appear to decrease as locus becomes increasingly displaced from the fovea. Hecht and Verrijp (1933) present CFF curves which appear quite flat at a distance of 15° from the fovea, although intensity is an increasing function.

2. CFF as a Function of Area:

A linear relation between CFF and the logarithm of the stimulus area has been described by Granit and Harper (1930). As an equation, it is stated thusly: $F = c \log A + d$ where F = CFF, A is stimulus area, and "c" and "d" are constants. Brown (1965) suggests that an increase in stimulus area produces summation which results in an enhancement of flicker. As with the Ferry-Porter relation, the Granit-Harper Law is also subject to restriction. The relation is dependent upon intensity levels, and is not linear at extremely low ranges. At these lower levels, only the rods are activated, whereas at higher intensity levels both rods and cones function and the relation holds. Also, Berger (1953) has shown that the relation may be altered by the presence or absence of a surround field.

The increase in CFF that occurs as stimulus area becomes greater may be a direct result of the corresponding increase in the number of receptors stimulated. Weale (1958) describes this relation as follows: $F = k \log LN^p + k'$, where F = CFF, N is the number of receptors stimulated (as estimated from retinal area and receptor density), p is the index of retinal summation, and "k" and "k'" are constants.

3. Relation of Pulse-to-Cycle Fraction (PCF) and CFF:

The proportion of stimulation in the cycle (PCF) is one of the major factors in determining the rate at which intermittent light stimuli appear to fuse (CFF).

In 1937, Bartley attempted to determine the relation of PCF and CFF. He obtained a curve which rises to a peak as PCF increases, then declines as PCF becomes even larger. At low luminance levels, the curve peaks at PCF 1/2, while at high luminance levels, the maximum occurs at a low PCF (Throsby, 1962). More recently, Nelson et al., (1964) have noted that at low intensities, the curve does not peak to as great a degree, i.e., varying PCF does not produce a large change in CFF.

When cycle length is held constant, increase in PCF lengthens pulse duration, as well as shortens the null interval. At short pulse durations, inter-pulse interval is of primary importance to the production of flicker. When pulses are separated by lengthy intervals, each stimulation does not contribute to the perception of flicker, but appears as one of a series of separate events. At long pulse durations, the important process is recovery. If the pulse is long, irregularities in density (see p. 11) are reduced. As mentioned previously, fusion is achieved when the reductions of these irregularities reaches a critical level. The longer the recovery interval, the larger the number of channels which will respond with a burst to the next stimulation, and require a longer period for all to respond uniformly. As PCF is varied, different types of neural discharges emerge and are suppressed. At low intensity levels, and with short pulses, the level of activity may not undergo a large change, and therefore result in low CFF's. Bartley (1958) describes the production of CFF at short pulse durations (small PCF's) at higher luminance levels in the following way:

> "With a very short stimulus of a given intensity and a low enough rate of intermittency, flicker will ensue. If the same intensity and pulse rate are retained but the pulse length is increased, the pulse now occupies a greater fraction of the intermittency cycle. Whereas previously a train of pulses at the same rate did not succeed in producing uniform sensation owing to the extreme brevity of the pulses and the long intervals between them, uniformly in sensory end result is brought about by lengthening the pulses. Hence, we pass from flicker to fusion."

Bartley and Nelson (1961) suggest that the maximum in CFF which occurs for a further increase in pulse length may be explained by the presence of an "off" effect contributing to the perception of flicker. Electrophysiological studies have shown that the "off" effect does not occur at short photic durations, but appears when pulse duration becomes longer. The decline of the curve at long pulses would therefore appear difficult to explain, since the "off" effect occurs under these conditions as well as mid-range conditions. However, Bartley and Nelson suggest that the "off" effect at long pulse durations is inhibited by the "on" response to the stimulation of the succeeding flash. The peak, or CFF maximum, would therefore be the result of stimulation with a PCF having a pulse long enough to produce the "off" effect, combined with an inter-pulse interval of sufficient length that the "off" effect is not inhibited by the "on" effect of the next pulse. The CFF maximum would occur at this optimum value of PCF within the possible range from zero to one.

It should be mentioned that other researchers (Ives, 1922; Winchell and Simonson, 1951; Lloyd and Landis, 1960) have reported that CFF decreases linearly with increases in PCF, or in some instances, increasing as a function of PCF. Landis (1954) has studied the contradictory results and has not succeeded in finding a way to reconcile them. However, Bartley (1958) has found that under conditions compensated for brightness the curve will decrease continuously, and suggests that his interpretation of the role of the "off" response in the situation can reconcile the findings.

Fusion in Other Modalities:

A phenomenon analogous to CFF occurs in the auditory modality. The rate at which intermittent sounds appear to fuse (AFF) has been studied by varying the proportion of auditory stimulation in the cycle (ACF). Symmes, Chapman and Halstead (1955) produced ACF (Acoustic-Stimulation Fraction of Cycle). The visual correlate of ACF is PCF, and the correlate of AFF is CFF. The curves produced by Symmes et al., are not complete, however, as only PCF's from .50 to .95 are illustrated. The shape of the curve below PCF .50 can only be speculated upon, but it is possible that the curves rise to a maximum, as do the visual curves.

Hypotheses have been put forth concerning the factors determining the AFF threshold. Harbert, Young and Wenner (1968) determined

AFF thresholds by varying rise and decay times. Their results suggest that off-time is the major factor in determining the AFF threshold, whereas on-time produced no significant differences. Wever and Bray (1930) and Wever (1949) have suggested an underlying explanation of the auditory response which is viable for all frequencies including the high ranges. Their suggestion is similar to Bartley's alternation-of-response theory in that they postulate a redistribution of responding fibers.

Fusion phenomena are known to occur in modalities other than vision and audition. Kastorf (1919) refers to a study by Cords (1907) in which the fusion point for intermittent electrical stimuli was found (160 stimulations per second). The particular sensation evoked is difficult to determine, however. Kastorf also notes that a frequency of 300 to 600 stimulations per second results in sensory fusion produced by mechanical contact stimuli. Mountcastle et al.'s more recent studies (1967, 1968) indicate that flutter-vibration is a dual form of mechanical sensibility served peripherally by the different sets of fibers linked to two equally distinct sets of cortical neurons. Further, he notes that low frequency flutter is a result of the temporal pattern of the stimuli and is coded in the cortex by the temporal order of neuronal discharge. High-frequency discharge is also represented centrally. Mountcastle's explanation of mechanical flutter is similar to the alternation-of-response theory in that it is suggested that temporal patterns of discharge at central levels result in flutter (flicker).

Fusion of Warmth: Prior Research:

Temporal aspects of thermal sensations have seldom been studied. The exceptions are two almost unknown studies conducted early in the Twentieth Century. The first study was conducted by Basler (1913), who earlier (1911) had attempted to determine the conditions for visual two-flash thresholds. Basler varied the proportion of warm to neutral stimuli, producing, in effect, a warm-time fraction. His apparatus consisted of heated corks fitted into a mill rotated by an electric motor. Several body areas were stimulated, including the palm and the volar surface of the forearm. It is evident that there is some difficulty in Basler's paper concerning the proportion of stimulation in the cycle, however, a plot of the data given in his first table shows the fusion rate as a decreasing function of increasing pulse duration.

Kastorf's (1919) data, on the other hand, was produced with more modern equipment and yields a more precise result. He too employed the skin of the forearm, and in addition, blackened the surface with ink, in order to reduce reflectance. In order to avoid involving the sense of touch as Basler's apparatus had done, a radiant stimulus was used, in concert with lens arrangement and tin episcotister which provided different proportions of warmth and neutral.

It is possible to plot a thermal flicker curve from Kastorf's data for a PCF of .50 at three intensity levels (Figure 1), and also a thermal flicker curve for four PCF's (.12 to .50) at two intensity levels (Figure 2). Figure 1 illustrates that fusion rate increases as intensity increases, as predicted by Kastorf. No stimulus values are given, however, but are simply designated as "low", "medium", and "high". Figure 2 plots proportion of stimulation in the cycle vs. fusion rate. For both intensity levels, rate increases as PCF becomes larger, at least for PCF's up to .50. No larger PCF's were studied. It should be noted that both Figures 1 and 2 are for ascending judgments only, i.e., no trials were given which began at fusion rates and decreased to flicker. Both figures are composites of tables given by Kastorf.

Translated, Kastorf gives the following explanation of the fusion phenomenon:

> "...after a certain length of time or irradiation, closer fluctuations in the temperature of the skin are produced than at the beginning of the experiment. In many cases, despite the same frequency as at the beginning of the experiment, these closer fluctuations are in a position to bring the relatively slowly reacting sensory organs to a clearly perceptible change in their state of stimulation. This is not possible with the more graduated fluctuations at the beginning of the experiment."

Also of interest, is the fact that Kastorf notes that practice is necessary to acquire the skill of discriminating flicker and fusion.

Interest in the temporal aspects of the thermal senses seems to have again declined after these first attempts. The object of the

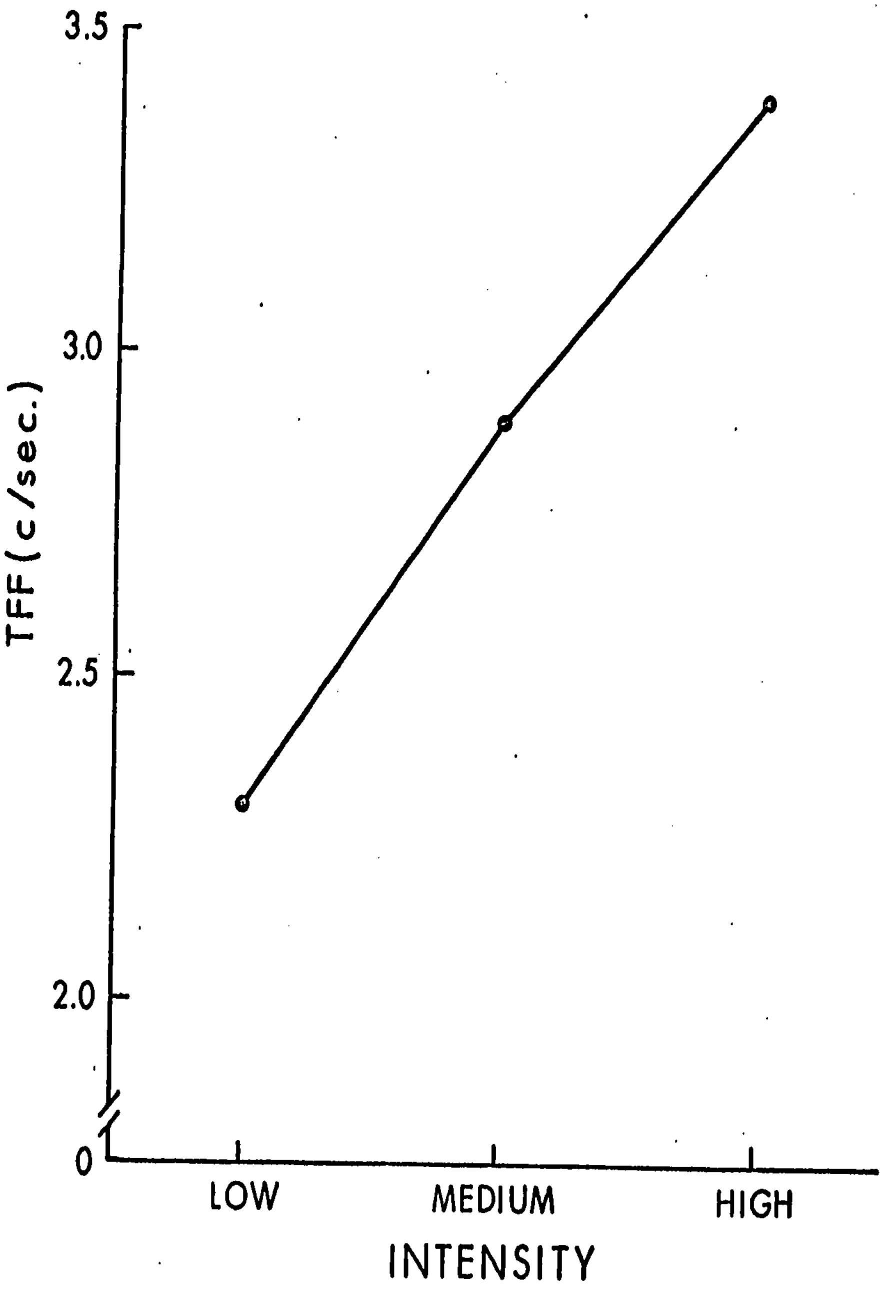


Figure 1

Kastorf's data plotted for fusion rate vs. intensity for one 0. PCF was held constant at .5 and three intensity levels (designated as "high", "medium", and "low") were employed.

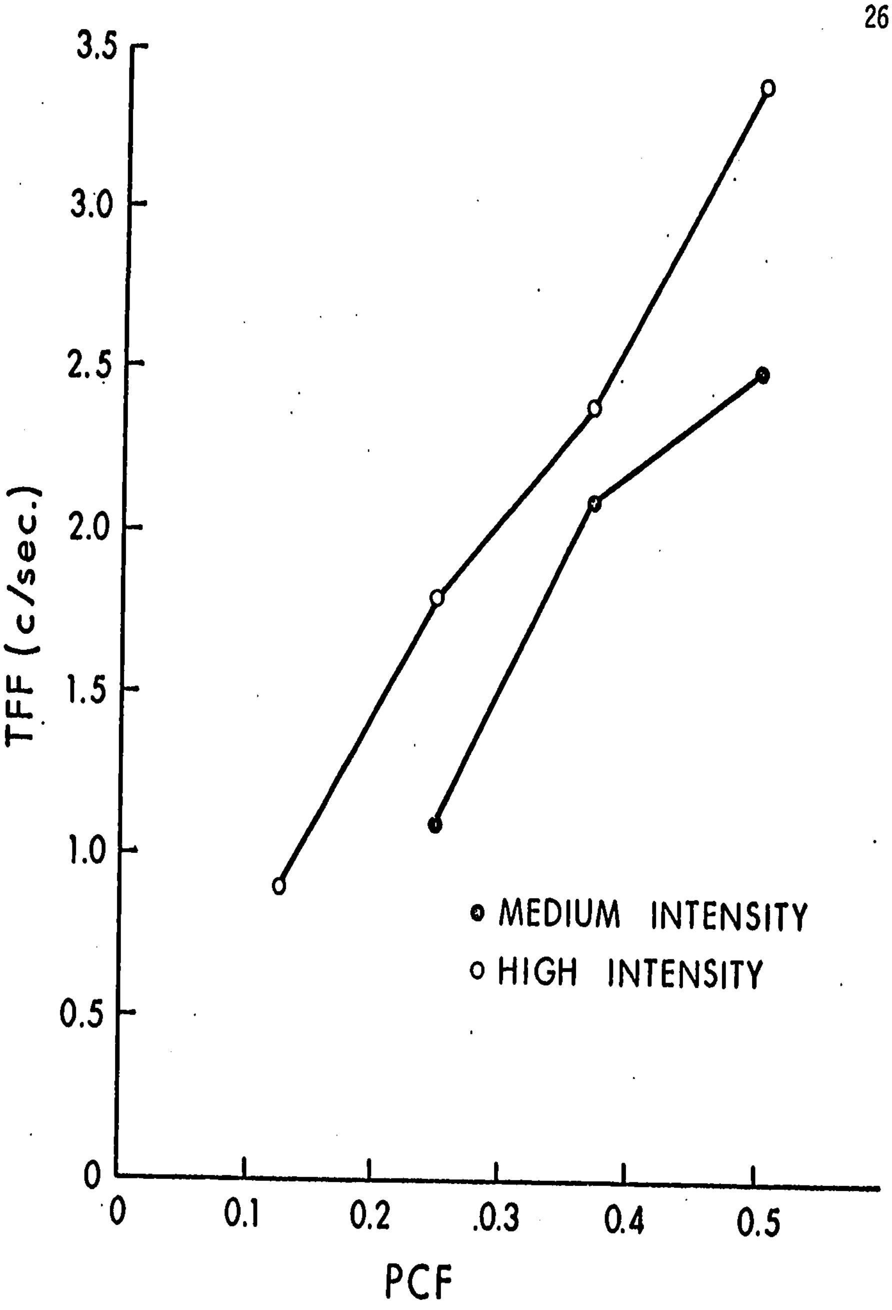


Figure 2

Kastorf's data plotted for fusion rate vs. PCF for two intensity levels ("medium" and "high"). Four PCF's were employed. The data for one O is shown.

present study is to extend the previous research, varying proportion of stimulation in the cycle or pulse-to-cycle fraction (PCF), intensity (I), stimulus area (A), and body area stimulated. Rate at which sensory fusion of warmth or Thermal Flicker Fusion (TFF) occurs is the dependent measure.

Predictions of Cutaneous Thresholds Based Upon the Alternation-of-Response Theory:

The hypotheses are formed essentially by analogy to the previously discussed visual correlates. The following will be tested:

1. As PCF is increased, TFF (Thermal Flicker Fusion) will rise to a maximum and then decline (all other factors held constant). The form of the curve is independent of the body area tested.
2. As I is increased, TFF will likewise increase, all other factors held constant. The relation is independent of body area tested.
3. As A is increased, TFF will likewise increase, all other factors held constant. The relation is independent of body area tested.
4. Although different body areas will be tested, the basic relation between the variables mentioned and TFF will not alter. Variation of body test site will only alter the absolute values of TFF, in accord with von Bekesy's (1959) prediction, i.e., the threshold will decrease as density of innervation increases. It is therefore expected that TFF thresholds will be lower for the forearm than for the back, i.e., thermal fusion is expected to occur at

higher frequencies on the forearm, as sensitivity (in this case, the ability to discriminate separations between pulses) increases with corresponding increases in fusion rates.

Analogy with the alternation-of-response theory would lead to similar predictions since increases in intensity or area likewise produce higher CFF rates. It has been suggested that increases in either variable leads to recruitment of additional first-order fibers, and result in higher CFF rates. Likewise, increasing the number of responding fibers through increases in density may likewise lead to higher fusion rates in both the visual and thermal systems. The prediction that TFF thresholds will be higher (in absolute values) on the forearm than on the back surface is therefore formulated from both von Bekesy's hypothesis and alternation-of-response information, i.e., increases in density of innervation will produce higher TFF rates.

Method

Observers

Four male observers (Os) between the ages of 17 and 29 were used. Three were paid. One O (SL) had prior experience in pilot studies, but all were naive with respect to the hypothesized result of the experiments. Each participated for approximately one hour per day for about five and one-half months.

Apparatus

Areas of Body Stimulated:

The upper back and the volar surface of the right forearm were tested. The area stimulated was initially blackened with India Ink to reduce reflectance.

Heat Source:

The stimulation was provided by a modified version of the Hardy-Wolff-Goodell apparatus (see Pain Sensations and Reactions, 1952). In this case, however, the dolorimeter used was designed to provide warmth rather than pain and calibrated to provide several different intensities at each of four different areas (see Table 1). It was comprised of two parts: a lens arrangement to focus the radiation, and a case containing the controls and mechanism to provide intermittency.

A long table supported the lens arrangement, which consisted of one fixed and one sliding aspheric condenser lens (diameter: 72.5 mm., focal length: 46.0 mm.), [3] a radiant energy source, [4] and a front

Table 1

Calibration of the modified dolorimeter for the four different areas employed. Range and divisions calibrated for each area are shown.

Diameter of Circle (in inches)	Range	Divisions
1	F = 78° - 250° or C = 30.0° C. - 121.1° C.	every 2°F. or 1.1° C.
1 3/4	F = 90° - 112° or C = 32.2° C. - 44.4° C.	every 2°F. or 1.1° C.
2 1/2	F = 75° - 135° or C = 23.9° C. - 56.7° C.	every 5°F. or 2.8° C.
4	F = 80° - 100° or C = 26.7° C. - 37.8° C.	every 5°F. or 2.8° C.

surface convex mirror (51.0 mm. in diameter, focal length: 22.0 mm.), all mounted on a Cenco optical bench 115 mm. in length. [5] Apparatus was aligned so that the skin surface to be tested would be at the focal point of the lenses. The sliding lens was adjustable to provide different areas of stimulation. [6]

Intermittent Stimulation:

The heat source was made intermittent through a system of a unijunction transistor (U.J.T.) oscillator in relay with an electronic switch or power driver. This oscillator provided frequency control of the cycling pulses (variation of rate ranging up to 6.25 c./sec.), whereas the electronics switch converted the pulses to square waves and also provided control of the duration of the pulse length. The power driver was used to limit the on/off time of the electronics switch. The combination of switches allowed different pre-determined PCF's to be set. PCF's used were 1/6, 1/3, 1/2, 2/3, and 5/6. Pulses were displayed on an oscilloscope which allowed the measurement in terms of cycle duration, the inverse of rate.

Controls:

The case containing the mechanism and controls of the dolorimeter was located in a separate room adjoining the main experimental room, so that the noise of an internal relay was not distracting.

The main experimental room contained the remaining apparatus, <u>O</u> and <u>E</u>. Apparatus for the forearm is illustrated in Figure 3. Two

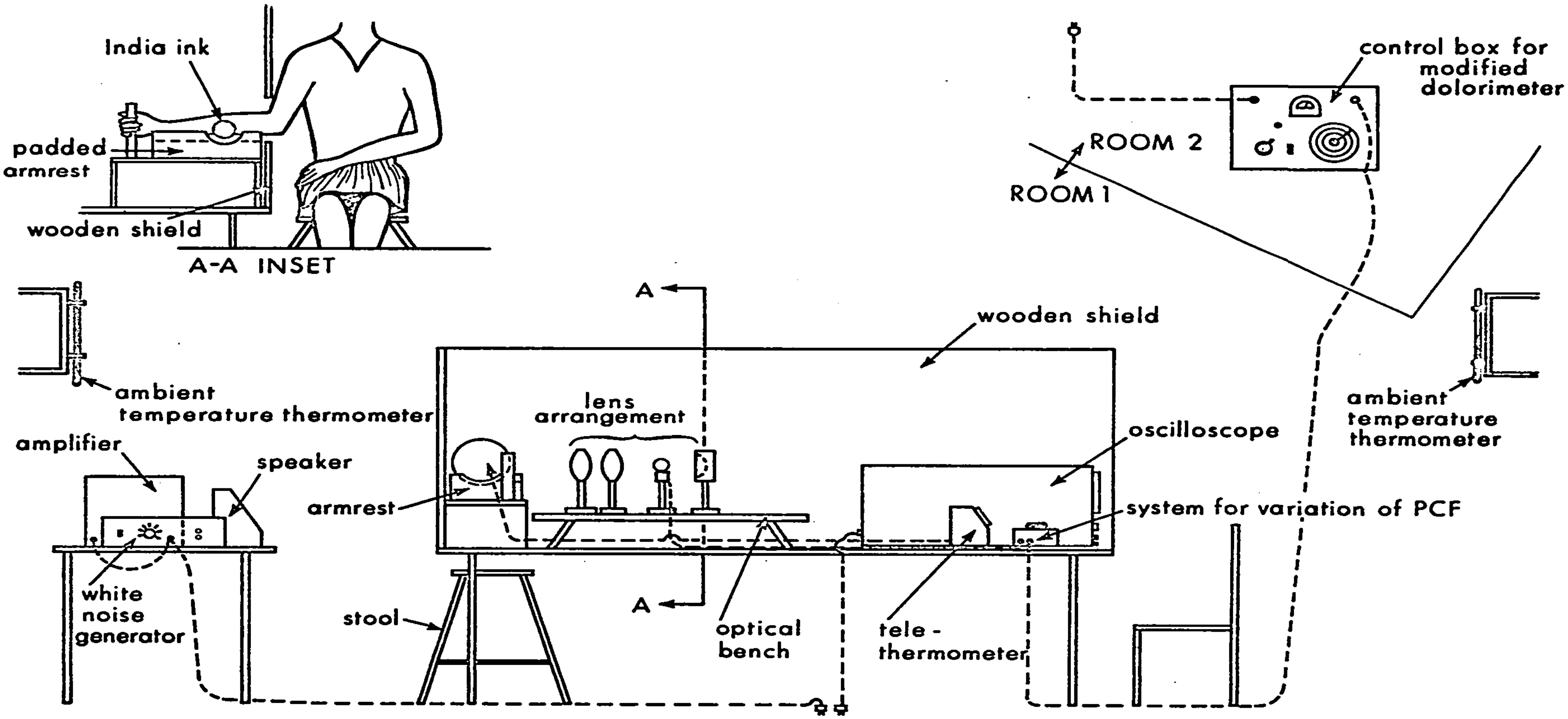


Figure 3: Schemata of apparatus for stimulating the forearm. Inset shows the cross-sectional view. The wooden shield and arm-rest were removed when stimulating the upper back.

