A PSYCHOPHYSIOLOGICAL STUDY OF THE NATURE OF HABITUATION IN INFANCY

By

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ABSTRACT

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A psychophysiological measure of sustained attention (decrement in heart rate variability) was used to test two competing models of habituation. The all-or-none model postulates that habituation occurs in a single trial following an increase in behavioral response during the preceding trial. The progressive decrement model describes habituation as a successive decline in response on each trial. Four-month-old infant subjects were repeatedly shown a checkerboard stimulus and then separated into habituation and nonhabituation groups on the basis of their total fixation times to the stimulus. These two groups were then compared to see whether the physiological measure of attention differentiated the two groups over all experimental trials. An additional comparison of the physiological response on the trials before and after the criterion for habituation was met was made for the habituation group. Results for both tests were negative. A further test of differences on the physiological response between the last habituation and dishabituation trials was also nonsignificant.

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Taken together, these findings question the validity of use of a decrease in heart rate variability as a measure of sustained attention. However, certain methodological problems in the present study may have introduced biases against positive findings. These problems are discussed along with more recent psychophysiological approaches for studying attention and cognition.

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CHAPTER 1

INTRODUCTION

The past two decades have seen a resurgence of interest in the study of both child development and infancy. Despite the introduction of new experimental methodologies that have been developed for use with verbal children, experiments with infants are still restricted by many factors. Especially limiting are difficulties associated with the experimenter's inability to adequately quantify many aspects of the infant's response repertoire, and the necessity of maintaining an alert biobehavioral state throughout the duration of an experimental session. Since relatively little progress has been made toward solving such methodological problems of infant research, the basic paradigms of habituation, operant conditioning, and classical conditioning continue to be prominent methods for investigating infant behavioral development.

Both habituation and conditioning paradigms are well defined experimental procedures and have been invaluable in the study of infant perceptual development (see Bower (1974) and Cohen & Gelber (1975) for reviews). However, the conclusions of studies in which these procedures were used have been discussed far more than the methods of study themselves. For habituation (the focus of this study), the relative lack of inquiry into the process of habituation no doubt stems from the common interpretation and acceptance of habituation as a progressive decrement of response to the repeated presentation of a stimulus. Support for this belief depends on the analysis and interpretation of group data plotted over trials of presentations [e.g., see Field, Dempsey, Hatch, Ting, & Clifton (1979)]. The progressive decrement in response (when the group curves are plotted) was thought to represent the gradual attainment by the infant of a mental "image" of the stimulus. This idea was explicitly incorporated by Sokolov (1963) into his theory of the orienting reflex. The operational definitions of orienting theory by Sokolov have since been incorporated into much of the research on habituation and cognitive development and have been quite influential in developmental psychology (Graham & Clifton, 1966; Lewis, 1971).

Indeed, the practice of plotting group habituation curves over trials also brings into question the exact nature of the habituation process from the first trial onward. If curves are plotted backwards from criterion [similar to the backward plotting of learning curves by Zeaman and House (1963)], the curves describe an all-or-none model of habituation; i.e., the curves appear level until the habituation trial; then responses decline dramatically. This was first noted by Cohen and Gelber (1975) as an alternative to the decremental (or negative exponential) model of habituation. Yet, as Cohen later pointed out (1976), the apparent rapid decline in response could be a statistical artifact in the determination of a habituation criterion which forces randomly short trials to be included in the habituation trials. This effect acts to make the backwardly plotted data responses to decline more precipitously when the habituation criterion is reached than is possibly true. Results of a mathematical simulation by Cohen and Menten (1981) further confound the issue of the true nature of habituation. Their results indicated that whether or not their simulation used parameters to describe either an all-or-none habituation or a progressive decrement in response, the data obtained from such a simulation, when plotted, appear as an all-or-none habituation (also see McCall, 1979).

The question as to which model is the more nearly correct with respect to the period of infancy is a theoretically significant issue, as certain learning theories (e.g., Jeffrey, 1968) as well as biologically oriented theories of habituation (Thompson & Spencer, 1966) assume the progressive decrement to be true. Conversely, certain information-processing models using Markovian models (Kintsch, 1967) offer some support for viewing learning and habituation as all-or-none phenomena. A third possibility is that neither model is always correct, but that either stimulus or subject variables account for the observed patterns of behavior. This suggests that both patterns can occur, but that different stimulus properties (or methodological variables, e.g., interstimulus intervals or stimulus length) interact to yield the observed pattern. Similarly, biobehavioral differences between infants may yield intersubject variability in response pattern.

Psychophysiologic measures (e.g. heart rate, galvanic skin response, evoked potentials) have been particularly useful in infant studies, both as dependent measures for an experimental manipulation (see Berg & Berg, 1979, for a review) and as measures intrinsically important by themselves as indices of psychological development (Graham & Jackson, 1970). The meaning of these autonomic measures (specifically heart rate) as a causal influence on behavior in adults (e.g., Lacey & Lacey, 1974) currently is a controversial issue (Obrist, 1981). However, the use of autonomic responses solely as a dependent measure that covaries with certain psychological processes is well established, especially with infants (Berg & Berg, 1979). Heart rate is a very widely used autonomic measure, and its prevalent use has led to several refinements in the measurement and analysis of EKG records. Investigators originally handscored polygraph outputs for simple measures of HR acceleration or deceleration; more recently the change in heart rate variability (Porges, 1974) has been proposed as a meaningful indicator of certain attentional states (described below), as has the interrelationship between respiration and heart rate assessed by spectral analytic techniques (Porges, 1976). These two examples (like many others) represent attempts by psychophysiologists to acquire additional insight and meaning by different analytic approaches to the same physiological responses.

Although the exact nature of habituation remains an unsettled issue, many investigators have sought to relate the group curves obtained from habituation procedures to heart rate measures. Most often, this involves using parallel changes in heart beat responsitivity (acceleration or deceleration) to infer that habituation has occured (Graham, 1973). This experimental strategy usually has presented with problems in two areas -- assumptions about the nature of habituation itself, and the appropriate method for analysis of the heart rate response data. Previous studies have implicitly (and often explicitly) assumed a progressive decrement in response as the model for habituation as opposed to the all-or-none phenomenon. An entirely different course of physiological change would be expected if heart rate does parallel an all-or-none model of habituation rather than a progressive decrement one. The other problem in these studies is the use of an appropriate psychophysiologic response measure. As will be discussed below, certain theoretical interpretations of heart rate patterns predict different courses of habituation for different components of an EKG record. Analysis of only acceleration-deceleration (the most common method of analyzing EKG data) ignores potentially more interesting aspects of the data.

The present study was designed to analyze the relationship between habituation and heart rate; specifically (a) multiple components of the heart rate response and (b) progressive decrement vs. all-or-none models of habituation. The experimental procedure involved repeated presentations of visual stimuli to four-month-old infants. A review of the relevant literature followed by a statement of the specific hypotheses of this study is presented below.

CHAPTER 2

LITERATURE REVIEW

The literature review is divided into three parts. The first part discusses theories of habituation relevant to the present study. In it, Sokolov's work is introduced and is further discussed in the second section describing psychophysiological measures of attention. The last section discusses studies of habituation in infancy (both with heart rate and visual fixation measures) and some of the important methodological issues in this area of research.

