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THE CUTANEOUS VASOMOTOR ORIENTING RESPONSE AND ITS HABITUATION

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CHAPTER I

INTRODUCTION

The interest of American psychophysiologists in the work of E. N. Sokolov has resulted in a number of recent attempts to replicate and extend his findings. Sokolov's theory (Vinogradova & Sokolov, 1957; Sokolov, 1960; Sokolov, 1963) deals primarily with unconditional responses, which can be divided into three classes: adaptive responses, orienting responses and defensive responses.

Orienting responses are non-specific and quickly habituate. Any change in the stimulus configuration may result in an orienting or, in Pavlov's terms, a 'what-is-it' response. This response can be observed on the gross behavioral level, where it includes cessation of ongoing behavior and turning of the appropriate receptor organs toward the source of stimulation. Orienting responses can also be observed at the autonomic response level, or at the electrophysiological level within the nervous system itself. Any change in stimulation, *i.e.*, the onset or termination of a stimulus, variation in its intensity, or changes in any other parameter, may result in an orienting response. If the change in stimulation is repeated, the orienting response will eventually habituate. According to Sokolov's theory, incoming stimuli are conveyed to the cerebral cortex, where they are compared with traces of previous stimuli. If the stimuli do not match the previously laid traces, the cortex sends excitatory impulses to the reticular formation and the orienting response takes place. If the stimuli match, the cortex sends inhibitory impulses to the afferent collaterals, blocking input into the non-specific arousal system and preventing the orienting response (1960).

Adaptive responses appear after habituation of the orienting response, and represent the attempt of a specific system of the body to cope with a specific stimulus. For example, when a cold stimulus is applied to a finger, the blood vessels in the skin of that finger constrict (Zimny & Miller, 1966). If the stimulus is warm, the vessels dilate. Adaptive responses show little habituation.

The defensive response is elicited by stimuli which are very intense or psychologically threatening, and does not appear until habituation of the orienting response has occurred. The distinction between orienting and defensive responses is crucial to Sokolov's theory. On the autonomic level, the distinction rests entirely upon the behavior of cutaneous blood vessels in the fingers and forehead. Defensive responses can also be distinguished from orienting responses by virtue of the failure of the defensive response to habituate. Although Sokolov does not discuss the neural mechanisms of the defensive response, it can be assumed that it is highly specific, since inhibition of all autonomic behavior does not occur.

Sokolov maintains that the cutaneous vasomotor orienting response always consists of vasoconstriction in the finger and vasodilation in the forehead (Vinogradova & Sokolov, 1957; Sokolov, 1960; Sokolov, 1963). Sokolov (1960, 1963) suggests, as did Hertzman & Dillon in 1939, that vasodilation observed in the skin of the forehead reflects a concomitant increase in blood supply to the brain. This increased cerebral blood supply increases the sensitivity of the brain. The defensive response, on the other hand, always results in constriction of forehead vessels, thus reducing the blood supply to the brain, allegedly desensitizing it, and protecting it from overstimulation. This seems unlikely. The skin of the face and neck is supplied with blood primarily by the external carotid artery. The internal carotid supplies the brain. For forehead skin to reflect cerebral circulation, the control of regional flow should be located in the common carotid artery. There is no evidence that this is so. Blood flow to an area or organ is thought to be controlled primarily by the precapillary resistance vessels, not by changes in large arteries.

Both the amplitude of the orienting response and its habituation rate are, for Sokolov, dependent primarily upon stimulus intensity. The more intense the stimulus, the greater the orienting response amplitude and the slower the rate of habituation. It is particularly relevant to the interpretation of this study that the total response to intense stimulation is a combination of orienting and defensive components. With frequent repetition of such intense stimuli, the orienting components gradually disappear (habituate).

Distinction between Orienting and Defensive Responses

A number of studies have attempted to replicate the findings on which the orienting-defensive response distinction is based. The work of Hertzman & Dillon (1939) found either vasodilation of forehead vessels in response to auditory stimuli or no change at all. The cold pressor test, however, when it elicited a response, resulted in forehead vasoconstriction. After Sokolov's work became available in English, Royer (1965), recording from the center of the forehead, reported vasodilation to stimuli of moderate intensity. He did not attempt to elicit the defensive response, nor did he present any quantification of his data. Raskin, Kotses & Bever (1969a), recording photoplethysmographic forehead responses from above the left eyebrow, heart rate, skin potential and skin conductance responses to auditory stimuli varied intensity from 40 to 120 dB. They reported that forehead vasomotor responses did not distinguish between stimuli of low and high intensity. In fact, no reliable relationship with stimulus intensity was found. In a subsequent study (Raskin, Kotses & Bever, 1969b), the same authors recorded two components of the forehead vasomotor response, i.e., forehead pulse volume and forehead blood volume, during presentation of either 80 or 120 dB bursts of white noise. Again, no distinction between orienting and defensive responses was found; blood volume increased and pulse volume decreased to stimuli of both intensities.

Brotsky (1969), using 100 dB bursts of white noise and recording photoplethysmographically, failed to elicit the defensive response, although the orienting response habituated quickly. Difficulty was found in reliable scoring of the data because of variability in the response itself. Cohen & Johnson (1969) presented 60 or 100 dB tones to a group of subjects and found that while vasomotor responses from the finger differentiated between the tones, responses from the center of the forehead did not.

Replication of the distinction between orienting and defensive responses on the basis of forehead vasomotor responses has not been reported in this country. However, as will be discussed below, the precise experimental conditions used by Sokolov have not been repeated. Laboratories in the Soviet Union and in several European countries have been able to replicate the distinction between orienting and defensive responses by using a technique more nearly approximating that used by Sokolov (Figar, 1965; Lynn, 1966).

Stimulus Intensity

According to Sokolov, the amplitude of the orienting response increases with the intensity of the stimulus. That this is true for electrodermal responses has been demonstrated (*e.g.*, Hovland & Riesen, 1940; Davis *et al.*, 1955; Leavy & Geer, 1967). Few studies have examined the relationship between stimulus intensity and vasomotor responses. Raskin, Kotses & Bever (1969a) and Cohen & Johnson (1969) found no relationship when vasomotor responses were measured from the forehead. Hovland & Riesen (1940) found that response amplitude from the finger increased linearly with intensity of a shock stimulus. Uno & Grings (1965) and Cohen & Johnson (1969) have reported increased finger vasoconstriction with increased auditory intensity, but did not examine the nature of the relationship. In these three cases different groups of subjects were presented different stimulus intensities, and no correction for prestimulus response levels is reported. The data suggest a linear relationship between amplitude of finger vasomotor responses and stimulus intensity, but do not themselves demonstrate such a relationship.

Habituation

The importance of habituation in investigating relationships between the central nervous system and behavior can hardly be overemphasized. Habituation is ubiquitous. It occurs in all species tested, from simple one-celled animals to man. Some theorists consider habituation the simplest form of learning, while others think of it as a basic component of the perceptual filtering process (Sokolov, 1963; Horn, 1965). Recent studies indicate that habituation yields information about the neuropsychological health and efficiency of the organism (Davidoff & McDonald, 1964; Holloway & Parsons, 1970). Despite the importance of habituation, not only for psychophysiology but for neuropsychology and learning theory, research in the area has not progressed significantly over the past few years. Most investigators, realizing the important information which habituation data may hold, have used it directly as a tool. Methodological and theoretical problems also exist in habituation research. These problems will receive the greatest emphasis here.

The extent to which different measures of habituation agree is not known. Behavioral indices of habituation tend to show faster habituation than autonomic or neurophysiological measures, but this may be due entirely to the sensitivity of the measures, rather than to the disappearance of the behavior. Within the autonomic system, some evidence has been presented indicating that autonomic responses habituate at different rates, the rate being dependent upon the function of the response in a given environmental situation (McDonald, Johnson & Hord, 1964; Cook, 1968). Even within a single autonomic response system, components may habituate at different rates. Loveless & Thetford (1966) have shown that the positive skin potential response habituates more rapidly than the negative, and Cook (1968) has presented evidence that this is stimulus specific. An analogous situation seems to exist with regard to the vasomotor response. When stimulus intensity is held constant, the habituation rate of vasomotor responses appears to depend upon whether pulse or blood volume responses are observed. A summary of relevant studies is presented in Table 1. In all cases where blood volume changes are reported habituation occurred. Habituation of pulse volume was found in two of five studies of the finger, and in two of two studies of the forehead. The two measures were recorded simultaneously by Uno & Grings (1965) and by Cohen & Johnson (1969). Uno & Grings found the overall effect of stimulus repetition to be nonsignificant. A significant repetition-by-intensity interaction for finger blood volume changes, however, indicated that habituation of blood volume changes was occurring to stimuli of low intensity. Cohen & Johnson (1969) found similar results. They reported a significant habituation of finger blood volume and a significant trials-by-intensity interaction for finger pulse volume. Forehead blood volume responses have also been reported to habituate (Luria & Vinogradova, 1959; McDonald, Johnson & Hord, 1964; Raskin, Kotses & Bever, 1969a, 1969b; Cohen & Johnson, 1969). Forehead pulse volume may also habituate, but insufficient data have been examined to determine whether this result is reliable.

Besides the behavioral or physiological system which is measured as a determinant of habituation rate, the criteria for identifying habituation appear to be of critical importance. Definitions of habituation have included per cent of total subjects responding, trials to criterion, decrease in response amplitude, and the occurrence of dishabituation. No evidence is available on the relationship of these measures, although it is apparent that they measure different sorts of processes. When habituation is determined on the per cent subjects responding, it is most sensitive to a probability effect. No information is given in this analysis about the behavior of the individual subject, nor is any central nervous system process reflected in the definition. Trials-to-criterion would be most efficient if habituation were considered an all-or-none process, _i.e._, if the subject were considered to be in one of two states, habituated or not habituated. It has the advantage of providing a comparable measure of habituation for each subject. Use of analysis of variance of response amplitude as a measure of habituation implies an ordered decrease in the amplitude of the response, and is therefore quite different from the two measures previously discussed, which are based on the occurrence or non-occurrence of the response. Dishabituation, _i.e._, the increase in response amplitude which occurs when a stimulus of lesser intensity is intruded into an habituation series, was originally used to distinguish habituation from the effects of receptor fatigue, but has since come to be a common definition of habituation itself. Again, it depends upon response amplitude, rather than upon occurrence of a response. It is clear that the methods used to summarize and test statistically for habituation will greatly influence the results reported. In order to compare these definitions, and to determine their effect upon the relationship between habituation rate and stimulus parameters, habituation was evaluated by means of each criterion.

Only three of the many investigators who have studied the habituation of the vasomotor orienting response have systematically varied stimulus intensity. Uno & Grings (1965) recorded finger blood volume and finger pulse volume changes to stimuli varying from 60 to 100 dB and found significant habituation (as defined by analysis of variance) only to stimuli of 60 dB. Cohen & Johnson (1969) found slower habituation to stimuli of greater intensity. No relationship between stimulus intensity and forehead responses has been reported.

TABLE 1

HABITUATION OF PULSE VOLUME AND BLOOD VOLUME COMPONENTS OF THE VASOMOTOR ORIENTING RESPONSE

Site	Pulse Volume		Blood Volume	
			Cohen & Johnson, 1969	+
	Cohen & Johnson, 1969	+	Gale & Stern, 1968	+
Finger	Furedy, 1968	-	McDonald *et al.*, 1964	+
or	Furedy, 1969	-	Raskin *et al.*, 1969b	+
Hand	Johnson & Lubin, 1967	+	Shmavonian, 1959	+
	Uno & Grings, 1965	-	Uno & Grings, 1965	+
			Zimny & Miller, 1966	+
			Cohen & Johnson, 1969	+
Fore-	Cohen & Johnson, 1969	+	Luria & Vinogradova, 1959	+
head	Raskin *et al.*, 1969a	+	McDonald *et al.*, 1964	+
			Raskin *et al.*, 1969a	+

A plus sign indicates that habituation was found, and a minus sign indicates that it was not.

The relationship between stimulus intensity and habituation rate is not clear; it is confounded both by criteria of habituation and by whether blood volume or pulse volume is measured. The data indicate that blood volume changes habituate more rapidly than pulse volume changes, and that habituation is slower with stimuli of greater intensity.

Problems of Replication

The consistent failure to find distinctions between orienting and defensive responses in the forehead points up two of the most pervasive problems in psychophysiology. Although several attempts have been made to 'replicate' Sokolov's work, none have in fact precisely reproduced his experimental conditions. Sokolov used the technique reported by Luria & Vinogradova (1959). A volume plethysmograph was placed on the skin over the temporal artery, and the resulting deflections photographically recorded. This was referred to as a 'photoplethysmograph,' which has led to much confusion. The transducer was directly coupled to the amplifier, and the blood volume component of the response measured. Stimuli apparently consisted of pure tones (Vinogradova & Sokolov, 1957; Luria & Vinogradova, 1959; Weinman, 1967).

Western workers have in general recorded forehead vasomotor activity from the middle of the forehead or from just above the left eyebrow. The transducer has been of the photoreflectance type, and pulse volume has been, until very recently, the response component of interest. Stimuli have usually been pulses of white noise. Since none of the reported experiments have accurately adhered to Sokolov's experimental technique, no conclusion can be reached as to the reliability of his findings.

Problems of Interpretation

A common problem in psychophysiology is the necessity of using a physiological measure as a tool without understanding the physiology of the response or its function in the adaptive performance of the individual. We have seen that the response from the forehead is variable, depending upon the location from which it is recorded, the type of transducer used, and whether pulse volume or blood volume components are evaluated. Habituation rate also appears to depend upon the response component measured and upon the part of the body from which the response is observed. Brief consideration of vasomotor responses from a physiological point of view might serve to clarify some of these effects.