(Fisher Scientific) ambient-temperature thermometers (calibrated to .10 degrees C.) were fixed on opposite walls. The long table also supported a plywood shield designed to eliminate visual cues. The shield contained a circular aperture large enough to accommodate _O_'s upper arm. The aperture was masked with cloth to further prevent visual cues. A rest provided arm support.

Apparatus providing stimulation to the back was very similar. However, the shield and armrest were not used, and _O_ was seated so that the energy from the source impinged directly on the surface of the upper back. Visual cues were therefore not a problem, as _O_ faced away from the apparatus.

The masking device for the forearm consisted of three interlocking concentric circles of pliable plastic with apertures of diameters one inch, one and three-quarter inches, and two and one-half inches. The masking device for the back was similar in that three interlocking concentric circles were used. However, it was shaped from cardboard, and the diameters of the apertures were one inch, two and one-half inches, and four inches. Adhesive tape affixed the masking device to the skin.

Auditory cues were further reduced by an arrangement of an amplifier, speaker and white noise generator positioned directly behind and to _O_'s right. White noise was generated at eighty-eight decibels, as measured by an A band decibel meter (Type 1400G Dawe Instruments).

This white noise effectively masked the sound of the internal relay of the dolorimeter, which otherwise may have served as a cue, in as much as its sound kept pace with increasing rate of stimulation.

The YSI Model 42SF tele-thermometer was fitted with a probe designed to measure skin temperature. Temperature in the main experimental room was fixed to provide a constant ambient temperature. O sat on a stool.

Procedure:

Training:

Large inter- and intra-observer variability in response in pilot studies indicated that in the major studies, preliminary training would be necessary. To this end, all were initially trained for ten one-hour sessions to observe standard criteria for flicker and fusion. Os were shown a chart (see Appendix "A") describing the changing experiences a trained O had reported occurring at various rates for large, medium, and small PCF's. When the training sessions were completed all Os stated that the experiences described on the chart were representative of their sensations. It was then assumed that all Os would use the same criteria in their judgments.

Room Temperature:

A preliminary study tested for effect on threshold rate of variation of room temperature. Factors, other than room temperature, were held constant at PCF 1/2, I = 120° F. (48.9° C.); and area = 2 1/2" d. Effects are stated in "Results".

Thresholds:

Each individual's warmth and pain thresholds for the body surfaces employed were determined. The skin was blackened with India Ink to reduce reflectance. No attempt was made to mask out stray energy. Area and PCF were held constant, and intensity was increased in step-fashion. Trials of thirty seconds duration were given, and at the conclusion of each, O̲ was questioned as to whether warmth, pain or no sensation was experienced. Twenty thresholds for each condition were gathered over five days.

General Procedure:

In the principal experiments, the skin surface (either the upper back or the right volar forearm) to which the stimulation was applied was blackened with India Ink, and the masking device was aligned so that the "hot spot" produced by the filament impinged on the open portion. The masking device was secured in place with adhesive tape and the temperature probe, used to monitor skin temperature, attached within the aperture with a small bit of tape. The appropriate PCF, area and intensity were then selected. In each study, two factors were held constant, whereas the third was presented according to a schedule of randomization. Descending judgments always followed ascending, and were made for the same stimulus conditions as the preceding ascending condition. Ascending judgments began at rates well below fusion, when O̲ indicated he could detect the flicker, and terminated when he signalled the fusion threshold.

Responses were given verbally. When a descending judgment was required, E̲ began the trial with rate at its highest value, and began decreasing when O indicated he could detect a steady sensation of warmth. The descending trials terminated when O said that he felt the first vestiges of flicker. Five ascending and five descending trials were given for each condition. Inter-trial interval depended upon the length of time necessary for O's skin temperature to return to its initial state. This interval never exceeded one minute at maximum.

Each daily session was terminated when O's skin temperature either rose considerably during one trial, or did not return to its base level within approximately one minute. Room temperature was recorded at the beginning and termination of each session. Body temperature was also recorded at the beginning of each session.

Procedure When Stimulating the Back:

Six separate studies were run initially (see Table 2 for details of conditions). Studies #1-3 employed the upper back. In Study #1, PCF was varied while intensity and area were held constant. Initially, PCFs 1/3, 1/2, 2/3 and 5/6 were run. At that time, PCF 1/6 was not possible with the equipment available. However, a latter experiment on this skin surface tested PCF 1/6 and 1/3 only, with intensity and area held constant.

In Study #2, intensity was varied, while area and PCF were held constant. Four set intensities (100° F. to 130° F. at 10° F. intervals, or 37.8° C. to 54.4° C. at approximately 5.5° C. intervals) were run for all Os on the back.

In Study #3, area was varied with PCF held constant. Areas used were of diameters one inch, two and one-half inches, and four inches - an area ratio of approximately 1:6:16. A lower limit for variation of area exists for all skin surfaces, as Hardy et al., (1952) note that heat transfer to the skin with an area less than three quarters of an inch in diameter does not result in warmth, but in thermal pain. The smallest area used was therefore one inch in diameter.

Intensity could not be held constant for all variations in area. This was because 100° F. (37.8° C.) represented the upper limit available with an area four inches in diameter, and Os could not detect warmth or flicker when 100° F. (37.8° C.) was combined with an area one inch in diameter. An adjustment was therefore made and data on the back run at two different intensity levels, with 1:6 run at 120° F. (48.9° C.) where the sensation could be detected, and 6:16 at 100° F. (37.8° C.).

Procedure When Stimulating the Forearm:

Studies #4-6 employed the volar surface of the forearm. In Study #4, PCF was varied while area and intensity were held constant. Five PCFs were run, i.e., PCF 1/6, 1/3, 1/2, 2/3, and 5/6. For two Os, it was necessary to run PCF 1/2 and 1/6 at higher intensities, since O could not detect the sensation at PCF 1/6 at any frequency, with intensity held constant at the midpoint of his warm to pain range.

In Study #5, intensity was varied, while PCF and area were held constant. However, it was impossible to use equal intensities on the forearm for all Os (as had been possible on the back), since certain temperatures were below the warm threshold for one O, but above the pain threshold for another. Intensities run on the forearm were, therefore, made dependent on each individual's average warm and average pain thresholds. Intensities represented one-fourth of the range between warm and pain (warmth threshold plus one-quarter the temperature range), the midpoint of the range, the three-quarter mark (pain threshold minus one-quarter the temperature range), whereas the highest intensity was a point just below the pain threshold (pain minus one degree).

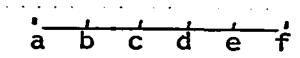
In Study #6, area was varied, with PCF and intensity held constant. However, areas tested on the forearm differed from those tested on the back because of the limitations of available area. Areas tested on the forearm were of diameters one inch, one and three-quarter inches, and two and one-half inches - an area ratio of approximately 1:3:6.

Succeeding Study:

A succeeding study retested those factors for each O that either did not produce significance in the analysis of variance in the first studies, or deviated highly from the other O's data for the same stimulus conditions. The latter occurred in one instance only.

Table 2

Detailed experimental conditions for each of the six principal studies. Each of four observers received all conditions randomized and replicated ten times. Rate is the dependent measure.

Study No.	Study #1	Study #2	Study #3	Study #4	Study #5	Study #6
Body Area Tested	BACK			FOREARM		
Variable:						
PCF	PCF's tested: 1/3, 1/2, 2/3, 5/6 a succeeding study tested PCF 1/6 and 1/3	held constant at 1/2	held constant at 1/2	PCF's tested: 1/6, 1/3, 1/2, 2/3, and 5/6	held constant at 1/2	held constant at 1/2
Intensity	held constant at 120° F.	Impinging I tested: 100° F. (37.8° C.) 110° F. (43.3° C.) 120° F. (48.9° C.) 130° F. (54.4° C.)	held constant at: 100° F. (37.8°C.) at 6:16 120° F. (48.9° C.) at 1:6	held constant at midpoint of each individual's average warm and average pain thresholds	I's tested were determined separately for each individual in terms of scale distance between the average warm and average pain thresholds 	held constant at the midpoint of the average warm and average pain thresholds

(continued)

Table 2 (continued)

Study No.	Study #1	Study #2	Study #3	Study #4	Study #5	Study #6
Body Area Tested	BACK			FOREARM		
Variable: Intensity (cont'd.)					a is the warm threshold b is 1/4 scale distance c is the mid-point d is three quarter distance e is 1° F. below pain f is the pain threshold b, c, d, and e were tested	
Area	held constant at 2 1/2 inches in diameter	held constant at two and one half inches in diameter	Area diameter tested: 1 inch 2 1/2 inches 4 inches Ratio of Areas: 1:6:16	held constant at one and three quarter inch in diameter	held constant at one and three quarter inches	Areas tested: 1 inch 1 3/4 inches 2 1/2 inches (in diameter) Ratio of Areas: 1:3:6

Results

Preliminary Results:

A preliminary study indicated that room temperature was an important factor in determining the TFF threshold. A line fitted to a scattergram of room temperature vs. threshold rate (for one PCF, with intensity and area held constant) indicated that thresholds increased as room temperature increased for both "ascending" and "descending" judgments (plotted separately). It was, therefore, important that room temperature be kept as constant as possible in the principal experiments.

Another experiment explored the warm "spot" sensitivity of the volar forearm and back for one male and one female observer, using a punctate stimulus at 102° F. (38.9° C.). It was thought that once the relative sensitivities of the two surfaces were known, the sizes of the areas stimulated could be equated according to the number of warm spots contained. For both observers, the number of warm spots on the volar forearm was approximately 5.3 per $cm.^2$, whereas the number of warm spots on the back was larger for both observers, i.e., $9/cm.^2$ for the male observer and $7/cm.^2$ for the female observer. Table 3 shows the approximate number of warm spots included in each stimulated area, according to the punctate data collected. It should be mentioned that the results gained from this experiment do not agree with von Skramlik's (1937) result (0.4 warm spots per $cm.^2$ on the volar

Table 3

Approximate number of warm "spots" for each area stimulated. Diameters of area are shown. Number of warm "spots" for areas on the volar forearm are calculated on the basis of 5.3 spots/cm.^{2} Number of warm "spots" for areas on the back are calculated for two different densities: 7 "spots"/cm.^{2} and 9 "spots"/cm.^{2}, since two observers produced results indicating differing densities of warm "spots" on the back.

VOLAR FOREARM		BACK			
(5.3 warm spots/cm.^{2})		(7 warm spots/cm.^{2})		(9 warm spots/cm.^{2})	
Area	No. of Spots	Area	No. of Spots	Area	No. of Spots
2 1/2" d	∝ 168	4" d	∝ 569	4" d	∝ 731
1 3/4" d	∝ 82	2 1/2" d	∝ 221	2 1/2" d	∝ 284
1" d	∝ 27	1" d	∝ 36	1" d	∝ 46

forearm) but do have close correspondence with results obtained using more adequate instrumentations (Dallenbach, 1927). Testing the upper forearm, he found 6 - 8 warm points per $cm.^2$ with a stimulus temperature of 107.5° F. (41.9° C.). Due to the discrepancies among the results of various investigators, area was not equated for number of "spots" as it was thought that the inconsistencies might be a matter of individual differences among _Os_.

A pilot study employing untrained _Os_ produced large intra- and inter-observer variability (as mentioned previously). The curves for different _Os_ varied in shape, and large standard deviations around each point were seen. The observers used in the principal studies were therefore initially trained to observe standard criteria for flicker and fusion.

Another pilot study employing trained _Os_ varied area, intensity, and PCF simultaneously in one large split-plot design. All conditions were randomized, so that _O_ observed one combination of PCF, area, and intensity; and on the next trial all three factors were changed. Again, large inter- and intra-observer variability was present. It is suggested that _O_ may not be able to discriminate thresholds accurately in a complex situation, i.e., varying all factors at once may lead to confusion on the part of _O_.

Principal Experiments:

The results were analyzed separately for "ascending" and "descending" trials, since large discrepancies between these two sets of data were often seen. "Total" trials also received statistical treatment, and were the average of "ascending" and "descending" trials. These three different components of the data ("ascending", "descending" and "total" trials) are hereafter referred to as "data treatments".

Thresholds:

As mentioned previously, average warm and average pain thresholds were determined for each individual The threshold data for the forearm were used to determine experimental conditions in Studies #3 - 6. The thresholds on the back were studied at two different areas to determine whether large differences would occur. Although statistical analyses were not applied, no large differences were seen. However, this statement is complicated by the fact that at the smaller area used 112 - 114° F. (44.4° C. - 45.6° C.) was considered to be an upper limit, since tissue damage is thought to occur at slightly higher intensities (see Hardy et al., 1952). The apparatus was calibrated to 135° F. (56.7° C.) for the larger area used. The averages for twenty thresholds for each condition are found in Appendix "B", along with their standard deviations.

In Study #1, PCF was varied, and body area stimulated was the back. Results are summarized in Appendix "C". In brief, a two-way analysis of variance showed both the O's factor and the PCF factor to be significant or approach significance for "ascending", "descending", and "total" judgments, calculated separately. An analysis of variance calculated individually for each observer showed two observers to produce significant (or near significant results) on all three data treatments ("ascending", "descending", "total"), one O to produce significance on all but the "total" treatment, and one O to produce non-significant results on all three data treatments. Duncan's New Multiple Range Test was calculated for the data of each O. Average rates produced from five Ascending and five Descending trials, and their standard deviations are tabled. "Total" is comprised of Ascending and Descending judgments, and is therefore calculated for ten trials.

The curves (Figure 4) show an increase to a peak at PCF 1/2 to 2/3, followed by a decline, for all Os and all data treatments. A two-factor trend (Os; PCF) shows O x PCF not significant, as is the linear component of PCF. However, the quadratic component of PCF is significant. A trend analysis was also calculated for the data of each O. It should be noted that the quadratic component is but one factor of the deviations component, and is therefore not tested if "deviations" prove not significant.

The experiment varying PCF 1/6 and 1/3 was examined by means of a Mann-Whitney U-test used to nonparametrically test independent samples by ordinal measurement. A rather stringent test, it yielded significance in only five of a possible twelve instances. Testing PCF 1/3 from this experiment against the results of PCF 1/3 from the prior study yielded significant differences in seven of a possible twelve instances (see Appendix "C").

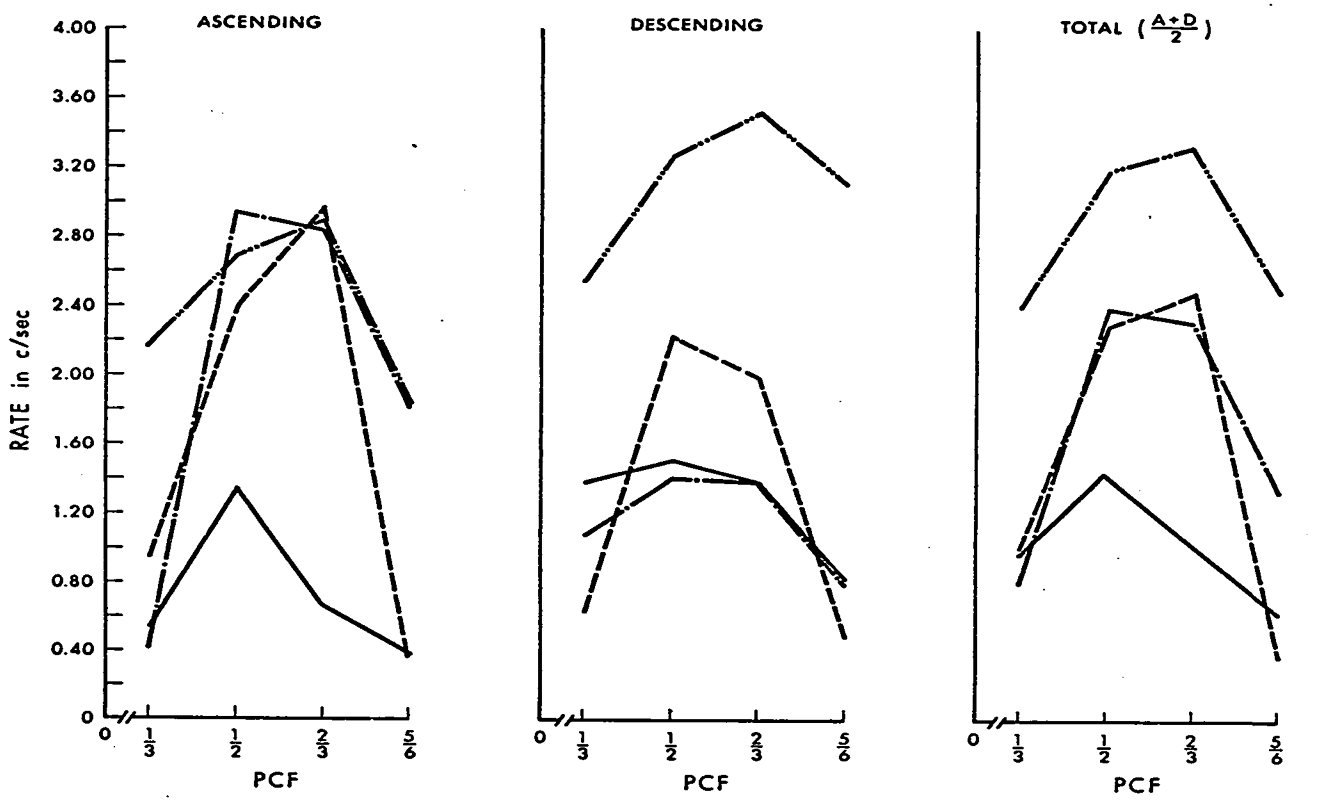


Figure 4: Thermal Flicker Fusion thresholds in c./sec. for the variable of PCF (with A and I held constant) for each of Ascending, Descending and Total (average A and D) judgments. The data for four male observers are shown. Each point on Ascending and Descending trials is the average of five judgments; on total trials, each point is the average of ten judgments. Body area tested is the upper back.

In Study #2, intensity was varied and body area stimulated was the back. Results are summarized in Appendix "D". In brief, the two-way analysis of variance for Os and I showed both factors to be significant at the .01 level for all data treatments. However, the analysis of variance calculated for the data for each O showed significance for one observer and near significance for another on "ascending" judgments only. All other results were not significant. Duncan's test was also calculated.

The form of the curves for all Os and all data treatments appears to increase for increases in stimulus intensity (see Figure 5). "Descending" curves do not produce large differences when intensity is varied. The "total" curves are therefore flattened due to this influence. The two-factor trend produced significance on the linear component of the "ascending" and "total" trials only. The trend analysis for the data of each O produced significance for the linear component of the "ascending" and "total" trials for two Os only, with "deviations" on the "total" trials of one O also significant. The average thresholds and their standard deviations are also tabled in Appendix "D".

In Study #3, area was varied and body area stimulated was the back. Results are summarized in Appendix "C". The analysis of variance could not be run on this data, as only two areas were available at each of two intensity levels. The Mann-Whitney U-test was therefore used to compare the two points at each intensity level, and also applied

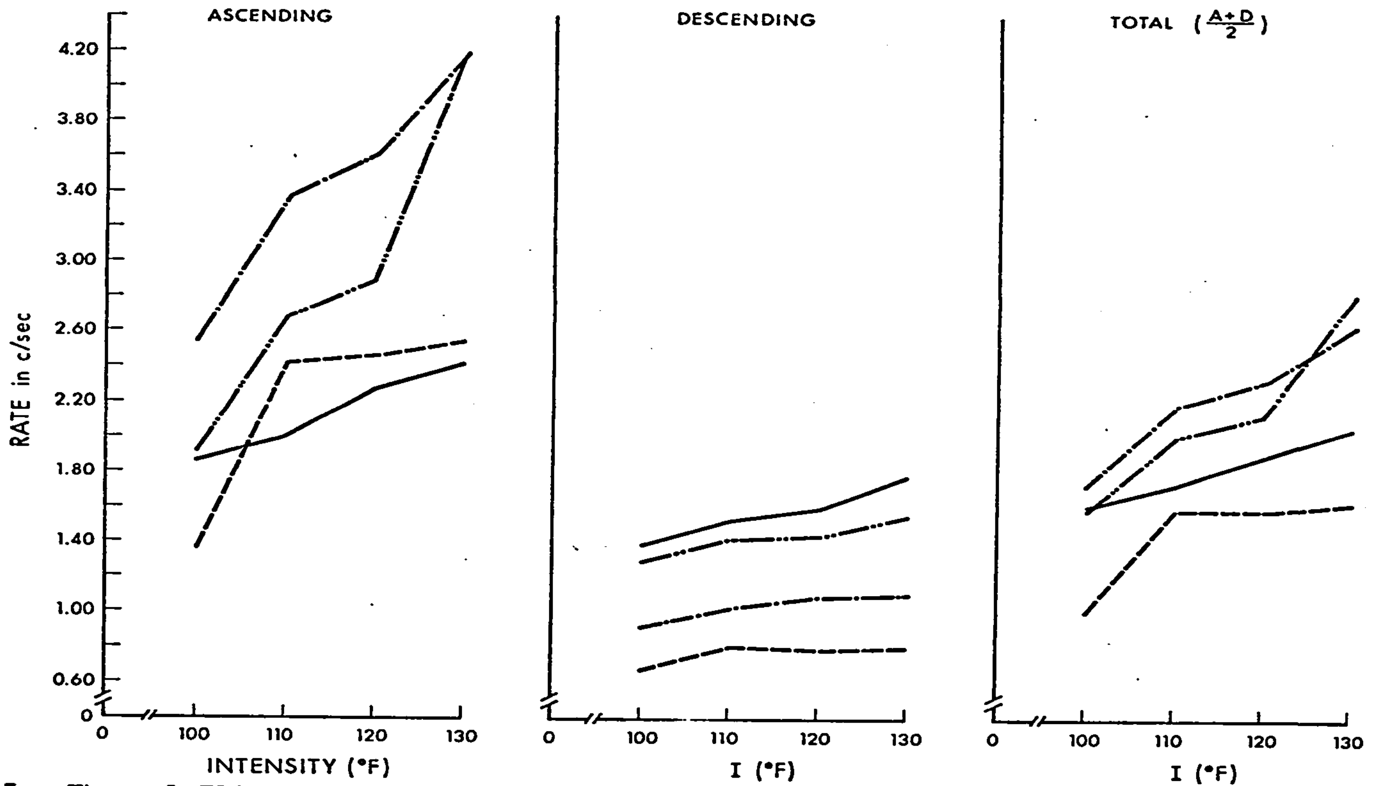


Figure 5: Thermal Flicker Fusion thresholds in c./sec. for the variable of Intensity (in degrees F.) for each of Ascending, Descending and Total (average A and D) judgments. PCF and A are held constant. The data for four male observers are shown. Each point of Ascending and Descending trials is the average of five judgments; on total trials, each point is the average of ten judgments. Body area tested is the upper back.

to the comparison of the same area presented at two different intensities. Results showed that the large area vs. the medium area produced significant differences for two Os at all data treatment, whereas the medium vs. the small area produced significant results for one other O at all data treatments. Only in one instance were significant differences found between the data for the medium area at two intensity levels. The curves can be seen in Figure 6. The summary of the U-tests and the averages and their standard deviations can be found in Appendix "E".

In Study #4, PCF was varied and body area stimulated was the forearm. The results are summarized in Appendix "F". As mentioned previously, PCF 1/6 could not be detected by two Os at the intensity chosen for this study. However, PCF 1/6 and 1/3 were later run at intensities that could be perceived by each O.