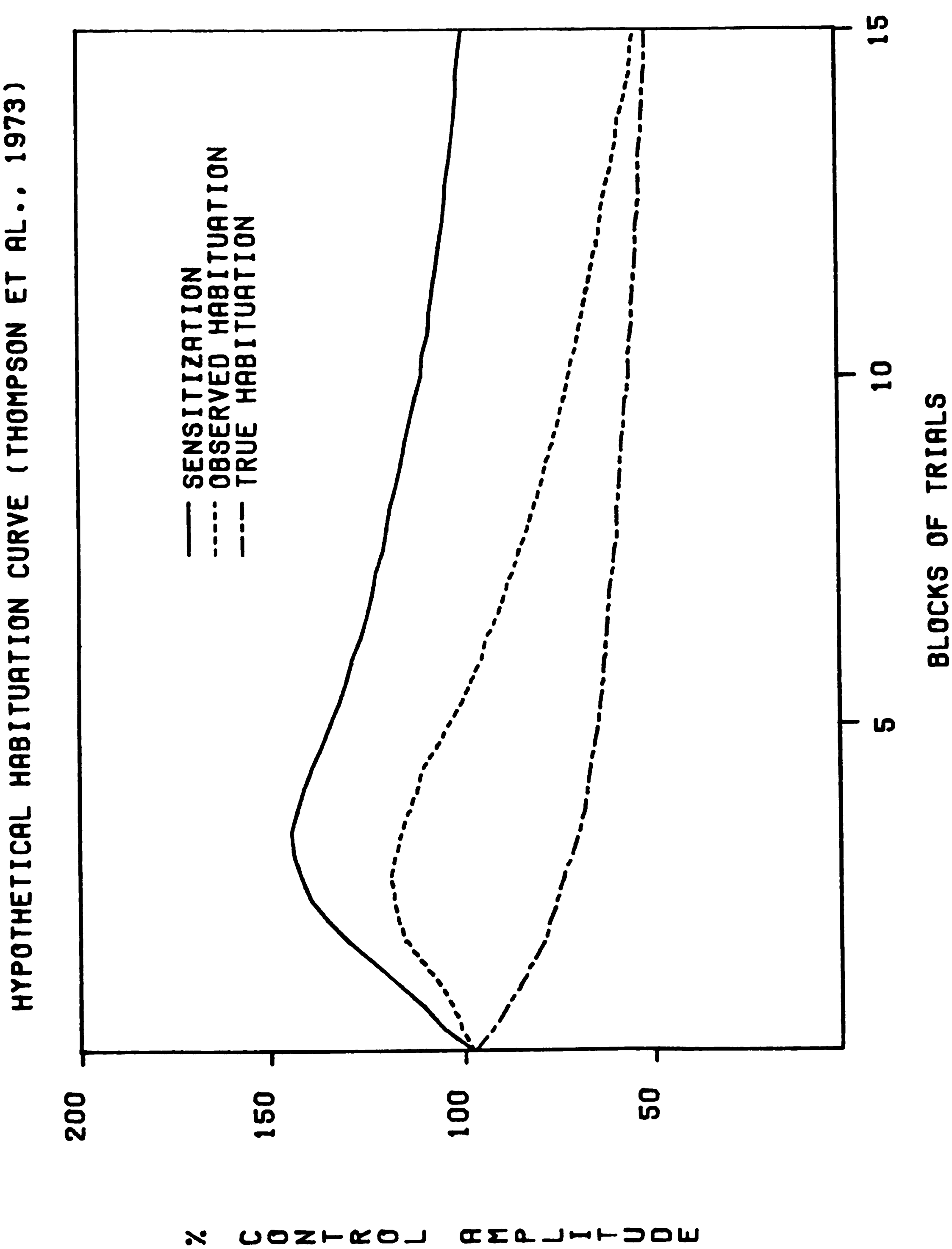
Theories of Habituation

Popular awareness of habituation no doubt preceded both its "discovery" and operational definition in experimental psychology. Sherrington (1906; 1961) and James (1890; 1950) each discussed it early in this century, although from two different perspectives that somewhat mirror debate and discussion in theories of habituation today. Sherrington's view could be characterized as a more inductive approach.

Noting "reflex fatique" in the peripheral musculature of a spinal dog preparation, Sherrington inferred from the observed decline in leg flexion-extension reflexes in response to electrical stimulation, a centrally occuring inhibitory process that similarly served as the mechanism of habituation in more complex, common stimulus situations. Conversely, James discussed habituation deductively from the perspective of cortical inhibition, assuming that higher cortical functions existed to mediate the behavioral change in response systems. James' ideas were derived by observing the decline in response by man to repeated, common complex stimuli. He assumed that cortical mechanisms were the focal point for ignoring stimuli such as the "din of the machinery in the mill", and for other changes (e.g., motor inhibition) that we associate with the colloquial use of the term habituation.

In the early 1960's, two theories with equivalent predictions of the course of habituation, although from different theoretical and empirical approaches, emerged in experimental psychology. Primarily through work with the cat spinal flexion response, Thompson and Spencer (1966) proposed the dual-process theory of habituation. In this conception, habituation is viewed as two simultaneously occurring processes: response decrement in the particular system of the animal under investigation and a general "sensitization" occuring in all systems of the animal. Dishabituation was defined in the dual-process framework as the increase in behavioral response to a stimulus different from that used during habituation training (Thompson & Spencer, 1966). (To avoid possible confusion, note the difference between this and the classic Pavlovian definition of dishabituation as the recovery of the original unconditioned response to a stimulus after a period during which the stimulus was not presented). Dishabituation is described as the behavioral response to the increased sensitization that has occured over the habituation trials (see Figure 1). The theoretical sensitization curve is superimposed on the theoretical habituation response such that the observed behavioral responses over time are the product of the shape of the two curves at that particular instant; increasing sensitization therefore acts to mask somewhat the theoretical rate of decline, since its effect is to raise the probability of responding. In other words, on the early trials of a habituation paradigm sensitization is high and increasing more than true habituation response is declining; thus the observed behavioral response to a stimulus actually increases on the first few stimulus presentations since the balance of sensitization and true habituation favors sensitization. As stimulus presentation is repeated sensitization decreases and true habituation continues. The observed response also declines in tandem, ultimately to the level of the true habituation curve since sensitization returns to the prestimulus level and no longer influences response amplitude. Recent reviews by Groves & Thompson (1973) and Thompson & Glanzman (1976) cite evidence supporting this view of habituation in species ranging from invertebrates to man to indicate its postulated role as a general mechanism of learning in all species.

Figure 1. Hypothetical habituation curve (Thompson et al., 1973).