Physiology of the Vasomotor Response

As measured plethysmographically, the cutaneous vasomotor response consists of changes in two major components, i.e., pulse volume and blood volume. Pulse volume refers to the small changes in the volume of the part which occur as a result of each heart beat. The blood volume is a more slowly changing component, and represents blood content, upon which the pulse volume appears as a small, rapid fluctuation. Pulse volume is measured from the diastolic trough (point 1 on Figure 1) to the systolic peak (point 2), and is best seen in capacitatively coupled recordings under high amplification (Brown, 1967; Weinman, 1967). Blood volume can best be monitored by DC recording with low amplification. An example of the two components, recorded simultaneously from the same transducer, is shown in Figure 1. At point A, the experimenter spoke to the subject; blood volume and pulse volume were both reduced, although a slight increase in pulse volume occurred three pulse beats after the

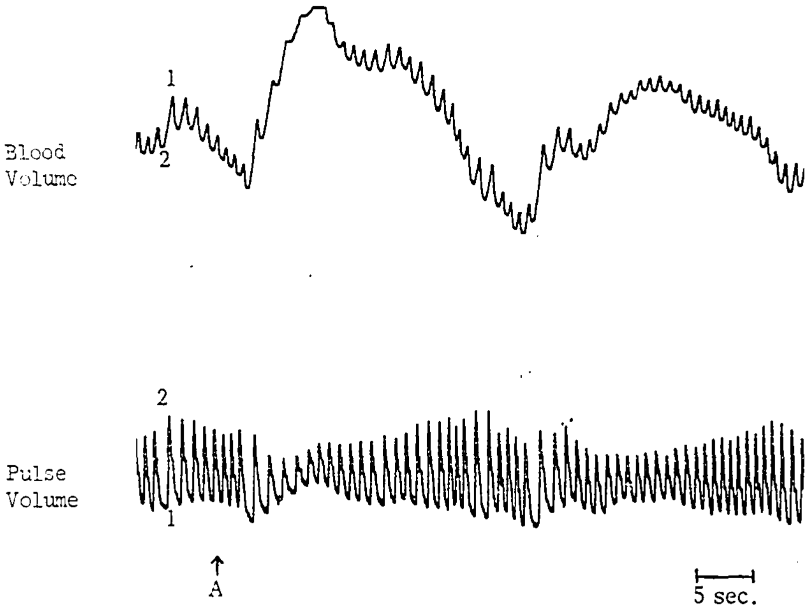

Figure 1. Blood volume and pulse volume components of the vasomotor orienting response recorded simultaneously from the left thenar eminence with a photoreflectance transducer. Blood volume is shown as an upward deflection. Pulse volume time constant .03 seconds.

start of stimulation.

Physiologically, the plethysmographic responses represent the transient difference between the flow of blood into a part and the flow of blood out of that part. As such, they are dependent upon both the arterial and venous sides of the cutaneous vascular bed. Some investigators have assumed that the entire vasomotor response is a result of changes in capillary and precapillary vessels. It has been demonstrated, however, that reflex venoconstriction, dependent upon sympathetic innervation, also occurs (Duggan et al., 1953; Best & Taylor, 1961), and that such constriction can be independent of arteriolar constriction. Changes in venous tone can be monitored by pressure changes in an isolated venous segment, and show an orienting response to novel stimuli which can be conditioned (Burch & Murtadha, 1956; Burch & DePasquale, 1965). Thus, arterioles and venules both contribute to vasomotor responses, although serving different adaptive functions in the body. For example, arteriolar and precapillary changes assist in the maintenance of blood pressure and control the differential flow of blood to various body parts to meet metabolic and other needs. In the cutaneous circulation, they alter blood flow as a major contribution to temperature regulation. They constrict in response to tissue trauma, thus reducing bleeding.

The main characteristic of the venous system is its distensibility, a property consistent with its function as a blood reservoir. Venomotor activity assists in the prevention of blood pooling, helps to maintain cardiac output by increasing venous return to the heart, and is part of the vasomotor defense against cold. Venous constriction also occurs with trauma to the skin, reducing bleeding and, by virtue of the veni-vasomotor reflex, giving added stimulus to arteriolar constriction.

Considerable evidence has accumulated indicating that pulse volume is proportional to arteriolar tone, while blood volume primarily reflects venous changes (Turner et al., 1937; Hertzman & Dillon, 1940; Goetz, 1950). Effects of postural changes (Turner et al., 1937; Goetz, 1950), changes in venous pressure (Abramson & Katzenstein, 1941) and relationships between volume changes and blood flow (Burch, 1954) have supported this contention. If this is the case, we are provided with a means of investigating arteriolar and venous changes separately under various conditions, and testing the hypothesis that they have different functional significance.

Despite this general knowledge of the functions of arterial and venous motor components of cutaneous circulation, the functional significance of the vasomotor orienting response remains unknown. It has been hypothesized that the response may be part of preparation for motor activity (Ackner, 1956; Kelly, 1966; Cook, 1968). It is known that the cutaneous vascular bed can serve as a blood reservoir; constriction of vessels in this bed could shunt blood into the muscles when motor activity is anticipated. In support of this hypothesis, it has been shown that vessels in the muscles of the forearm dilate concomitantly with constriction in the skin of the hand (Kelly, 1966), and this dilation is thought to be in preparation for the increased metabolic needs in the muscle associated with motor activity. Venous constriction, then, might serve to shunt blood to the thoracic cavity, enhance the filling of the heart, and thereby increase cardiac output. Two findings mitigate against this explanation. If the cutaneous vasomotor response is part of preparation for motor activity, it should habituate very rapidly when motor activity is not required by the task at hand. Although habituation of pulse volume changes is faster when the subject simply listens to tones than when he is involved in a motor task, the habituation rate is still lower than for other autonomic responses (Cook, 1968). Also, one would expect constriction of vessels in all areas of the skin. It has been demonstrated that the response occurs primarily in the hands and feet, implying a regionally organized mechanism.

Since the response is found primarily in hands and feet, it may be associated with tactile sensitivity. This hypothesis was investigated by Edelberg (1961), who found increased tactile sensitivity during vasomotor activity, whether such activity was spontaneous or due to external stimulation. Subsequent work, however, indicated that subjects with unilateral sympathectomy showed very little lateral difference in the increase in tactile sensitivity attending an autonomic response, even though the cutaneous vasomotor response on the sympathectomized side was completely abolished (Edelberg, personal communication).

Neither of these explanations, even if acceptable, would account for the differential characteristics of the forehead response. If, as Sokolov proposes, changes in forehead vessels reflect concomitant changes in cerebral circulation, and these changes function to alter the sensitivity of the brain, one should find a very short latency response from the forehead, and it should be a clear and distinct response. The literature indicates that, far from being clear and distinct, the response is quite variable, and that when it exists, it has a long latency (Cohen & Johnson, 1969).

The paradoxical dilation of blood vessels in the forehead need not be viewed as a reflection of cerebral circulation. The nature of cerebral circulation in fact makes this a most unlikely explanation. In addition to active, centrally controlled vasomotion, blood vessels can be passively dilated by increased blood pressure. It is possible then, that vasodilation in the forehead over the temporal artery is a result of transient increases in blood pressure. Since plethysmograms obtained from transducers placed over a major artery confound changes in that artery and vasomotor changes in the skin itself, such a finding would explain the difficulties encountered in replicating Sokolov's results. Western scientists, recording from areas where no major arteries are located, have not found Sokolov's orienting-defensive distinction. Soviet scientists, using the temporal artery site, have been able to replicate the findings (Figar, 1960; Lynn, 1966).

Statement of the Problem

None of the explanations of cutaneous vasomotor response are completely supported by experimental data. Considerable ambiguity exists as to the nature of the experimental results. It seems therefore premature to approach research in this area from a theoretical point of view. More experiments are needed to provide data on regional differences in the orienting response, its dependence upon stimulus qualities, its habituation, and on the concomitant events within the cardiovascular system. Moreover, these should be observed under well-described and standardized conditions, using well-described techniques, and using in a single experiment an array of measures enabling an integrated as well as focussed view of the response system. The experiments to be reported were designed to provide empirical information pertinent to the above questions. Specifically, the following problems were investigated:

(1) What is the relationship between cutaneous vasomotor responses and stimulus intensity? Pulse volume and blood volume responses from finger and forehead were measured during presentation of stimuli ranging from 65 to 135 dB in a subjects-by-treatment design.

(2) Can orienting and defensive responses by distinguished on the basis of changes in the forehead over the temporal artery using a photoreflectance plethysmograph as commonly employed in the U.S.? Both pulse volume and blood volume changes were evaluated in answering this question.

(3) Does rate of habituation of vasomotor responses differ with stimuli of differing intensity? Three different definitions of habituation were used to answer the question.

(4) Is the rate of habituation different for the two major components of the vasomotor orienting response? Again, three definitions of habituation were used in evaluating the results.

(5) What other cardiovascular events accompany the vasomotor orienting response and its habituation? To investigate this problem, blood pressure and blood flow were continuously recorded during presentation of stimuli which evoked orientation, defense or habituation. The results of these experiments are discussed in terms of the functional significance of the vasomotor orienting response and the meaning of its habituation.

(6) The vasomotor orienting response is thought to depend primarily upon changes in tone of the precapillary resistance vessels. If this is so, changes in the state of these vessels should influence the response. Changes in environmental temperature served to change the tone of the resistance vessels, and concomitant changes in pulse volume, blood volume, blood pressure and blood flow were observed.

CHAPTER II

METHODS AND PROCEDURES

Subjects

Subjects were forty paid volunteers, ranging in age from sixteen to thirty-six and randomly assigned to twelve experimental groups. Four of the subjects were not used in the final analysis of the data, two because of instrumentation difficulties and two because they failed to complete the experiment.

Experiments were run in June and July. On arrival at the laboratory, the subject was briefed on the general nature of the study, and its painless, comfortable procedures stressed. A thirty-minute period was allowed for him to adjust to the laboratory temperature of 76 degrees, and during this period, psychological tests were administered. At the end of the testing time, subjects were asked to lie on a bed, and the transducers were applied. As each unit was put into place, its purpose was explained to the subject. Eight different measures were obtained from a total of six transducers.

Measurement of Physiological Responses

Photoplethysmographs

The subject's finger tip and an area of skin over the temporal artery were cleaned with acetone, and rubbed with a small amount of glycerin to render the skin optically clear. A piece of Stomaseal double-backed adhesive larger than this area and overlapping dry skin was placed over the site, and pressed firmly down. A miniature neon bulb (Chicago Miniature Lamp # NE-2), all but one side of which was encased in black rubber tubing and wrapped with electrician's tape, was pressed onto the Stomaseal. A separately housed photocell (Clairex CL907N) was pressed onto the Stomaseal adjacent to the bulb. Lead wires were secured so that slight movements did not alter the relationship between bulb and photocell, and the entire area covered with black cloth to exclude room light. This transducer differs from the usual joint housing of bulb and photocell. A typical transducer, when applied to the forehead, proved to be very sensitive to movement. Binding it to the forehead with enough pressure to significantly reduce the movement artifact was found to alter the shape of the pulse wave. The lighter, more flexible separate housings reduced movement artifact to a tolerable level without unusual pressure on the skin, and did not alter the wave shape.

The rationale behind photoplethysmography has recently been discussed by Brown (1967) and by Weinman (1967). As the amount of blood in the skin decreases, more light is reflected. A sensitive photocell reacts to this change with decreased resistance. This change in resistance formed one leg of a constant current Wheatstone bridge similar to that described by Edelberg (1967). The output of the bridge was directly coupled to a Beckman Dynagraph, Model R, and the gain adjusted so that gross changes in blood volume could be seen, pulse volume appearing as small deflections riding on the larger blood volume changes. The output of the bridge was also fed in parallel to another amplifier channel using capacitative coupling with a time constant of .03 seconds. Greater gain was used for these recordings, so that pulse volume changes themselves could be adequately evaluated. A sample recording can be seen in Figure 2. Because of insufficient Dynagraph channels, forehead blood volume was recorded on a Rectiriter galvanometric recorder.

Although the photoplethysmograph may be calibrated in terms of a standard change in light, it is not possible to calibrate it in terms of blood volume without a prohibitively involved procedure. Because of this, relative measures were used. For evaluation of pulse volume changes, the log of the mean of three pre-stimulus pulses, less the log of the sixth post-stimulus pulse, was used as the basic datum (Cook, 1968). This log ratio is dimensionless, and corrects for correlation of response amplitude and base level. Blood volume changes were similarly evaluated, the log of the resistance of the photocell before the stimulus, less the log of the resistance at point of greatest deflection being used.

Volume Plethysmographs

The entire distal phalanx of the subject's finger was enclosed in a small, rigid plastic tube, and the container sealed with Plethysmoseal. Rubber tubing connected the container with a transducer designed by Edelberg (personal communication). This consisted of a U-tube partly filled with water, one arm of which was located between a neon light bulb and a photocell. The U-tube, bulb and photocell were located inside a sealed box. Increases in finger volume caused the water level between the bulb and the photocell to rise, converting the glass tubing into a cylindrical lens. This caused an increase in light falling upon the photocell, decreasing its resistance. A small amount of detergent in the water decreased surface tension and increased the linearity of the

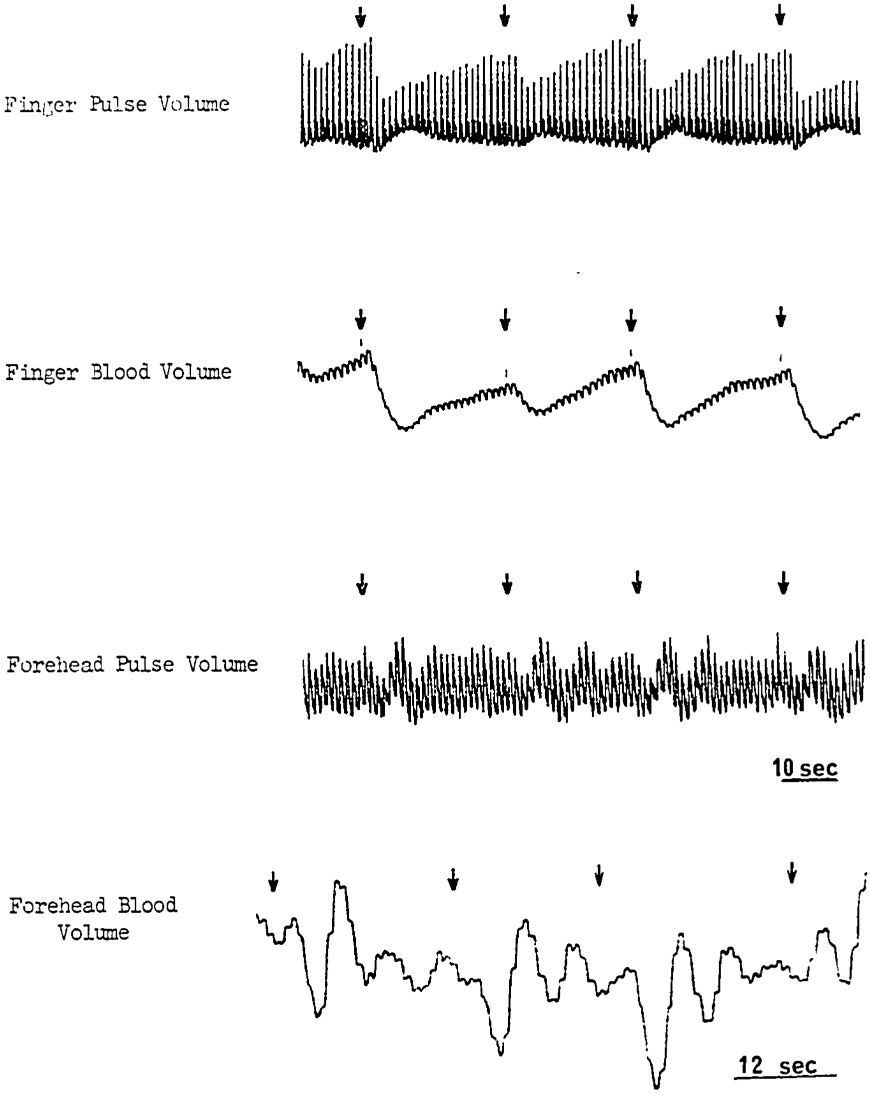

Figure 2. Sample recordings of finger pulse volume, finger blood volume, forehead pulse volume and forehead blood volume. Arrows mark the onset of stimulus presentation.

transducer. The resistance changes thus obtained formed one leg of a constant voltage Wheatstone bridge. The output of the bridge was amplified and recorded on a Rectiriter galvanometric recorder. The apparatus was calibrated during each experiment by injecting 50 mm^3 of air into the transducer. Periodically during each experiment the plethysmograph was opened to the atmosphere and allowed to equilibrate. A sample recording is shown in Figure 3.