In the two-factor analysis of variance (Os; PCF), only the four larger PCF's were used, since (as mentioned) complete data were not available for PCF 1/6. Both factors (Os; PCF) were significant at "ascending", "descending" and "total" trials, with the exception that the PCF factor did not produce significance when "ascending" trials were tested. The analysis of variance for each O's data was run for either four or five PCF's (whichever was available), and proved significant, with two exceptions, i.e., the data for one O were not significant on "ascending" trials, and the data for another O were not significant on "descending" trials. Duncan's test was also calculated.

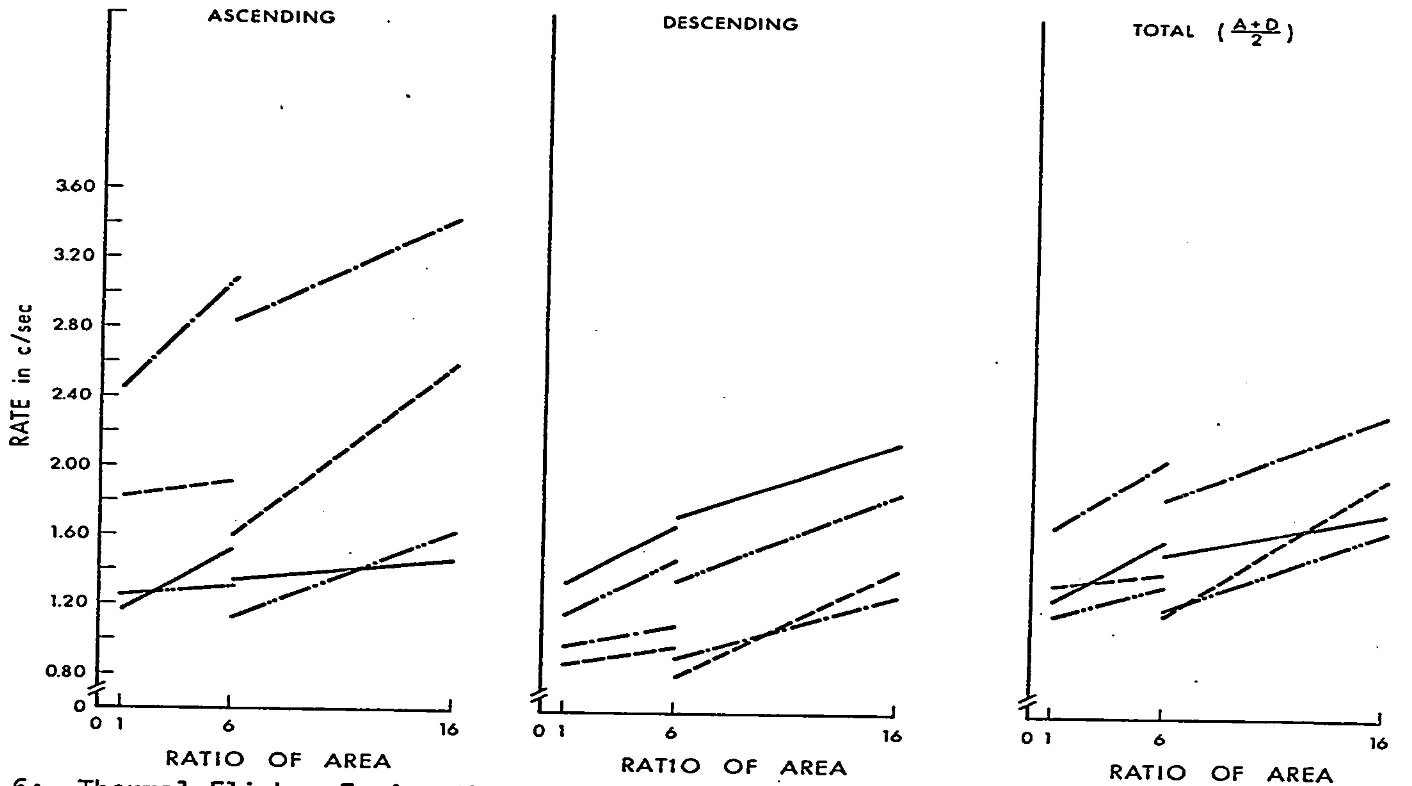


Figure 6: Thermal Flicker Fusion thresholds in c./sec. for the variable of Area for each of Ascending, Descending and Total (average A and D) judgments. PCF is held constant. Split-curves are shown, as two different intensity levels were employed. The area ratio of 1:6 was run at 100° F.; the ratio of 6:16 was run at 120° F. Curves are for four male observers. Each point on Ascending and Descending trials is the average of five judgments; on total trials, each point is the average of ten judgments. Body area tested is the upper back.

The data for two observers compared PCF 1/6 and PCF 1/3 and also PCF 1/3 at mid-point intensity vs. PCF 1/3 at higher intensity by means of a Mann-Whitney U-test. The results showed PCF 1/6 vs. PCF 1/3 not significant in all data treatments for both Os, while PCF 1/3 at two different intensities showed significant differences in four of a possible six instances.

The form of the curve is shown in Figure 7. The two-factor trend analysis employed the four largest PCF's only (again because of the incompleteness of data at PCF 1/6). Results showed the Os, PCF and O x PCF factors significant for all three data treatments. The linear trend on PCF was significant for "descending" trials only, whereas the quadratic trend on PCF was significant for all three data treatments. Both the linear and quadratic components of the O x PCF factor were significant for all three data treatments. The trend analysis on individual data for PCF on the forearm was carried out for four or five PCF's, whichever was available, and resulted in significance on the linear component for one O at "descending" and "total" treatments and for another on "ascending" trials only. The deviation and quadratic component of PCF was significant for all Os and all data treatments, with one exception that occurred for one O on "descending" trials. The summary of the trend analyses can also be found in Appendix "F", as can the average thresholds and their standard deviations.

In Study #5, intensity was varied and the forearm was stimulated. The results are summarized in Appendix "G". In brief, the two-factor

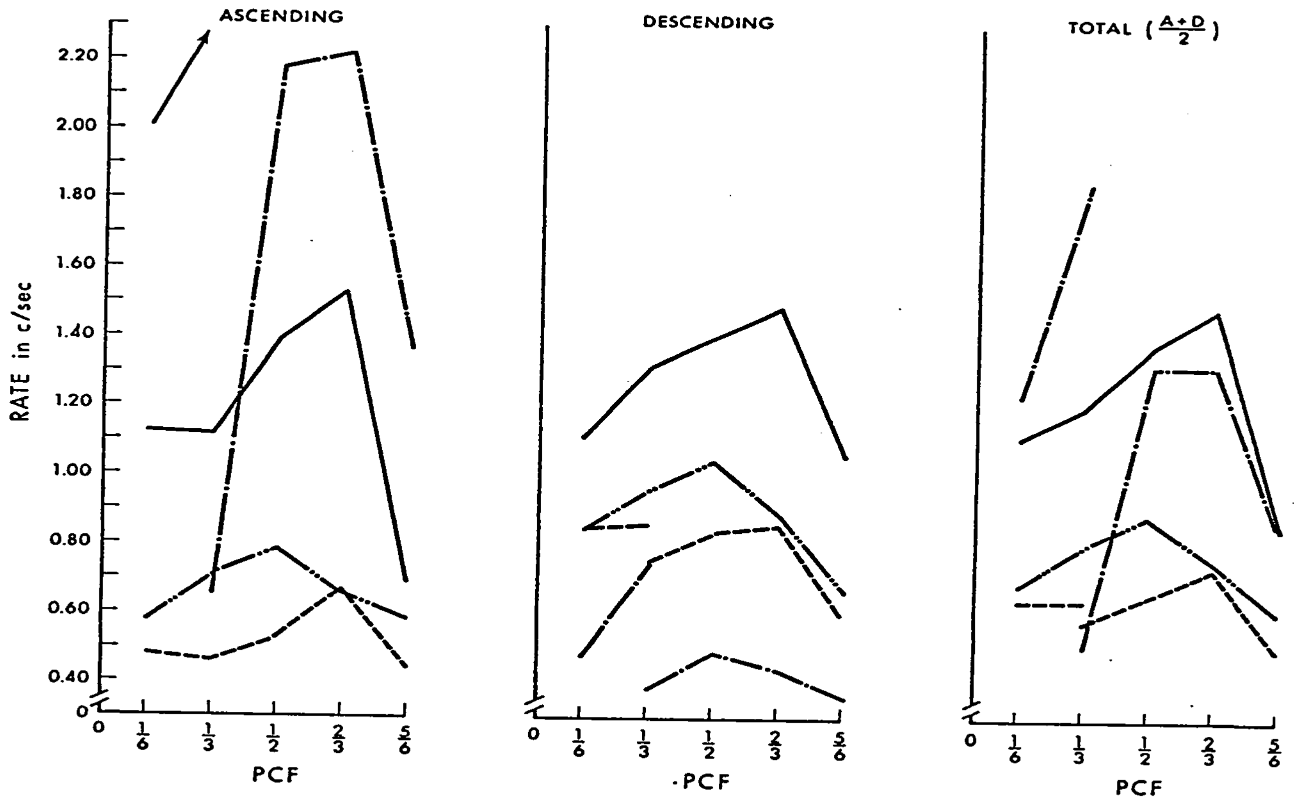


Figure 7: Thermal Flicker Fusion thresholds in c./sec. for the variable of PCF for each of Ascending, Descending and Total (average A and D) judgments. Area is held constant, as is intensity, with the exception that, for two Os PCF 1/6 and 1/3 were run at a higher intensity where the smaller PCF could be detected. Split curves are therefore seen for two Os in all data treatments. The bottom curve on the Ascending condition does not actually join at PCF 1/3: two intensities were run at PCF 1/3, producing identical average judgments. The data for four male observers are shown. Each point on Ascending and Descending trials is the average of five judgments; on total trials, each point is the average of ten judgments. Body area tested is the volar forearm.

analysis of variance for Os and I produced significance for both factors at all data treatments. The individual analysis of variance on I indicated significance under "ascending" treatment condition for all Os, significance under "descending" treatment condition for three Os and significance under "total" treatment condition for two Os. Duncan's test showed that the lowest intensity and highest intensity for all data treatments proved significant in the analysis of variance. The lowest intensity vs. the next highest intensity was significant in one instance only. The other comparisons do not yield as clear-cut a result.

Figure 8 illustrates the form of the curve. The two-factor trend analysis shows the Os and I factors to be significant under all data treatments. The O x I factor is not significant in all data treatments, whereas the quadratic component is significant on "total" trials only.

The trend analysis on individual data showed the linear trend on intensity to be significant in nine of a possible twelve instances. The deviations component was significant for one O on "ascending" trials, and for another O on "descending" trials. In the latter instance, the quadratic component was also significant. See Appendix "G" for trend analyses, and the average thresholds and their standard deviations.

In Study #6, area was varied and the forearm was stimulated. The results are summarized in Appendix "H". The two-way analysis

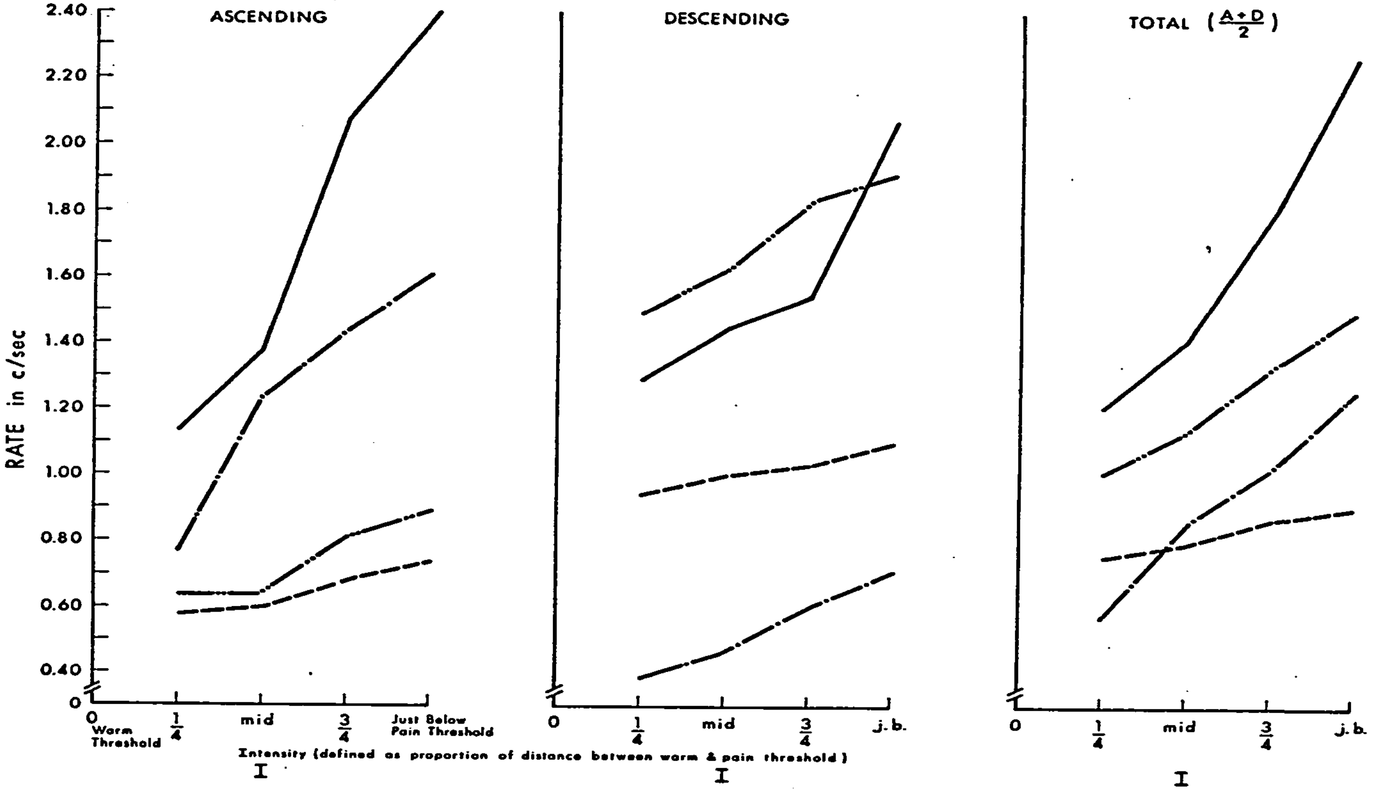


Figure 8: Thermal Flicker Fusion thresholds in c./sec. for the variable of Intensity (defined as proportion of distance between the average warm and average pain thresholds) for each of Ascending, Descending and Total (average A and D) judgments. PCF and A were held constant. The data for four male observers are shown. Each point on Ascending and Descending trials is the average of five judgments; on total trials, each point is the average of ten judgments. Body area tested is the volar forearm.

of variance resulted in significance for the Os and Area terms for all data treatments. The analysis of variance on the data for each individual showed significance for three observers on "ascending" trials, and significance for two observers on "descending" and "total" trials. Duncan's test showed that the small area differed from the medium area in one instance only, whereas the small area differed significantly from the large area in all instances that were tested (since these proved significant in the analysis of variance also). The medium area differed significantly from the large area in the majority of instances tested.

The form of the curves can be seen in Figure 9. The two-factor trend analysis showed the Os and Area factors to be significant for all data treatments. The O x A factor proved not significant on "descending" trials only. The linear component of the area factor was significant for all data treatments, whereas the quadratic component was not. The linear component of the O x A factor was significant on "ascending" and "total" trials, whereas the "descending" trials were not tested (O x A was not significant). The "ascending" trials proved significant when the quadratic component of the O x A factor was tested, whereas the "total" trials proved not significant. "Descending" trials were again not tested. The results of the trend analyses on individual data, average thresholds, and standard deviations for each condition of area for four Os can also be found in Appendix "H".

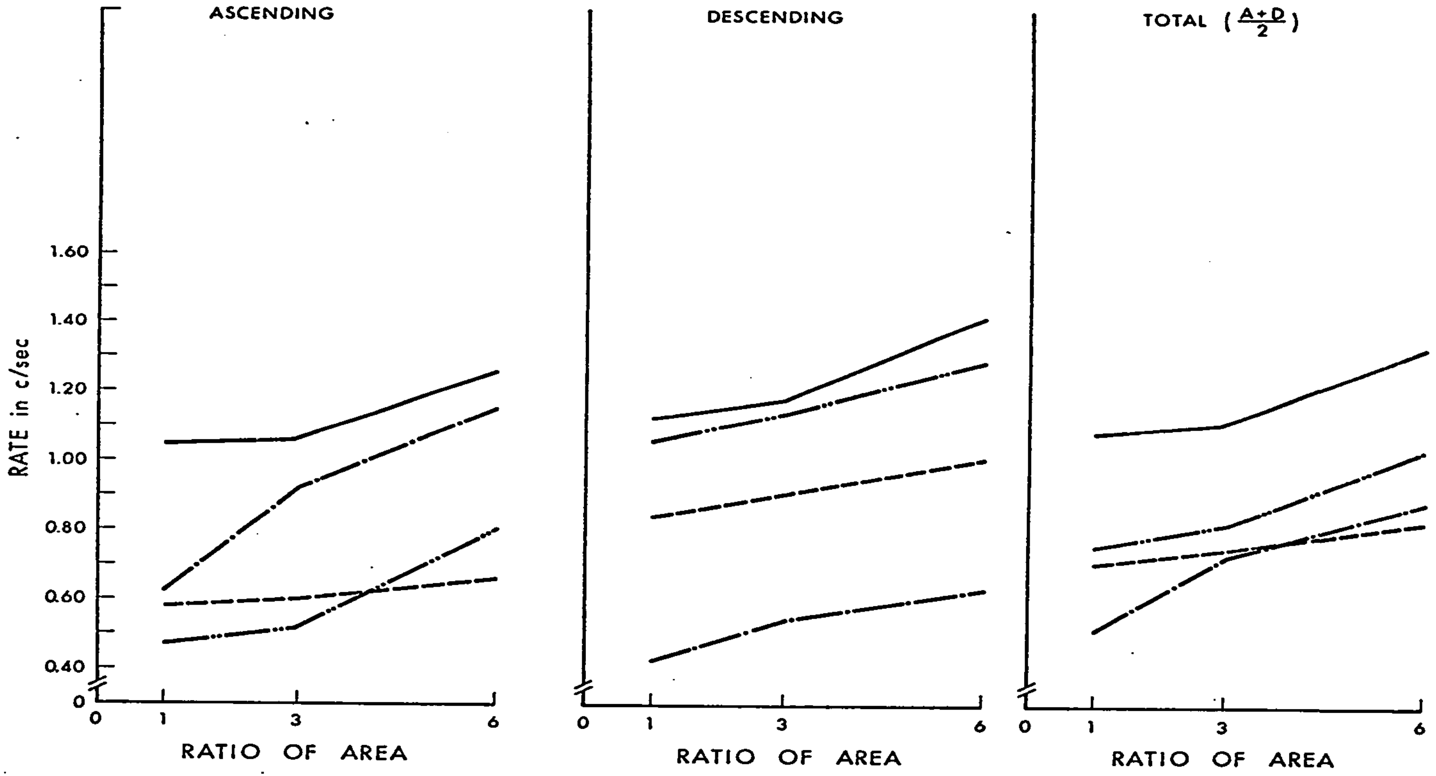


Figure 9: Thermal Flicker Fusion thresholds in c./sec. for the variable of Area (PCF and I held constant) for each of Ascending, Descending and Total (average A and D) judgments. The data for four male observers are shown. Each point on Ascending and Descending trials is the average of five judgments; on total trials, each point represents the average of ten trials. Body area tested is the volar forearm.

A succeeding study tested those factors not producing significance in the analysis of variance of each of the principal studies. In general, results as indicated by statistical tests were replicated (see Appendix "I").

Principal Hypotheses Related to Results

Hypothesis #1 predicted that TFF will rise to a maximum and then decline as PCF is made larger, all other factors held constant. Curves for all Os peak, albeit not always to the degree of significance chosen as criterion ($p < .05$). Hypothesis #1 also predicts that the form of the curve will be independent of the body area tested. This was confirmed. Curves for both body areas at all data treatments peak and then decline. All curves appear to peak in the PCF 1/2 to 2/3 range.

Hypothesis #2 predicts TFF to increase as intensity is increased, all factors held constant. Curves do tend to increase but those plotted for "descending" trials on the back appear flattened and increase only gradually. In general, while the evidence is not ideal, one may hold that increases in intensity lead to reliable increases in TFF. Hypothesis #2 also predicts that the form of the curve would be independent of body area tested. This hypothesis is confirmed in some conditions. On "ascending" trials, TFF does increase as I increases. Curves for back surfaces are flattened, while those from the forearm are in good correspondence with the hypothesis.

Hypothesis #3 leads one to expect that TFF will increase as area is increased, all other factors held constant. In general, this is confirmed. The curves appear to be increasing functions. The complication is that because of the stringency of the U-tests applied to the data from the back, only approximately one-half of these comparisons reached significance, making some positive conclusions difficult. The data gathered from the forearm shows increases in threshold with corresponding increases in area; but this result was not always significant in the analysis of variance. Hypothesis #3 also states the form of the TFF curve will be independent of body area tested. Although this comparison is complicated by the split-curves from the data on the back, it appears that TFF threshold increases with corresponding increases in area, regardless of body surface tested, even though significance at the .05 level was not always achieved.

Hypothesis #4 proposes that variation in body surface tested will not alter the basic relation between the variable examined and TFF. Data are in general agreement to expectations. In addition to the evidence mentioned in regard to the preceding hypothesis, consideration of the trends is worthwhile. Comparing the two-factor trends for the back and forearm for the PCF factor shows _O_s and _PCF_ significant in every instance. However, the interaction factor (_O_ x PCF) is significant for data from the forearm but not from the back. The linear component of PCF, in general, is not significant (the exception being "descending" data from the forearm). The quadratic factor is significant in every instance. Both the linear and quadratic components of O x PCF are significant for the forearm data, whereas they were not tested for the data on the back (due to nonsignificance of the O x PCF factor). The individual trend analysis resulted in significance of the quadratic component of PCF in the majority of instances on the back, and lacked significance in one instance on the forearm.

The two-factor trend for Os and INTENSITY is more complex. In general, there is a significant linear component on I, whereas the quadratic factor is not significant. The linear and quadratic factors of O x I on the back were not tested; however, significance was found in three of six possible instances on the forearm. The individual trends on I show the linear component to be significant in many instances on the forearm, but in only a few cases on the back. The deviations component seldom reached significance. The quadratic component reached significance once, for SL on "descending" trials on the forearm.

Since an analysis of variance could not be run on the back, no trends were tested for the AREA variable on this body surface. Nevertheless, as mentioned previously, the basic relation seems to be increases in TFF threshold corresponding to increases in area.

Hypothesis #4 also states that variation of body site will only alter the absolute values of TFF in the direction of lower thresholds on the arm than on the back, assuming the density of innervation is less on the back than on the forearm, as suggested by von Bekesy, 1959 (see Introduction). The data illustrate that thresholds are higher on the forearm as compared to the back, i.e., fusion rates are lower on the forearm than the back, and sensitivity (decreases in threshold) correspond to increasing fusion rates. Inspection of the PCF curves show peaks for three Os at rates above 2.80 c./sec. on the back (for "ascending" trials). The corresponding data on the forearm shows peak at approximately .65 c./sec., .80 c./sec., and 2.20 c./sec. One O holds constant at approximately 1.30 - 1.50 c./sec. (for both body surfaces). The same result occurs for "descending" trials (and "total" trials, since they are composed of the average "ascending" and "descending" trials): the same three Os give higher thresholds on the back than on the forearm, while the fourth O (SL) remains constant. The two sets of intensity data for different body areas are not entirely comparable, due to the different method of varying I. However, threshold rates on the back are in general much higher than those from the forearm. Likewise, the area data are not entirely comparable, due to the different area ratios employed. Comparing only the 1:6 ratio for the different body surfaces tested, it can be seen that the back always produced higher threshold rates at both areas than did the forearm, for each data treatment. Table 4 illustrates this comparison for "ascending" and

Table 4

Comparison of threshold rates at fusion for each O on the area variable for the back and forearm. Areas in the ratio of 1:6 are shown as is the data for Ascending and Descending trials.