HYPOTHETICAL HABITUATION CURVE (THOMPSON ET AL., 1973)
SENSITIZATION
OBSERVED HABITUATION
TRUE HABITUATION
% CONTROL AMPLITUDE
200
150
100
50
BLOCKS OF TRIALS
5
10
15

To further describe the anatomical basis for dual-process theory, Thompson [Thompson & Glanzman (1976); Thompson, Rinaldi, Berry & Berger (1978)] has developed a hypothetical neuronal model to explain the mechanisms mediating reflex decrement in a research preparation, the cat spinal reflex. The model proposes that sensitization occurs in a separate pathway that receives afferents from the interneurons in the habituation pathway, and sends its efferents into a state system that simultaneously enables the increased response to stimuli different from the habituation stimulus. The pattern of habituation which follows from this concept is one of exponential decrement in response (see Figure 1). Its physiological analogue is decrement of response or of activity in the interneurons of the habituation pathway. This hypothesis has much support from single cell recordings in a variety of species (see Thompson et al., 1978) and is conceptually reasonable in the context of recent developments in neuroscience that identify specific loci for pre- and post- synaptic inhibition (e.g., see Shepard, 1979). The relevant aspect of the dual-process hypothesis for the present study is that it specifically predicts a progressive (or exponential) course of response decrement during habituation. This refers to a pattern of habituation where there is a decline in response on each repeated trial of stimulus presentation, ultimately reaching an asymptotically low level of response. There has been much debate of this model (e.g., Hinde, 1970), and little consensus on the proposed universality of the neuronal mechanisms postulated by Thompson et al.

The second prominent model of habituation stems from the work of Sokolov (1963, 1969) and is cited far more often in the child development literature. A major factor contributing to its popularity has been its perceived simplicity in describing habituation, particularly of what is often referred to as the orienting response (OR). Many investigators have adopted Sokolov's early model of habituation, frequently referred to as the "match-mismatch" hypothesis. Simply put, this model postulates that a neuronal model of a stimulus is built up as the stimulus is presented repeatedly, with concurrently occuring cortical inhibitory processes acting to dampen an orienting reaction that would normally occur in response to the stimulus. When a novel, or dishabituating stimulus is presented, the "mismatch" to the neuronal model causes the reoccurence of the orienting response, and a dishabituation of the response. An orienting response, as described by Sokolov, is a general activation of the body's physiological state to facilitate the "taking in" or attentional response to an environmental stimulus (Graham & Jackson, 1970). This will be discussed more fully below; however, the concept that orienting responses facilitate learning by mediating attentional responses and, very importantly, are measurable as part of a general physiological response is critical to many of the studies of infant perception and learning (for reviews, see Berg & Berg, 1979; Jeffrey, 1968; Sameroff, 1971).

However, as discussed by Velden (1978), the earlier version of Sokolov's work no longer adequately reflects further revisions in orienting theory by Sokolov. The most recent formulation by Sokolov (1969) is an information theory, or "entropy" model, of orienting, which stresses the informational value of a stimulus. In a habituation paradigm, it is proposed that the information value of the stimulus on repeated presentation diminishes, and thus the OR habituates. Consequently, the OR functions as an "information regulator" and is most applicable to stimuli having some form of signal value; it also accounts for the continued presence of the orienting response in classical conditioning paradigms, since the conditional stimulus continues to have informational value as a predictor of future events. In addition, since reaction to a stimulus demands its being "taken in", simultaneous habituation of the behavioral and orienting response to a stimulus must occur.

Unfortunately, the new form of Sokolov's theory fails to address two additional aspects of orienting that have been discussed by other researchers. One is the subject's motivation for the task, which can be defined as the relevance of the stimulus for the subject (e.g., see O'Gorman, 1973). As Velden points out, there most likely exists a multiplicative relationship between the signal value of a stimulus and the elicitation of an OR (i.e., all factors being equal, a subject will give a greater OR to a relevant stimulus). A second aspect of current orienting theory neglected by Sokolov is orienting on the basis of different non-signal physical properties, or stimulus novelty, which Velden calls "orienting incentive" to distinguish it from "informational novelty" in Sokolov's theory. The stimulus novelty aspect of orienting has been the one most widely studied in investigations of infant orienting, as it follows directly from the earlier match-mismatch hypothesis. Similarly, in infant habituation paradigms the distinction between the habituation and dishabituation stimulus most often also reflects a change in stimulus properties. A recent example which illustrates the informational perspective is the set of habituation studies of Schwartz and Day (1979). Their approach was to use the magnitude of a dishabituation response (or in context of the present discussion, the return of an orienting reflex) to a set of stimuli different from the habituation stimuli to index the learning of a property of the stimuli. The test stimuli varied from the repetitive stimuli along a number of dimensions; from the test responses could be discerned the degree to which the infants perceived the relevant dimension, i.e. the informational value in the new stimuli. (For a review of older studies, see Cohen & Gelber, 1975).

From Sokolovian theory, again a decremental model of habituation is postulated. The informational value of a repetitive stimulus should decline on each presentation of the stimulus as centrally mediated inhibitory pathways from the brain decrease behavioral response to the declining stimulus informational value. In this form, Sokolov's model can be readily integrated into the information-processing models currently prominent in cognitive psychology (Ohman, 1979). Other theorists, notably Piaget (Ginsburg & Opper, 1979), predict a similar course of habituation due to the buildup of a memory engram.

Other prominent approaches to habituation theory have been from learning theory (Lubow, Weiner, & Schnur 1981) and developmental psychology (Cohen, 1973; Cohen & Gelber, 1975). Both also predict a decremental pattern of habituation, although Cohen's model is cited by the authors of the latter paper as also "consistent" with all-or-none habituation response (see below). The Lubow et al. hypothesis is particularly interesting for its interpretation of habituation as "conditioned inattention" of an attentional response (defined as a unconditioned response (UCR) to the stimulus). Habituation (or conditioned inattention) is also postulated to be the pivotal factor in explaining latent inhibition effects. A definitive set of rules derived from classical conditioning principles is used by the authors to predict the behavioral effects including habituation under the rubric of conditioned attention theory. The focus of habituation in conditioned attention theory is not on response decrement per se but on the effects of habituation to a stimulus on the later associability of the stimulus when it is acting as the CS (or UCS) in a traditional classical conditioning paradigm. The role of habituation as affecting the salience of the stimulus for later associability parallels Jeffrey's (1976) discussion of the importance of habituation as a mechanism for perceptual development in the infant. Lubow et al. also cite evidence that the OR elicitation (and also habituation of the OR) does not correlate with later associability of the stimulus as a CS, contrary to certain interpretations of OR theory. Jeffrey (1976) makes a similar point in reference to infant learning.

The Cohen model is also interesting and, although described as a model of infant visual attention, owes much to Sokolovian and information-processing theories from which it has borrowed heavily. An important feature of the model is the postulate of two separate processes in infant visual attention: an attention getting process and an attention holding process. The attention getting process is responsive to the physical and sensory properties of a stimulus; it is hypothesized as the site of integration where the decision whether an orienting response will occur to a stimulus is made. The attention holding process is mediated by components of long and short term memory; it is described as responding to the familiarity or complexity of an environmental stimulus. The attention-holding process is viewed as interacting with the former process to either inhibit or to sensitize the orienting response. Both systems are thought to be able to habituate separately as well as interact to yield the observed behavior. Cohen (Cohen & Gelber, 1975, pg. 396) uses this model to account for all-or-none habituation patterns by postulating that the attention getting process acts within a threshold of recognition, above which no response occurs. Wagner's (1976) model of habituation also relies heavily on the distinction between two components in habituation, but it stresses even more heavily than Cohen the separate involvement of short and long term memory in each process. Wagner's work centers around the importance of the "priming" of the stimulus in short-term memory, and how this stimulus representation can account for two empirically difficult issues in habituation studies: the distinction between short- and long- term habituation, and the reason for greater retention of habituation (or less classical (Pavlovian) dishabituation) in paradigms using longer interstimulus intervals. None of the infant literature appears to cite the Wagner model, which has been generated solely on animal experiments, specifically eyeblink reflex studies in rabbits (although Ohman (1979) uses many of Wagner's ideas in his information-processing model of orienting). Lubow et al. (1981) briefly criticize some of the Wagner model predictions and its inappropriate generalizability. Jeffrey (1976) similarly criticizes Cohen's model as being based primarily on adult verbal memory studies using artificial conditions, and then being inappropriately applied to infancy.