Calibrations made it possible to evaluate results either in terms of mm^3 of change, or in terms of changes in conductance of the photocell, but for the purposes of this dissertation, the latter was simpler and adequate. The basic datum for analysis was the log of the pre-stimulus conductance less the log of the post-stimulus conductance at the point of maximal change.

Carotid Pulse

Carotid pulse was recorded by means of a Statham venous gauge (0-50 mm Hg range) coupled to a Beckman Dynagraph. The carotid artery was located by palpation, and a hard rubber stethoscope bell attached over the artery with a band of Velcrocloth. Every attempt was made to attach the pick-up with a firm, constant pressure from subject to subject, as recordings have been shown to be best when the unit is attached with 20-30 mm Hg pressure (Freis, 1967). A sample recording is shown in Figure 4.

Approximations of both pulse pressure and systolic and diastolic blood pressure can be obtained from measurements of carotid pulse (Wiggers, 1952). In order to calibrate the output of the Statham gauge, blood pressure is taken by auscultation, and the determinations of systolic and diastolic pressures assigned to the appropriate pulses on the write-out.

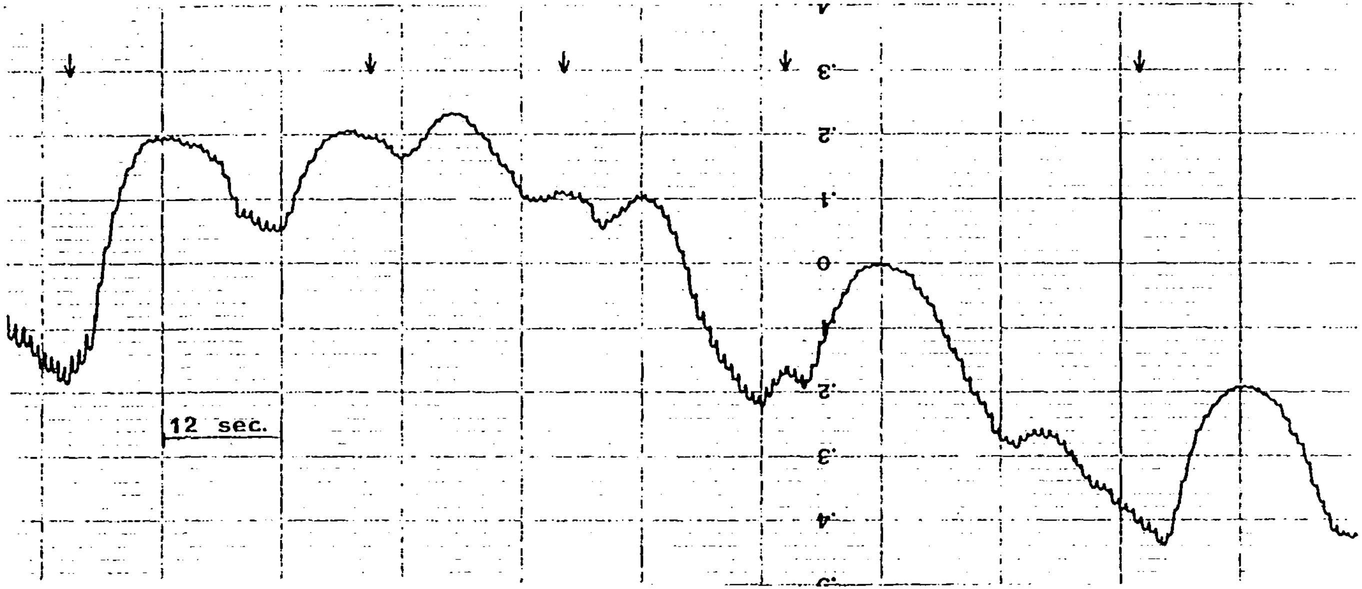

Figure 3. Sample recording of volume plethysmograph. Arrows mark the onset of stimulus presentation.

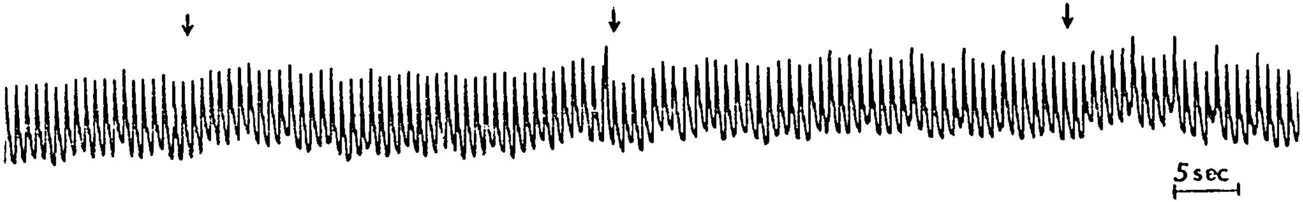

Figure 4. Sample recording of carotid pulse. Arrows mark the onset of stimulus presentation.

The distance between the two is then subdivided into equal units, these units serving as the calibration for changes in blood pressure and in pulse pressure. The original experimental design called for this approach to data analysis. It was assumed in error that negligible change in blood pressure would occur during auscultation. It became apparent on examining the recordings that, while systolic pressure was correctly calibrated, diastolic pressure varied so greatly during measurement that pulse pressure could not accurately be determined from the recording. For this reason, no attempt was made to report the data in physiologic units. Instead, change in systolic pressure from pre-stimulus to post-stimulus conditions was used as the basic datum, and is reported in arbitrary units. While this technique does not provide accurate blood pressure measurement, it does permit evaluation of direction of change of systolic pressure.

Radial Pulse

Radial pulse was recorded with a graphite pressure transducer mounted on the end of a small rod (Edelberg, personal communication). The transducer was secured in styrofoam in such a way that the pressure transducer extended as a small projection above the unit. The transducer was applied over the radial artery with firm, even pressure, and held there with elastic bandage. Since the unit was extremely sensitive to movement, the arm was supported either with a molded plastic form or with rolled towels. Figure 5 shows a sample recording. No attempt to calibrate this measure was made, and the method of data reduction was similar to that for the carotid pulse.

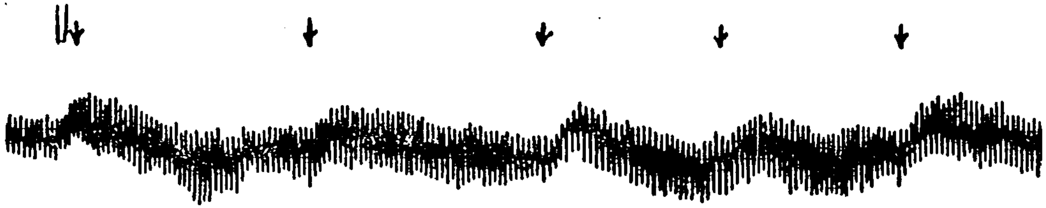

Figure 5. Sample recording of radial pulse. Arrows mark the onset of stimulus presentation.

Cutaneous Blood Flow

As blood flow increases, the amount of heat radiated by the skin increases. This relationship is the basis for the technique used to measure cutaneous blood flow (Edelberg, personal communication). A constant flow of air was pumped through a water bath to achieve constant temperature and into a small chamber placed on the palmar aspect of the thumb. A hole in the chamber allowed the air to escape. A small thermocouple junction coated with black paint absorbed the heat radiated by the skin, and was compared with another at constant temperature. The change in potential thus generated was directly coupled to the polygraph. No method of calibrating this measure has been developed, and results are reported in arbitrary units. A sample recording is shown in Figure 6.

After all transducers were applied and recording properly, calibrations were made as specified in the preceding sections. Calibrations were repeated several times during the course of each experiment.

Stimuli and Experimental Design

Experimental Design

The experimental design is shown in Table 2. After the presentation of orienting stimuli, subjects were divided into three groups. Twelve presentations of the habituation stimulus were given, followed by one presentation of a dishabituation stimulus. Each of the three groups heard habituation stimuli of different intensity. At the end of the habituation trials, subjects performed perceptual and motor tasks, the results of which will not be reported here. This constituted Phase I of the experiment.

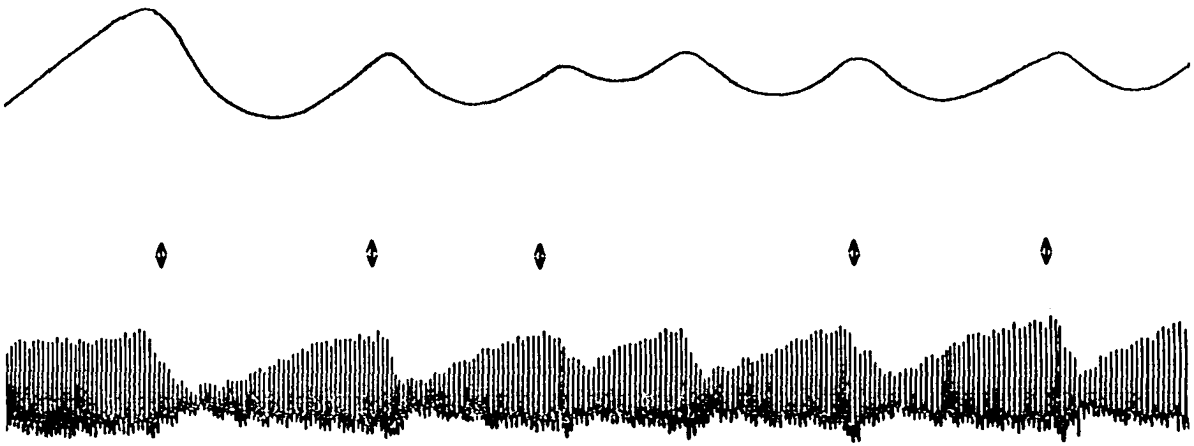

Figure 6. Sample recording of blood flow (upper trace). A simultaneously recorded sample of finger pulse volume is shown in the lower trace for comparison. Arrows mark the onset of stimulus presentation.

TABLE 2

EXPERIMENTAL DESIGN

Group	Phase I				Phase II			
	Orienting	Habituation			Orienting	Habituation		
		75	95	125		75	95	125
Hot	a	aa	ab	ac	a	aa	ab	ac
Cold	b	ba	bb	bc	b	ba	bb	bc
Control	c	ca	cb	cc	c	ca	cb	cc

a, b, c: N=12
aa, ab, *etc.*: N=4

One-third of the subjects in each habituation group then rested with no change in temperature. One-third experienced cooling of the room during the rest period, and the final third was heated. This resulted in nine groups of four subjects each. At the end of the rest period, Phase II began. Phase II of the experiment duplicated exactly the orienting and habituation portions of Phase I.

Auditory Stimuli

All auditory stimuli were presented binaurally through earphones. The seven orienting stimuli ranged from 65 to 135 dB (standard reference level of .0002 microbar), and all were at a frequency of 600 Hz. Orienting stimuli were presented in three blocs of seven stimuli for each subject, each bloc containing one stimulus at each intensity. Order of presentation within each bloc was randomly determined for each subject. Interstimulus interval also varied randomly, with a mean interval of 30 seconds. Background noise with all equipment in operation varied from

52 to 58 dB.

Three of the orienting stimuli served for testing habituation. Subjects were randomly assigned to habituation groups, one-third of them receiving habituation stimuli of 75 dB, one-third stimuli of 95 dB, and one-third stimuli of 115 dB. Interstimulus intervals were random, with a mean of approximately 30 seconds. Immediately after the presentation of the orienting stimuli, the subjects were instructed that they would hear one of the tones several times; habituation tones were then presented twelve times, followed by one presentation of a less intense tone to provide a measure of dishabituation.

At the end of the habituation period, subjects were given some reaction time and perceptual tasks which are not directly related to the subject of this dissertation. At the end of these tasks, the second phase of the experiment began.

Temperature Changes

During the first phase of the experiment, efforts were made to keep the subject room at a constant temperature of 76 degrees F. and free of draughts. Because the thermostatic temperature control of the room was found to allow too much variation, the air conditioning and heating systems were manually controlled. A thermistor was mounted in the room near the subject, and changes in room temperature carefully monitored via an indicator in the operator's room. If change exceeded one degree F., appropriate adjustments in air conditioning or heating were made. Fluctuations were in practice restricted to ±2 degrees F.

During the second phase of the experiment, effects of changes in temperature on the cutaneous vasomotor responses were evaluated.

One-third of the subjects, four from each habituation group, served as controls. They were given a rest period, after which the stimuli from the first portion of the experiment were repeated. For another third of the subjects, room temperature dropped during the rest period to approximately 60 degrees F., and was maintained there while the auditory stimuli were repeated. The remaining subjects experienced an increase of room temperature to approximately 90 degrees F. during the rest period, the increased temperature being maintained while the stimuli were repeated.

CHAPTER III

STIMULUS INTENSITY AND THE VASOMOTOR ORIENTING RESPONSE

Response Consistency

Zero-mu t-tests were computed on the difference between pre-stimulus and post-stimulus values for each measure and for each subject during Phase I Orienting. A subject was assumed to have a consistent response in any measure for which the values of the t exceeded that necessary for the tabled .05 level of confidence. To determine whether the population as a whole showed consistent responses, sign tests were made for each measure using the sign of the t value. Responses at or beyond the .0001 level of significance (two-tailed test) were found for all measures from the fingers, as well as for the two pulse measures (Table 3). It is especially noteworthy that neither of the forehead measures showed a consistent response for the group.