	Ascending		Descending	
	Back	Forearm	Back	Forearm
Observer	Area 1 - 6	Area 1 - 6	Area 1 - 6	Area 1 - 6
CW	1.24 - 1.28	.47 - .80	1.13 - 1.45	1.06 - 1.29
IC	1.79 - 1.87	.58 - .66	.88 - ..97	.84 - 1.01
WF	2.44 - 3.09	.62 - 1.15	.96 - 1.08	.43 - .63
SL	1.17 - 1.50	1.04 - 1.26	1.34 - 1.67	1.08 - 1.34

"descending" trials. This aspect of Hypothesis Four would, therefore, appear not to be confirmed: TFF thresholds are usually higher when the forearm is tested than when the back is tested.

In summary, from evidence presented at this point, Hypothesis #4 in part, appears confirmed. The basic relation between TFF and the variables tested does not alter greatly when different body areas are tested. However, variation of body test site does not alter the absolute values in TFF in accord with von Bekesy's (1959) prediction, i.e., the threshold decreases as density of innervation increases. Assuming the forearm to be more densely innervated than the trunk, the prediction is not confirmed that TFF thresholds are in general lower for the forearm than for the back. Decision on this prediction must be held in abeyance, however, for there are other complications that are at best discussed later. The data discussed are those of Run #1 - the principal studies.

The partial replication of the data resulted in a greater correspondence of inter-_O_ data. These data are not discussed in terms of the hypotheses. It is obvious, however, that the resulting reduction in variability would tend to increase the likelihood of acceptable significance levels. It is possible that neater results will be produced by practiced _O_s.

Discussion

Several authors, including Cohen (1969), have suggested that the skin senses are "minor" or less important ways of making contact with the environment as contrasted to vision and audition. However, it is likely that "moral" principals have favored interest in vision and audition to the detriment of cutaneous study. Inhibitions present since the time of the early monks are declining, as exemplified by widespread participation in sensitivity or "T" groups, which stress the importance of cutaneous stimulation.

Nevertheless, there exists a dearth of material relating to the cutaneous modalities as compared to vision and audition. Possibly, this lack is due to ignorance of the abilities of the skin, not to its inherent limitations. In any case, the gaps in knowledge should serve to alert us to our ignorance of the many details of cutaneous stimulation deserving of closer consideration. A brief review of some of the evidence suggestive of the major importance of cutaneous sensitivity follows.

Cutaneous senses serve many functions that vision and audition cannot replicate, e.g., flavor implicates the sense of touch through appreciation of texture, etc. The skin can detect the texture of objects in circumstances where vision is not useful, e.g., dark of night or other reduced conditions. Further, vision and audition cannot replace the part that cutaneous contact plays in various physiological functions, e.g., puppies will die of uremic poisoning if their mother does not lick their stomachs. This action is a releaser mechanism for elimination (Hafez, 1962). Harlow (1960) has also pointed out the importance of tactile stimulation in the forming of emotional bonds. Other evidence that no suitable substitution exists for the skin senses is provided by victims of analgesia, who cannot substitute other senses for loss of the cutaneous sensitivity. Moreover, the skin senses have further importance in that personal space (our body space) is largely cutaneous, and not a visual or auditory dimension. Hall (1969) has suggested that the many aspects of the self, ie., the visual, kinesthetic, tactile and thermal senses, may either be inhibited or encouraged to develop by the environment. The thermal senses have generally not developed, as this aspect is often associated with intimate or personal proxemic distances.

The present study has shown that the skin is capable of relatively refined temporal discrimination as a thermal modality. The TFF thresholds determined in the present study, were just over 4 c./sec. at maximum. However, in the case of mechanical stimulation of the cutaneous surface sensory fusion is much more finely differentiated, occurring at approximately 300 - 600 stimulations per second (Cords, 1907). Visual thresholds range from 10 - 60 c./sec. (dependent upon experimental conditions). The eye is, therefore, capable of finer temporal discriminations than the thermal receptors of the skin, but does not possess the sensitivity of the touch receptors.

In the auditory modality, AFF thresholds cover a larger range than do the TFF or vibratory thresholds. AFF thresholds vary from approximately 30 - 1000 interruptions per second, depending primarily on Acoustic-Stimulation Fraction of Cycle (Symmes et al., 1955). None of the cutaneous systems excels the temporal acuity of the auditory system.

The reverse of the above is true for the spatial discriminations. The eye, under optimal conditions of illumination makes the finest discriminations; and the ear the poorest. Although there is variation from one part of the body to the next and between cutaneous systems, two-point thresholds are incomparably finer than the separations between sources necessary to produce an auditory threshold. The skin is, therefore, superior to the eye in the instance of temporal discrimination, and to the ear in the instance of spatial discrimination.

The complexity of cutaneous experience is well exemplified in the results of the experiments reported. Differences observed in "ascending" and "descending" data seen in the graphs, are reflected in the large standard deviations on their composite or "total" trials. Two possible reasons for this cutaneous variability and difference can be put forth. First, the different results may indicate different underlying neural processes mediate these responses. The nature of these processes would perhaps be difficult to describe because thermal reception, under even the simplest instances of stimulation, has not been adequately explained. The second possibility is that the skin becomes pre-heated in "descending" trials. This is a likely explanation in the present case, even though trials were as brief as possible. Under conditions of intermittent stimulation, heat has less opportunity to dissipate during the null period with rapid cycling than it does during a longer off-phase. Pre-heating would keep the system in "alternation", with the result that differences in threshold would be expected.

Pre-heating may be regarded as a form of structural (tissue and vascular systems, etc.) adaptation. Three types of adaptation phenomena have been described in vision. These have limited explanatory power because they represent a more delimited condition. Rather than solely a neural or intra-cellular phenomenon, the tissue itself increases its radiation, thus there is only limited value in comparing the thermal mechanism to visual since the inertia of the skin is related to heat dissipation. The skin has the mechanism involved in vision but another mechanism in addition, making analogy incomplete.

The three types of adaptation involved in vision are: (1) the effects from long (5 min.) photic or long (20 min.) non-photic conditioning (Baker, 1970)[7], (2) effects from moderate time amounts of pre-conditioning (Granit and von Ammon, 1930, Ginsburg, 1966), and (3) effects from very short (1.0 sec.) photic or non-photic conditioning periods (Nelson and Nilsson, 1971).[8]

Although trials were as brief as possible, "descending" trials of the thermal study inevitably involved some pre-stimulation. The resulting absolute differences in rate between "ascending" and "descending" trials are not inconsistent with the effects reported by visual investigators: all the visual factors are involved. The largest amount of variability between "ascending" and "descending" (and also between the visual and thermal flicker-fusion thresholds) is a result of the thermal inertia of the skin.

The experiments in the thermal study reinforced Kastorf's suggestion that practice is necessary to acquire high skill in judging flicker and fusion. After training, inter- and intra-$\underline{O}$ variability decreased, possibly due to the effects of practice. This is also the case in vision, but effects are smaller there too (Nelson, Bartley, and De Hardt, 1960). Again in contrast, variability in vision seems to change independently of the average CFF value, whereas both average and variability tend to change as practice in judging thermal intermittency is gained.

The current studies further agree with Kastorf's results in so far as increases in intensity level leads to corresponding increases in TFF. Stimulating the volar forearm and with PCF held constant at .5, TFF increases with increases in intensity level in both studies. But absolute values attained do not closely correspond; Kastorf's $\underline{O}$ produced TFF rates from approximately 2.3 c./sec. to 3.4 c./sec., depending on intensity. Looking only at data from the present study determined by the same method used by Kastorf, the volar forearm at low intensities show threshold values from approximately 0.60 c./sec. to 1.20 c./sec., where high intensity TFF's range from about 0.70 c./sec. to 2.40 c./sec., depending on O. Discrepancy could be due to a number of factors, e.g., differences in room temperature, amount of clothing worn, or (possibly most important) the different apparatus used to produce the stimulus. The episcotister arrangement used by Kastorf has the disadvantage of slow stimulus onset and decline (Lloyd and Landis, 1960). In vision, when rectangular pulses are not employed, CFF rates are affected (Bartley and Nelson, 1960). The on's- and off's of the energy source used in the current study were much faster than Kastorf was able to produce even though square pulse forms were not attained due to inertial properties of the filament. Also Kastorf, unfortunately for present purposes, specifies intensity levels as "low", "medium", and "high", making comparison of results approximate.

The "ascending" curves from the back correspond more closely to the absolute values attained by Kastorf. As mentioned previously, Kastorf's range was 2.3 c./sec. to 3.4 c./sec. over 3 levels of I (for the volar forearm). In comparison, the lowest intensity employed in the current experiment on the back produced TFF rates ranging from approximately 1.40 c./sec. to 2.60 c./sec., whereas the highest intensity employed produced TFF rates from approximately 2.20 c./sec. to 4.20 c./sec.

The PCF curves can be compared in similar fashion, Kastorf's curves from PCF .30 to .50 are roughly comparable to PCF 1/3 to 1/2 in the current series. The current "ascending" data from the forearm shows large inter-_O_ variability as compared, for example, to vision or audition. However, curves increase similarly for all _Os_. Likewise, Kastorf's curves for both "medium" and "high" intensity also increase over this range.

The maximum PCF employed by Kastorf was .50, therefore, no comparison with the current data at larger PCF's is possible. However, the data are similar enough in other respects that one might expect a peak at PCF 1/2 to 2/3, followed by a decline if Kastorf had extended his conditions.

Absolute values recorded at fusion can also be compared. In Kastorf's data, with "medium" intensity and PCF .5, sensory fusion occurs at 2.40 c./sec.. The current experiment shows one _O_ to produce a TFF of approximately 2.20 c./sec. at PCF 1/2, with a peak at PCF 2/3 at a rate of 2.40 c./sec. (approximately). The other three _Os_ (also on "ascending" trials) produced lower TFF's. Again, differences in the experimental situation and the stimulus may have created the discrepancies in the absolute values recorded. These differences should not obscure the fact that the form of each of the curves over the comparable range of PCF's are very similar: increases in PCF leads to increases in threshold in both the prior and current studies.

Visual and thermal fusion curves produced by varying PCF's are similar in that they increase to a maximum and then decline. Further, the quadratic factor of the trend analysis on the thermal data is generally significant in both cases demonstrating that curvilinearity does exist. Of course, absolute values at which flicker and fusion occur are considerably different, vision having the higher values.

Variation in intensity levels does not produce entirely similar curves in the two modalities. The visual curve will increase as intensity increases (Ferry-Porter Law) until extreme luminance levels are reached (Nelson and Bartley, 1965). At this point they decline. Thermal curves also show increases in TFF with increased intensity, but do not decline when high intensity levels are reached.

This discrepancy in results suggests a basic difference in the thermal and visual modalities. However, one might just as well consider thermally-induced pain an extension of the warmth modality. This is possible since the transmission system of thermal and pain systems have much in common and possibly the projection system also. If thermally-induced pain is regarded as an extension of warmth, then intuitively, the Ferry-Porter Law would not hold as pain has a lingering sensory component; thus lower fusion rates would likely be seen with higher thermal levels. An extension of the thermal study into the pain dimension would probably lead to a decline in the curve, similar to that seen in vision with increases in intensity.

This extension is not to be undertaken, however, because tissue damage is inevitable within the range of pain. A consideration of a warmth-pain continuum can be generally justified because, after all, the difference between the visual and thermal curves is not based upon a change in the _type of energy_ but upon the _quality of sensation_. More specifically, the Ferry-Porter Law deals solely with changes in fusion rate as photic intensity is varied while separation of warmth from pain in the presence of a single continuum of energy (thermal) relies upon a qualitative dimension. Or to put it another way, the Ferry-Porter Law is restricted only to portions of the energy continuum activating the photopic visual system and ignores the discomfort engendered by the high luminances provoking the change in direction, presumably because in contrast to the cutaneous surface, no damage will occur. This range of discomfort might nevertheless be thought a visual analogue of cutaneous pain.

The present study employed only the warmth modality and did not deal with thermally-induced pain. If the analysis just projected is acceptable, no decline in the curve would be expected in the range tested in the study and no decline was found. An extension of the problem into the region of pain would result in a decline similar to that seen in visual curves, if such an extension were not impossible.

The data produced by varying area are also very similar in form for the two modalities. A linear relation (the Granit-Harper Law) has been employed to describe the visual data, and the thermal data are similar in that, in general, they illustrate a significant linear trend. Summation may be operative in both modalities, or as Weale (1958) suggested (in an attempt to explain the visual result), increased thresholds may be a result of the correspondingly increased number of receptors stimulated. The form of the curves produced by varying area is similar for the two modalities discussed, although the absolute values differ.

Combining suppositions underlying the alternation-of-response theory as applied to vision with current knowledge of tactile receptor response provides a view, albeit rather incomplete, of the underlying response to temporally distributed thermal stimuli. Bartley's (1959) discussion of the relation of the alternation-of-response theory to other modalities lends validity to such an analogy (see Introduction). However, more information is necessary to confirm and extend this analogy.

The alternation theory states that visual flicker will result when there are critical irregularities of discharge density, due to different latencies and recovery times for various channels. The visual system is able to respond to separate bursts of discharges up to a point marked by the sensory fusion threshold. Above this point, elements begin to discharge only after several inputs with the result that bunching or synchrony of discharge is reduced. A-synchrony has fusion as one sensory end result. We should, therefore, consider whether thermal flicker and fusion are results of a similar process.

The physiology of the visual system is such that when using very small PCF's, the burst of discharges to each stimulus is short and quickly reduces to a single spike as rate is increased. This results in low fusion rates because critical levels of irregularity in pathway activity are difficult to maintain. At very long PCF's, fusion rates are also low, not only due to inhibition of the "off" discharge by the "on" discharge of the following stimulation, but also because the pulse itself is long enough to produce channel alternation. The figures dealing with thermal input also show that in the mid-ranges, optimum levels occur; that is, small and large PCF's have low TFF values. It <u>may</u> be that under conditions at which thresholds reach maximum, the moderately long bursts of discharges are slow to reduce to a single spike, and the "on" responses do not inevitably inhibit the "off" response. This combination of conditions would lead to higher fusion rates similar to what occurs in vision within mid-range PCF conditions.

A discrepancy exists between the PCF at which the visual and thermal curves peak. Photopic visual curves (Bartley, 1961) reach an absolute peak at PCF 1/4, whereas the thermal curves peak at PCF 1/2 to 2/3. However, a shift in peak (toward higher PCF's) occurs in CFF curves when low intensities are employed. Again, however, the difference in PCF at which the curves peak may simply be due to the inability to employ high enough intensities in the thermal study (without implicating pain). Were it possible to extend intensities into the range of thermal pain, a shift in peak toward a TFF maximum at lower PCF's would be expected.

Setting aside the alternation-of-response therory for the moment, four other means of conceptualization might be considered. First, Throsby (1962) has suggested an alternative method for plotting CFF data, i.e., the stimulus parameters of log dark time (log t_D) vs. time of one flash (t_L). She proposed that by plotting curves in this manner, the well-known inconsistencies among the data of various investigators could be reduced. A similar plot of TFF curves for four Os at fusion for the two body areas stimulated can be seen in Figure 10. Throsby predicts linear curves for the visual data; however, the thermal data from the back produces linearity for only one O. The data from the forearm, however, is in better agreement. The lack of linearity in data from the back is associated with a large standard deviation around each point on the curve.

Throsby re-plotted Bartley's data for uncompensated brightness conditions, i.e., "Talbot's Law (or the Talbot-Plateau Law) states that the apparent brightness at fusion, i, of a test patch, is determined by the product of the maximum luminance, I, and P_L*, that is,

$$i = I.P_L$$

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*P_L = proportion of light-to-cycle.

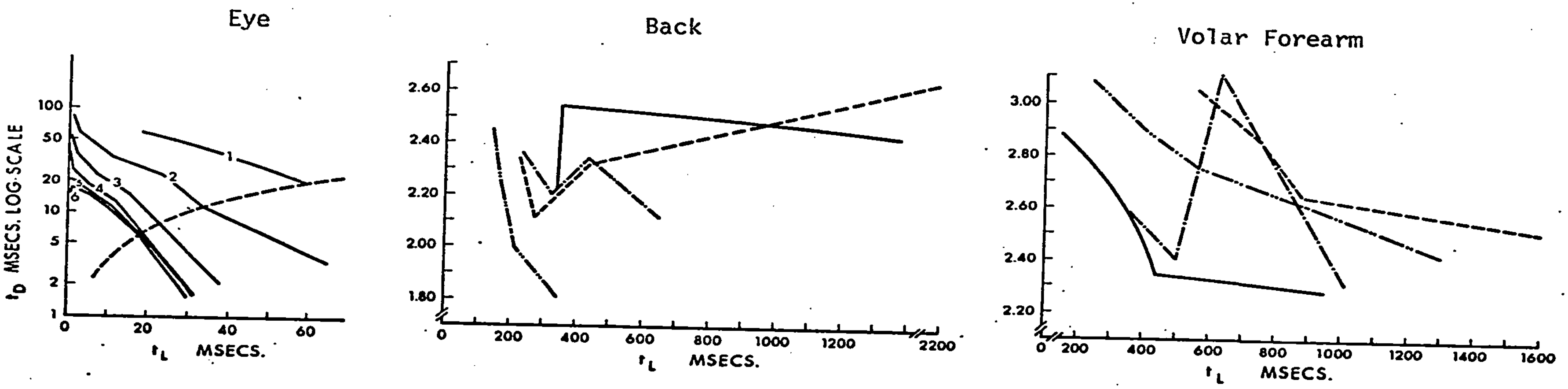

Figure 10: Throsby's method of plotting fusion curves. The stimulus parameter of log dark time (log t_D) is plotted against time of one flash (t_L). The graph on the left is Throsby's re-plot of Bartley's uncompensated CFF data (reproduced from Throsby, 1962). The dotted line gives values for P_L = 0.75. The middle graph presents the thermal data (varying PCF) from the back, and the graph on the right presents the thermal data (varying PCF) from the forearm in the thermal studies. Each line represents the data for one O with uncompensated conditions.

This equation has been shown to hold at and above fusion frequency. If I is changed as P_L is changed so that the fused brightness, i, as defined by Talbot's Law, remains constant, then this is referred to as a compensated experiment. On the other hand, if I is kept constant so that the fused brightness, i, changes with P_L, then this is referred to as an uncompensated experiment." By this definition, or its analogy, the thermal experiment was likewise run for uncompensated conditions. The discrepancy between Throsby's curves and the TFF curves, therefore, cannot be attributed to this difference.

Pieron (1964) suggested another method for plotting fusion curves, also devised to produce greater correspondence between the curves presented by various investigators. Pieron's curves decrease in a linear fashion when the limiting duration of intermittence (dark time at fusion) is plotted against the relative duration of the light phase (PCF). The thermal curves plotted on the same axes for four Os is shown in Figure 11. The data from the back show variability in the shape of the curves, with only one O producing a linear decreasing curve. The forearm data are more regular, with all Os presenting similar decreasing curves. Again, the between-O inconsistencies seen in the data from the back may be due to the large variability around each point on the curves. The TFF data from the forearm is similar to Pieron's CFF curves in that the limiting duration of intermittency appears to be a function of increasing PCF. [9]

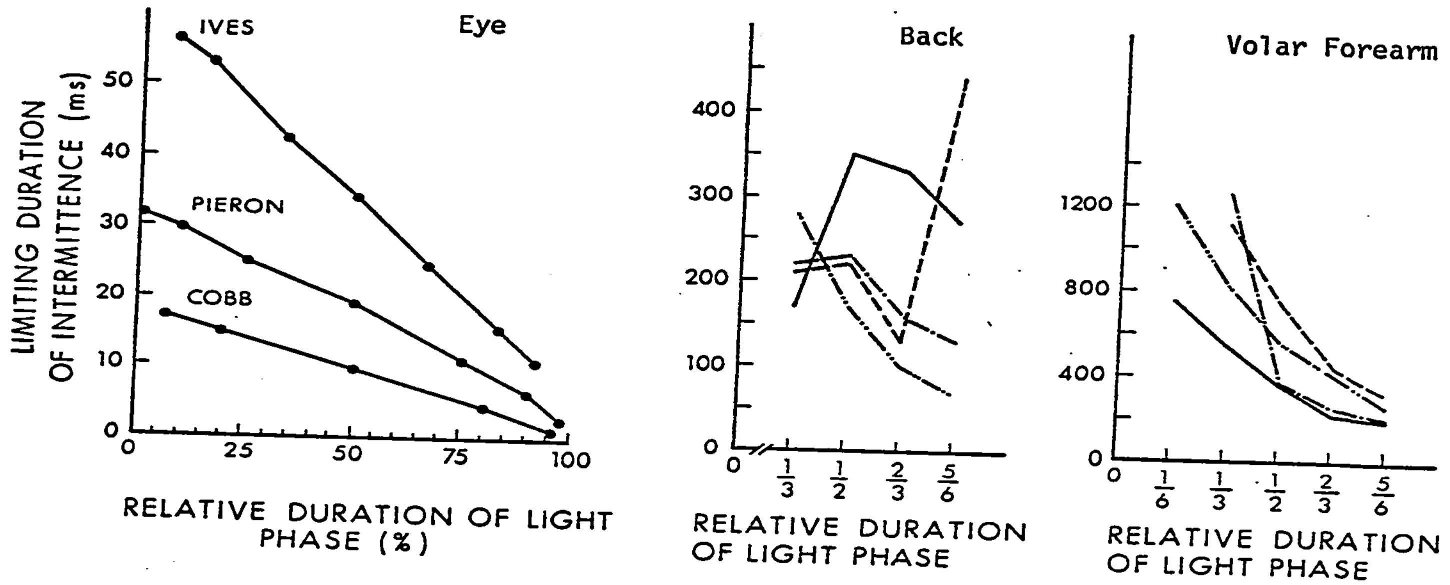

Figure 11: Pieron's method of plotting fusion curves. The limiting duration of intermittence (or dark time at fusion) is plotted against the relative duration of the light phase (PCF). The graph on the left is Pieron's plot of three independent CFF studies (reproduced from Pieron, 1964), the middle curve presents the thermal data (varying PCF) from the back, and the curve on the right presents the thermal data (varying PCF) from the forearm in the thermal studies. Each line represents the data for one O.

Third, and as mentioned earlier, one of the major parameters affecting fusion rates is intensity. In vision, this is described as the Ferry-Porter Law. This law states that CFF is a linearly increasing function of intensity or luminance. However, Nelson and Bartley (1965) suggest that this hypothesis is not complete, in that CFF increases to a point, and then decreases at extremely high intensity levels. They have also shown that it is dependent upon the number of pulses in the train and therefore, by implication, stimulus duration. The TFF curves with intensity only varied show increases with increases in intensity, with the exception that "descending" data from the back rises only gradually, if at all. High thermal intensities were tested, particularly on the forearm, where a point one degree below pain was used. No decrease in TFF at these extreme intensities falling within the <u>warmth range</u> was seen, suggesting a close correspondence to the Ferry-Porter Law. The TFF intensity curves, therefore, might be taken to illustrate a deviance from the predictions of the alternation theory. However, if it is again possible to argue that thermally-induced pain should be regarded as an extension of the thermal reception system, TFF would probably decline in accord with alternation-of-response findings. Surely there is a great amount of overlap in projections, even if the peripheral elements are structurally different.

Size of area is likewise an important factor in determining CFF rates. The Granit-Harper Law, although not as firm a law as the Ferry-Porter, expressed CFF as an increasing function (for mid-range values) of areas given sufficient intensity. The TFF curves are similar in that increases in area likewise produce increases in TFF rate. This function may be due to the effects of summation, also hypothesized to play a role in increased CFF rates. If summation does occur in the thermal modality, the effect may be due to the increased number of receptors stimulated as area is increased - a relation similar to that suggested by Weale for the visual modality. As Pieron (1964) notes, the simple relation of CFF with the logarithm of the retinal area stimulated has often been interpreted as a consequence of the increase in brightness correlative to the increase in area. He further notes that this approximate law is complicated by several effects, i.e., the lowering of the difference threshold and the increased probability of stimulating receptors of greater sensitivity. However, an analogy to brightness has not been explored in the thermal system, nor is there any great probability of a certain region of warm receptors being more sensitive than any other. A complete analogy with the visual system is therefore not to be recommended.