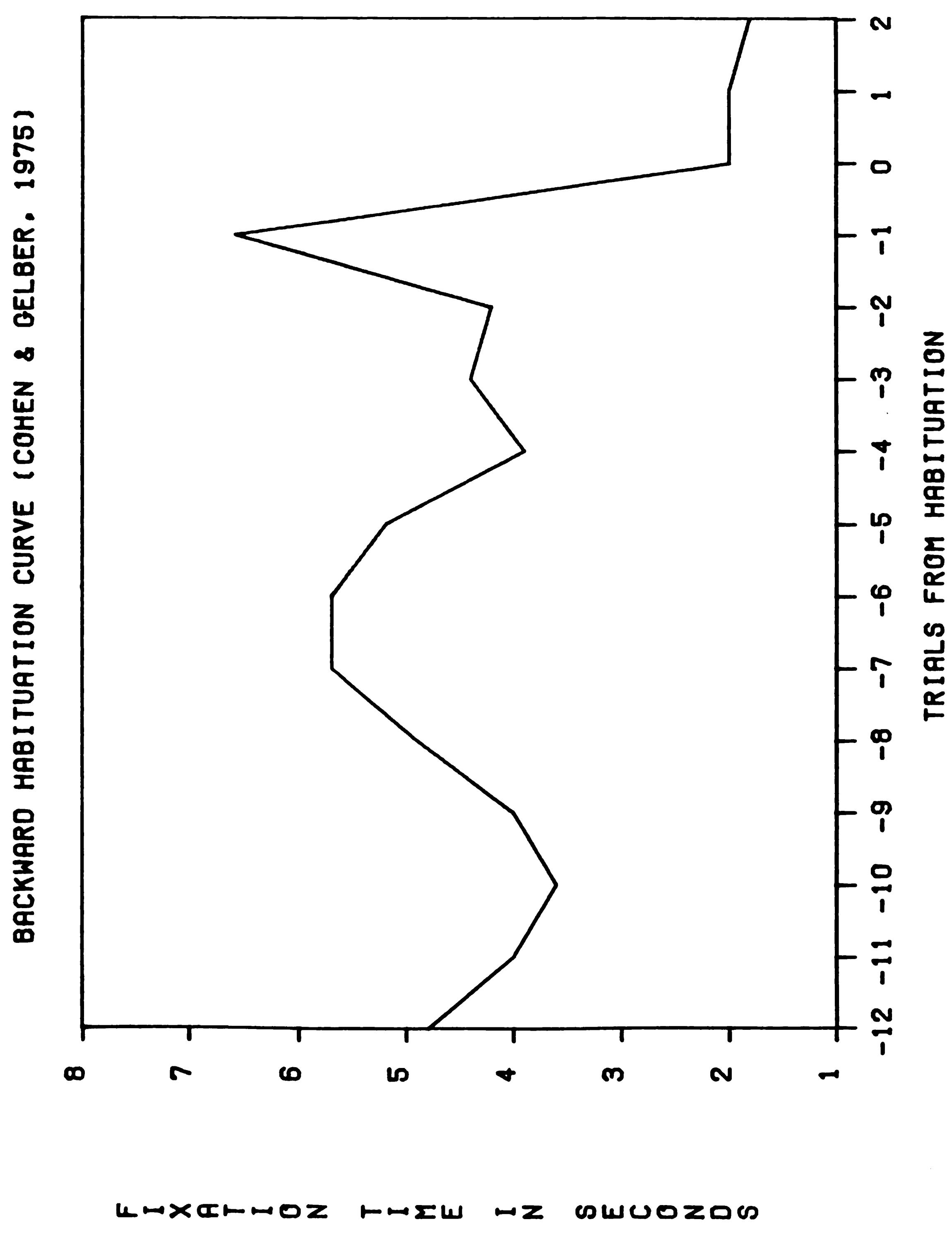
Two additional developmental theorists deserve mention: Lewis (1971) and McCall (1971; McCall & McGhee, 1977). Lewis' theory of the development of a cognitive schema during habituation differs only slightly from the original Sokolovian proposal and adds little to habituation theory. McCall's research has proposed that the attentional response of infants to varying stimuli is an inverted-U shaped function of the degree of discrepancy of a test stimulus from a previously exposed standard (see below). However, this theory does not account for certain experimental findings (e.g., DeLouche, 1976), and is difficult to test empirically. (For a critical review of these latter two proposals, see Cohen & Gelber, 1975, pp. 293-295.)

The alternative hypothesis to a decremental model of habituation is an all-or-none model (Figure 2), first discussed by Gelber and Cohen (1975). As Figure 2 demonstrates, when behavioral data from a habituation paradigm are plotted backwards, habituation appears to occur in a single trial following an increase in attention on the preceding trial. The continuous decline in behavioral response that characterizes the progressive decrement model is inapparent. In contrast to the well-developed models of Sokolov and Thompson, this model has had little theoretical discussion in the literature. Following Cohen and Menten (1981), it could be predicted from discrepancy theory (e.g., McCall, 1971) that the continued presentation of a stimulus that is sufficiently discrepant could lead to increases in looking time which serve to successively reduce the discrepant nature of the stimulus. At the point of maximal interest, an immediate decline in stimulus interest would occur, corresponding to an all-or-none decrement in responsitivity. If a stimulus is unfamiliar, perhaps the infant increases looking time until the discrepancy function is optimal, and then attention declines immediately. McCall (1979) offers an essentially similar explanation for this phenomenon.

Psychophysiological Studies of Attention

Early in this century, attempts were made to use non-invasive physiological processes to index psychological functioning. An important example of this was the attempt to examine the "fight or flight

Figure 2. Backward habituation curve (Cohen & Gelber, 1975).


BACKWARD HABITUATION CURVE (COHEN & GELBER, 1975)
FIXATION TIME IN SECONDS
TRIALS FROM HABITUATION
1 2 3 4 5 6 7 8
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2

responses" and their relationship to sympathetic arousal and subjective perception (Cannon, 1929). Similarly, James' (1890; 1950) discussion of emotion (later known as the James-Lange theory) sought to describe emotion solely as the response to the physiological (often autonomic) changes. This early work stressed the idea that psychological function is inseparable from concurrent metabolic processes, a concept implicit in much of the research done in both psychosomatic medicine and psychophysiology (Obrist, 1981). Psychophysiologists have long tried to identify physiological concomitants of personality and intellectual characteristics (e.g., Orlebeke & Feij, 1979; Zeiner, 1979). In psychosomatic medicine research, the established relationship between Type A typologies and coronary heart disease underscores the complex interaction of physical and mental states (Blumenthal et al., 1978).