It was expected that the defensive response would not develop during the orienting phase of the experiment, and that dilation would therefore be found at the forehead for all stimuli. However, if it is the case that the defensive response develops very quickly so that the response to more intense stimuli changes from an initial dilation to constriction, no difference between pre-stimulus and post-stimulus conditions would be expected. Further analysis of forehead data was carried out to examine this possibility. Pulse amplitude of three pre-stimulus and fifteen post-stimulus pulses were determined for the first presentation of three stimulus intensities, 65, 95, and 125 dB. Averaged response curves were constructed, and are presented in Figure 7. No clear pattern of response emerges, and analysis of variance revealed no significant differences between the three curves, indicating that forehead pulse volume does not show an orienting response when measured photoplethysmographically from the temporal area.

TABLE 3

SIGN TESTS SHOWING PROBABILITY OF OCCURRENCE OF THE OBSERVED NUMBER OF POSITIVE *t*s IF THE PHYSIOLOGICAL MEASURE IN FACT DID NOT RESPOND TO THE STIMULUS

Measure	N[a]	Number of Ss with (+) $p < .05$	z	p <
Finger Pulse Volume	36	34	-5.17	.0001
Finger Blood Flow	33	29	-5.26	.0001
Finger Blood Volume (Photo)	36	34	-5.50	.0001
Finger Blood Volume (Vol.)	36	33	-5.50	.0001
Forehead Pulse Volume	35	10[b]	-1.00	.1587
Forehead Blood Volume	36	19[c]	-0.83	.2083
Carotid Pulse	29	14	-3.70	.0001
Radial Pulse	23	13	-4.17	.0001

a. Because of instrumentation difficulties, data for all measures were not available for all subjects.

b. Of the 10 *t* values which met the criterion, 6 were positive and 4 were negative.

c. Of the 19 *t* values which met the criterion, 10 were positive and 9 were negative.

Averaged response curves were also constructed for forehead blood volume responses, and these curves are presented in Figure 8. For moderate

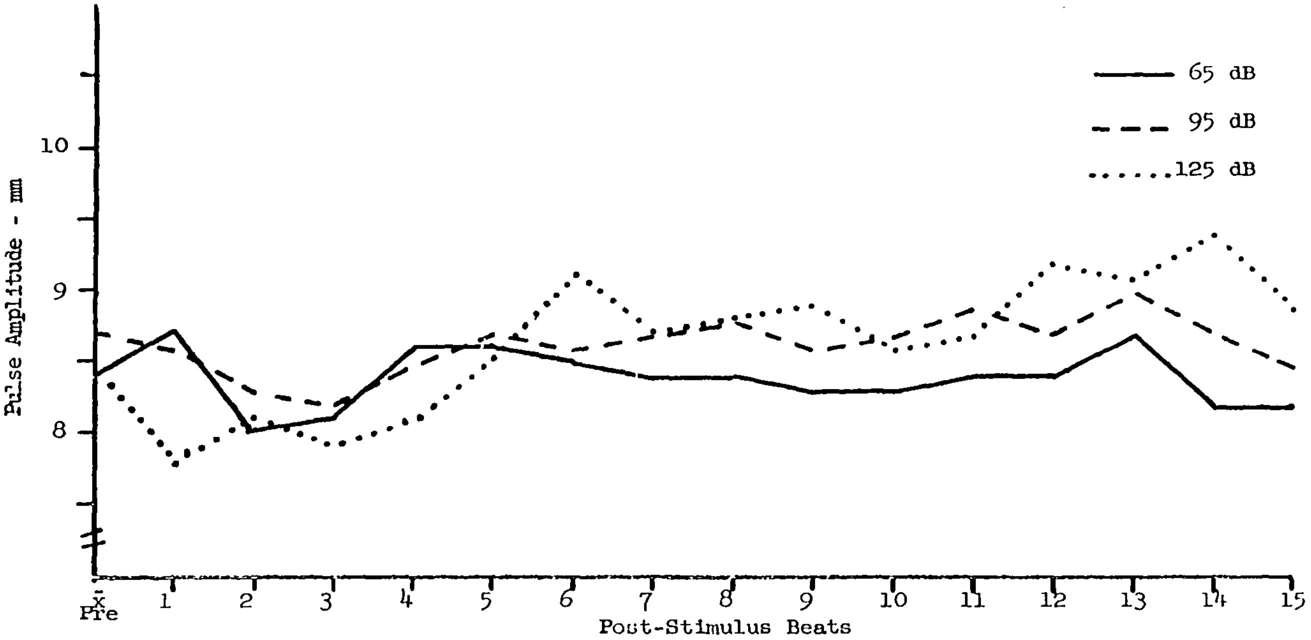

Figure 7. Averaged forehead pulse volume response curves.

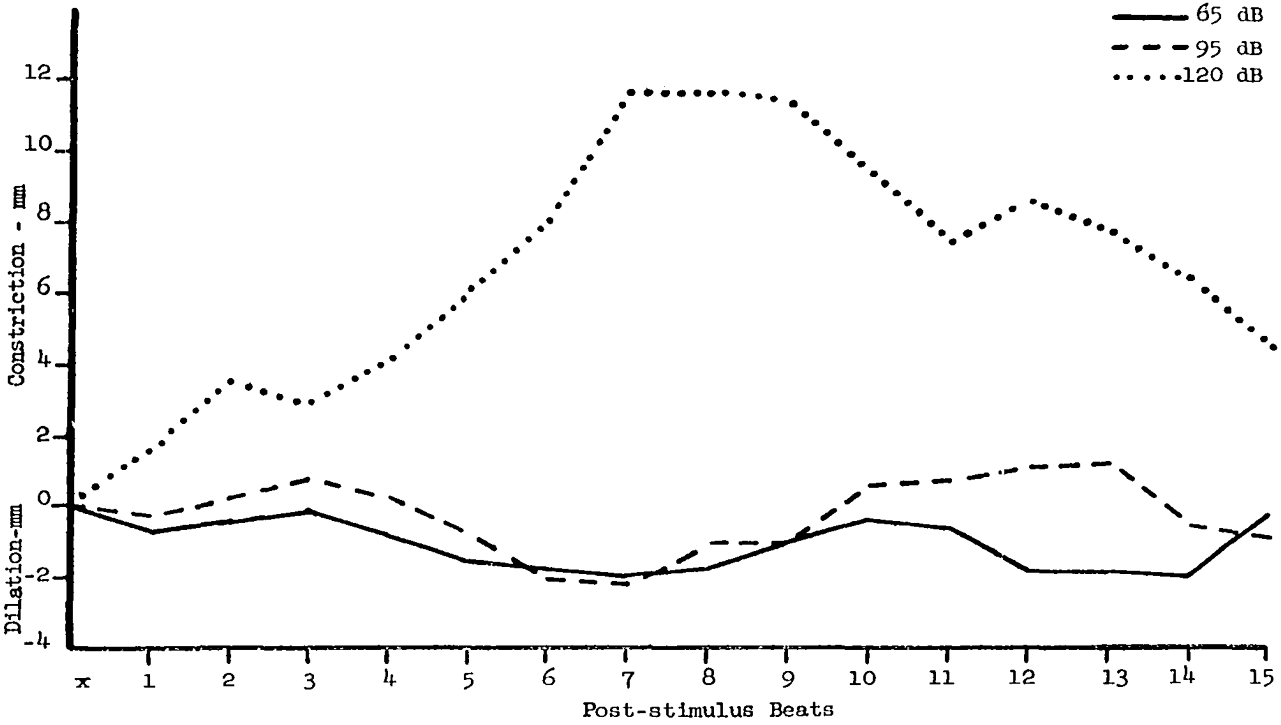

Figure 8. Averaged forehead blood volume response curves.

stimuli, the dilation did not differ significantly from zero ($t=.88$). For intense stimuli no dilation occurred, despite the fact that only the response to the first presentation of the stimulus was included in the analysis to preclude the habituation of the orienting response. On the contrary, a significant decrease in forehead blood volume to the intense stimulus was found ($t=2.57$, $p<.01$). The data upon which these curves were based (Table 4) were subjected to analysis of variance (Appendix, Table 22) and an intensity main effect was found, significant beyond the .05 level using conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959). Since forehead blood volume responses of a constrictive nature appear to occur to very intense stimuli, the data from the forehead were included in the analyses for determination of the relationship between stimulus intensity and response amplitude. Forehead pulse volume was not included in these analyses.

Relationship between Response Amplitude and Stimulus Intensity

Means of the three presentations at each intensity were computed for each subject. T-scores based on the mean of these means for each response variable were used as the basic data for analysis of variance. The measures from the finger, *i.e.*, finger pulse volume, the two measures of finger blood volume, and finger blood flow, all show highly significant main effects for intensity and highly significant linear trends, accounting for 89 to 95% of the variance. Tables 5, 6, 7 and 8 present the relevant means and standard deviations, and the trends are shown graphically in Figure 9. Results of the analyses of variance, which are shown in the Appendix (Tables 23, 24, 25, 26), were confirmed by non-parametric methods.

TABLE 4

AVERAGED FOREHEAD BLOOD VOLUME RESPONSE CURVES AT THREE STIMULUS INTENSITIES

Intensities		Beats																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
65 dB	Mean	99.2	99.5	100.1	99.2	98.4	98.6	98.0	98.2	99.0	99.6	99.4	98.3	98.2	98.2	99.7	99.2	98.4	98.2	96.11
	S.D.	4.38	7.87	8.91	9.59	10.19	12.00	12.96	13.16	12.72	12.26	11.72	12.71	13.84	13.69	9.81	9.12	8.77	8.10	46.48
95 dB	Mean	99.8	100.3	100.8	99.9	98.7	97.4	97.5	98.7	99.0	100.3	100.5	101.0	101.2	99.5	99.2	98.9	99.2	99.5	96.76
	S.D.	3.60	4.0	4.51	4.49	5.90	5.25	7.58	9.11	7.43	5.37	4.99	5.36	6.53	7.92	8.05	8.27	7.97	7.84	28.71
125 dB	Mean	102.0	103.4	102.7	103.8	105.3	106.2	108.7	109.1	109.0	107.6	105.7	106.9	106.0	104.8	103.3	102.2	102.5	100.5	102.07
	S.D.	5.52	8.49	10.25	11.79	12.99	14.88	16.92	15.94	16.32	18.94	19.31	13.38	12.95	13.83	13.81	14.80	13.74	12.77	60.78

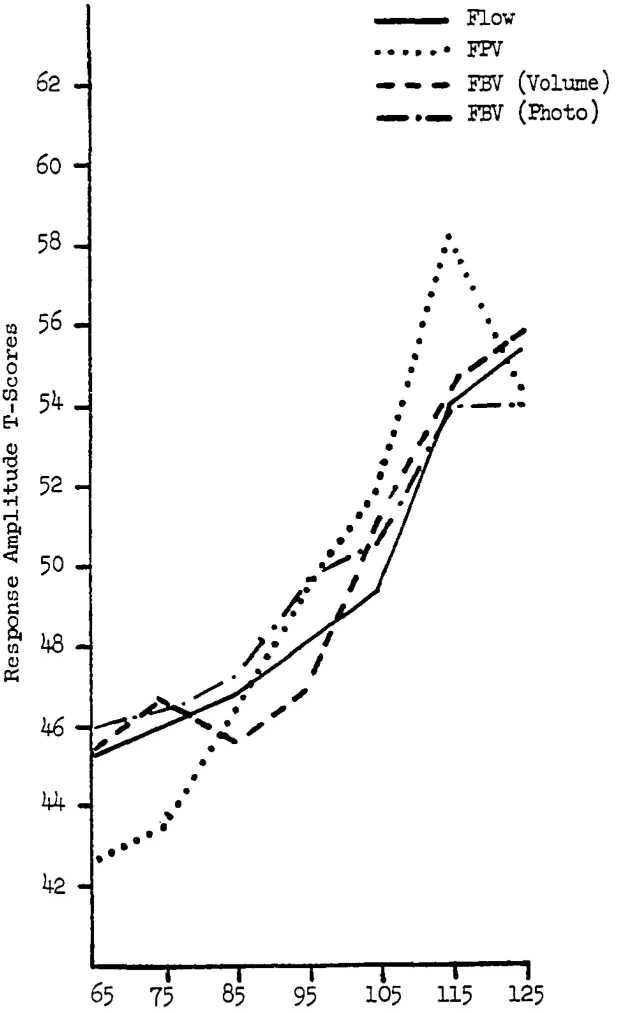

Figure 9. Relationship between stimulus intensity and response amplitude from the hand.