The fact that a complete analogy with the visual system is not possible may suggest that although visual and thermal sensory results illustrate similarities in the shape of the curves and the functions achieved by varying similar parameters, mechanism and neural conditions differ too sharply to warrant the attempt to apply a single theory, e.g., the differential sensitivity of the retina from fovea to periphery likely has no correlate in the thermal system. However, the general similarity in results may illustrate that although these differences in mechanism can be pointed out, similarity in mechanisms at a functional level exist and these seem directly involved in the reception and transmission of information along the parameters varied in the thermal study. Coding of temporal information may be similar in the two modalities, as may the integration and interpretation at higher centers. But again, lack of information concerning thermal reception prevents more than a tentative hypothesis concerning temporal aspects.

An issue similar to the architectural may be raised in connection with the data. In defense, it might be said that the differences that occur between absolute CFF and TFF rates may be produced by the different characteristics of visual and thermal systems previously acknowledged. The fact that TFF rates are lower may be due to the amount of energy necessary to stimulate the thermal receptors in comparison with that required to activate the visual sensors. The disparity observed may also be partly due to the large amount of energy the skin retains between pulses. An experiment should be designed to test this. It might involve a pulse train in which the energy does not drop to zero as it traditionally does in visual CFF experiments.

Another possible explanation of the difference in absolute visual and thermal fusion rates might invoke the difference in the number of receptors stimulated. As mentioned, an increase in the size of the area stimulated results in a corresponding increase in the number of receptors involved. Also, rates at which fusion occurs increases with increments in area in both the visual and thermal systems. From these two facts, it could be hypothesized that the higher fusion rates in vision may in some way result from stimulation of a greater number of receptors. Consistent with this hypothesis is the decline in CFF with decline in input as stated by the Ferry-Porter Law. From this relation, it could be assumed that if it were possible to stimulate an equal number of visual receptors in an equivalent area as thermal receptor density, it might be expected that CFFs would be very low. In fact, if it were possible to stimulate a visual mosaic equivalent in density to the thermal mosaic, the range of flicker-fusion might not be too different. Hence, the discrepancy in rate may be more apparent than real.

Finally, assuming that density of innervation of a particular area is reflected by the number of sensitive "spots" recorded, it is possible to draw some conclusions regarding von Bekesy's (1959) hypotheses that thresholds are related to density of innervation. It is commonly thought that the forearm is a more sensitive area than the trunk, an assumption implied by von Bekesy, who charted increasing sensitivity from the shoulder to the finger tip. Von Bekesy's hypothesis suggests that nerve density on the cortex (likely matched by density of innervation at the periphery) increases from the trunk to the periphery, and corresponds to a lowering of thresholds (particularly the two-point threshold in his example).[10]

Von Bekesy's contention regarding sensitivity would appear to be inconsistent with the results of our preliminary investigation, in which warm "spot" sensitivity was recorded. This study showed that density of warm "spots" was _greater on the back than on the forearm_ for two _O_s, contrary to his expectation. Likewise, comparison of thermal fusion rates for the two body areas employed in the present study shows that TFF thresholds are higher on the forearm than on the back. Two possible explanations could be put forth. First, von Bekesy's contention that the forearm is more densely innervated than the back may not be correct. Second, if the data from our punctate sensitivity study are accepted, and the back is more densely innervated than the forearm, absolute values of TFF are in accord with von Bekesy's hypothesis. However, supporting evidence for von Bekesy's hypothesis can be found in Mountcastle (1959)[11] and indirect evidence comes from alternation-of-response expectations, as well as the evidence from the current punctate experiment.[12] This leads to the conclusion that von Bekesy's implication that the forearm is more densely innervated than the back is correct, and therefore, TFF thresholds are not in accord with the prediction based on density of innervation.

Summary and Conclusions

The study was designed to test the temporal characteristics of the thermal modality. The parameters varied were chosen through analogy with similar investigations in the visual modality. Pulse-to-Cycle Fraction (PCF), intensity and area were proven to be important factors in the determination of CFF, and were, therefore, varied in the thermal study. In addition, two body areas were tested. Stimulation apparatus permitting greater precision than that used by Basler and Kastorf were employed. Preliminary experiments were run to provide information for the controls used in the principal experiments with the method of limits used to determine fusion thresholds.

The results from the main studies obtained from varying the parameters mentioned in the thermal experiment were like those produced by varying parameters in the visual modality. More specifically, varying PCF over a large range in either modality results in a fusion curve that increases to a peak and then declines. The fusion curves produced by varying area are similar for both modalities in that fusion rates appear to increase in an approximately linear relation with increasing area.

Differences occurred when intensity (or luminance) is varied. The thermal fusion curve increases steadily over a large range, whereas the visual fusion curve rises and then declines at extremely high luminance levels. The absolute threshold rates for the two modalities differ in that visual fusion rates tend to be much higher than thermal fusion rates.

The results achieved by stimulating the volar forearm and upper back were also compared and related to an hypothesis put forth by von Bekesy concerning the absolute measures at threshold. Von Bekesy's hypothesis was not confirmed if certain assumptions about the current study are made. Throsby's and Pieron's model were also briefly related to the data. A theoretical explanation of the results was suggested in terms of the alternation-of-response theory.

References

Baker, H.D. and Baker, B.N. Visual sensitivity. Annual Rev. Psychol., 1970, 21, 307-338.

Bartley, S.H. The neural determination of critical flicker frequency. J. Exp. Psychol., 1937, 21, 678-686.

Bartley, S.H. Principles of Perception. Harper and Row, New York, 1958, Ch. 17.

Bartley, S.H. Some facts and concepts regarding the neurophysiology of the optic pathway. A.M.A. Arch. Opth., Part II, 1958, 60, 775-791, (ref. p. 782).

Bartley, S.H. Central mechanisms of vision. Handbook of Physiology, Section I: Neurophysiology, Vol. 1, Amer. Physiol. Soc., Washington, D.C., 1959.

Bartley, S.H. A clarification of some of the procedures and concepts involved in dealing with the optic pathway, in The Visual System: Neurophysiology and Psychophysics - Freiburg Symposium, Jung, R. and Kornhuber, H. (Eds.), Heidelberg, 1961.

Bartley, S.H. Vision. Hafner, New York, 1963.

Bartley, S.H. Temporal features of input as crucial factors in vision. In W.D. Neff's (Ed.), Contributions to Sensory Physiology. Academic Press, New York, 1965, V. 3.

Bartley, S.H. A general theory of sensory response mechanisms, Symposium on Alternation-of-Response. J. Gen. Psychol., 1971, 84, 142-151.

Bartley, S.H. and Nelson, T.M. Some relations between pulse-to-cycle fraction and critical flicker frequency. Percept. Mot. Skills, 1960, 10, 3-8.

Bartley, S.H. and Nelson, T.M. A comparison of three rates of pulse onset and decline in producing critical flicker frequency. J. Psychol., 1960, 49, 185-194.

Bartley, S.H. and Nelson, T.M. A further study of pulse-to-cycle fraction and critical flicker frequency. A decisive theoretical test. J. Opt. Soc. Amer., 1961, 51, 41-45.

Bartley, S.H. and Nelson, T.M. Some relations between sensory end-results and neural activity in the optic pathway. J. Psychol., 1963, 55, 121-143.

Basler, A. Uber die Verschmelzung von zwei nacheinander erfolgenden Lichtreizen. *Pflug. Arch. ges. Physiol.*, 1911, *143*, 245-251.

Basler, A. Uber die Verschmelzung rhythmischer Warme-und Kalzeempfindungen. *Plfug. Arch. ges. Physiol.*, 1913, *151*, 226-247.

Bazett, H.C. and McGlone, B. Studies in sensation: II. The mode of stimulation of cutaneous sensations of cold and warmth. *Arch. Neurol. Psychiat.* (Chic.), 1932, *37*, 1031-1069.

Bekesy, G. von. Funnelling in the nervous system and its role in loudness and sensitivity on the skin. *J. Acoust. Soc. Amer.*, 1958, *30*, 399-412.

Bekesy, G. von. Similarities between hearing and skin sensations. *Psychol. Rev.*, 1959, *66*, 1-22, (ref. p. 8).

Benzinger, T.H. Peripheral cold and central warm reception. *Proc. Nat. Acad. Sci.*, 1963, 832-839.

Benzinger, T.H., Kitzinger, C., and Pratt, A.W. The human thermostat in *Temperature: Its Measurement and Control in Science and Industry*. Vol. 3, (Ed. C.M. Herzfeld), Part 3, *Biology and Medicine*, (Ed. J.D. Hardy), Reinhold, N.Y., 1963.

Berger, C. Area of retinal image and flicker fusion frequency. *Acta Physiol. Scand.*, 1953, *28*, 224-233.

Brooks, B. Neurophysiological correlates of brightness discrimination in the lateral geniculate of the squirrel monkey. *Exper. Brain Res.*, 1966, *2*, 1-17.

Brown, J.L. Flicker and intermittent stimulation, in Graham (Ed.), *Vision and Visual Perception*, Wiley, N.Y., 1965.

Bruesch, S.R. and Arey, L.D. The number of myelinated and unmyelinated fibers in the optic nerve of vertebrates. *J. Comp. Neurol.*, 1942, *77*, 631-635.

Cohen, J. *Sensation and Perception II*. Eyewitness Series in Psychology, Rand McNally, 1969.

Cords, R. Verschmelzungsfrequehz bei period. Nethautreizungern usw. *Arbeiten a.d. Physiolog. Antalz zu Leipzing*, 1907, 5.161.

Corso, J.F. *Experimental Psychology of Sensory Behavior*. Holt, Rinehart and Winston, N.Y., 1967.

Cottle, W. Personal Communications, 1970.

Dallenbach, K.M. The temperature spots and end-organs. *Amer.*, *J. Psychol.*, 1927, *39*, 402-427.

Dessior, M. Uber den Hautsinn. *Arch. Physiol.*, 1892, *16*, 175-339.

Edwards, A.L. *Experimental Design in Psychological Research*. Holt, Rinehart and Winston, N.Y., 1965.

Frey, M. von. Beitrange zur Sinnesphysiologie den Haut. *Ber. sachs. Ges. Wiss.*, *math-phys. Cl.*, 1895, *47*, 166-184.

Geldard, F.A. *The Human Senses*. Wiley, N.Y., 1953.

Ginsburg, N. Local adaptation to intermittent light as a function of frequency and eccentricity. *Amer. J. Psychol.*, 1966, *79*, 296-300.

Graham, C.H. (Ed.). *Vision and Visual Perception*. Wiley, N.Y., 1965.

Granit, R. *Receptors and Sensory Perception*. Yale University Press, New Haven, 1955, (ref. p. 60).

Granit, R. and von Ammon, W. Comparative studies on the peripheral and central retina: III. Some aspects of local adaptation. *Amer. J. Physiol.*, 1930, *95*, 229-241.

Granit, R. and Harper, P. Comparative studies on the peripheral and central retina: II. Synaptic reactions in the eye. *Amer.*, *J. Physiol.*, 1930, *95*, 211-227.

Hafez, E. *The Behavior of Domestic Animals*, Williams and Wilkins, Baltimore, 1962.

Han, H. Uber den erregungsvorgang der temperaturenerven. *Pflug. Arch. ges. Physiol.*, 1928, *65*, 41-54.

Hall, E.T. *The Hidden Dimension*. Anchor Books, Garden City, N.Y., 1969, (ref. p. 52-53).

Harbert, F., Young, I.M., and Wenner, C.H. Auditory flutter fusion and envelope of signal. *J. Acoust. Soc. Amer.*, 1968, *44*, 803-806.

Hardy, J.D., Wolff, H.G., and Goodell, H. Pain Sensations and Reactions. Williams and Wilkins, Baltimore, 1952, Ch. 3-4.

Harlow, H.F. Of love in infants. Natural History, 1960, 69, 18-23.

Hecht, S. and Verrijp, C.D. Intermittent stimuation by light, III. The relation between intensity and critical fusion frequency for different retinal locations. J. Gen. Physiol., 1933, 17, 251-265.

Helmendach, R.H. and Meehan, J.P. Thermoregulatory responses of dogs after alteration of peripheral sensitivity. Amer. J. Physiol., 1962, 202, 1237-1240.

Helmholtz, H.L.F. von. Physiological Optics. (Trans. J.P.C. Southhall), Vol. II. Rochester, N.Y., Optical Society of America, 1924.

Hensel, H. and Boman, K.K. Afferent impulses in cutaneous sensory nerves in human subjects. J. Neurophysiol., 1960, 23, 564-578.

Hensel, H. and Zotterman, Y. Action potentials of cold fibers and intracutaneous temperature gradient. J. Neurophysiol., 1951, 14, 377-385.

Hensel, L.M. and Zotterman, Y. The effect of menthol on the thermoreceptors. Acta Physiol., Scand., 1952, 24, 27-34.

Hurvich, L.M. and Jameson, D. The Perception of Brightness and Darkness. Allyn and Bacon, Boston, 1966.

Hyvarinen, J., Sakata, H., Talbot, W.H., and Mountcastle, V.B. Neuronal coding by cortical cells of the frequency of oscillating peripheral stimuli. Science, Dec., 1968, 162, 1130-1132.

Ives, H.E. Critical frequency relations in scotopic vision. J. Opt. Soc. Amer., 1922, 6, 254-268.

Kastorf, F. Uber die Verschmelzung der Warmeempfindung bie rhythmisch erfolgenden Reizen. Arch. f. Biol., 1920, 71, 1-18, (ref. p. 14).

Kenshalo, D. and Scott, H.A. Jr. Temporal course of thermal adaptation. Science, March, 1966, 1095-1096.

Landis, C. Determinants of the critical flicker fusion threshold. Physiol. Rev., 1954, 34, 259-286.

Lele, P.P., Wardell, G., and Williams, C.M. The relationship between heat transfer, skin temperature and cutaneous sensibility. J. Physiol., (London), 1954, 126, 206-234.

Lloyd, V.V. and Landis, C. Role of the light-dark ratio as a determinant of the flicker-fusion threshold. J. Opt. Soc. Amer., 1960, 50, 332-336.

Locke, J. An Essay Concerning Human Understanding. 1690, reprinted 1937, New York.

Lythgoe, R.J. and Tansley, K. The relation of the critical frequency of flicker to the adaptation of the eye. Proc. Roy. Soc., (London), 1929, 105, 60-92.

Morgan, C.T. Physiological Psychology, 3rd Ed., McGraw-Hill, New York, 1965.

Mountcastle, V.B. Some functional properties of the somatic afferent system, in W. Rosenblith (Ed.), Sensory Communication. M.I.T. Press, Cambridge, Massachusetts, 1961.

Mountcastle, V.B., Talbot, W.H., Darian-Smith, I., and Kornhuber, W.H. Neural basis of the sense of flutter-vibration, Science, Feb., 1967, 155, 597-600.

Mueller, C.G. Sensory Psychology. Prentice-Hall, New Jersey, 1965.

Nafe, J.P. The pressure, pain and temperature senses, in C. Murchison (Ed.), Handbook of General Experimental Psychology. Clark University Press, Worchester, Massachusetts, 1934.

Nelson, T.M. and Bartley, S.H. Theoretical interpretation of various qualitative and quantitive aspects of flicker and fusion phenomena. J. Psychol., 1965, 59, 185-194 (ref. p. 191).

Nelson, T.M. and Bartley, S.H. Description of a central mechanism related to diverse brightness phenomena. J. Psychol., 1964, 58, 379-395, (ref. p. 381).

Nelson, T.M. and Bartley, S.H., and De Hart, D. A comparison of variability of three sorts of observers in a sensory experiment. J. Psychol., 1960, 49, 3-11.

Nelson, T.M. and Nilsson, V. CFF for short pulse trains preceded by variable periods of stimulation, Symposium on Alternation-of-Response. J. Gen. Psych., 1971, 84, 51-56.

Pieron, H. Vision in intermittent light: Laws and mechanisms of the critical frequency for fusion, in W.D. Neff (Ed.) Contributions to Sensory Physiology, Academic Press, N.Y., 1965.

Ranson, S.W. Regulation of body temperature, in J.F. Fulton et al., (Ed.). Assoc. for Res. in Nerv. and Ment. Dis.: The Hypothalamus and Central Levels of Autonomic Function., Williams and Wilkins, Baltimore, Md., 1939.

Rose, J.E. and Mountcastle, V.B. Touch and kinesthesis, in H.W. Magoun (Ed.) Handbook of Physiology, Sec. I, Vol. 1, Amer. Physiol. Soc., Washington, D.C., 1959.

Rosenblith, W. (Ed.) Sensory Communication. M.I.T. Press, Cambridge, Massachusetts, 1961.

Siegel, S. Non-parametric Statistics for the Behavioral Science, McGraw-Hill, York, P.A., 1956.

Sinclair, D. Cutaneous Sensation. Oxford University Press, London, England, 1967.

Skramlik, E. von. Psychophysiologie der Tastsinne. Arch. ges. Psychol., Erganzungbd., 1937, 4, 275-294.

Steen, E.B. and Montagu, A. Anatomy and Physiology, Vol. 2, Barnes and Noble College Outline Press, New York, 1959.

Stevens, S.S. Handbook of Experimental Psychology, Wiley, N.Y., 1951.

Symmes, D., Chapman, L.F., and Halstead, W.C. Fusion and intermittent white noise. J. Acoust. Soc. Amer., 1955, 27, 470-473.

Thompson, R.F. Foundations of Physiological Psychology, Harper and Row, N.Y., 1967.

Throsby, A. Proportion of light to cycle as a determinent of critical flicker fusion frequency. Psychol. Bull., 1962, 59, 510-519, (ref. p. 511).

Vendrik, A.J.H. and Eijkman, E.G. Psychophysical properties determined with internal noise, in D. Kenshalo (Ed.) The Skin Senses, Thomas, Springfield, Ill., 1968.

Weale, R.A. The effect of test size and adapting luminance on foveal critical fusion frequencies. Visual Problems of Color, H.M. Stationery Office, London, 1958, II, 445-459.

Wever, E.G. Theory of Hearing. Wiley, New York, 1949.

Wever, E.G. and Bray, C.W. The perception of low tones and the resonance-volley theory. J. Psychol., 1937, 3, 101-114.

Winchell, P. and Simonson, E. Effect of the light: dark ratio on the fusion frequency of flicker. J. Appl. Physiol., 1951, 4, 188-192.

Woodworth, R.S. Experimental Psychology, Holt, New York, 1938, Ch. 19.

Footnotes

[1] Refers to intervening variables in the sense used by Thompson, 1967. He gives the chemical theory of synaptic transmission as an example.

[2] On the animal level, Helmendack and Meehan (1962) found that when menthol was placed on the skin, shivering was stimulated in dogs.

[3] Equipment available from Edmund's.

[4] BMY General Electric, 100 Watts.

[5] Position of components of lens arrangement measured as distance from _0_: fixed aspheric lens: 23.5 cm., source: 28.0 cm., convex mirror: 35.5 cm.

[6] Position of sliding lens (measured as distance from _0_) corresponding to the different areas used:

diameter of circle	distance
1 inch	27.5 mm.
1 3/4 inches	41.5 mm.
2 1/2 inches	59.5 mm.
4 inches	87.5 mm.

[7] Conditioning refers to recovery of _channels_ rather than elements, i.e., the receptivity of channels to re-activation.

[8] The evidence for the effects of long pre-conditioning has some support at a body level (Brooks, 1966) but comes largely from flicker experiments. Neural levels are implicated in the early parts of dark conditioning, whereas photochemical regeneration is thought to supply only the terminal improvement in these curves (Baker, 1970). However, the mechanism of light adaptation has not been fully explained (Brown, 1969). Visual flicker-fusion has been shown to be affected by long pre-conditioning periods, both null (dark adaptation) and photic (light adaptation). Lythgoe and Tansley (1929) have demonstrated that when dark adaptation precedes testing, a decrease in CFF results, i.e., a null preconditioning period provides a decrease in CFF. However, their results indicate a rise in CFF with light adaptation.

However, moderate amounts of prior stimulation produce different effects than long conditioning periods under certain conditions. Granit and von Ammon (1939) and Ginsburg (1966) report a local adaptation phenomenon in which exposing the eye to moderate amounts of intermittent photic input prior to threshold determination results in a lowering of CFF. Central levels are implicated by Ginsburg (1966) in changes evoked by local adaptation.

The phenomenon resulting from short conditioning periods is thought to involve neural levels. Data from Nelson and Nilsson (1971) employing brief adaptation times support the contention that with short pulse trains, fusion is reached at lower rates with no prior stimulation than when the system is pre-stimulated. (No differences are seen with long pulse trains.) Pre-stimulation of the system produces a situation in which portions of the system are in action constantly while other portions are recovering. Without benefit of prior stimulation, input produces a summed discharge while, in contrast, pre-stimulation puts the system in alternation prior to the introduction of intermittency. Thus, with pre-stimulation, a supra-threshold amount of stimulation occurs with the second pulse, while without any other prior stimulation the first pulse discharges all available channels, greatly reducing the likelihood that a second stimulus will fall upon a population just under threshold, and therefore, ready to fire.

9 No statistical analysis of linearity was applied to the thermal curves (analogous to Pieron's visual curves). The conclusions stated in the text are drawn from the form of the curves as seen in Figure 11.

10 Von Bekesy also reported that just noticeable amplitude variations may be smaller when the area stimulated is reduced (and, therefore, less receptors are involved). Paradoxically, he also notes that "a consequence of a large nerve supply seems to be that the sense organ is more sensitive." A solution to this inconsistency may be the hypothesis that when fewer receptors are stimulated, the threshold may be more sharply differentiated; i.e., only small stimulus changes may be necessary to produce threshold reports.

11 Mountcastle (1959) describes smaller cutaneous receptive fields on peripheral areas as compared to trunk surfaces. Density of innervation is directly related to peripheral receptive field size in that smaller fields are more densely innervated than their large counterparts.

12 No other data exists in the literature describing the density of warm "spots" on the back. The literature yields contradictory information concerning the density of warm "spots" on the volar forearm, with one experiment in agreement with the present study, while another result differs (see Results). The data from the present study is scant, employing two Os for one trial each. Further, one of these two Os also acted as an observer in the principal studies. This O (SL) tended to differ from the other Os in his responses in that he showed no difference in absolute values on "ascending" and "descending" trials. In addition, the absolute values of his responses at threshold tended to be lower than the other Os for data from the forearm. Further, the warmth thresholds of this O tended to be considerably higher than the other three Os for back surfaces, but not for the forearm determination. 13

13 No consistent interaction was apparent when warmth thresholds from each body surface were compared to TFF thresholds for each O. No statistical test was applied, as only the mentioned difference between Os was seen for warmth thresholds and this difference appeared to be independent of TFF thresholds.

APPENDIX

Appendix "A"

Training criteria for flicker and fusion under conditions of PCF and rate. "Direction" indicates whether the trial began above or below fusion. "Sensation" describes the experiences of a trained observer under various experimental conditions. Four observers were trained to use these criteria for flicker and fusion.

PCF	Direction	Sensation
short e.g. 1/3	flicker → fusion	at low rates - sharp peaks followed by a null period as rate increases - sharpness of the peak decreases, separation becomes finer no wax or wane, i.e., the end-point is easily detected - fusion is well-defined
short	fusion → flicker	at high rates - fusion is well-defined no wax and wane - flicker is eaily picked out
mid e.g., 1/2	flicker → fusion	at low rates - flicker is well-defined, remains well-defined until near the fusion point great deal of wax and wane - near fusion, the change is not well-defined
mid	fusion → flicker	the threshold is well-defined - flicker is easily detected
long e.g., 5/6	flicker → fusion	at low rates - flicker is easily detected and the null period feels cool as rate increases - the null portion becomes less well-defined as the end-point is approached, there is a great deal of wax and wane - the null period fades gradually and is more difficult to detect than the on cycle - greatest wax and wane under these conditions
long	fusion → flicker	flicker is well-defined

Flicker is more easily detected than fusion. Also, when the direction of the trial is from fusion to flicker, there is an increase in the sensation of warmth which is merely a concomitant of the situation and should be ignored.