Though there is little question that psychological and physiological processes do interact, the specification of this interaction and the degree to which one process affects the other is an area of ongoing research and debate in psychophysiology. An example of this is the study of evoked potentials, which are the EEG potentials in response to a stimulus averaged over many trial presentations. Although a frequently-used dependent measure in psychophysiological research, there is still much disagreement on the psychological meaning and interpretation of the various waveform peaks as mirrors of cognitive processes (e.g., Walker & Sandman, 1979).

Cardiac electrophysiology, another frequently used psychophysiological variable, is far easier to measure and quantify than the complex waveforms derived from EEG studies that confound analysis; however, it similarly has generated much theoretical controversy. The ease of noninvasive measurement and the large body of physiological knowledge about cardiac function have made measures derived from EKG records widely used dependent variables. Despite its wide use, there has been no lull in the controversy over whether HR changes are an independent measure of certain cognitive processes. The Laceys (1970, 1974) have long argued for the utility of heart rate as a measure of "psychological set". Specifically, heart rate deceleration is thought to accompany the facilitation of stimulus intake (e.g., attention to the signal in a reaction time task), whereas heart rate acceleration is thought to underlie rejection of the sensory environment (e.g., doing mental arithmetic). In this formulation, the change in HR is viewed as potentially either a response to the occurence of an external event (stimulus generated), or as internally generated, timed to precede an anticipated event. A more controversial aspect of the Laceys' work is their belief that the change in heart rate is the cause of the difference in attention to the environment and that the change in heart rate mediates cortical changes via decreased inhibitory feedback on the brainstem from aortic and carotid baroreceptors. The Laceys have also extended this to the level of analyzing behavioral changes as a function of the time within an R-R cycle that a stimulus occurs (Lacey & Lacey, 1978).

The Lacey hypothesis has generated much criticism (see Carroll & Anastasiades, 1978; Elliott, 1974; Green, 1980), primarily discussions of experimental findings that conflict with their theoretical framework. The most prominent alternative to the Laceys' work has been the cardiac-somatic hypothesis developed by Obrist and co-workers (Obrist et al., 1974; Obrist, 1981, for reviews). The cardiac-somatic hypothesis views the change in heart rate directionality (described by the Laceys as "directional fractionation") as solely secondary to the metabolic demands of the body at that instant. In this framework, deceleration is viewed as secondary to the motoric inhibition that occurs when the need for attentional responding arises. A recent review (Obrist, 1981) cites a large set of studies showing results often contradictory to those predicted by the Lacey hypothesis. Especially supportive of the somatic interpretation of cardiac events are studies using pharmacological blockade of sympathetic responses (and thus attenuating the ability of the heart to respond to sympathetic stimulation) but showing no change in behavioral performance as would be predicted by the Lacey hypothesis.

Despite the currently unresolved conflict over the meaning of HR changes, the earlier publications by the Laceys were a critical influence on the theories of psychophysiological attention developed by Graham and her co-workers (Graham & Clifton, 1966; Graham & Jackson, 1970). Graham observed that the heart rate fractionation observed by Lacey could serve to distinguish between the orienting and defensive reflexes described by Sokolov (1963). As previously mentioned, the Sokolovian orienting responses are a series of physiological changes that occur concurrently with sensory stimulation to increase the "taking in" of the stimulus. Conversely, the defensive reflex serves to mediate stimulus rejection, e.g., as response to an overly intense noise. Many predictions were derived from this basic assumption; most important for the present experiment is that the orienting response habituates over trials whereas the defensive reflex (DR) usually does not, or does so with great difficulty. The utility of HR is that it is potentially one of the few measures that distinguish the OR and DR of Sokolvian theory (in addition to cephalic vasodilation, obviously far more difficult to use experimentally). The majority of psychophysiological measures that occur with OR elicitation are cited by Sokolov as also components of the DR, and thereby can be viewed only as general responses to stimulation without any psychological interpretation.

This hypothesis of a relationship between heart rate directionality and psychological set was an immediate source of theoretical discussion and empirical testing. This was especially true in developmental psychology where few useful measures exist to index subjective psychological states; acceleratory vs. deceleratory HR response appeared to be well suited for this task. Furthermore, Graham & Jackson (1970) also noted a "deceleratory shift", or a change in the newborn HR response from acceleration to simple stimuli at birth, to deceleration to the same stimuli at approximately three months. The change in response was hypothesized to be related to a change in the infant's ability to show orienting or defensive reflexes, and thereby a source of the limitations on newborn learning (Jeffrey, 1968; Sameroff, 1971). Other studies used the converse strategy, e.g., interpreting a change in HR response from deceleration at three months when placed on a visual "cliff" to acceleration at older ages when placed in the same situation as reflecting the development of certain cognitive abilities (Campos, Langer, & Krowitz, 1970; Campos, 1976). The well documented deceleratory shift stimulated a number of attempts, ultimately successful, in demonstrating newborn deceleratory responses (Friedman, 1972; Sameroff, Cashmore, & Sykes 1973). This resulted in identification of a number of factors important in studies of newborn responsitivity. For auditory stimuli, control of stimulus parameters [e.g., rise time (Berg, 1974)] proved necessary to elicit newborn HR deceleration. More importantly, the need for controlling biobehavioral state (Clifton & Nelson, 1976) was also a byproduct of these studies. In fact, the analyses presented by the authors of the latter paper demonstrate that in context of the expected alert periods for a newborn, many of the earlier attempts to show newborn orienting (and similarly, newborn habituation) were severely biased against obtaining positive results by paradigms lasting longer than the infant's alert intervals.

Although the deceleratory shift has been interpreted as paralleling a psychological shift in orienting ability, alternative explanations have been offered in the literature. Porges (1976) discusses the shift solely as an increase in vagal tone over the first three months of life; some support for this proposal is provided by a recent cross-sectional study by Ackles (Note 1). Berg & Berg (1979) also discuss this possibility in their review. Demonstrations of conditionability to stimuli not usually eliciting a cardiac deceleration early in infancy (e.g., auditory square waves) also argue against the necessity of HR deceleration for learning to occur (see Fitzgerald & Brackbill, 1976).

The theoretical disputes over the meaning of HR response are currently unresolved and can charitably be described as a confusing body of literature (Velden & Schumacher, 1979). Volumes on these issues (e.g., Kimmel et al., 1979, Obrist et al., 1974) offer chapter by chapter disagreements on HR interpretation. Despite this, the reliability of the response itself is unquestioned and has favored its popularity in psychological studies. As a covariate of attentional reponse the measure holds much utility and was used this way in the present study. Most investigators in the field (e.g., Graham, 1979) assume the presence of a metabolic component, but question its relevance for using HR as a dependent variable (although a recent study (Svebak, Dalen, & Storfjell, 1981) specifically manipulated both cognitive task and concurrent physical demand, and found an effect for cognitive task above the metabolic effects secondary to different physical tasks). Whether change in HR is secondary to respiratory or motoric quieting, the fact that these changes reliably occur allows this measure to be used in similar studies. The importance of primary mechanisms for HR control arises when results anomalous to those predicted by either the Lacey or Obrist models occur; this is not of concern in the present study.