TABLE 5

FINGER PULSE VOLUME RESPONSE AMPLITUDE TO STIMULI OF DIFFERENT INTENSITIES

T Score	Stimulus Intensity						
	65dB	75dB	85dB	95dB	105dB	115dB	120dB
Mean	42.63	43.38	46.53	49.25	51.87	58.19	54.46
S.D.	6.55	6.44	7.25	8.29	9.39	10.39	9.76

TABLE 6

FINGER BLOOD VOLUME (PHOTOMETRIC) RESPONSE AMPLITUDE TO STIMULI OF DIFFERENT INTENSITIES

T Score	Stimulus Intensity						
	65dB	75dB	85dB	95dB	105dB	115dB	120dB
Mean	45.90	46.52	47.33	49.69	50.68	54.07	54.05
S.D.	6.89	5.66	8.17	8.91	9.42	12.76	12.35

TABLE 7

FINGER BLOOD VOLUME (VOLUMETRIC) RESPONSE AMPLITUDE TO STIMULI OF DIFFERENT INTENSITIES

T Score	Stimulus Intensity						
	65dB	75dB	85dB	95dB	105dB	115dB	120dB
Mean	45.40	46.70	45.62	48.97	51.26	54.38	55.79
S.D.	6.33	9.04	7.60	7.22	9.50	11.45	11.72

TABLE 8

FINGER BLOOD FLOW RESPONSE AMPLITUDE TO STIMULI OF DIFFERENT INTENSITIES

T Score	Stimulus Intensity						
	65dB	75dB	85dB	95dB	105dB	115dB	120dB
Mean	45.39	45.99	46.85	47.99	49.41	54.17	55.35
S.D.	3.35	5.58	6.32	5.80	6.65	12.47	11.42

Despite the significant forehead blood volume intensity effect when only one presentation of each of three stimuli was analyzed, there was no significant intensity effect when all three presentations and all seven stimulus intensities were included (Appendix, Table 27). Figure 10 shows the results of this analysis, and demonstrates that the overall response to stimuli of less than 120 dB was dilation. Zero-mu <u>t</u>-tests were made at each stimulus intensity to determine whether the response differed significantly from zero. Only at 65 and 85 dB was a significant difference observed, and the constriction at 120 dB did not differ significantly from zero. Sign tests indicate, however, that responses to the 120 dB stimulus were more frequently constrictive than those to the 95 dB stimulus ($z=1.67$, $p=.0475$ for one-tailed test). The linear trend for stimulus intensity was not significant, nor was the cubic. The quadratic trend, however, was significant beyond the .05 level of confidence ($F=5.26$, df 1, 35), apparently due to the ordered decrease in dilation from 95 to 120 dB. To determine whether the constrictive response increased as the orienting response habituated, <u>t</u>-tests were made on the habituation data. No significant differences were found between 65 dB stimuli and stimuli greater

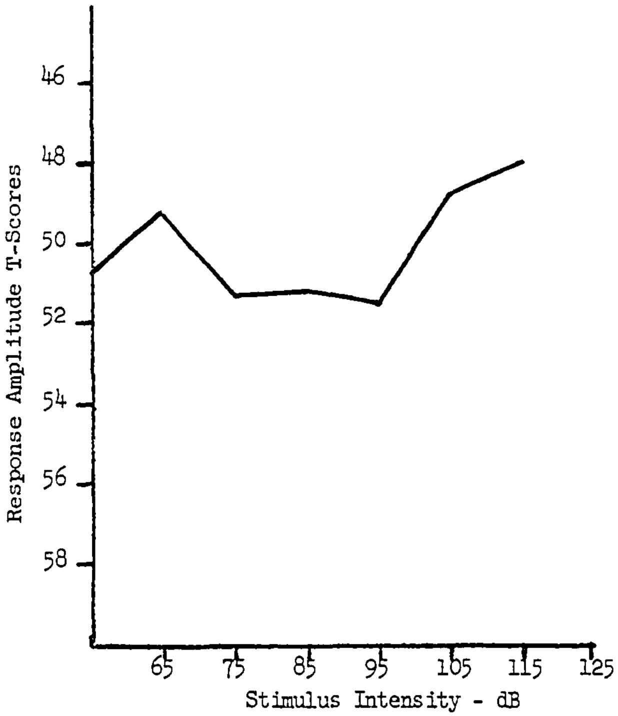

Figure 10. Relationship between stimulus intensity and amplitude of forehead blood volume responses.

than 120 dB, either at Habituation Trial 1 or Habituation Trial 12, indicating that repeated stimulus presentation did not result in increased forehead vasoconstriction.

Data for carotid pulse and radial pulse are presented in Tables 9 and 10, and are shown graphically in Figure 11. Analyses of variance are shown in the Appendix, Tables 28 and 29. Although consistent increases in pressure were found for the population as a whole (Table 3), and for many of the individual subjects, no relationship between the amplitude of these increases and the intensity of the stimulus was found.

TABLE 9

CAROTID PULSE RESPONSE AMPLITUDE TO STIMULI
OF DIFFERENT INTENSITIES

T Score	Stimulus Intensity						
	65dB	75dB	85dB	95dB	105dB	115dB	120dB
Mean	49.91	48.63	47.84	50.45	49.17	50.52	51.08
S.D.	6.25	8.05	9.81	8.35	8.36	10.53	13.74

TABLE 10

RADIAL PULSE RESPONSE AMPLITUDE TO STIMULI
OF DIFFERENT INTENSITIES

T Score	Stimulus Intensity						
	65dB	75dB	85dB	95dB	105dB	115dB	120dB
Mean	50.97	51.04	50.76	49.32	51.33	49.40	49.99
S.D.	9.63	9.00	6.96	7.57	8.38	13.70	10.54

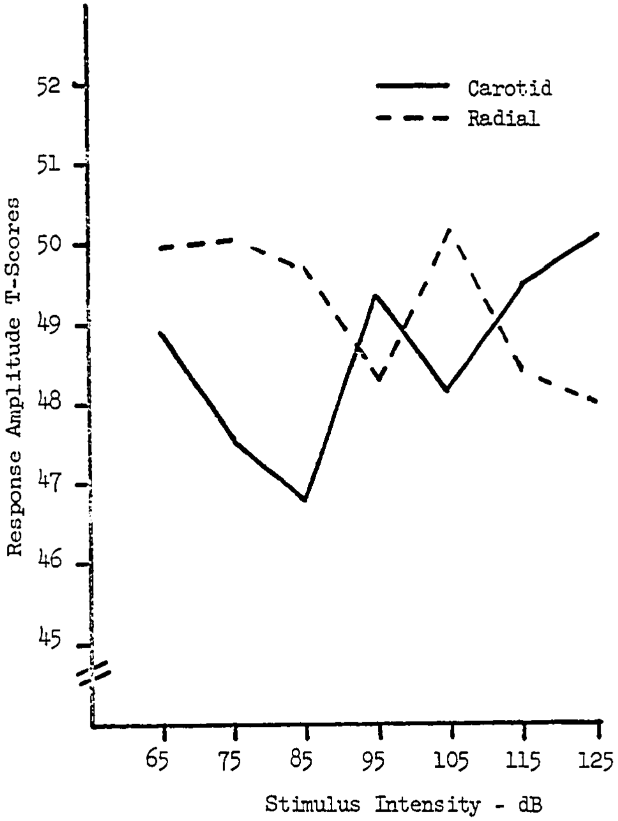

Figure 11. Relationship between stimulus intensity and amplitude of change in carotid and radial systolic pulse.

The hypothesis that forehead blood volume changes are a passive result of changes in blood pressure was not supported by correlational analysis. Although blood pressure increased and the overall response of the forehead was dilation, correlations between carotid pressure, response amplitudes and forehead response amplitudes were not significant. However, since different criteria were used in reducing the data of the two variables, this correlational approach was not felt to give an adequate answer to the question. Twelve subjects were therefore selected randomly, the only restriction being that recordings of carotid pulse and forehead blood volume be clear and contain a minimum amount of artifact. The recordings were examined to determine whether, when systolic pressure changed, a corresponding change could be observed in forehead blood volume (Table 11). For six of the subjects, the points to be examined were selected by using the carotid pulse record as a criterion. That is, two points on the carotid pulse recording were selected because a change occurred between these two points that was clearly visible upon examination of the recording. The forehead blood volume record was then examined to determine whether a corresponding change occurred. Of the twenty changes so examined, 18 showed corresponding changes in forehead blood volume. For the remaining six subjects, points were selected by reference to the forehead blood volume recording, and the carotid pulse recording examined. Of the 21 changes, correspondence was found in 17. No such relationship was found between finger blood volume and systolic blood pressure. This finding, together with the similar behavior of the two variables, is consistent with the hypothesis that forehead blood volume as measured over the temporal artery reflects changes in systolic pressure.

TABLE 11

INCIDENCE OF CORRESPONDENCE BETWEEN CHANGES IN SYSTOLIC PRESSURE, FOREHEAD BLOOD VOLUME AND FINGER BLOOD VOLUME

Criterion Measure	Number of Changes	Correspondence with Forehead Blood Volume		Correspondence with Finger Blood Volume	
		#	%	#	%
Blood Volume	21	17	81	8	38
Blood Pressure	20	18	90	7	35
Total	41	35	85	15	37

Conclusions

As predicted from the review of the literature, both finger pulse volume and finger blood volume show consistent constriction, the amplitude of which is linearly related to the intensity of the stimulus. No clear distinction between the two measures was found, although finger blood volume had a slightly more linear relationship with stimulus intensity than did finger pulse volume. In addition to these commonly measured variables, finger blood flow was monitored, and was found to decrease consistently to auditory stimulus presentation. The amplitude of the decrease in blood flow was linearly related to stimulus intensity. Measures of arterial pulse showed systolic increases to presentations of auditory stimuli, but these increases did not vary systematically with stimulus intensity.

No distinction between the orienting and defensive responses as discussed by Sokolov can be made on the basis of forehead blood volume responses when these responses are monitored photoplethysmographically from the forehead over the temporal artery. Although instances of constriction were found with very intense stimuli, the effect was not statistically significant and did not develop as the orienting response habituated. The amplitude of the dilation measured from the forehead did not show a regular relationship with stimulus intensity.

Forehead results are consistent with the hypothesis that dilation over the temporal artery is a passive result of changes in blood pressure. Because the skin of the forehead is not as rich in sympathetic innervation as is the skin of the hands, greater activation might be necessary for constriction of skin vessels to override the passive changes induced by blood pressure.

Although forehead responses could, under some circumstances, be observed, they were highly variable and appear to be primarily the result of passive changes in the vessels due to changes in blood pressure. The usefulness of the forehead response in psychophysiological studies is highly doubtful. Further development of methods for the indirect, continuous measurement of blood pressure changes holds more promise for meaningful future research.

CHAPTER IV

HABITUATION OF THE VASOMOTOR ORIENTING RESPONSE

The habituation phase of the experiment was designed to investigate: (a) whether the different physiological functions monitored have different rates of habituation and, if so, whether this information is useful in the adaptive interpretation of the response; and (b) whether rate of habituation and its relationship with stimulus intensity is substantially affected by the method of analysis used.

Habituation data were analyzed by each of three methods appearing frequently in the literature: trials to criterion (_e.g._, Koepke & Pribram, 1967), occurrence of dishabituation (_e.g._, Thompson & Spencer, 1966), and decrease in response amplitude (_e.g._, Cohen & Johnson, 1970). A fourth analysis not previously reported for vasomotor responses, the ratio of responses to the first and fourth stimuli, was also made. This measure was used by Edelberg (1970) in the habituation analysis of electrodermal activity and finger pulse volume responses. The independent variables of the experiment will be discussed in relation to each of these measures of habituation.

At the end of the orienting phase of the experiment, subjects were randomly divided into three groups. Each group received twelve habituation trials, followed by a single presentation of a stimulus of lesser intensity (the dishabituation trial). For one group of subjects, the stimulus intensity was 75 dB, and the dishabituation stimulus was 65 dB. The second group received stimuli of 95 dB, with dishabituation of 85 dB, while the third heard 125 dB tones, followed by a dishabituation stimulus of 115 dB.

Trials to Criterion

The number of trials to a predetermined response criterion would be the most sensitive means of measuring habituation if it were assumed to be an all-or-none process. A criterion of two consecutive no-response trials was chosen (Koepke & Pribram, 1967). Table 12 shows the per cent subjects reaching criterion by the end of the twelve stimulus presentations. The numbers in the column headed "Across Intensities" represent the per cent subjects who reached criterion for that measure, regardless of stimulus intensity. In similar fashion, entries in the row labeled "Across Measures" refer to the per cent subjects who reached criterion for that stimulus intensity regardless of which physiological measure was evaluated.

TABLE 12

PER CENT SUBJECTS REACHING CRITERION OF TWO NO-RESPONSE TRIALS

Measure	Stimulus Intensity			Across Intensities
	75	95	125	
Finger Blood Flow	44	44	11	33
Finger Pulse Volume	50	25	0	25
Finger Blood Volume (Ph.)	67	17	0	28
Finger Blood Volume (Vol.)	33	25	17	26
Across Measures	59	27	7	28

Because of the intercorrelations among the physiological response measures, it is not feasible to make a quantitative test of significance on these data. The Lyerly-Lubin test (Lyerly, 1952; Lubin, 1961) is a useful descriptor in such circumstances. This test measures the extent to which observed rank orders agree with an hypothesized rank order. In this case, the hypothesized rank order is dependent upon stimulus intensity; more subjects are expected to reach criterion for the least intense stimulus, and the fewest to reach criterion for the most intense stimulus. The per cent subjects reaching criterion for each physiological measure can then be rank ordered, and the correspondence between the observed and hypothesized rank orders determined. For the data presented in Table 12, the test resulted in a K of .87, indicating a high degree of agreement between the hypothesized and the observed results.

When the trials-to-criterion definition of habituation is used, it is customary to present a large number of trials, and subject the results to analysis of variance. Because truncation and skew in the distribution resulted when only twelve trials were presented, the data did not meet the assumptions of analysis of variance. Table 13, which shows the mean trials to criterion for those subjects who habituated, does not, however, indicate any significant differences between response measures.

If the experimental conditions were such that a trials-to-criterion analysis could be properly accomplished, such an analysis would be sensitive to the effects of stimulus intensity, but probably would not differentiate between response measures.

TABLE 13

MEAN TRIALS TO CRITERION FOR SUBJECTS WHO HABITUATED

Measure	Stimulus Intensity			Across Intensities
	75	95	125	
Finger Blood Flow	5	8	a	6.5
Finger Pulse Volume	7	6	b	6.5
Finger Blood Volume (Ph.)	7	6	b	6.5
Finger Blood Volume (Vol.)	6	9	a	7.5
Across Measures	6	7		

a Only one score available.
b No scores available.

Dishabituation

Habituation has been distinguished from effects of fatigue by the occurrence of dishabituation (Sokolov, 1963; Thompson & Spencer, 1966), and this has become a common criterion of habituation. Response to a stimulus can, by this definition, be said to have habituated when a stimulus of lesser intensity elicits a response of greater amplitude. To evaluate habituation by such a criterion, it was determined whether dishabituation occurred for each subject and for each physiological measure, and simple non-parametric statistics applied to arrive at a probability level of such occurrences. Table 14 shows the per cent subjects who dishabituated under each of the experimental conditions. A Cochran Q-test (Siegel, 1956) on the physiological measures resulted in a significant difference, beyond the .001 level. This significant difference is apparently due to the fact that dishabituation occurred more frequently for finger pulse volume and finger blood volume as measured volumetrically than it did for either finger blood flow or finger blood volume measured plethysmographically.

To evaluate the effect of stimulus intensity upon the number of subjects showing dishabituation, chi-square was computed for each response measure. None were significant, although chi-square for photometric finger blood volume approached the .05 level (chi-square=5, $p<.10$). Despite the fact that no significant differences were found when each measure was analyzed separately, the pattern of response was quite consistent (Table 15). A Lyerly-Lubin test, based upon the hypothesis that the more intense the stimulus, the less frequent the dishabituation, resulted in K=.50. Although this does not represent a high degree of relationship, reference to the table demonstrates that all physiological measures showed the same rank order with regard to stimulus intensity. This rank order differed from the hypothesized rank order and from the results of the trials-to-criterion analysis. According to the dishabituation analysis, greater habituation occurred to the 125 dB stimulus than to the 95 dB stimulus. Dishabituation appears to distinguish between both response measures and stimulus intensity, although the relationship between stimulus intensity and rate of habituation is not in the expected direction.