Appendix "B"

Averages and standard deviations (in degrees F.) for warmth and pain thresholds for one area on the forearm and two areas on the upper back. Data for four observers is shown. Plus signs indicate that threshold lies above the upper limit tested.

	BACK								FOREARM			
	Area = 2 1/2" d				Area = 1 3/4" d				Area = 1 3/4" d			
	warmth		pain		warmth		pain		warmth		pain	
Observer	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
CW	78.3	1.68	132.0	7.27	90.3	1.19	114+	0.0	88.4	0.49	104.8	7.01
SL	104.6	1.43	135+	0.0	114.0	0.23	114+	0.0	90.2	0.51	110.0	2.39
IC	86.8	4.86	121.4	10.0	90.2	1.11	112+	0.14	92.2	2.32	112+	0.53
WF	84.6	2.96	124.0	4.82	90.3	1.46	114.0	0.27	91.5	2.22	112+	0.0

APPENDIX "C"

Summary of the data analysis for the variable of PCF (I and A held constant) when testing the back.

Table C-1

Summary of the Two-Way Analysis of Variance for Os and PCF showing levels of significance achieved:

	Ascending	Descending	Total
Os	.05	.01	.01
PCF	.05	.05	.05

Table C-2

Summary of the Analysis of Variance for each O showing levels of significance achieved:

Observer	Ascending	Descending	Total
CW	-	-	-
IC	.01	.01	.01
WF	.05	.05	-
SL	.01	-(.09)	.01

- = p > .05

Table C-3

Summary of Duncan's New Multiple Range Test comparing each PCF with every other for four Os:

Observer	Data Treatment	PCF 1/3 vs. 1/2	PCF 1/3 vs. 2/3	PCF 1/3 vs. 5/6	PCF 1/3 vs. 2/3	PCF 1/3 vs. 5/6	PCF 1/3 vs. 5/6
CW	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
IC	A	-	√	-	-	√	√
	D	√	√	-	-	√	√
	T	√	√	-	-	√	√
WF	A	√	√	-	-	-	-
	D	-	-	-	-	√	√
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
SL	A	√	-	-	√	√	√
	D	-	-	√	-	√	√
	T	√	-	-	√	√	√

n.t. = not tested due to $p > .05$ in the analysis of variance

\- = not significant

√ = $p < .05$

Table C-4

Average threshold rates for each observer at each of four PCF's for all data treatments. Standard deviations are also shown. Intensity and area were held constant. I = 120° F.; A = 2 1/2 inches in diameter.

Obser-ver	PCF	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviation Total
CW	1/3	2.17	2.51	2.34	1.64	.57	1.24
	1/2	2.68	3.25	2.96	1.99	.52	1.48
	2/3	2.89	3.31	3.10	1.68	1.20	1.47
	5/6	1.83	3.09	2.46	1.78	1.27	1.67
IC	1/3	.94	.62	.78	.44	.20	.38
	1/2	2.37	2.21	2.28	.75	.68	.72
	2/3	2.96	1.99	2.48	2.36	.77	1.77
	5/6	.28	.47	.38	.04	.13	.12
WF	1/3	.48	1.06	.77	.10	.40	.41
	1/2	2.92	1.39	2.16	1.78	.34	1.49
	2/3	2.83	1.37	2.10	.86	.32	.97
	5/6	1.79	.78	1.28	.84	.55	.79
SL	1/3	.56	1.38	.97	.07	.31	.47
	1/2	1.36	1.50	1.43	.19	.52	.40
	2/3	.66	1.38	1.02	.14	.13	.39
	5/6	.38	.84	.61	.08	.34	.34

Table C-5

Summary of the two-factor trend analysis for _O_s and PCF.

				PCF		_O_ x PCF	
	_O_s	PCF	_O_ x PCF	Linear	Quadratic	Linear	Quadratic
Ascending	✓	✓	-	-	✓	n.t.	n.t.
Descending	✓	✓	-	-	✓	n.t.	n.t.
Total	✓	✓	-	-	✓	n.t.	n.t.

✓ = $p < .05$

\- = $p > .05$

n.t. = not tested (because prior analysis of the factor proved not significant, e.g., the trends on _O_ x PCF are not tested because the prior analysis [Column 3 of the above table] proved not significant.

Table C-6

Summary of the trend analysis on PCF for each O. The quadratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	-	-	n.t.
	D	-	-	n.t.
	T	-	-	n.t.
IC	A	-	✓	✓
	D	-	✓	✓
	T	-	✓	✓
WF	A	-	✓	✓
	D	-	✓	✓
	T	-	-	n.t.
SL	A	✓	✓	✓
	D	-	-	n.t.
	T	✓	✓	✓

- = $p > .05$
n.t. = not tested
✓ = $p < .05$

Table C-7

Average threshold rates for each observer at PCF 1/6 and 1/3 for all data treatments. Standard deviations are also shown. Intensity and area were held at the same values as in the previous study; however, PCF 1/6 was not available to be run in the initial study.

Observer	PCF	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviation Total
CW	1/6	2.78	1.08	1.93	.86	.08	1.05
	1/3	4.76	1.91	3.34	1.02	.33	1.57
IC	1/6	.30	.94	.62	.01	.18	.34
	1/3	.29	1.69	.99	.01	.40	.76
WF	1/6	1.74	.91	1.32	.51	.18	.56
	1/3	2.06	1.16	1.61	.65	.02	.64
SL	1/6	1.47	1.33	1.40	.17	.11	.14
	1/3	1.47	1.60	1.54	.11	.16	.15

Table C-8

Summary of the Mann-Whitney U-test for four Os for all data treatments comparing PCF 1/3 with PCF 1/6. Significance levels achieved are shown.

Observer	Ascending	Descending	Total
CW	-	-	-
IC	-(.08)	.01	-
WF	-	.05	-(.07)
SL	.05	.01	.05

- = p > .05

Table C-9

Summary of the Mann-Whitney U-test for four Os for all data treatments comparing PCF 1/3 from the original study with PCF 1/3 from the following study (when equipment became available to test PCF 1/6). Significance levels achieved are shown.

Observer	Ascending	Descending	Total
CW	.05	-	-
IC	.01	.01	-
WF	.01	-	.01
SL	.01	-	.01

- = p > .05

APPENDIX "D"

Summary of the data analysis for the variable of intensity (PCF and A held constant) when testing the back.

Table D-1

Summary of the two-way analysis of variance for Os and I showing levels of significance achieved.

	Ascending	Descending	Total
Os	.01	.01	.01
I	.01	.01	.01

Table D-2

Observer	Ascending	Descending	Total
CW	-(.08)	-	-
IC	-	-	-
WF	-	-	-
SL	.05	-	-

- = $p > .05$

Table D-3

Summary of Duncan's New Multiple Range Test comparing each I with every other for four Os.

Obser-ver	Data Treat-ment	100 vs. 110 (°F.)	100 vs. 120 (°F.)	100 vs. 130 (°F.)	110 vs. 120 (°F.)	110 vs. 130 (°F.)	120 vs. 130 (°F.)
	A	-	-	√	-	-	-
CW	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
IC	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
WF	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	A	-	-	√	-	√	-
SL	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.

- = $p > .05$

√ = $p < .05$

n.t. = not tested due to $p > .05$ in the analysis of variance.

Table D-4

Summary of the two-factor trend analysis for Os and I.

				I		O x I	
	Os	I	O x I	Linear	Quadratic	Linear	Quadratic
Ascending	-	√	-	√	-	n.t.	n.t.
Descending	√	-	-	n.t.	n.t.	n.t.	n.t.
Total	-	√	-	√	-	n.t.	n.t.

- = p > .05

√ = p < .05

n.t. = not tested (because prior analysis of the factor proved not significant.)

Table D-5

Summary of the trend analysis on I for each O. The quadratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	√	-	n.t.
	D	-	-	n.t.
	T	√	-	n.t.
IC	A	-	-	n.t.
	D	-	-	n.t.
	T	-	-	n.t.
WF	A	-	-	n.t.
	D	-	-	n.t.
	T	-	-	n.t.
SL	A	√	-	n.t.
	D	-	-	n.t.
	T	√	√	-

- = p > .05

√ = p < .05

n.t = not tested

Table D-6

Average threshold rates for each observer at each of four intensities for all data treatments. Standard deviations are also shown. PCF = 1/2; A = 2 1/2 inches in diameter.

Observer	I	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviation Total
CW	100	1.89	1.31	1.60	.70	.26	.39
	110	2.67	1.41	2.04	.97	.39	.96
	120	2.87	1.42	2.14	.32	.40	.81
	130	4.21	1.56	2.88	1.76	.44	1.83
IC	100	1.34	.68	1.01	2.12	.27	1.54
	110	2.41	.81	1.61	1.92	.43	1.60
	120	2.46	.78	1.62	2.54	.18	1.90
	130	2.53	.80	1.66	1.94	.24	1.56
WF	100	2.53	.91	1.72	1.26	.43	1.24
	110	3.38	1.02	2.20	.54	.12	1.24
	120	3.60	1.09	2.34	1.80	.21	1.79
	130	4.21	1.10	2.66	1.28	.35	1.86
SL	100	1.85	1.37	1.61	.22	.26	.34
	110	1.98	1.52	1.75	.31	.25	.36
	120	2.26	1.59	1.92	.12	.25	.39
	130	2.40	1.76	2.08	.36	.52	.44

APPENDIX "E"

Summary of the data analysis for the variable of area (PCF and I held constant) when testing the back.

Table E-1

Summary of the Mann-Whitney U-test for four Os for all data treatments comparing areas in the ratio of 1:6 (intensity held constant at 120° F.), areas in the ratio of 6:16 (intensity held constant at 100° F.), and the same area at two different intensity levels (100° F. and 120° F.). PCF is held constant at 1/2. Significance levels achieved are shown.

		Diameter of Areas		
Observer	Data Treatment	4" vs. 2 1/2" (16:6)	2 1/2" vs. 2 1/2" (100° F. vs. 120° F.)	2 1/2" vs. 1" (6:1)
CW	A	.01	-	-
	D	.05	-	.05
	T	.001	-	-(.10)
IC	A	.05	-	-
	D	.01	-(.06)	-
	T	.01	-	-
WF	A	-	-	.05
	D	.01	-	-
	T	-	-	-
SL	A	-	-	.05
	D	.01	-	.05
	T	-(.07)	.05	.01

- = $p > .05$

Table E-2

Average threshold rates with their standard deviations for each observer for two areas at each of two intensities for all data treatments. PCF is held constant at 1/2.

Observer	I	Diameter of Area	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviations Total
CW	100° F.	4"	1.61	1.88	1.69	.19	.34	.31
		2 1/2"	1.10	1.34	1.22	.20	.11	.20
	120° F.	2 1/2"	1.28	1.45	1.36	.20	.25	.25
		1"	1.24	1.13	1.18	.28	.16	.24
IC	100° F.	4"	2.56	1.42	1.99	.81	.34	.84
		2 1/2"	1.54	.81	1.18	.18	.13	.92
	120° F.	2 1/2"	1.87	.97	1.42	.42	.09	.55
		1"	1.79	.88	1.34	.75	.16	.58
WF	100° F.	4"	3.42	1.28	2.35	1.14	.14	1.34
		2 1/2"	2.82	.91	1.86	.86	.16	.88
	120° F.	2 1/2"	3.09	1.08	2.08	.36	.24	1.05
		1"	2.44	.96	1.70	.74	.18	.84
SL	100° F.	4"	1.46	2.12	1.79	.13	.23	.38
		2 1/2"	1.33	1.71	1.52	.09	.09	.21
	120° F.	2 1/2"	1.50	1.67	1.58	.17	.23	.22
		1"	1.17	1.34	1.26	.13	.10	.14

APPENDIX "F"

Summary of the data analysis for the variable of PCF (I and A held constant) when testing the forearm.

Table F-1

Summary of the Two-way analysis of variance for Os and PCF showing levels of significance achieved:

	Ascending	Descending	Total
Os	.01	.01	.01
PCF	-	.01	.05

- = p > .05

Table F-2

Summary of the analysis of variance for each O showing levels of significance achieved:

Observer	Ascending	Descending	Total
CW	-	.01	.01
IC	.05	.01	.01
WF	.05	-	.01
SL	.01	.01	.01

- = p > .05

Table F-3

Summary of Duncan's New Multiple Range Test comparing each PCF with every other for four Os.

Observer	Data Treatment	1/6 vs. 1/3	1/6 vs. 1/2	1/6 vs. 2/3	1/6 vs. 5/6	1/3 vs. 1/2	1/3 vs. 2/3	1/3 vs. 5/6	1/2 vs. 2/3	1/2 vs. 5/6	2/3 vs. 5/6
CW	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	D	-	-	-	✓	-	-	✓	✓	✓	✓
	T	✓	✓	-	-	-	-	✓	✓	✓	✓
IC	A	n.d.	n.d.	n.d.	n.d.	-	✓	-	✓	-	✓
	D	n.d.	n.d.	n.d.	n.d.	-	-	-	-	✓	✓
	T	n.d.	n.d.	n.d.	n.d.	-	✓	-	-	✓	✓
WF	A	n.d.	n.d.	n.d.	n.d.	✓	✓	-	-	-	-
	D	n.d.	n.d.	n.d.	n.d.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.d.	n.d.	n.d.	n.d.	✓	-	-	✓	-	-
SL	A	-	✓	✓	✓	✓	-	✓	✓	✓	✓
	D	✓	✓	✓	-	-	✓	✓	-	✓	✓
	T	-	✓	✓	✓	✓	✓	✓	-	✓	✓

✓ = $p < .05$
- = $p > .05$
n.t. = not tested due to $p > .05$ in the analysis of variance
n.d. = no data available for testing, since O could not detect PCF 1/6 at the intensity level employed

Table F-4

Summary of the Mann-Whitney U-test for the two Os who could not detect PCF 1/6 at the intensity employed in the original study. PCF 1/6 and 1/3 were therefore run at a higher intensity where the short pulses could be detected. Significance levels achieved are shown in the table, which compares PCF 1/6 with PCF 1/3, and also PCF 1/3 at two intensity levels (PCF 1/3 from the present data vs. PCF 1/3 from the original data).

Comparison	Name	Ascending	Descending	Total
PCF 1/6 vs. PCF 1/3	IC	-	-	-
	WF	-	-	-
PCF 1/3 vs. PCF 1/3 (at different intensity levels)	IC	-	.05	-
	WF	.01	.05	.01

- = $p > .05$

Table F-5

Summary of the two-factor trend analysis for Os and PCF.

				PCF		O x PCF	
	Os	PCF	O x PCF	Linear	Quadratic	Linear	Quadratic
Ascending	✓	✓	✓	-	✓	✓	✓
Descending	✓	✓	✓	✓	✓	✓	✓
Total	✓	✓	✓	-	✓	✓	✓

✓ = $p < .05$
\- = $p > .05$

Table F-6

Summary of the trend analysis on PCF for each O. The quadratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	-	✓	✓
	D	✓	✓	✓
	T	✓	✓	✓
IC	A	-	✓	✓
	D	-	✓	✓
	T	-	✓	✓
WF	A	-	✓	✓
	D	-	-	n.t.
	T	-	✓	✓
SL	A		✓	✓
	D	-	✓	✓
	T	-	✓	✓

\- = $p > .05$
✓ = $p < .05$
n.t. = not tested

Table F-7

Average threshold rates with their standard deviations for each O for all data treatments. For two Os, PCF 1/6 - 5/6 is shown, with intensity held constant at the mid-point of the average warm and average pain thresholds. For the other two Os, 1/3 - 5/6 is shown with intensity also held constant at this same level. However, for these two Os, PCF 1/6 and 1/3 were presented at the higher intensities indicated, where O could detect PCF 1/6. Area was held constant at a circle one and three-quarter inches in diamter.

Observer	I	PCF	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviation Total
CW	mid-point	1/6	.57	.84	.70	.06	.12	.20
		1/3	.70	.96	.83	.12	.08	.17
		1/2	.77	1.04	.90	.14	.04	.17
		2/3	.66	.90	.78	.08	.10	.15
		5/6	.59	.68	.64	.11	.09	.37
IC	high intensity (107° F.)	1/6	.48	.84	.66	.06	.32	.22
		1/3	.46	.86	.66	.05	.04	.21
	mid-point	1/3	.46	.75	.60	.07	.09	.53
		1/2	.52	.84	.68	.04	.08	.54
		2/3	.67	.86	.76	.13	.17	.19
		5/6	.45	.58	.52	.03	.08	.09
WF	high intensity (112° F.)	1/6	2.01	.57	1.29	.54	.17	.77
		1/3	2.98	.75	1.87	1.81	.33	1.71
	mid-point	1/3	.66	.39	.53	.16	.09	.60
		1/2	2.18	.49	1.34	.69	.08	.98
		2/3	2.21	.45	1.33	.93	.12	1.13
		5/6	1.27	.37	.82	.60	.11	.62
SL	mid-point	1/6	1.12	1.11	1.12	.11	.08	.10
		1/3	1.11	1.33	1.22	.05	.16	.16
		1/2	1.39	1.40	1.40	.11	.11	.11
		2/3	1.52	1.49	1.50	.16	.09	.13
		5/6	.69	1.05	.87	.05	.05	.19

APPENDIX "G"

Summary of the data analysis for the variable of intensity (PCF and A held constant) when testing the forearm.

Table G-1

Summary of the two-way analysis of variance for Os and I showing levels of significance achieved.

	Ascending	Descending	Total
Os	.01	.01	.01
I	.01	.01	.01

Table G-2

Summary of the analysis of variance for each O showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	.01	.05	-
IC	.01	-	-
WF	.01	.01	.05
SL	.01	.01	.01

- = $p > .05$

Table G-3

Summary of Duncan's New Multiple Range Test comparing each intensity level with every other for four *O*s. "1/4" refers to this point in the range between average warm and average pain. "Mid" is the midpoint of the range. "3/4" is pain minus one-quarter the number of degrees in the range. "j.b." refers to a point just below pain.

Observer	Data Treatment	1/4 vs. mid	1/4 vs. 3/4	1/4 vs. j.b.	mid vs. 3/4	mid vs. j.b.	3/4 vs. j.b.
CW	A	-	√	√	√	√	-
	D	-	√	√	-	√	-
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
IC	A	-	√	√	-	√	-
	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
WF	A	√	√	√	-	-	-
	D	-	√	√	√	√	√
	T	-	√	√	-	-	-
SL	A	-	√	√	√	√	√
	D	-	√	√	-	√	√
	T	-	√	√	√	√	√

n.t. = not tested due to $p > .05$
in the analysis of variance

- $p > .05$

√ $p < .05$

Table G-4

Summary of the two-factor trend analysis for Os and I.

				I		O x I	
	Os	I	O x I	Linear	Quadratic	Linear	Quadratic
Ascending	✓	✓	✓	✓	-	✓	-
Descending	✓	✓	-	✓	-	n.t.	n.t.
Total	✓	✓	✓	✓	-	✓	✓

- p > .05

✓ p < .05

n.t. = not tested (because prior analysis of the factor proved not significant).

Table G-5

Summary of the trend analysis on I for each O. The quadratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	✓	-	n.t.
	D	✓	-	n.t.
	T	-	-	n.t.
IC	A	✓	-	n.t.
	D	-	-	n.t.
	T	✓	-	n.t.
WF	A	-	✓	-
	D	✓	-	n.t.
	T	✓	-	n.t.
SL	A	✓	-	n.t.
	D	✓	✓	✓
	T	✓	-	n.t.

- p > .05

✓ p < .05

n.t. = not tested

Table G-6

Average threshold rates for each observer at each of four intensities for all data treatments. Standard deviations are also shown. PCF and area were held constant. PCF = 1/2; A = 1 3/4 inches in diameter.

Observer	I	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviations Total
SL	1/4	1.12	1.28	1.20	.15	.10	.16
	mid	1.36	1.43	1.40	.12	.12	.13
	3/4	2.05	1.52	1.78	.29	.15	.35
	j.b.	2.45	2.06	2.26	.23	.18	.28
WF	1/4	.75	.38	.57	.15	.23	.30
	mid	1.23	.45	.84	.25	.08	.43
	3/4	1.42	.59	1.00	.24	.13	.45
	j.b.	1.59	.70	1.24	.28	.06	.49
CW	1/4	.63	1.48	1.00	.07	.13	.44
	mid	.63	1.61	1.12	.06	.17	.57
	3/4	.80	1.83	1.32	.11	.25	.55
	j.b.	.87	1.90	1.38	.12	.15	.53
IC	1/4	.57	.93	.75	.05	.11	.20
	mid	.59	.99	.79	.07	.18	.24
	3/4	.67	1.02	.84	.04	.10	.20
	j.b.	.73	1.08	.90	.06	.11	.21

APPENDIX "H"

Summary of the data analysis for the variable of area (PCF and I held constant) when testing the forearm.

Table H-1

Summary of the two-way analysis of variance for Os and area showing levels of significance achieved.

	Ascending	Descending	Total
Os	.01	.01	.01
Area	.05	.01	.01

Table H-2

Summary of the analysis of variance for each O showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	.01	-	-
IC	-	-	-
WF	.01	.05	.05
SL	.01	.01	.01

- = $p > .05$

Table H-3

Summary of Duncan's New Multiple Range Test comparing each Area with every other for four Os.

		Diameter of Areas		
Observer	Data Treatment	1" vs. 1 3/4" (1:3)	1" vs. 2 1/2" (1:6)	1 3/4" vs. 2 1/2" (3:6)
CW	A	-	✓	✓
	D	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.
IC	A	n.t.	n.t.	n.t.
	D	n.t.	n.t.	n.t.
	T	-	✓	-
WF	A	✓	✓	✓
	D	-	✓	-
	T	-	✓	-
SL	A	-	✓	✓
	D	-	✓	✓
	T	-	✓	✓

✓ = $p < .05$

- = $p > .05$

n.t. = not tested due to
$p > .05$ in the analysis
of variance.

Table H-4

Summary of the two-factor trend analysis for Os and Area.

				A		O x A	
	Os	Area	O x A	Linear	Quadratic	Linear	Quadratic
Ascending	✓	✓	✓	✓	-	✓	✓
Descending	✓	✓	-	✓	-	n.t.	n.t.
Total	✓	✓	✓	✓	-	✓	-

✓ $p < .05$

- $p > .05$

n.t. = not tested (because prior analysis of the factor proved not significant).

Table H-5

Summary of the trend analysis on Area for each O. The quadratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Treatment	Linear	Deviations	Quadratic
CW	A	✓	✓	✓
	D	✓	-	n.t.
	T	-	-	n.t.
IC	A	-	-	n.t.
	D	-	-	n.t.
	T	✓	✓	-
WF	A	✓	-	n.t.
	D	✓	-	n.t.
	T	✓	-	n.t.
SL	A	✓	-	n.t.
	D	✓	-	n.t.
	T	✓	✓	✓

✓ $p < .05$

- $p > .05$

n.t. = not tested

Table H-6

Average threshold rates for each observer at each of three areas for all data treatments. Standard deviations are also shown. Intensity and PCF were held constant. PCF = 1/2; I = mid-point of the warm and pain thresholds.

Observer	Diameter of Area	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviations Total
SL	2 1/2"	1.26	1.42	1.34	.09	.09	.12
	1 3/4"	1.06	1.18	1.12	.07	.06	.09
	1"	1.04	1.12	1.08	.04	.07	.07
IC	2 1/2"	.66	1.01	.84	.09	.15	.21
	1 3/4"	.60	.91	.76	.06	.06	.16
	1"	.58	.84	.71	.03	.05	.14
WF	2 1/2"	1.15	.63	.89	.34	.10	.36
	1 3/4"	.92	.54	.73	.35	.06	.32
	1"	.62	.43	.52	.15	.06	.21
CW	2 1/2"	.80	1.29	1.04	.06	.27	.31
	1 3/4"	.52	1.14	.83	.04	.08	.32
	1"	.47	1.06	.77	.03	.09	.30

APPENDIX "I"

Summary of the data analyses for the auxiliary study. This retested factors of the main study that did not produce significance in the analysis. Resulting differences are considered for each study.

APPENDIX "I"

As mentioned previously, a succeeding study retested those factors that did not produce significance in the initial analysis of variance. The difference in results will be discussed separately for each study.