The heart rate response described above is the change in absolute heart rate during a period of interest (e.g., the foreperiod of a reaction time task or the time immediately pre- and post- stimulus presentation). Another measure that has been derived from EKG records has been the variability of the interbeat intervals. Porges (1974; Porges, Arnold, & Forbes, 1973; Porges & Humphrey, 1977; Porges & Raskin, 1969; Walter & Porges, 1976) has hypothesized the change in variability (specifically a decline in variability) to be a measure of sustained attention. This is part of the older statement of Porges's psychophysiological theory of attention. In this conception, the immediate acceleration-deceleration response that occurs to stimulus onset or offset is a measure of phasic, or involuntary, attention. The sustained, or active, component is measured by the change in variability of the cardiac response. Porges postulates these to parallel the James' similar concept (1890; 1950) of attention. Porges also cites evidence to indicate that these two measures are statistically independent even though obatined from the same cardiac record. This finding also has been noted and replicated by others (e.g., Lacey, 1967; Siddle, 1980). The variability measure has also been used to classify infants on the basis of baseline (or tonic) variability to then predict performance in conditioning studies; infants with higher baseline variabilities are shown to learn conditioned discriminations easier than infants with lower baseline variabilities (Stamps & Porges, 1975; Stamps, 1977). Since heart rate variability can be considered synonomous with the amount of vagal influence on the heart (Mulder & Mulder, 1981), Porges (1976) later attempted to quantify the degree of vagal tone on the heart as an estimate of parasympathetic influence. The methodology he proposed was to use the estimate of the coherence function when cross-spectral time series analysis is done between heart rate and respiration (since respiratory cycling affects heart rate) as an estimate of the parasympathetic effect. Unfortunately, after this one proposal, very little additional supporting evidence has been published by the author or has appeared in the literature, and these papers have been mostly confined (as was the original research) to work with hyperactive children (e.g., Porges, Bohrer, Keren, Franks, & Drasgow, 1981; Porges, Coles, Cheung, Drasgow, & Bohrer (1979) with normal subjects). An unpublished study by Ackles (Note 1) finds little support for the Porges hypothesis. Other studies have appeared, however, that use spectral estimates of heart rate frequencies as dependent measures but avoid the theoretical emphasis put forth by Porges. Mulder & Mulder (1981) have used the strength of particular spectral components (or the power at that frequency) to estimate the regularity in variability changes to stimuli presented at that particular frequency. A major problem with this technique, especially when applied to rapid, non-repetitous experimental designs, is the requirement of a bare minimum of at least 100 equidistant time points; even with .5 second intervals, obtaining this number in infant studies would require a very long stimulus presentation. This is probably not a difficulty with older subjects, and adult studies have been successful in showing spectral changes independent of respiratory effects in response to certain cognitive tasks, particularly situations requiring prolonged attention.

Heselgrave, Ogilvie, & Furedy (1979) have replicated Porges's work on variability changes in adults (Porges & Raskin, 1969; Walter & Porges, 1976) and has shown a decrease in variability during cognitive processing (mental arithmetic in this case). As mentioned previously, Lacey (1970) has also described a decrease in heart rate variability that occurs during cognitive processing; Siddle (1980) also replicates this finding. Heselgrave et al. have also proposed an alternative to variability calculation of s^2 by using $delta^2/2$, a measure that removes the effects of linear trends present in heart rate data that have highly correlated successive measurements. In a comparison of two measures applied to their data, Heselgrave et al. conclude that the "appropriate HR variability analysis for the cardiac-activity variability hypothesis should involve the $delta^2/2$ variability statistic" (pg. 155). However, Wastell (1980) discusses the falliability of using the $delta^2/2$ measure, and why its properties make it inappropriate as a substitute for the traditional variability measure.

Porges (1976), in his discussion of the variability measure, hypothesizes it to represent a prolonged attentional response, the latter half of his two component model of attention (the first component being the phasic change in heart rate to the physical properties of a stimulus). This definition implies continuous "mental work" or processing, as in the aforementioned mental arithmetic tasks; it is most likely not true in a paradigm such as the one used in this experiment where attention to the stimulus is not constant over the interval of stimulus presentation. However, in habituation studies this confound can be used to advantage, since one variable of interest is the degree to which subjects manifest cardiac responses supposedly compatible with sustained attention over trials. This will be further discussed below.

Studies of habituation and orienting in infancy

Habituation has been one of the most widely used techniques for studying perceptual development in infancy. Through use of the paired comparison technique (Fantz, 1975) and habituation-dishabituation paradigms (Fagan, Fantz, & Miranda, 1975), much of the empirical knowledge about infant development has been acquired. Both of these procedures involve visual habituation to a stimulus and then use the response to a different stimulus as a reflection of the infant's ability to remember the former stimulus and discriminate between it and the latter. In these studies the variable of interest is the infant's ability to make the discrimination. Often the occurence of visual habituation to the standard stimulus is not even tested for (e.g., Welch, 1974).

Despite the wide use of habituation experimentally, the exact definition of when habituation occurs has been a persistent problem in both the animal literature (Ratner, 1970; Thompson & Glanzman, 1973), and the human literature (Cohen & Gelber, 1975). The two basic alternatives are using either an absolute criterion (i.e., habituation occurs after a response is at a certain absolute asymptotic level) or a relative criterion (i.e., habituation has occured after a certain per cent decrement in response is present). The use of an absolute criterion leads to potentially absurd conclusions; if a subject doesn't respond on the first trial (a not infrequent occurence in infancy studies), the conclusion of single trial habituation is drawn. The relative criterion approach also has problems, the most obvious being the question of what the criterion should be. The studies by Cohen most often use a decrement of 50% from the average of the first three habituation trials; if that figure needs to be lowered to get an adequately "habituated" sample, as in Olson (1976), at what point can it be conclusively said that the "habituated" 40% decrement sample reliably differs from a slightly less declining group ? Another obvious problem involves determining which trials should be used as the criterion. As McCall (1979) points out, the trial of peak response in infant studies is very infrequently the first; a 50% decline from the first few trials is potentially misleading. As discussed below, these problems were recognized in the design of the present study but nevertheless were potentially serious problems.