Decrease in Response Amplitude

Analysis of variance has recently been the most frequent way of analyzing habituation data. The amplitude of the response to each presentation of the stimulus is the customary datum. Tables of means and standard deviations for such analyses for each response measure are shown in Tables 16, 17, 18, and 19, and the analysis of variance tables are shown in the Appendix. Habituation approached significance only for volumetric finger blood volume and for blood flow, and even for these measures no significant interaction with stimulus intensity was found. One-tailed _t_-tests for correlated measures between the first and last habituation presentations (used because the direction of difference was predictable) were significant for finger pulse volume ($t=1.69$, $p=.05$), blood flow ($t=2.00$, $p<.05$) and finger blood volume (vol.) ($t=3.36$, $p<.001$), indicating that habituation was occurring for these measures, although not in a regular fashion.

TABLE 14

PER CENT SUBJECTS WHO DISHABITUATED

Measure	Stimulus Intensity			Across Intensities
	75	95	125	
Finger Blood Flow	50	11	22	27
Finger Pulse Volume	73	40	50	55
Finger Blood Volume (Ph.)	60	8	42	35
Finger Blood Volume (Vol.)	63	23	40	41

TABLE 15

RANK ORDER OF DISHABITUATION RESPONSES TO STIMULI OF DIFFERING INTENSITY

Measure	Stimulus Intensity		
	75	95	125
Finger Blood Flow	3	1	2
Finger Pulse Volume	3	1	2
Finger Blood Volume (Ph.)	3	1	2
Finger Blood Volume (Vol.)	3	1	2

TABLE 16

FINGER PULSE VOLUME HABITUATION

Stimulus Intensity	Response Amplitude	Stimulus Presentation											
		1	2	3	4	5	6	7	8	9	10	11	12
75 dB	Mean	.1724	.0888	.0850	.1510	.1901	.0539	.1265	.1741	.1354	.2248	.1149	.1306
	S.D.	.1704	.0736	.0820	.1794	.1620	.0738	.1471	.1598	.1096	.2375	.1548	.1439
95 dB	Mean	.2256	.2231	.2235	.2511	.2072	.2402	.1454	.1904	.1920	.3184	.2323	.1517
	S.D.	.1915	.1864	.1518	.1735	.1641	.1712	.1280	.1545	.1309	.1672	.1871	.1044
120 dB	Mean	.3317	.2745	.3454	.3041	.2801	.3161	.3193	.2664	.3258	.2601	.3024	.2689
	S.D.	.2237	.2070	.2021	.1471	.1878	.2128	.1342	.2261	.0267	.2126	.1847	.1727
Total	Mean	.2432	.1677	.2179	.2354	.2044	.2034	.1966	.2103	.2178	.2678	.2165	.1837
	S.D.	.2022	.2068	.1834	.1747	.2887	.1940	.1600	.1823	.1553	.2055	.1882	.1521

TABLE 17

PHOTOMETRIC FINGER BLOOD VOLUME HABITUATION

Stimulus Intensity	Response Amplitude	Stimulus Presentation											
		1	2	3	4	5	6	7	8	9	10	11	12
75 dB	Mean	.0174	.0130	.0093	.0156	.0165	.0720	.0079	.0152	.0112	.0293	.0090	.0174
	S.D.	.0187	.0179	.0141	.0295	.0122	.0114	.0164	.0217	.0173	.0676	.0182	.0438
95 dB	Mean	.0116	.0170	.0142	.0178	.0111	.0113	.0074	.0113	.0091	.0127	.0125	.0139
	S.D.	.0122	.0184	.0134	.0158	.0152	.0100	.0055	.0100	.0105	.0084	.0071	.0152
120 dB	Mean	.0127	.0107	.0132	.0167	.0103	.0146	.0104	.0104	.0138	.0126	.0106	.0140
	S.D.	.0077	.0063	.0134	.0152	.0105	.0173	.0089	.0095	.0114	.0134	.0084	.0179
Total	Mean	.0139	.0135	.0122	.0167	.0126	.0117	.0085	.0130	.0112	.0182	.0107	.0151
	S.D.	.0138	.0155	.0138	.0205	.0130	.0134	.0114	.0148	.0134	.0399	.0122	.0281

TABLE 18

VOLUMETRIC FINGER BLOOD VOLUME HABITUATION

Stimulus Intensity	Response Amplitude	Stimulus Presentation											
		1	2	3	4	5	6	7	8	9	10	11	12
75 dB	Mean	.0160	.0107	.0086	.0082	.0160	.0032	.0095	.0108	.0089	.0108	.0073	.0036
	S.D.	.0118	.0089	.0077	.0100	.0095	.0032	.0138	.0126	.0084	.0055	.0032	.0032
95 dB	Mean	.0120	.0155	.0227	.0194	.0144	.0188	.0135	.0147	.0396	.0186	.0152	.0094
	S.D.	.0089	.0095	.0118	.0122	.0134	.0167	.0105	.0110	.0569	.0167	.0130	.0077
120 dB	Mean	.0217	.0152	.0238	.0202	.0142	.0195	.0127	.0126	.0182	.0177	.0116	.0074
	S.D.	.0173	.0134	.0195	.0089	.0126	.0126	.0063	.0095	.0134	.0138	.0100	.0045
Total	Mean	.0166	.0138	.0184	.0159	.0148	.0138	.0119	.0127	.0222	.0157	.0114	.0068
	S.D.	.0134	.0109	.0152	.0118	.0118	.0141	.0149	.0110	.0355	.0130	.0105	.0055

TABLE 19

BLOOD FLOW HABITUATION

Stimulus Intensity	Response Amplitude	Stimulus Presentation											
		1	2	3	4	5	6	7	8	9	10	11	12
75 dB	Mean	1.61	0.93	0.76	0.93	0.82	0.30	1.56	0.19	1.02	2.40	0.21	0.92
	S.D.	0.87	1.38	1.36	1.11	0.49	0.57	1.99	1.06	1.34	2.35	1.27	1.55
95 dB	Mean	3.28	2.01	2.58	2.82	0.90	3.58	2.34	1.52	2.08	2.54	1.82	2.21
	S.D.	6.28	2.97	2.85	2.58	1.65	4.78	3.44	1.66	2.92	3.18	2.21	2.67
120 dB	Mean	3.90	2.97	2.50	3.08	2.91	2.92	1.78	2.02	2.47	2.24	2.16	2.53
	S.D.	3.25	2.65	1.65	1.66	1.50	1.08	1.32	1.20	1.43	1.34	1.19	1.50
Total	Mean	2.93	1.97	1.94	2.28	1.66	2.27	1.78	1.24	1.86	2.40	1.40	1.89
	S.D.	4.08	2.48	2.16	2.06	1.49	3.09	2.35	1.50	2.05	2.32	1.78	2.03

Ratio Analysis

If, as has been postulated by many investigators, (*e.g.*, Thompson & Spencer, 1966), the habituation curve takes the form of a negative exponential function of the number of response trials, the logarithm of the ratio between two points on the curve would provide a direct measure of rate of habituation. Table 20 presents an analysis of variance of such data. The ratio between the response to the first stimulus and the response to the fourth stimulus was multiplied by 100 to eliminate negative characteristics, and the logarithm of the ratio determined. A significant difference was found among stimulus intensities ($F=5.45$, $p<.05$), but not among physiological measures. Simple effects analyses showed significant intensity effects for all measures other than finger pulse volume, the greatest differences being found for blood flow. It is interesting to note, however, that intensity differences were not as expected. The ratio was higher for stimuli of 120 dB or greater than for 95 dB stimuli, indicating that rate of habituation was greater for the more intense stimulus, a result which agrees with that of the dishabituation analysis.

TABLE 20

RATIO ANALYSIS OF HABITUATION

Stimulus Intensity	Log Ratio 1:4	Measures			
		FPV	BF	FBV	VP
75 dB	Mean	2.29	2.56	2.33	2.50
	S.D.	1.18	.48	.77	.71
95 dB	Mean	2.03	1.69	1.80	1.92
	S.D.	.96	.82	.48	.69
120 dB	Mean	1.96	2.12	1.96	2.11
	S.D.	.80	.68	.33	.52

Comparison Between Measures

Choice between these measures of habituation could be made on the basis of the sensitivity of the measure, the correspondence between measures, or the degree to which they correspond with theoretical assumptions about the nature of the habituation process. The four different measures yielded different results. When trials-to-criterion is the measure of habituation, significant differences are found for stimulus intensity, but not for response measures. When dishabituation is taken as the criterion, stimulus intensity is an effective variable, but bears an unpredictable relationship and disagrees with the results of the trials-to-criterion analysis. The physiological measures do show significant differences in habituation rate with finger pulse volume being most rapid. Analysis of variance found no significant habituation when main effects were the criterion. The response to the first stimulus was, however, significantly greater than that to the twelfth for three of the four measures, with volumetric finger blood volume showing the greatest habituation. Analysis based on the ratio of the first and fourth responses found a significant intensity difference, but no significant differences between the measures.

Conclusions

The ideal measure of habituation should be reliable, should be sensitive to changes in the experimental situation, should provide an estimate of the rate of habituation for the individual subject, and should be derived from stated assumptions about the nature of the habituation process. Both the trials-to-criterion and ratio methods of data analysis appear to meet these requirements. The choice between them rests upon assumptions the investigator is willing to make with regard to the habituation process. The idea that habituation might be an all-or-none process has only recently received serious consideration, and no experimental evidence which might help in making such a decision is presently available. Evidence from neurophysiological studies is available to support the hypothesis that habituation is a negative exponential function of the number of stimulus presentations (Thompson & Spencer, 1966). Ratio analysis appears therefore to be the most logical choice in interpreting the results of habituation studies. Because its choice is based on clearly stated assumptions about the habituation process, evaluation of the method itself can be carried out on a rational basis. The method has the pleasant side effect of considerably reducing the amount of time required for habituation studies, thereby reducing sources of experimental error such as the state of consciousness of the subject.

Using the ratio measure as the method of choice, we find an unexpected relationship between rate of habituation and stimulus intensity. Habituation was greater for the 125 dB stimulus than for the 95 dB stimulus. Three possible explanations for this finding have been considered. First, we could be seeing the results of a "baseline" effect. Germana (1968) has pointed out that habituation may on occasion follow the law of initial values, _i.e._, the greater the original response the greater the habituation. To test this hypothesis, _t_-tests were computed between pre-stimulus levels for the 95 and 125 dB groups. No significant differences in pre-stimulus levels were found for the three measures for which such data were available. The amplitude of the response to the first habituation presentation was also compared between the two groups, and no significant differences were found, indicating that differences in base level between the groups cannot account for the results.

According to Pavlov, repeated presentations of an intense stimulus result in cortical inhibition which will eventually produce sleep. It is possible that such inhibition results first in reduction of autonomic responses. No evidence directly bearing on such an hypothesis is available.

Similarly, the subjects in the 95 dB group may have become drowsy. Sleep is known to interfere with the habituation process (McDonald, et al., 1964). If subjects in one group became drowsy more frequently than those in another, results such as those obtained in this study might be expected. There is, however, no reason to expect that subjects in the 95 dB group would tend to become drowsy or to sleep more than those in the 75 dB group. Behavioral observations did not reveal any sleeping subjects during the course of the experiment, but neurophysiological evaluation of sleep was not made.

A fourth possibility exists. The trials-to-criterion measure showed the expected relationship between stimulus intensity and habituation. It may well be that cessation of a response and reduction in response amplitude represent very different aspects of the habituation process, and that these aspects have different relationships with environmental variables.

No significant main effect for measures was found using ratio analysis. Simple effects indicated that intensity was an effective variable for all measures other than finger pulse volume, indicating that it is less sensitive to experimental variables than the other measures. No apparent clarification of the adaptive significance of the vasomotor responses was deduced from analysis of the habituation data.

CHAPTER V

PHYSIOLOGICAL EVALUATION OF THE VASOMOTOR RESPONSE

Some of the most striking results in psychophysiology have been obtained with cardiovascular measures. For example, Lacey & Lacey (1958) have demonstrated a relationship between heart rate response to a stimulus and reaction time, and have presented evidence indicating that heart rate increases to unpleasant stimuli and decreases to signal stimuli. Ackner (1956) found that finger pulse volume of anxious patients increased more during induced sleep than that of non-anxious patients or controls, conclusively demonstrating the relationship between emotional states and the behavior of blood vessels in the hand. More recently, Kelly (1966) has shown that forearm blood flow is much greater in anxious persons than in non-anxious persons. To the extent that the vasomotor response reflects both heart rate and blood flow, it promises to be a psychophysiological tool of great power. Little progress can be made in the use of the vasomotor response as a tool, however, until its physiological functions and mechanisms are better understood. Contributing to this goal has been one of the major purposes of the research reported here.

It will be recalled that the vasomotor response, as observed plethysmographically, has been described by Burch (1954) as the relationship between flow into an area and flow out of that area. Flow into an area, whether a digit, an area of skin, or an entire limb or organ, is determined by blood pressure, which provides the driving force for flow, and the resistance of the blood vessels. The major resistance of vessels occurs just before the capillary bed, in the arterioles and precapillary sphincters. These vessels are sympathetically innervated, and an increase in sympathetic discharge results in increased constriction of the vessels in the skin of most areas of the body, increasing resistance and thereby decreasing the flow of blood into the capillary bed. This is not, however, the only determinant of the vasomotor constriction observed plethysmographically. The veins, which are also involved in the response, are sympathetically innervated, and it has been shown that their behavior can be independent of the behavior of the arterioles. While veins have been shown to respond to auditory and other stimuli with constriction which can be conditioned, no such data is available for the arterioles.

Since arteriolar and venous functions differ in the body, an understanding of the contribution of each to the vasomotor response as observed plethysmographically would make interpretation of the response more meaningful. Hertzman and his colleagues have stated that finger pulse volume represents primarily the arteriolar component of the response, while finger blood volume represents primarily the venous component. If this were the case, we would have at hand a simple way to separate the two components, and if they provide information which is differentially meaningful for psychophysiology, such can be easily determined. If finger pulse volume actually reflects arteriolar and precapillary constriction, its amplitude is a function of blood pressure and either local reflexes or sympathetic discharge. Under most circumstances the local reflexes can be disregarded, and sympathetic discharge considered the primary determinant of constriction. Approximately 95% of the blood pressure is dissipated in the arterioles and capillary bed. Blood pressure should, therefore, not be a significant determinant of finger blood volume, if finger blood volume actually represents venous tone. Blood volume would then reflect primarily sympathetic discharge to the veins, while pulse volume would reflect both blood pressure and sympathetic discharge to the arterioles.

Hertzman's conclusions are not the only possible interpretation. Although pulse volume has been described as dependent upon inflow-outflow relations (Burch, 1954), another important consideration is the distensibility of the low pressure vessels, which act as a hydraulic capacitor. During the systolic portion of the pulse beat inflow increases, and will transiently distend these vessels in accordance with their compliance. Greater compliance will result in a larger volume increase during systole and hence a larger pulse volume; run-off resistance is assumed to be low and essentially constant.