Again, in Study #1, PCF was varied and body area stimulated was the back. The data for one O (CW) on "ascending" trials produced significance on the second attempt, as did the data for another O (SL) on "descending" trials. In Figure I-1, these significant curves replace the previous data, and are marked with an arrow. The data that achieved significance in the analysis of variance are the parenthesized results in Appendix "I-a". This appendix also summarizes the results from the two-factor analysis of variance and Duncan's test. The individual trends are also summarized in Appendix "I-a" as are the average thresholds and their standard deviations. Re-running the data for one O (SL) on "descending" trials produced the same result: nonsignificance in the analysis of variance.

In Study #2, intensity was varied and body area stimulated was the back. The data for two Os (CW and SL) on "descending" trials produced significance in the second attempt, as did the data for another O (WF) on all data treatments. The data producing significance replace the prior data in Figure I-2 and are marked with an arrow. The summarized results of the two-factor analysis of variance, the analysis of variance for each individual's data, Duncan's test, the two-factor trend analysis, individual trends, and average thresholds and their standard deviations for the data significant in the analysis of variance (the significant results of the second attempt are parenthesized) can be found in Appendix "I-b". Re-running this factor for one O (IC) yielded nonsignificance on "ascending", "descending", and "total" trials on Run #2, and also for CW on "ascending" trials on Run #2.

In Study #3, area was varied and body area stimulated was the back. Since an analysis of variance could not be employed in this study, the Mann-Whitney U-test was again applied. For one O (SL) on "ascending" trials, significant differences were found where they had not occurred previously (or had occurred less significantly). The remaining results of this test are summarized in Appendix I-c", as are the average thresholds and their standard deviations for "ascending" trials for two Os (SL and CW). Figure I-3 illustrates the significant results marked with an arrow.

In Study #4, PCF was varied and body area stimulated was the forearm. The data for one O (WF) proved significant in the analysis of variance on "ascending", "descending", and "total" trials on the second run. Four levels of PCF were run at one intensity, whereas, PCF 1/6 and 1/3 were run at a higher intensity where O could detect the shorter PCF. The results of the two-factor analysis of variance are summarized in Appendix "I-d", as are the results of Duncan's test (results proving significant on Run #2 are parenthesized). Only one change occurred in the U-tests and is parenthesized in the table in this appendix. Figure I-4 illustrates the curves, with those significant on Run #2 marked with an arrow. The table summarizing the trend analysis is found in Appendix "I-d", as are the average thresholds and their standard deviations. The data from the second attempt for CW on "ascending" trials again proved not significant.

In Study #5, intensity was varied and body area stimulated was the forearm. Only the "descending" condition for one O (IC) was re-run on the forearm. The data proved significant in the analysis of variance at the .01 level. The results of Duncan's test are summarized in Appendix "I-e", as are the two-factor analysis of variance, and the average thresholds and their standard deviations. Figure I-5, illustrates the curves produced from the data significant in the analysis of variance. These curves are marked by an arrow. The individual trend analysis did not change, except that the linear component of intensity proved significant, whereas the deviation component again proved not significant.

In Study #6, area was varied and body area stimulated was the forearm. The data for two Os (CW and IC) on the "ascending" condition proved significant in the analysis of variance. The summary of the analysis can be found in Appendix "I-f", as can the results of the two-factor analysis of variance and Duncan's test. The results proving significant in the second attempt are parenthesized. Figure I-6 illustrates these curves, marked with an arrow. The summary of the individual trend analysis can be found in Appendix "I-f", as can the average thresholds with their standard deviations. The data from the second attempt was again not significant for IC on "ascending" trials.

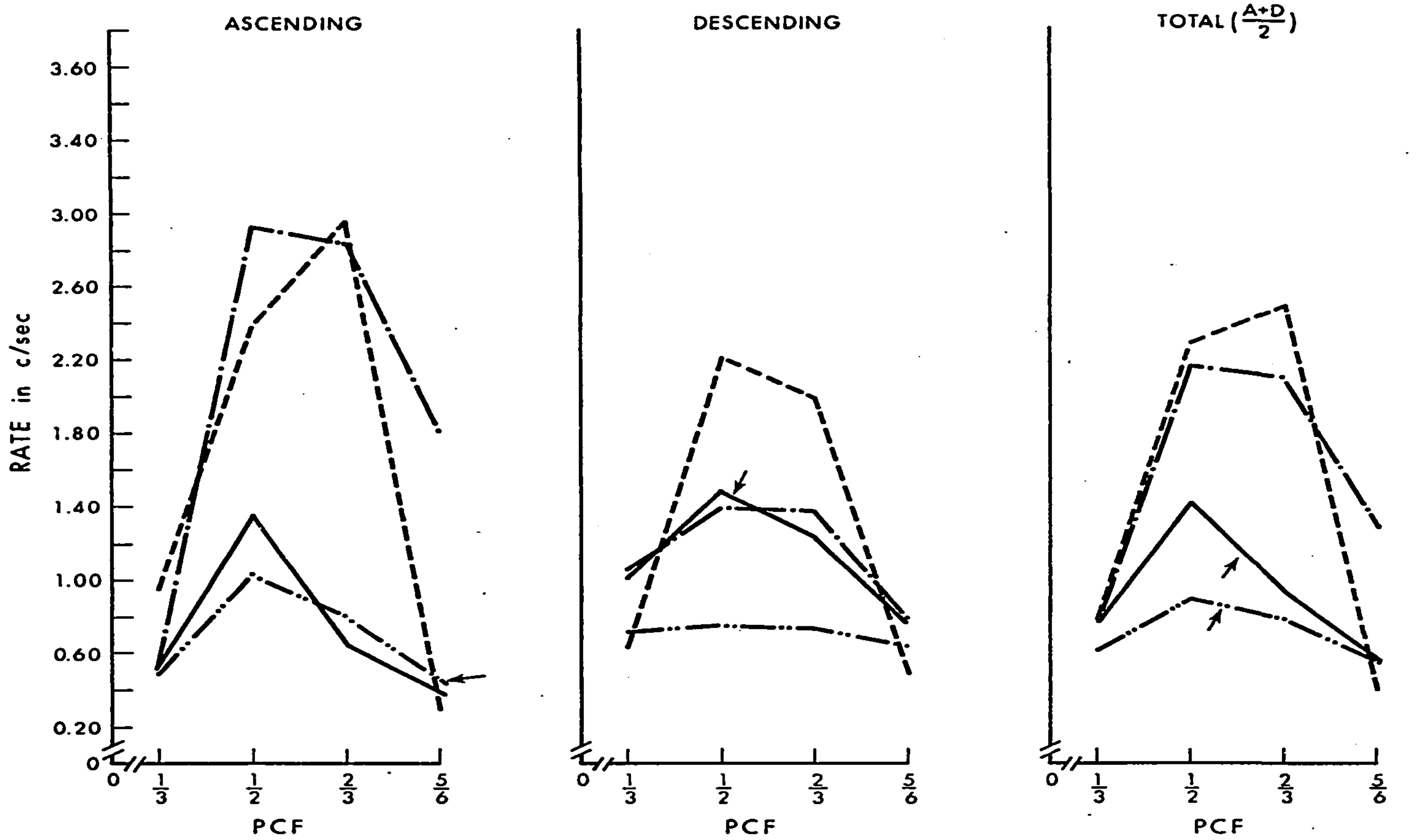

Figure I-1: Thermal Flicker Fusion thresholds in c./sec. for the variable of PCF (with A and I held constant). Body area tested is the upper back. The graphs differ from Figure 4 in that data which proved significant in the Succeeding Study replaces the nonsignificant data from the initial studies. The substituted curves are marked with an arrow.

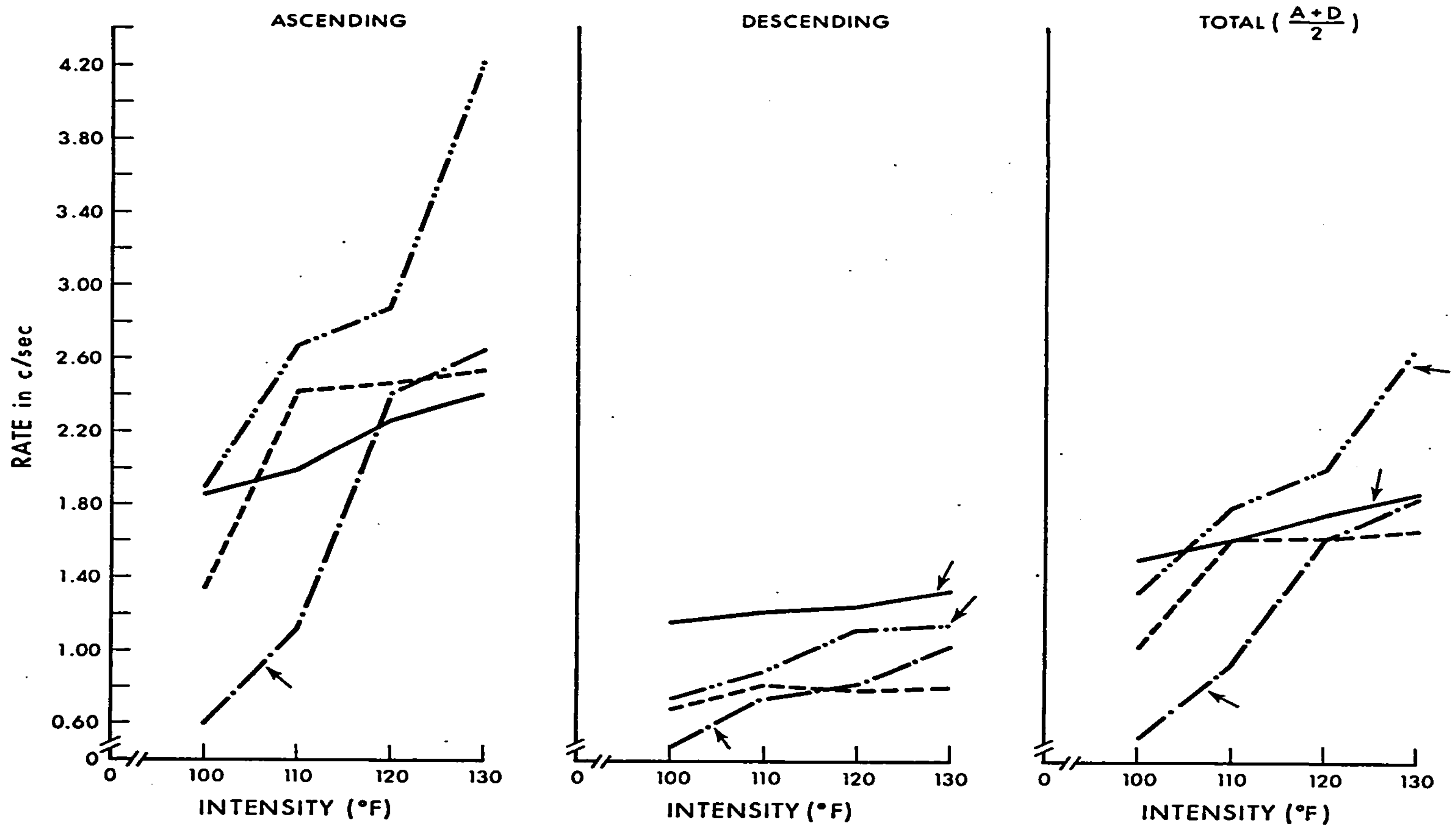

Figure I-2: Thermal Flicker Fusion thresholds in c./sec. for the variable of intensity (with PCF and A held constant). Body area tested is the upper back. The graphs differ from Figure 5 in that data which proved significant in the Succeeding Study replaces the nonsignificant data from the initial studies. The substituted curves are marked with an arrow.

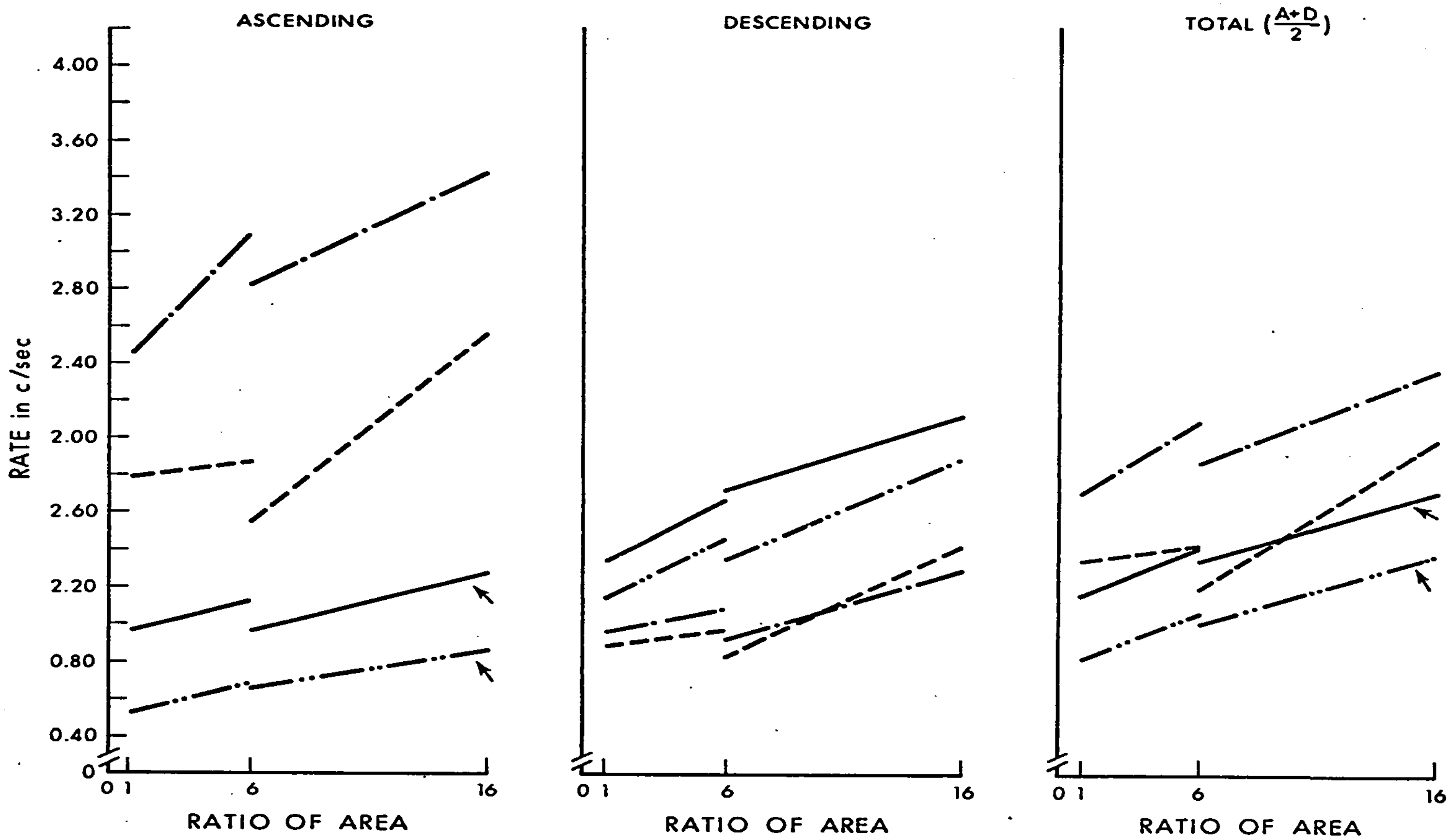

Figure I-3: Thermal Flicker Fusion thresholds in c./sec. for the variable of area (with PCF and I held constant). Body area tested is the upper back. The graphs differ from Figure 6 in that data which proved significant in the Succeeding Study replaces the nonsignificant data from the initial studies. The substituted curves are marked with an arrow.

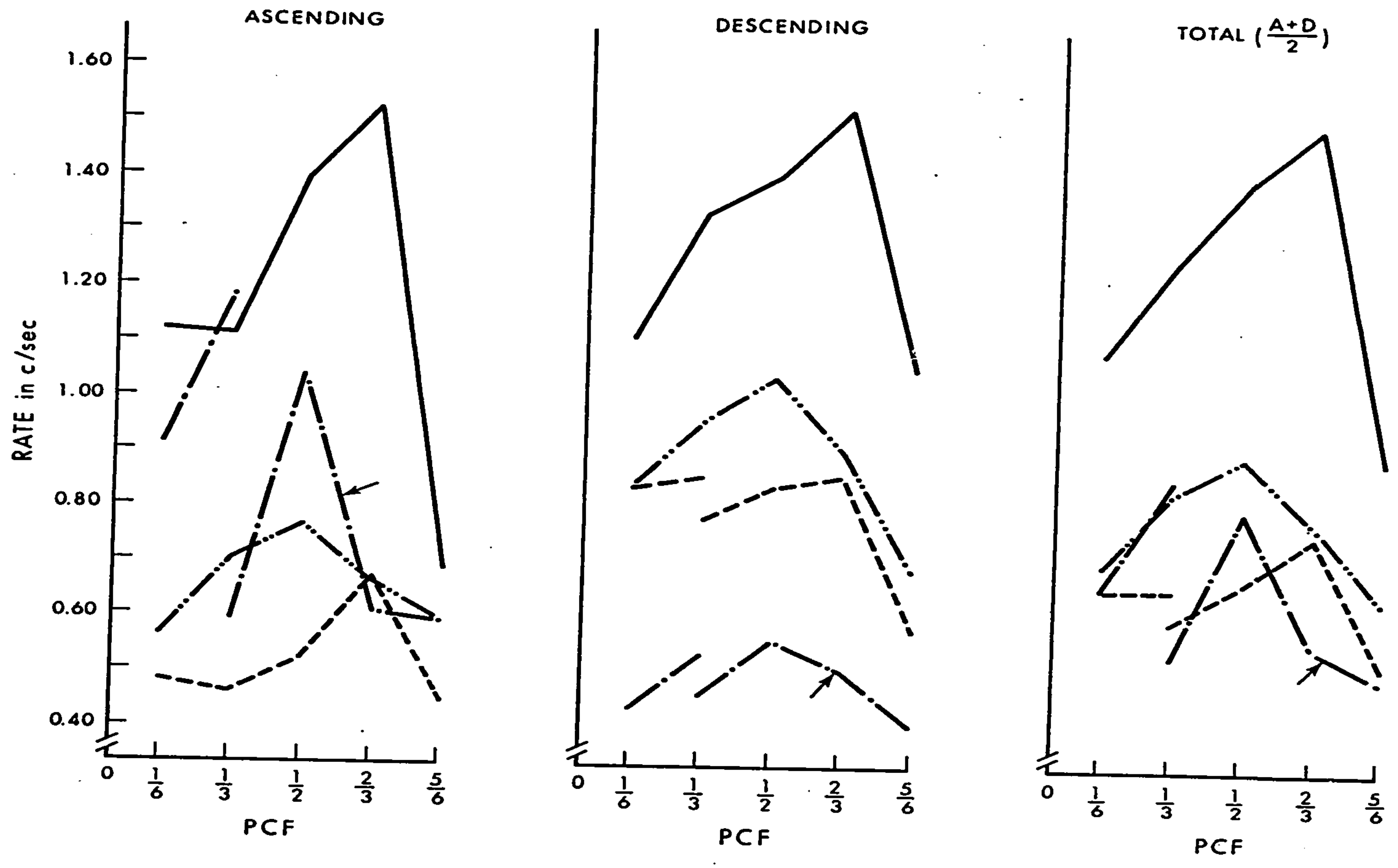

Figure I-4: Thermal Flicker Fusion thresholds in c./sec. for the variable of PCF (with A and I held constant). Body area tested is the forearm. The graphs differ from Figure 7 in that data which proved significant in the Succeeding Study replaces the nonsignificant data from the initial studies. The substituted curves are marked with an arrow.

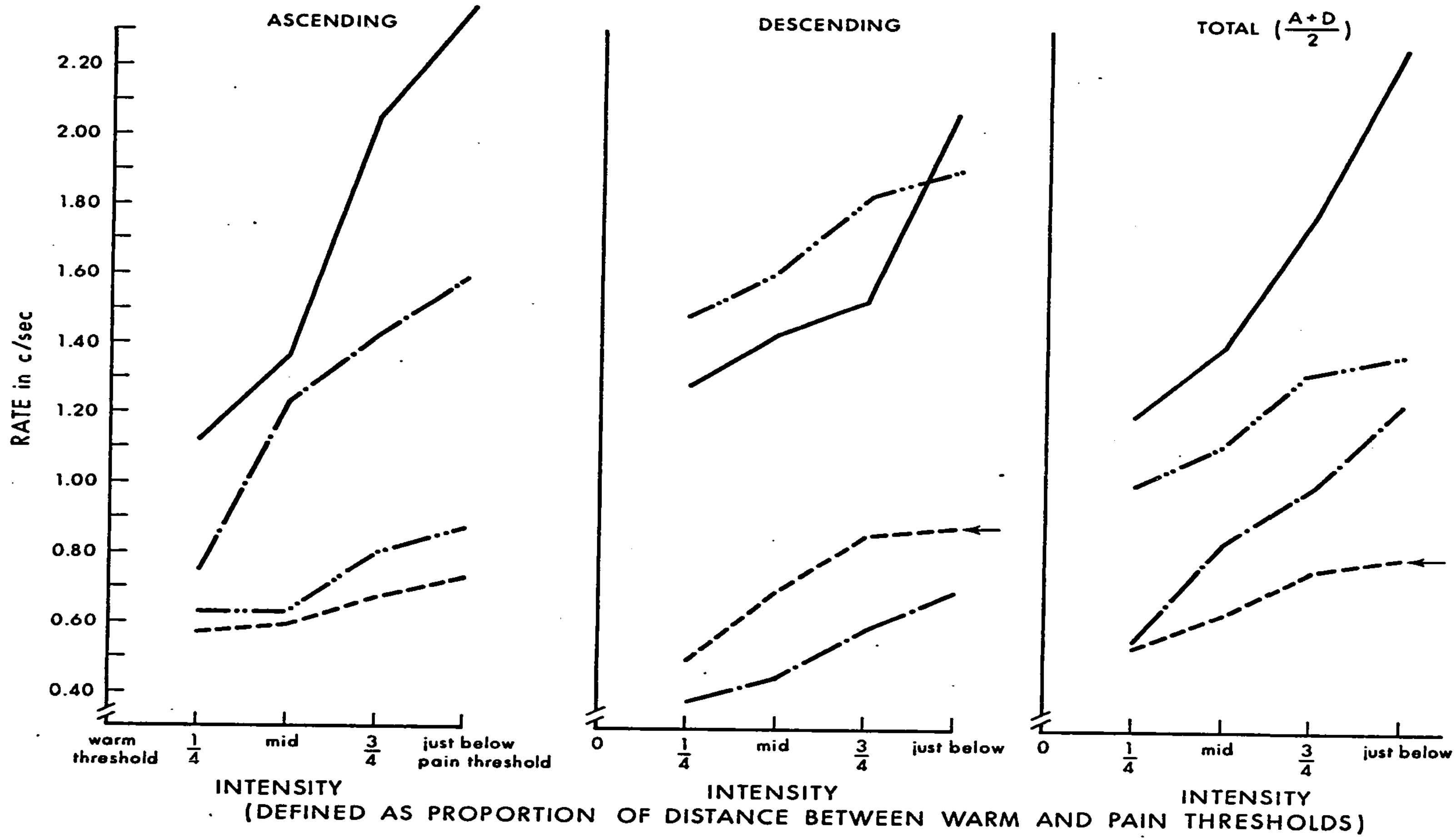

Figure I-5: Thermal Flicker Fusion thresholds in c./sec. for the variable of intensity (with PCF and I held constant). Body area tested is the forearm. The graphs differ from Figure 8 in that data which proved significant in the Succeeding Study replaces the nonsignificant data in the initial studies. The substituted curves are marked with an arrow.