Other than its use as a methodological technique for perceptual studies, the study of habituation itself has also been of interest to investigators for a variety of reasons. Habituation has often been described as the most primitive of learning and has been documented in almost all phyla (Ratner, 1970). For this reason alone, attempts have been made to demonstrate habituation in newborns and infants to illustrate the extent of cognitive development ontogenetically. As an extreme example of this approach, attempts by Brackbill (1973) and

Graham, Leavitt, Strock, and Brown (1978) to obtain OR habituation in anencephalic infants were made to examine the question of habituation at birth and specifically the role of the cortex in this process. Unfortunately, their results are conflicting (Brackbill reported no evidence of habituation but Graham found habituation) and allows little to be said definitively. The rate that an infant habituates has been used as a measure of individual differences and then related to other variables (e.g., Lewis, 1971). Similarly, groups differing on a variable of interest have then been tested to see whether they differ in rate or form of habituation pattern (e.g., nutritional status between groups, Lester, 1975; or number of congenital defects, Schexnider, Bell, Shebilske, & Quinn, 1981). Habituation items are also included on standard scales of infant development (Bayley, 1969; Coll, Spekoski, & Lester, 1981)

Until very recently, the course of habituation was assumed to be a progressive decrement in response as some form of cognitive representation was acquired. In agreement with this concept, experimental reports were usually plotted as forward habituation curves that demonstrated this trend. Clearly, if the nature of habituation is not a progressive decrement, the conclusions drawn from these early studies become questionable. Assumption of this model is implicit in the standard analysis of variance techniques used in analyzing habituation designs and can cause erroneously significant conclusions if this is not the true course of habituation (Cohen & Gelber, 1975). An example of this problem is the study by DeLoache [1973, cited in Cohen & Gelber

(1975)] that interpreted fast habituators as storing information more rapidly than slow habituators. The reanalysis of her data when plotted backwards by Cohen & Gelber (1975) superficially indicates that both groups habituated in a single trial. However, an unpubished study by Rissman (1976), cited by Cohen (1976), does offer support for DeLoache's conclusion. Another serious problem in early studies of habituation unrelated to the implicit or explicit model of habituation assumed is the frequent lack of control of infant biobehavioral state; both Cohen & Gelber (1975) and Clifton & Nelson (1976) have discussed this problem as a significant confound of early studies.

In the majority of infant studies using habituation paradigms, the dependent variable has been visual fixation. However, as discussed by Cohen (1973), visual fixation responses can be interpreted as reflecting two separate processes of attention-getting and attention-holding. Though Cohen's attempt to asssociate these experimentally with the number of fixations and the duration of each fixation (respectively) was unsuccessful (Cohen, 1976), the theme of two separate processes has been present in much of the theorizing about attention, as in the Porges model described before. Experimentally, Porges's model is especially attractive since it offers the possibility of assessing the two aspects of attentional responses psychophysiologically, separate from any behavioral response, and it has been moderately supported by studies in infancy (Porges, 1974).

As was mentioned previously, Sokolovian theory predicts habituation of the orienting response. When defined as the deceleratory HR response after stimulus onset, demonstrations of habituation of HR response in infancy are numerous (although this component of HR response is most often identified as the orienting response, there is disagreement over this interpretation (Graham, 1979; Velden & Shumacher, 1979). HR has been a preferred dependent variable response for habituation studies in infancy, since it can be used in studies without visual stimuli (e.g., auditory or gustatory stimuli) where there are not well-defined behavioral measures of habituation, and also because it is one of the responses predicted to distinguish orienting and defensive reflexes (see Clifton, 1974; Berg & Berg, 1979 for reviews). Although these studies are frequent, none report analyses of changes in the variability patterns of heart rate with the exception of Porges's work (e.g., Porges, 1974). The relationship between variability and behavioral measures is an active area of study in Europe (see Kitney & Rompelman, 1980) but little work in this area has been done in the United States.

Up to this point I have tried to summarize briefly the three overlapping fields of research relevant to the present study. The goal of this study was to analyze concurrently a psychophysiological measure of attention (the decline in the variability of heart rate) and a behavioral measure of habituation (visual fixation time) to observe whether parallel patterns of decline occur in both. It is uncertain whether the peak and then decline pattern of all-or-none habituation is artifactual. If a parallel decline were to occur in a separately measured index of attention, unrelated to the criterion judgment of habituation, a far stronger argument could be made for the true nature of habituation being rapid, few, or single trial learning, and not a gradual decline in response.

Before concluding this section, the recent important conceptual and methodological step by McCall (1979) in trying to unravel the relationships between cardiac measures of attention, visual fixation measures, and habituation must be mentioned. In this study, McCall essentially ignored the issue of the true course of habituation by using a multivariate technique to group infants by the pattern of visual fixation response from trial 1 onward to a visual stimulus. After clustering the response patterns into 3 groups, McCall then attempted to differentiate these groups by the cardiac patterns shown by the infants over habituation trials. The results of the behavioral clustering showed no relationship to a similar clustering of cardiac pattern. However, McCall reported no analysis for the variability pattern of the subjects; from Porges's work, it would be predicted that this is the component of cardiac function that would more likely show a relationship to behavioral orienting. However, McCall's work appears to be the first application to grouping subjects rather than variables via a multivariate approach, a strategy strongly advocated at a recent meeting of the Society for Psychophysiological Research (Kircher, 1982; Porges, 1982). This approach could not be used in the present experiment due to the relatively small sample size.

CHAPTER 3

METHOD

Subjects

The final sample analyzed consisted of 28 infants with a mean age of 125.2 days (SD = 18.5 days). There were 16 males, 12 females (see Appendix B). All infants were full term (birth within 3 weeks of expected due date), with no history of pre-, peri-, or post- natal complications as reported by the parents (see Appendix B). Four months was selected as the target age for two major reasons: a) the relative ease of using subjects at this age (at 2 months it is often difficult to maintain infants in an alert state; after 6 months, babies are often too fussy to use as subjects in a laboratory environment where movement artifact can cause errors in the physiological monitoring of subjects), and b) the numerous studies demonstrating habituation at this age to a variety of stimuli (e.g., Cohen, 1973; Clifton & Nelson, 1976). In addition, Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman (1976) found little change in heart rate or baseline variability in the period from three to six months (far less so than the preceding three-month period).

Seventy-two infants were tested to yield the final sample of 28. Of the 44 infants not included in the results, 28 were excluded due to inability to finish the experimental session (primarily due to state changes, e.g. crying or sleeping), and data from the remaining 16 were not analyzed due to equipment malfunctions or noise in the polygraph record that made computer scoring inaccurate. (It should be noted that this was the first study to be analyzed using the LSI-11 computer in the psychophysiological laboratory; as such, certain aspects of the recording of EKG records important for later computer analysis were unknown to the author when the study began. It is anticipated that future studies in the laboratory will not suffer such a large subject loss due to this problem.) Of the 28 subjects constituting the final sample, 2 were retested completely on a second occasion after the first experimental session could not be completed. Four additional babies were tested at the onset of the study to train observers and familiarize lab assistants with the experimental procedures.

Subjects were recruited by contacting families through a mailing on university letterhead (see Appendix A). The names of parents were obtained by examining the birth records for Ingham County, Michigan, which are open for public inspection. Addresses were found in the Lansing telephone directory. After receiving a reply card that was included with the letter, parents were contacted and asked to come to the laboratory at a time of day they thought the infant would be in an alert and cooperative state.