Evaluation of the respective roles of arteriolar and venous tone in determining pulse volume requires information on the amplitude of the pulse associated with each heart beat for blood pressure, flow and volume. Since the flow transducer used affords only a measure of average flow, there are limitations on how far the present experiments may be interpreted in this regard. They may, however, provide useful information if certain variables can be eliminated, and the type of recordings available allow such control. If during the course of a single experiment points are selected for which mean flow is the same, one may as an approximation derive vascular resistance from the expression

$$\text{Resistance} = \text{Constant}\left(\frac{\text{Mean Pressure}}{\text{Mean Flow}}\right)$$

where flow is a constant. Since resistance is almost entirely a function of the arteriolar state, and mean flow is constant, arteriolar constriction is directly related to mean blood pressure. Systolic-diastolic differences may, however, produce rather different wave-forms for the same mean levels of flow. Examination of the data indicate that, for a given individual, variation in blood pressure during an experimental session was primarily due to variation of systolic pressure. As a consequence, higher mean pressures were associated with higher pulse pressures. Under conditions of constant mean flow, and in the absence of change in venous tone, pulse volume should vary directly with pulse pressure, and larger pulse volumes should therefore be seen at higher pressures. The correlation between mean blood pressure and finger pulse volume should be positive.

The above discussion assumed constant venous tone; any change in venous tone would alter pulse volume, since at a given change in rate of inflow the change in volume is a function of the compliance of the venous vessels. Increase in tonus would reduce this compliance and would therefore reduce the pulse volume. If the vessels were absolutely nondistensible, no pulse volume could be observed. Thus, if at the same time blood pressure pulse increased, venoconstriction occurred, one might observe a reduction rather than an increase in pulse volume, and the expected positive correlation between blood pressure and pulse volume could be reversed. In fact, a negative correlation between pulse volume and blood pressure can be interpreted as evidence for the significant role of venomotor activity in the determination of pulse volume.

TABLE 21

RELATIONSHIP BETWEEN ARTERIOLAR CONSTRICTION AND FINGER PULSE VOLUME

Subject	Slope	Standard Error	Pearson's r
3	0.13	3.53	.12
7	-0.31	1.35	-.75
8	0.02	2.83	.02
13	-0.77	4.49	-.28
14	2.94	0.94	.94
17	-0.95	1.26	-.56
29	-0.12	2.46	-.27
31	0.01	2.21	.01
32	-0.46	0.53	-.85
32a	-0.52	0.61	-.85
33	-1.35	0.97	-.91
36	0.81	2.17	.74

The correlations in Table 21 provide strong support for the role of such a venomotor component. The high positive correlation found for subjects 14 and 36 can be explained without introducing a change in venous tone, but the high negative correlations found for subjects 7, 17, 32, 32a and 33 seem clearly to indicate venous activity. An examination of the pressure data for these subjects showed that in fact the higher mean pressures were associated with higher pulse pressures, and the role of a venous factor as a determinant of pulse volume seems imperative in these cases. The state of the resistance vessels, then, does not entirely account for finger pulse volume changes, even when variations in blood pressure are taken into account, and the unexplained variation must be due to changes in venous tone which exerts its effect by changing compliance, rather than by changing run-off rate.

Some indirect evidence is available to support the above conclusion. It is known that temperature changes differentially affect arterioles and veins. When a subject is comfortably warm, the veins are maximally dilated (Wood & Eckstein, 1958). Arterioles dilate further when heat is applied, and can greatly increase blood flow. When a subject is cooled, both arterioles and veins are affected, but a time difference is observed in this effect. When going from a warm environment to a cool environment, arterial constriction usually precedes venous constriction, while going from a cool to a warm environment, venous dilation (and therefore an increase in venous compliance) occurs first. Data from Phase II of the experiment, where environmental temperature was changed, are relevant to the discussion of the tentative working hypothesis that both finger pulse volume and finger blood volume are heavily dependent upon the tone of the venous vessels.

To the extent that veins are responsible for finger pulse volume, both base level and response amplitude should be unchanged by increased temperature (which causes no further venous dilation) but decreased by cooling. Figure 12 shows the effect of temperature change upon finger pulse volume base levels. No difference between Phase I and Phase II was found for the subjects who were heated, while the subjects who were cooled showed a marked drop in finger pulse volume ($p < .01$). However, the control group of subjects, who experienced no change in environmental temperature, also showed a significant drop in finger pulse volume ($p < .01$), probably due to time-locked physiological changes such as a filling bladder. The decline in pulse volume for the cold subjects was significantly greater than for the controls ($p < .01$), indicating that cold effectively reduced finger pulse volume base levels. But the difference between control and hot subjects was also significant ($p < .05$), indicating that heat had a vasodilating effect. Since this is not likely to be due to the venous component, finger pulse volume must be at least partly determined by the resistance vessels. No way of determining the proportion of venous contribution is available from these data.

Finger pulse volume response amplitudes were also affected by changes in temperature (Figure 13). Both hot and control groups showed a decline in response amplitude, possibly due to habituation since no significant difference between the two groups was found. Cold subjects on the other hand showed a decline in response amplitude which was significantly greater than for either hot or control subjects. The relationship between response amplitude and stimulus intensity was not changed for the hot or control groups, but was reduced by the cold condition. These changes in pulse volume response amplitude do not appear to be due to

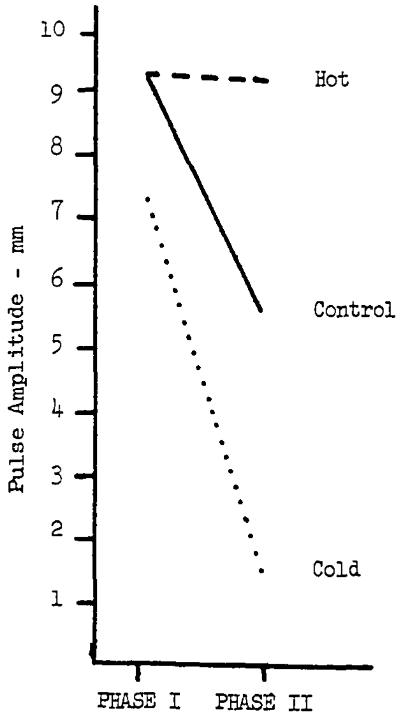

Figure 12. Finger pulse volume base levels.

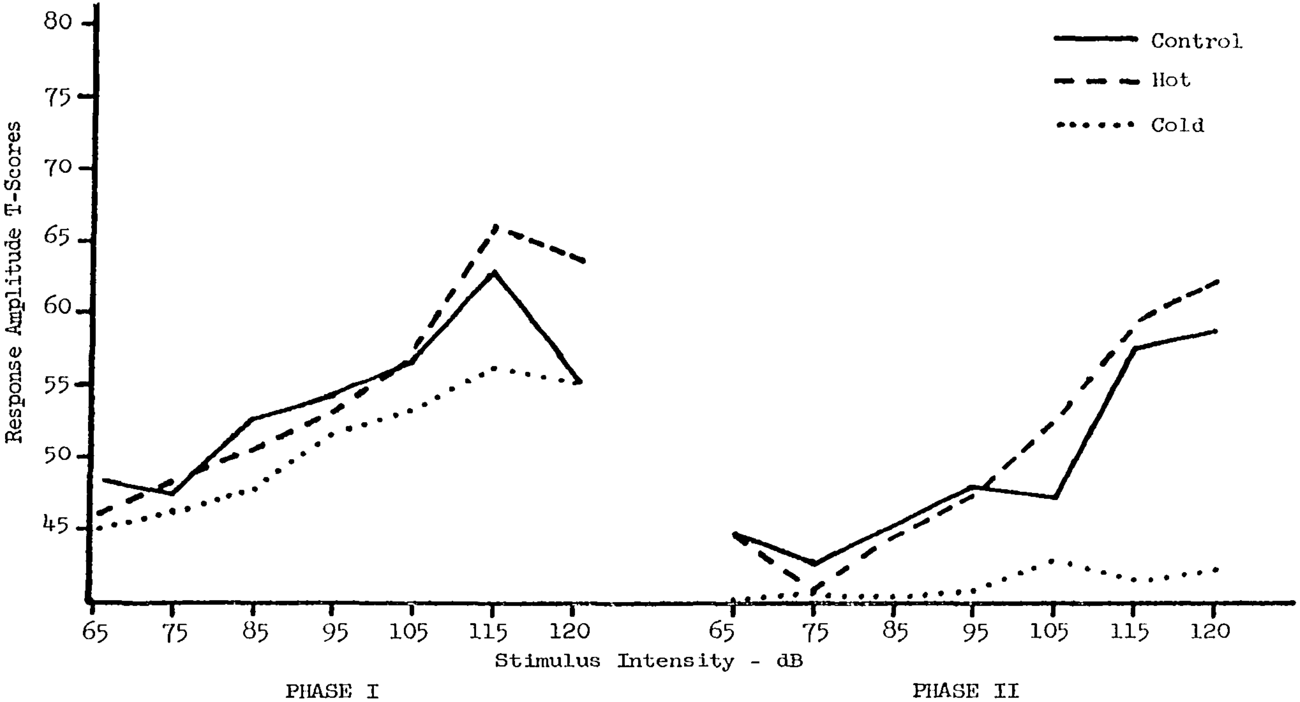

Figure 13. Finger pulse volume response amplitude to stimuli of different intensities under three temperature conditions.

changes in base level. The response measure was designed to remove the correlation of response amplitude and base level, and the regression coefficient of response on base level indicates that it was effective.

Heat appears to result in increased pulse volume, but does not affect response amplitude or the relationship between pulse volume response amplitude and stimulus intensity. Cold not only reduces base level pulse volume, but also reduces the amplitude of the pulse volume response and interferes with its relationship with stimulus intensity. These findings are not inconsistent with the hypothesis that venous tone is an important determinant of finger pulse volume base levels but are inconclusive because of the arteriolar component. The hypothesis that change in venous tone is involved in the finger pulse volume response is strengthened.

Figure 14 shows the effect of temperature change on blood flow response amplitude. Response amplitude decreased more for both hot and cold subjects than for control subjects. Similar blood flow results were reported by Abramson in 1940. As shown in Figure 14, the relationship between stimulus intensity and response amplitude was more systematic during Phase II than during Phase I. This can be explained in terms of the adjustment of the subject to the experimental conditions, and the partial habituation to tones which must by this time have taken place. Thus that portion of the finger pulse volume response which is arteriolar should show greater magnitude of response for the control subjects than for either hot or cold subjects, greater magnitude for hot than for the control subjects, and a continued linear relationship with stimulus intensity.

Comparison of Figures 13 and 14 indicates that a meaningful portion of the finger pulse volume response is not arteriolar in origin.

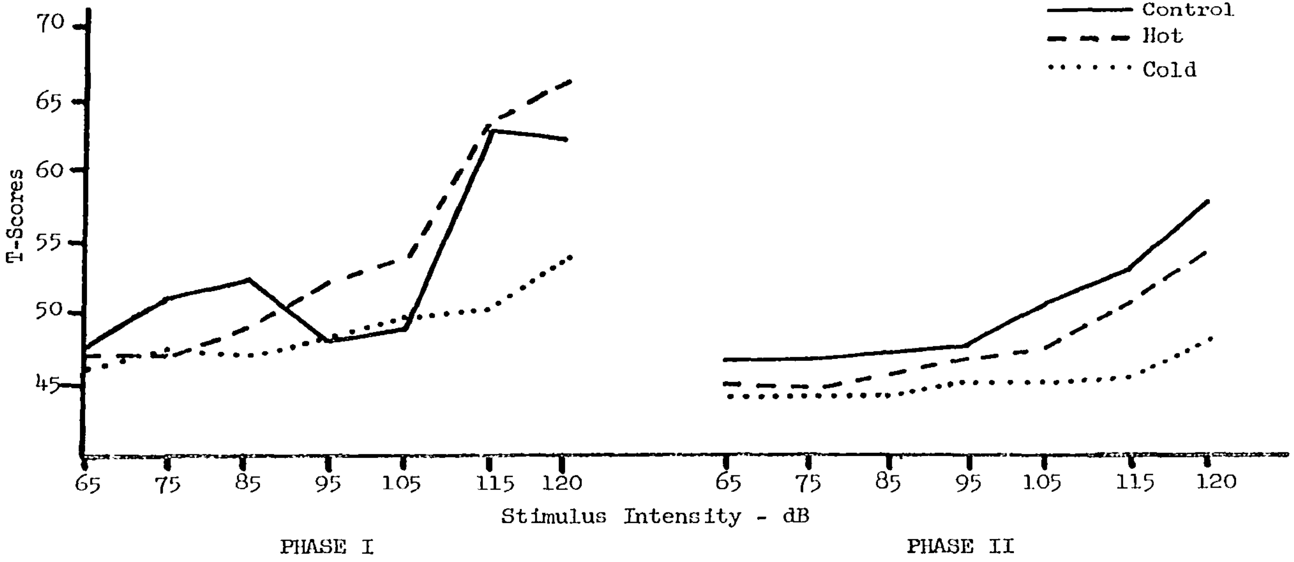

Figure 14. The relationship between blood flow response amplitude and stimulus intensity under control and experimental conditions.

It is possible that the relationship between the arterial and venous determinants of the response is different at high than at low stimulus intensities, and that this might account for the sharp changes in finger pulse volume at high stimulus intensities.

If finger pulse volume response amplitude is not, as has previously been thought, primarily arteriolar, then doubt is cast upon the interpretation of finger blood volume responses as primarily venous. To the extent that change in venous tone is responsible for finger blood volume responses, response amplitude should be unaffected by increased temperature, and reduced by cooling. Figure 15 shows the relationship observed. No change in response amplitude was seen for the hot subjects, while the cold subjects and the controls both showed decreased amplitude. Note that there is a decrease in the linear relationship between response amplitude and stimulus intensity for all three groups. This is interpreted as a time-locked change independent of changes in temperature. The results are consistent with the importance of venous mechanisms in determining finger blood volume response amplitude.