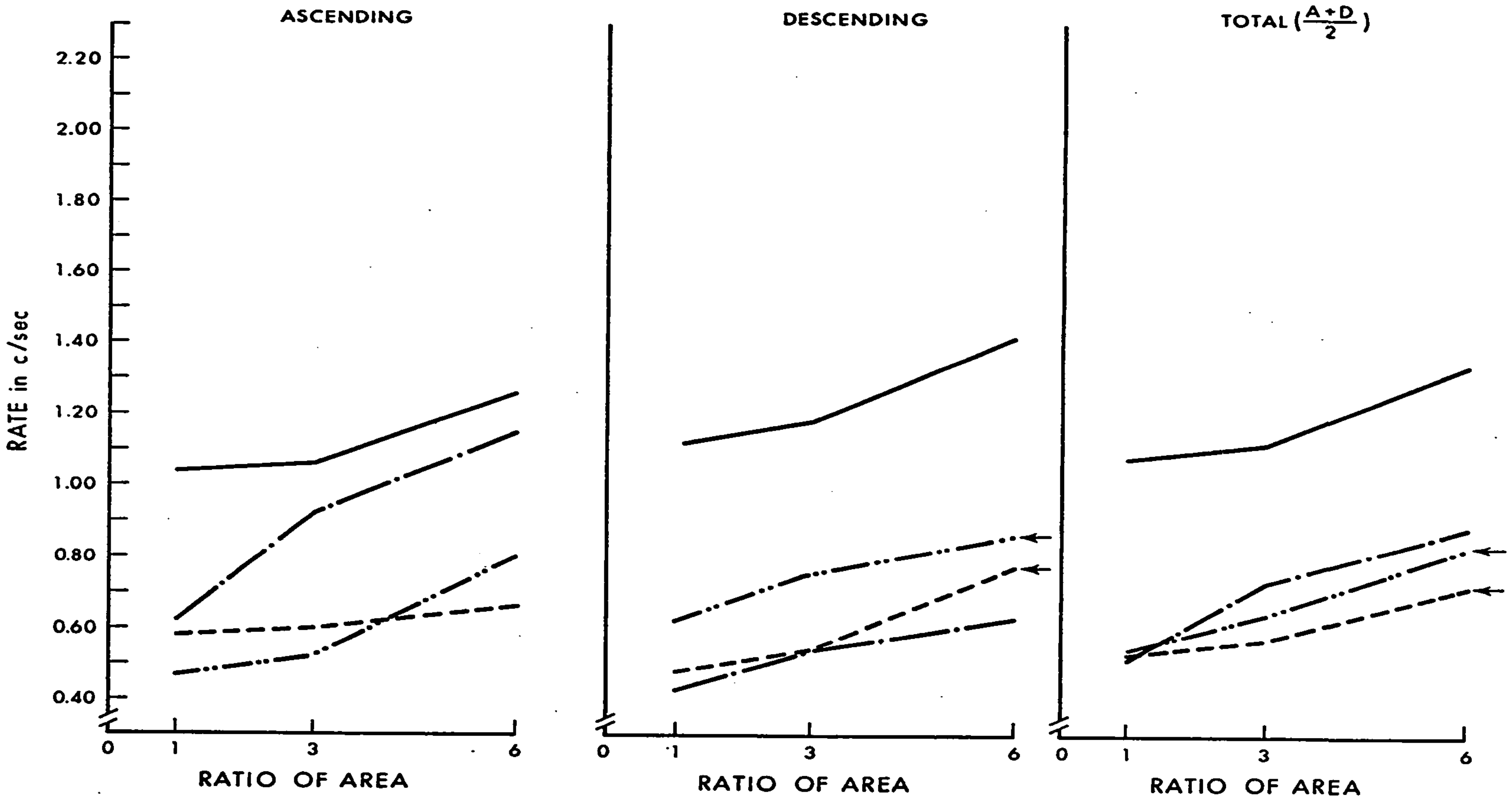

Figure I-6: Thermal Flicker Fusion thresholds in c./sec. for the variable of area (with PCF and I held constant). Body area tested is the forearm. The graphs differ from Figure 9 in that data which proved significant in the Succeeding Study replaces the nonsignificant data from the initial studies. The substituted curves are marked with an arrow.

APPENDIX "I-a"

Summary of the data analysis for the succeeding study for the variable of PCF (I and A held constant) when testing the back. Results significant on Run #2 are parenthesized.

Table I-a-1

Summary of the Analysis of Variance for each O showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	(.01)	-	(.01)
IC	.01	.01	.01
WF	.05	.05	-
SL	.01	(.01)	(.01)

- = $p > .05$

Table I-a-2

Summary of the Two-way Analysis of Variance for Os and PCF showing levels of significance achieved.

	Ascending	Descending	Total
Os	.05	- *	- *
PCF	.05	.05	.05

-* = $p > .05$ on Run #2,

$p < .01$ on Run #1

Table I-a-3

Summary of Duncan's New Multiple Range Test comparing each PCF with every other for four Os

Observer	Data Treatment	PCF 1/3 vs. 1/2	PCF 1/3 vs. 2/3	PCF 1/3 vs. 5/6	PCF 1/3 vs. 2/3	PCF 1/2 vs. 5/6	PCF 2/3 vs. 5/6
CW	A	(√)	(-)	(-)	(-)	(√)	(√)
	D$^{\Delta}$	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	(√)	(-)	(-)	(-)	(√)	(√)
IC	A	-	√	-	-	√	√
	D	√	√	-	-	√	√
	T	√	√	-	-	√	√
WF	A	√	√	-	-	-	-
	D	-	-	-	-	√	√
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
SL	A	√	-	-	√	√	√
	D	(√)	$-^{2}$	$\surd^{2}$	(√)	$\surd^{2}$	$\surd^{2}$
	T	$\surd^{2}$	$-^{2}$	$-^{2}$	$\surd^{2}$	$-^{*}$	$-^{*}$

$-^{2}$ or $\surd^{2}$ = same result on both Runs

$-^{*}$ = significant on Run #1, not significant on Run #2

(-) = not tested on Run #1, not significant on Run #2

√ = $p < .05$

Δ = n.t. on both Runs.

n.t. = not tested

- = $p > .05$

Table I-a-4

Summary of the trend analysis on PCF for each O. The quatratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	$-^{2}$	(✓)	(✓)
	D	$-^{2}$	$-^{2}$	n.t.^{2}
	T	$-^{2}$	(✓)	(✓)
IC	A	-	✓	✓
	D	-	✓	✓
	T	-	✓	✓
WF	A	-	✓	✓
	D	-	✓	✓
	T	-	-	n.t.
SL	A	✓	✓	✓
	D	(✓)	(✓)	(✓)
	T	✓^{2}	✓^{2}	✓^{2}

✓^{2}, $-^{2}$, n.t.^{2} = same result on both Runs

\- = $p > .05$

✓ = $p < .05$

n.t. = not tested

Table I-a-5

Average threshold rates with their standard deviations for two O's at each of four PCF's. Not all data treatments are shown. I and A were held constant at the same values as in Run #1.

Observer	PCF	Average Ascending	Average Total	Standard Deviation Ascending	Standard Deviation Total
CW	1/3	.50	.61	.13	.16
	1/2	1.03	.89	.32	.29
	2/3	.81	.78	.23	.22
	5/6	.46	.55	.07	.16

Observer	PCF	Average Ascending	Average Total	Standard Deviation Descending	Standard Deviation Total
SL	1/3	1.01	.78	.14	.25
	1/2	1.48	1.42	.06	.15
	2/3	1.23	.94	.09	.31
	5/6	.75	.56	.08	.21

APPENDIX "I-b"

Summary of the data analysis for the succeeding study for the variable of Intensity (PCF and A held constant) when testing the back. Results significant on Run #2 are parenthesized.

Table I-b-1

Summary of the two-way analysis of variance for Os and I showing levels of significance achieved.

	Ascending	Descending	Total
Os	(.05)*	.01	(.05)*
I	.01	.01	.01

* = p < .01 on Run #1

Table I-b-2

Summary of the analysis of variance for each O showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	-	(.05)	(.01)
IC*	-	-	-
WF	(.01)	(.01)	(.01)
SL	.05	(.05)	-

- = p < .05

* = p > .05 on Run #1 also

Table I-b-3

Summary of Duncan's New Multiple Range Test comparing each I with every other for four Os.

Observer	Data Treatment	100 vs. 110 (°F.)	100 vs. 120 (°F.)	100 vs. 130 (°F.)	110 vs. 120 (°F.)	110 vs. 130 (°F.)	120 vs. 130 (°F.)
	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
CW	D	-	(√)	(√)	-	(√)	-
	T	(√)	(√)	(√)	(√)	(√)	(√)
	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
IC*	D	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	A	(√)	(√)	(√)	(-)	(√)	(-)
WF	D*	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	T	(√)	(√)	(√)	(√)	(√)	(-)
	A	-	-	√	-	√	-
SL	D	(-)	(-)	(√)	(-)	(√)	(-)
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.

- = $p > .05$

√ = $p < .05$

(-) = not tested on Run #1, $p > .05$ on Run #2

* = not tested on both Runs due to $p > .05$ in the analysis of variance.

n.t. = not tested

Table I-b-4

Summary of the two-factor trend analysis for *O*s and I.

				I		*O* x I	
	*O*s	I	*O* x I	Linear	Quadratic	Linear	Quadratic
Ascending	-	✓	-	✓	-	n.t.	n.t.
Descending	✓	(✓)	-	(✓)	(-)	n.t.	n.t.
Total	-	✓	-	✓	-	n.t.	n.t.

✓ = $p < .05$

- = $p > .05$

(-) = not tested on Run #1, $p > .05$ on Run #2

n.t. = not tested (because prior analysis of the factor proved not significant)

Table "I-b-5"

Summary of the trend analysis on I for each O. The quadratic factor is but one component of the deviations factor and is therefore not tested if "deviations" proves not significant.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	√^{2}	-^{2}	n.t.^{2}
	D	(√)	-^{2}	n.t.^{2}
	T	√^{2}	-^{2}	n.t.^{2}
IC	A	(√)	-^{2}	n.t.^{2}
	D	-^{2}	-^{2}	n.t.^{2}
	T	-^{2}	-^{2}	n.t.^{2}
WF	A	(√)	-^{2}	n.t.^{2}
	D	(√)	-^{2}	n.t.^{2}
	T	(√)	(√)	(-)
SL	A	√	-	n.t.
	D	(√)	-^{2}	n.t.^{2}
	T	-*	-*	n.t.Δ

- = $p > .05$

-* = $p < .05$ on Run #1

Δ = $p > .05$ on Run #2

√ = $p < .05$

(-) = not tested on Run #1, $p > .05$ on Run #2

√^{2}, n.t.^{2}, -^{2} = same result on both Runs

n.t. = not tested

Table I-b-6

Average threshold rates with their standard deviations for three Os at each of four Intensities. Not all data treatments are shown. PCF and A were held constant at the same values as in Run #1.

Observer	I	Average Descending	Average Total	Standard Deviation Descending	Standard Deviation Total
CW	100	.74	1.32	.10	.76
	110	.88	1.78	.23	1.13
	120	1.11	1.99	.12	1.01
	130	1.13	2.67	.94	1.94

Observer	I	Average Descending	Average Total	Standard Deviation Descending	Standard Deviation Total
SL	100	1.16	1.50	.08	.16
	110	1.21	1.60	.02	.44
	120	1.24	1.75	.08	.52
	130	1.33	1.86	.07	.60

Observer	I	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviation Total
WF	100	.59	.47	.53	.14	.09	.13
	110	1.11	.74	.92	.61	.08	.50
	120	2.40	.82	1.61	.37	.22	.86
	130	2.64	1.03	1.84	.43	.17	.87

APPENDIX "I-c"

Summary of the data analysis for the succeeding study for the variable of Area (PCF and I held constant) when testing the back.

Table I-c-1

Summary of the Mann-Whitney U-test for four Os. Experimental conditions are the same as for Run #1. Significance levels achieved are shown. Results significant in Run #2, but not in Run #1, are parenthesized.

		Diameter of Areas		
Observer	Treatment	4" vs. 2 1/2" (16:6)	2 1/2" vs. 2 1/2" (100° F. vs. 100° F.)	2 1/2" vs. 1" (6:1)
CW	A	.05*	$-^{2}$	(.05)
	D	.05	-	$.05_{2}$
	T	-*	$-^{2}$	-
IC	A	$.05^{2}$	$-^{2}$	$-^{2}$
	D	-*	$-^{2}$	$-^{2}$
	T	-*	$-^{2}$	$-^{2}$
WF	A	$-^{2}$	$-^{2}$	-*
	D	.05*	$-^{2}$	$-^{2}$
	T	- 2	$-^{2}$	$-^{2}$
SL	A	(.01)	(.05)	(.01)
	D	.01	-	$.05_{2}$
	T	.05	-*	-

- = p > .05

* = either significance achieved, or significant to a higher degree, on Run #1.

$.05^{2}$, $-^{2}$ = same result on both Runs.

Table I-c-2

Average threshold rates with their standard deviations for two Os for two areas at each of two intensities. Not all data treatments are shown. PCF is held constant at 1/2.

Observer	I	Diameter of Area	Average Ascending	Average Total	Standard Deviation Ascending	Standard Deviation Total
SL	100 °F.	4"	1.27	1.70	.08	.46
		2 1/2"	.96	1.34	.08	.38
	120 °F.	2 1/2"	1.12	1.40	.06	.30
		1"	.96	1.15	.06	.21
CW	100 °F.	4"	.86	1.37	.12	.57
		2 1/2"	.65	1.00	.10	.36
	120 °F.	2 1/2"	.67	1.06	.12	.44
		1"	.52	.82	.05	.34

APPENDIX "I-d"

Summary of the data analysis for the succeeding study for the variable of PCF (I and A held constant) when testing the forearm. Results significant on Run #2, are parenthesized.

Table I-d-1

Summary of the analysis of variance for each *O* showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	-	.01	.01
IC	.05	.01	.01
WF	(.01)	(.01)	.01
SL	.01	.01	.01

- = p > .05

Table I-d-2

Summary of the two-way analysis of variance for *Os* and PCF showing levels of significance achieved.

	Ascending	Descending	Total
Os	.01	.01	.01
PCF	-	.01	.05

- = p > .05

Table I-d-3

Summary of Duncan's New Multiple Range Test comparing each PCF with every other for four Os.

Observer	Data Treatment	1/6 vs. 1/3	1/6 vs. 1/2	1/6 vs. 2/3	1/6 vs. 5/6	1/3 vs. 1/2	1/3 vs. 2/3	1/3 vs. 5/6	1/2 vs. 2/3	1/2 vs. 5/6	2/3 vs. 5/6
CW	A	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
	D	-	-	-	✓	-	-	✓	✓	✓	✓
	T	✓	✓	-	-	-	-	✓	✓	✓	✓
IC	A	n.d.	n.d.	n.d.	n.d.	-	✓	-	✓	-	✓
	D	n.d.	n.d.	n.d.	n.d.	-	-	-	-	✓	✓
	T	n.d.	n.d.	n.d.	n.d.	-	✓	-	-	✓	✓
WF	A	n.d.	n.d.	n.d.	n.d.	✓	(-)*	-	(✓)	(✓)	-
	D	n.d.	n.d.	n.d.	n.d.	(✓)	(-)	(-)	(-)	(✓)	(✓)
	T	n.d.	n.d.	n.d.	n.d.	✓	-	-	✓	✓	-
SL	A	-	✓	✓	✓	✓	-	✓	✓	✓	✓
	D	✓	✓	✓	-	-	✓	✓	-	✓	✓
	T	-	✓	✓	✓	✓	✓	✓	-	✓	✓

✓ = $p < .05$
(-) = $p > .05$ in Run #2; n.t. in Run #1
\- = $p > .05$
* = $p < .05$ in Run #1; $p > .05$ in Run #2
n.d. = no data available
n.t. = not tested

Table I-d-4

Summary of the Mann-Whitney U-test for two Os. Experimental conditions the same as in the principal study. Results significant on Run #2 are parenthesized.

Comparison	Name	Ascending	Descending	Total
PCF 1/6 vs. PCF 1/3	IC	-	-	-
	WF	-	-	-
PCF 1/3 vs. PCF 1/3 (at different intensity levels)	IC	-	.05	-
	WF	.01	.05	.05*

- = $p > .05$

* = $p < .01$ in Run #1

Table I-d-5

Summary of the trend analysis on PCF for each O.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	-^{2}	-*	n.t.*
	D	√	√	√
	T	√	√	√
IC	A	-	√	√
	D	-	√	√
	T	-	√	√
WF	A	-^{2}	√^{2}	√^{2}
	D	-^{2}	(√)	(√)
	T	-^{2}	√^{2}	√^{2}
SL	A	√	√	√
	D	-	√	√
	T	-	√	√

- = $p > .05$
* = $p > .05$
√ = $p < .05$

-^{2}, √^{2} = same result on both Runs
n.t. = not tested

Table I-d-6

Average threshold rates with their standard deviations for one O for all data treatments. Experimental conditions are the same as in the principal study.

Observer	I	PCF	Average Ascending	Average Descending	Average Total	Standard Deviation Ascending	Standard Deviation Descending	Standard Deviation Total
WF	high intensity (112° F.)	1/6	.91	.43	.67	.38	.10	.36
		1/3	1.18	.53	.86	.20	.03	.36
	mid-point	1/3	.59	.47	.53	.09	.03	.10
		1/2	1.03	.57	.80	.14	.05	.25
		2/3	.61	.51	.56	.12	.06	.11
		5/6	.59	.41	.50	.17	.06	.16

Table "I-e"

Summary of the data analysis for the succeeding study for the variance of Intensity (PCF and A held constant) when testing the forearm. Results significant on Run #2 are parenthesized.

Table I-e-1

Summary of the analysis of variance for each O showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	.01	.05	-
IC	.01	(.01)	(.01)
WF	.01	.01	.05
SL	.01	.01	.01

- = $p > .05$

Table I-e-2

Summary of Duncan's New Multiple Range Test comparing each intensity with every other for four Os. Experimental conditions the same as in the principal study.

Observer	Data Treatment	1/4 vs. mid	1/4 vs. 3/4	1/4 vs. j.b.	mid vs. 3/4	mid vs. j.b.	3/4 vs. j.b.
CW	A	-	√	√	√	√	-
	D	-	√	√	-	√	-
	T	n.t.	n.t.	n.t.	n.t.	n.t.	n.t.
IC	A	-	√	√	-	√	-
	D	(√)	(√)	(√)	(-)	(-)	(-)
	T	(-)	(√)	(√)	(-)	(√)	(-)
WF	A	√	√	√	-	-	-
	D	-	√	√	√	√	√
	T	-	√	√	-	-	-
SL	A	-	√	√	√	√	√
	D	-	√	√	-	√	√
	T	-	√	√	√	√	√

(-) = not tested in Run #1,
p > .05 in Run #2
√ = p < .05
- = p > .05
n.t. = not tested due to p < .05
in the analysis of variance

Table I-e-3

Summary of the two-way analysis of variance for Os and I showing levels of significance achieved.

	Ascending	Descending	Total
Os	.01	.01	.01
I	.05*	.01	.01

* = p < .01 on Run #1

Table I-e-4

Average threshold rates with their standard deviations for one O at each of four intensities. Not all data treatments are shown. Experimental conditions are the same as in the principal study.

Observer	I	Average Descending	Average Total	Standard Deviation Descending	Standard Deviation Total
IC	1/4	.50	.54	.07	.09
	mid.	.70	.64	.16	.14
	3/4	.86	.76	.13	.14
	j.b.	.88	.80	.14	.13

Table I-e-5

Summary of the trend analysis on I for each O.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	✓	-	n.t.
	D	✓	-	n.t.
	T	-	-	n.t.
IC	A	✓	-	n.t.
	D	(✓)	-^{2}	n.t.^{2}
	T	✓	-	n.t.
WF	A	-	✓	-
	D	✓	-	n.t.
	T	✓	-	n.t.
SL	A	✓	-	n.t.
	D	✓	✓	✓
	T	✓	-	n.t.

✓ = $p < .05$

- = $p > .05$

-^{2}, n.t.^{2} = same result on both Runs

n.t. = not tested

APPENDIX "I-f"

Summary for the data analysis for the succeeding study for the variable of Area (PCF and I held constant) when testing the forearm. Results significant on Run #2 are parenthesized.

Table I-f-1

Summary of the analysis of variance for each O showing levels of significance achieved.

Observer	Ascending	Descending	Total
CW	.01	(.01)	(.01)
IC	-	(.01)	(.10)
WF	.01	.05	*
SL	.01	.01	.01

- = p > .05

* = approaches significance

Table I-f-2

Summary of the two-way analysis of variance for Os and area showing levels of significance achieved.

	Ascending	Descending	Total
Os	.01	.01	.01
Area	.05	.01	.01

Table I-f-3

Summary of Duncan's New Multiple Range Test comparing each Area with every other for four Os.

		Diameter of Areas		
Observer	Data Treatment	1" vs. 1 3/4" (1:3)	1" vs. 2 1/2" (1:6)	1 3/4" vs. 2 1/2" (3:6)
CW	A	-	✓	✓
	D	(-)	(✓)	(-)
	T	(-)	(✓)	(✓)
IC	A	n.t.	n.t.	n.t.
	D	(-)	(✓)	(✓)
	T	-	✓	(✓)
WF	A	✓	✓	✓
	D	-	✓	-
	T	-	✓	-
SL	A	-	✓	✓
	D	-	✓	✓
	T	-	✓	✓

✓ = $p < .05$

- = $p > .05$

(-) = not tested on Run #1, $p > .05$ on Run #2

n.t. = not tested due to $p > .05$ in the analysis of variance

Table I-f-4

Summary of the trend analysis on Area for each O.

Observer	Data Treatment	Linear	Deviations	Quadratic
CW	A	✓	✓	✓
	D	✓^{2}	-^{2}	n.t.^{2}
	T	-	-	n.t.
IC	A	-	-*	n.t.*
	D	(✓)	-^{2}	n.t.^{2}
	T	✓	✓	-
WF	A	✓	-	n.t.
	D	✓	-	n.t.
	T	✓	-	n.t.
SL	A	✓	-	n.t.
	D	✓	-	n.t.
	T	✓	✓	✓

✓ = $p < .05$

- = $p > .05$

* = $p < .05$

n.t. = not tested

-^{2}, n.t.^{2} = same result on both Runs

Table I-f-5

Average threshold rates with their standard deviations for two Os at each of three areas. Not all data treatments are shown. PCF and I were held constant at the same values as in Run #1.

Observer	Diameter of Area	Average Descending	Average Total	Standard Deviation Descending	Standard Deviation Total
CW	2 1/2"	.86	.83	.15	.12
	1 3/4"	.75	.64	.03	.12
	1"	.62	.54	.04	.08
IC	2 1/2"	.77	.72	.06	.10
	1 3/4"	.54	.57	.09	.08
	1"	.48	.53	.06	.08

Glossary and Abbreviations

A = Area; the size of skin surface tested.

ACF = Acoustic Stimulation Fraction of Cycle; the proportion of auditory stimulation in the cycle.

AFF = Auditory Flutter Fusion; the rate at which intermittent sounds appear to fuse.

Alternation-of-Response Theory = A theory designed to describe how the visual system reacts to intermittent high stimulation and alters sensory experience of brightness and affects flicker-fusion thresholds.

CFF = Critical Flicker Fusion; the frequency at which an intermittent light appears fused.

c./sec. = Cycles per second; rate.

Episcotister = A sectored disk which, when placed in front of the source, produces intermittency.

Funnelling = The inhibition or complete suppression of a surround sensation which contributes to increasing the magnitude of the central sensation.

I = Intensity; physical measure of stimulus energy.

PCF = Pulse-to-Cycle Fraction; proportion of stimulation in the cycle.

Summation = "In sensation, the increase in experienced intensity when two stimuli are presented to a receptor in rapid succession; in neurology, the arousal of an impulse by two or more stimuli in rapid succession when any one of the stimuli is insufficient to arouse an impulse" (ref. <u>Dictionary of Psychology</u>, p. 488).

TFF = Thermal Flicker Fusion; the thermal analogy to CFF, i.e., the frequency at which an intermittent thermal stimulus is experienced as fused.

U-test - Mann-Whitney U-test = A non-parametric test for the significance of differences between means of unmatched groups; a powerful substitute for the t-test used with independently drawn random samples. The U-test may also be applied to test independent samples by ordinal measurement.