Results of temperature change suggest that while finger pulse volume base levels may be determined more by arteriolar than by venous changes, response amplitudes depend more heavily on changes in venous tone. It should be carefully noted that reference here to finger pulse volume base level does not refer to finger blood volume, but is used to describe the amplitude of pulses prior to stimuli or during a rest period. It is interesting to note in this context that the experiments supporting the arteriolar origin of finger pulse volume were all concerned with base levels, and not with response amplitude. In fact, in most of these

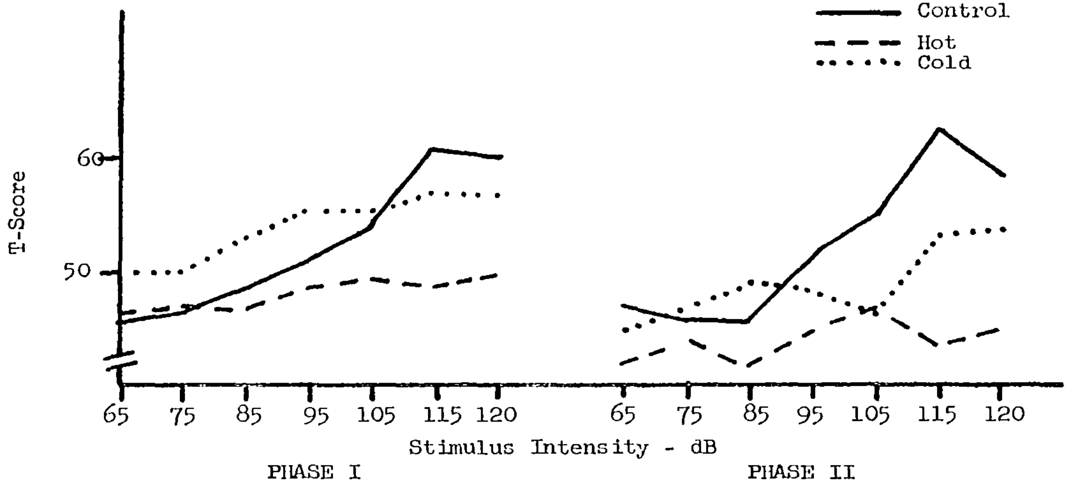

Figure 15. The relationship between finger blood volume response amplitude and stimulus intensity under three temperature conditions.

studies, great care was taken to prevent 'psychic' vasomotor responses which, it was felt, might contaminate the results. A few older studies support the interpretation of results presented here. Capps (1936) raised the venous pressure to 70 mm Hg by means of a cuff on the wrist. This effectively prevented venous constriction without materially affecting inflow into the hand. Under these conditions, a pinch did not produce the usual vasomotor response. He interpreted this as evidence that the normal reflex was due to constriction of the veins and venules. Abramson & Ferris (1940) were able to reproduce these results, although they found that a very strong noxious stimulus would elicit a response. Burch (1954) also presented evidence that the primary source of the vasomotor response was venous. While many explanations have been suggested for these results, none deal convincingly with the evidence of the venomotor orienting reflex and its conditionability provided by the isolated venous segment technique.

The fact that Abramson & Ferris (1940) found that a very strong noxious stimulus would elicit a response even under conditions of elevated venous pressure, together with the break in the finger pulse volume and blood flow curves as shown in figures 13 and 14 suggest that the arterial component of the finger pulse volume response becomes of greater importance when the organism is under very intense stimulation.

Conclusions

Under normal circumstances, both arterioles and veins show an orienting response. However, the response observed with the photoplethysmograph is primarily venous in origin, whether pulse volume response or blood volume response is recorded. There is a possibility that, under very intense stimulation, arteriolar changes are also observed photoplethysmographically. The difference in effect of the two changes on the vasomotor response is apparently one of magnitude, and may be due to the important metabolic and temperature control functions of the arterioles.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The research reported here investigated the cutaneous vasomotor orienting response, its relationship with stimulus intensity, its habituation and its physiological mechanisms. By presenting random blocs of stimuli varying in intensity, a within-subjects analysis of the relationship between the vasomotor orienting response and stimulus intensity was possible. Habituation of the response, and the relationship between rate of habituation and stimulus intensity, were studied with between-subjects methods. Changes in ambient temperature changed the state of the cutaneous blood vessels, and aided the physiological analysis of the response.

Distinction between Orienting and Defensive Responses

According to Sokolov, orienting and defensive responses can be distinguished by changes in forehead vasomotor responses; the orienting response consists of forehead vasodilation, while the defensive response can be identified by forehead vasoconstriction. In this study, both pulse volume and blood volume were measured photoplethysmographically from the area of the temporal artery. Neither showed the expected distinction between orienting and defensive responses. Although forehead blood volume responses were observed for most subjects, they were quite variable in both amplitude and direction, and did not have the expected relationship with stimulus intensity. Forehead results were consistent with the hypothesis that dilation over the temporal artery is primarily a passive result of changes in blood pressure. Since this is the case, and since the blood pressure response appears to contain more information pertinent to personality and behavioral variables, the further investigation of forehead responses seems of questionable value. Instead, investigation of carotid pulse recordings, improvement of blood pressure measurement techniques, and a systematic investigation of variables affecting the carotid pulse would be more meaningful.[1]

Sokolov also distinguished orienting from defensive responses by differences in the rate of habituation. He found the defensive response to be highly resistant to habituation. Trials-to-criterion analysis of habituation was consistent with this hypothesis. Analyses based upon changes in response amplitude, rather than on occurrence of a response, showed greater habituation to the most intense stimulus, a finding also reported by Germana (1968) for electrodermal responses. Whether orienting and defensive responses can be distinguished on the basis of habituation rate appears to depend upon the method of determining that rate.

Sokolov's entire theory does not, of course, rest upon the distinction between orienting and defensive responses, but the results of

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[1] It should be noted that Pearson's r of .41 ($p < .02$) was found between scores on the Ego Strength scale of the MMPI and the amplitude of blood pressure responses, subjects with high ego strength tending to show large blood pressure increases. Blood pressure responses also correlated with results of the Repressor-Sensitizor scale, where the repressors showed greater response amplitude ($p < .01$). No other physiological measures were so highly correlated with personality variables.

this and other studies suggest that his analysis of unconditioned reflexes is in error. The amount of research generated by his work should, however, provide data for a new and more accurate set of hypotheses about unconditional responses and their behavior as a function of stimulus parameters.

Relationship between Response Amplitude and Stimulus Intensity

Within-subjects analysis clearly demonstrated a linear relationship between response amplitude and stimulus intensity for all measures from the hand (finger pulse volume, finger blood volume and blood flow). The responses from the forehead were not systematically related to stimulus intensity, nor were the measures of blood pressure. The fact that a linear relationship is found in the hands but not in the forehead is consistent with a function either in preparation for motor activity or in tactile sensitivity.

Habituation

Differing criteria for habituation resulted, as expected, in quite different results. Choice between criteria was therefore based upon whether it provided a measure of habituation for each individual subject, and upon assumptions about the nature of the habituation process. A ratio analysis, based upon the assumption that habituation involves a gradual reduction in the amplitude of the responses, was selected. Using this measure of habituation, little difference was found between the pulse volume and blood volume components of the vasomotor system. The measure indicated a difference between rate of habituation for the stimulus intensities, but not in the expected direction. Habituation was faster to the most intense stimulus than to the moderate stimulus. Since the trials-to-criterion measure, which is based upon whether the response occurred or did not occur, found stimulus intensity to have the expected relationship with rate of habituation, it was suggested that these two measures might represent quite different aspects of the habituation process, and that these aspects might have different relationships with environmental variables.

Physiological Analysis

Physiological analysis of the vasomotor response resulted in an unexpected finding. While finger pulse volume base levels appear, as assumed in earlier literature and supported by many experiments, to depend upon the state of the precapillary resistance vessels, the response itself depends primarily upon venous constriction. Arteriolar effects may prove to be more important when stimuli are of great intensity than under conditions of moderate stimulation.

The results of the physiological analysis provide further evidence against the hypothesis that the response is primarily a preparation for motor activity. To prepare for motor activity, blood would be shunted from the skin, where metabolic needs are low, to the muscle, where metabolic needs during motor activity are high. Since it is the resistance vessels, not the capacitance vessels, which control the flow of blood into different vascular beds, the motor activity hypothesis implies that the response is primarily arteriolar. The data suggest that, on the contrary, the response is primarily venous.

The hypothesis that the response serves a major role in tactile sensitivity is worth further investigation. It will be recalled that decrease in the volume of the finger is associated with a decrease in tactile thresholds. The only evidence contrary to the interpretation of the vasomotor orienting response as a mechanism for controlling the sensitivity of peripheral receptors comes from the work of Edelberg (personal communication). He found that subjects with unilateral sympathectomy showed very little lateral difference in the increase in tactile sensitivity attending an autonomic response, even though the cutaneous vasomotor response on the sympathectomized side was completely abolished. Since alternative pathways for regulating tactile sensitivity probably exist, the hypothesis that the response serves a major role in tactile sensitivity is still tenable. Since the arteriolar vessels serve both metabolic and temperature regulation needs, the primary task of reducing blood volume in order to increase tactile sensitivity might well fall upon the venous vessels. Only in cases of very intense stimulation, where more profound adjustment of bodily function is necessary, does the contribution of the arterial side of the bed become more important than that of the venous side. This is the working hypothesis upon which further research will be based.

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APPENDIX

TABLE 22

ANALYSIS OF VARIANCE OF AVERAGED FOREHEAD BLOOD VOLUME RESPONSE CURVES

SOURCE	df	SS	MS	F	p<	p*<
Intensity	2	14,238	7,119	6.65	.01	.05
Beats	17	1,314	77	1.13	.01	NS
Intensity x Beats	34	3,886	114	2.38	.01	NS
Replications	34	54,339	1,598			
Intensity x Replications	68	72,746	1,070			
Beats x Replications	578	39,313	68			
Intensity x Beats x Rep.	578	55,465	48			
Total - 1	1,889	241,302				

TABLE 23

ANALYSIS OF VARIANCE OF FINGER PULSE VOLUME RESPONSES

SOURCE	df	SS	MS	F	p<	p*<
Intensity	6	7,173	1,195	27.63	.01	.01
Replications	35	8,312	238	5.49	.05	.05
Intensity x Replications	210	9,086	43			
Total - 1	251	24,571				
Linear Trend (89% of Variance)			6,377	147.42	.01	
Quadratic Trend			59	1.35	NS	

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*Probability based on conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959).

TABLE 24

ANALYSIS OF VARIANCE OF FINGER BLOOD VOLUME RESPONSES (PHOTOMETRIC)

SOURCE	df	SS	MS	F	p<	p*<
Intensity	6	2,486	818	22.26	.01	.01
Replications	35	14,316	409	11.12	.01	.01
Intensity x Replications	210	7,721				
Total - 1	251	24,523				
Linear Trend (95% of Variance)			2,371	64.08	.01	
Quadratic Trend			27	1	NS	

TABLE 25

ANALYSIS OF VARIANCE OF FINGER BLOOD VOLUME RESPONSES (VOLUMETRIC)

SOURCE	df	SS	MS	F	p<	p*<
Intensity	6	3,823	637	34.91	.01	.01
Replications	35	10,448	298	16.32	.01	.01
Intensity x Replications	210	3,833	18			
Total - 1	251	18,104				
Linear Trend (92% of Variance)			3,503	194.61	.01	
Quadratic Trend (4% of Variance)			161	8.94	.01	

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*Probability based on conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959).

TABLE 26

ANALYSIS OF VARIANCE OF FINGER BLOOD FLOW RESPONSES

SOURCE	df	SS	MS	F	$p<$	$p^*<$
Intensity	6	3,394	566	25.19	.01	.01
Replications	35	10,811	309	13.52	.01	.01
Intensity x Replications	210	4,801	23			
Total - 1	251	19,006				
Linear Trend (90% of Variance)			3,063	133.17	.01	
Quadratic Trend (7% of Variance)			225	9.78	.01	

TABLE 27

ANALYSIS OF VARIANCE OF CAROTID PULSE RESPONSES

SOURCE	df	SS	MS	F	$p<$	$p^*<$
Intensities	6	233	39	1	NS	NS
Replications	28	4,745	169	2.16	NS	NS
Intensities x Replications	168	13,161	78			
Total - 1	202	18,139				

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*Probability based on conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959).

TABLE 28

ANALYSIS OF VARIANCE OF RADIAL PULSE PRESSURE

SOURCE	df	SS	MS	F	p<	p*<
Intensity	6	94	16	1	NS	NS
Replications	22	3,790	172	2.17	NS	NS
Intensity x Replication	132	10,476	79			
Total - 1	160	14,360				

TABLE 29

ANALYSIS OF VARIANCE: FINGER PULSE VOLUME HABITUATION

SOURCE	df	SS	MS	F	p<	p*<
Intensity	2	1.89	0.95	7.75	.01	.01
Trials	11	.21	0.02	1	NS	NS
Intensity x Trials	22	.49	0.02	1.13	NS	NS
Intensity x Replications	33	4.04	0.12			
Intensity x Trials x Rep	363	7.17	0.02			
Total - 1	431	13.80				

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*Probability based on conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959).

TABLE 30

ANALYSIS OF VARIANCE: FINGER BLOOD VOLUME HABITUATION (PHOTOMETRIC)

SOURCE	df	SS	MS	F	p<	p*<
Intensities	2	.0003	.00015	1	NS	NS
Trials	11	.0029	.00026	1.24	NS	NS
Intensities x Trials	22	.0037	.00016	1	NS	NS
Intensities x Replication	33	.0750	.00227			
Intensities x Trials x Rep	363	.0772				
Total - 1	431	.1591				

TABLE 31

ANALYSIS OF VARIANCE: FINGER BLOOD VOLUME HABITUATION (VOLUMETRIC)

SOURCE	df	SS	MS	F	p<	p*<
Intensities	2	.0047	.00235	3.46	.05	.10
Trials	11	.0048	.00043	3.07	.01	.10
Intensity x Trials	22	.0060	.00027	1.93	.01	NS
Intensity x Replication	27	.0186	.00068			
Intensity x Trials x Rep	297	.0440				
Total - 1	359	.0781				

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*Probability based on conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959).

TABLE 32

ANALYSIS OF VARIANCE: FINGER BLOOD FLOW HABITUATION

SOURCE	df	SS	MS	F	p<	p*<
Intensity	2	168.18	84.09	33.11	.01	.01
Trials	11	61.17	5.56	2.19	.05	NS
Intensity x Trials	22	57.81	2.89	1.14	NS	NS
Intensity x Replication	24	904.03	37.67			
Intensity x Trials x Rep	264	670.81	2.54			
Total - 1	323	1,862.00				

TABLE 33

ANALYSIS OF VARIANCE FOR HABITUATION RATIO SCORE

SOURCE	df	SS	MS	F	p<	p*<
Intensity	2	7.97	3.98	5.45	.01	.05
Measures	3	0.39	0.13	1	NS	NS
Intensity x Measures	6	1.26	0.21	1	NS	NS
Intensity x Replications	33	24.15	0.73			
Intensity x Measures x Rep	99	42.96	0.43			
Total - 1	143	76.74				

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*Probability based on conservative degrees of freedom for repeated measures (Greenhouse & Geisser, 1959).