Procedure

On arrival at the laboratory, parents were greeted by the experimenter who explained the experimental procedure. Parents were also told that they had the option to withdraw their infant from the study at any time during the session and that all records for their infant would be destroyed; none of the parents exercised this option during the experiment. Parents were then asked to sign an informed consent form (included in Appendix A) indicating their approval of the experimental procedures. If the infant subsequently completed the entire session, parents were asked to fill out a short biographical questionnaire (see Appendix A) requesting information about the baby's birth and present status. After this introduction, the parents and infant were escorted to the laboratory where two heart rate electrodes and an electrode ground (standard Beckman Ag/AgCl biopotential miniature electrodes) were placed on the infant to monitor the electrocardiogram. The two conducting electrodes were attached via a non-irritating adhesive electrode collar approximately 1 cm. below the infant's nipple. To increase conductivity, Synapse brand electrode paste was used to fill the space between the electrode and an adhesive collar. The paste is described as both non-irritating and hypo-allergenic, and no parent subsequently called to report a rash or other adverse reaction to the paste. The ground electrode, prepared in the same manner as the other two electrodes, was placed approximately 2.5 cm. above the infant's navel. After the electrodes were securely attached by micropore surgical tape, the parents were asked to place the subject in an infant seat chair in the experimental booth. The booth was a large, sound attenuated chamber, where the forward wall had a large section removed and replaced by a 48.5 cm. by 41.5 cm. rear projection screen. The infant seat was a standard infant car seat adjusted so that the infant was strapped in securely and reclining at approximately a 20-degree angle from vertical. Two infants were tested in their own car seats at parental suggestion due to fussiness in the laboratory seat. The seat was .75 meters from the screen during stimulus presentations.

The HR electrodes were plugged into a junction box attached via shielded cable to a Grass Model 7 Polygraph. A Phipps-Bird pneumograph was placed around the infant's chest to monitor respiratory movements on the polygraph, and the output from this transducer was also fed into the polygraph. A parent was seated in the chamber with the infant at all times directly behind the infant seat and out of the infant's sight. A white noise signal was continuously played in the chamber to mask the noise of the experimental equipment and any outside noise. Although the ambient noise level was not measured for this study, a previous study in the laboratory using the same white noise signal reported its value to be 55 db re .2000 dynes/cm2 (Ackles, Note 1). After the infant was seated comfortably, the experimenter monitored the EKG and respiratory movements on the polygraph in an adjoining room, making appropriate adjustments on the polygraph when necessary. All physiological measures, stimulus markers, and signals from the assistants monitoring the infant's looking behavior were simultaneously recorded on a Vetter Model 700 tape recorder for later digitization and analysis by a DEC PDP 11/03 computer system. The same computer system was used to control stimulus presentation and timing during experimental sessions.

If the infant was judged to be in an alert state (State 5 using the Brackbill and Fitzgerald (1969) scale for monitoring infant state), the experimental procedure was begun. An assistant, viewing the infant through a .65 cm. peephole in the front wall of the experimental chamber, constantly observed the infant's state and looking behavior throughout the experiment. A microswitch was mounted on the front wall in easy reach of the assistant; by depressing the button, the assistant indicated whether or not the infant was looking toward the screen. Reliability training was done (see below) with all assistants before testing began.

Following a one minute prestimulus baseline period, each subject was given 10 repetitive stimulus trials followed by a dishabituation trial to a novel stimulus. For each subject, the repetitive stimulus was an 8x8 square red and white checkerboard; the dishabituation stimulus in each case was a 16x16 square red and white checkerboard. During intertrial intervals, a black slide with a center hole was used to present a 2 cm. white spot on the screen. Stimulus images were projected from 2x2 slides mounted in a Kodak Model 700 projector; when presented, the side of each checkerboard was 28.2 cm., each square having a side of either 1.75 or 3.50 cm. The slide showed the checkerboard against a blue background so that the entire stimulus image was 36 cm. by 36 cm. Both 8x8 and 16x16 checkerboards (with black and white checks) have been shown to elicit prolonged looking behavior by the infant at 3 months (Horowitz, 1975). The duration of each stimulus presentation was 18.4 seconds. For the first 20 subjects, the ITI's varied with a mean of 12.1 seconds and a standard deviation of 1.8 seconds. For the remainder, the ITI values were fixed for each ITI with a mean of 11.8 seconds and a 1.7 second standard deviation. The ITI values were varied in order to prevent any temporal conditioning to stimulus onset. The entire experimental procedure, including calibration and baseline, was usually completed in under 10 minutes to minimize the possible confounding influence of state changes.

Dependent Variables

Heart Rate

Heart rate was monitored continuously throughout the experiment. The raw EKG signal was recorded on magnetic tape time locked to the other physiological and experimental signals. The EKG was then fed into a peak detector-Schmitt trigger circuit (Shimizu, 1978) which identified R waves in the EKG signal. The digital pulse output was fed into a PDP 11/03 computer which timed the R-R interval (i.e., heart period) in milliseconds (although the computer resolution is in milliseconds, a 1% flutter in the tape record playback introduced some error in the heart rate measurements). Heart period values then were converted to the weighted averages for each .5 second interval relative to stimulus onset and offset. Although there is disagreement in the literature about whether interbeat interval (IBI) values or their conversion to heart rate are the appropriate unit for later analysis, (Graham, 1978; Heselgrave, Ogilvie, & Furedy, 1978; Richards, 1980; Sayers, 1980), the arguments favoring the use of heart rate in beats per second (the reciprocal of the IBI multiplied by 60,000) seemed far more compelling. HR variability estimates were derived by dividing the first 18 seconds of stimulus presentation into 4 periods of 4.5 seconds each. The weighted average for the IBI's in each .5 second interval in the 4.5 second unit were transformed to heart rate per .5 second interval, and then used for the variability calculations. Therefore, estimates for each period were based on 9 data points.

Visual Fixation

Visual fixation measures were recorded by research assistants viewing the infants through .65 cm. peepholes at the sides of the front of the experimental booth. Infant fixation was assessed via the corneal reflection technique (Fantz, 1975) where observers look for the image of the stimulus on the infant's cornea. When this was observed, a silent microswitch mounted on the booth wall was depressed. Reliability training was done with all observers. For each .5 second interval after stimulus onset the computer recorded whether each observer signaled that the infant was looking. Two separate estimates of reliability were obtained; the first measured all intervals, including intervals where both observers agreed that the infant was not looking. This is the traditional method of calculating reliability (e.g., Ackles, Note 1), and yielded estimates from 76% agreement to 96% agreement, with a mean value of 88%. An alternative method for calculating reliability when fixation is the dependent variable is to examine only the intervals where one or the other observer judged the infant to be looking at the stimulus. In this case, the reliability is not truly per cent agreement but is estimating the probability that if one of the two observers judged the infant to be looking, then the other will also. For this measure, the mean was 73%, with a range of 64% to 81% agreement. Thus, although the traditional reliability estimate is respectable, the measure of agreement when the infant is looking is less so; the possible problems introduced by this measure will be discussed later. When two assistants were observing the infant during reliability training, one peephole on each side of the booth was used; when only a single observer was present, the side the observer preferred was used. Visual fixation responses were recorded on the polygraph record and also time-locked to stimulus presentation on tape. Computer analysis of these data yielded estimates for the total fixation time, length of first fixation, and total number of fixations, although only total fixation time was used for later analysis.

A recent report (Maurer & Lewis, 1979) demonstrates substantial peripheral vision in three-month-olds. This can be interpreted as weakening the view that the infant is not fixating or scanning the stimulus when the corneal reflection is not perfectly over the center of the cornea. Although the traditional technique of scoring fixation when the image is over the center of the cornea was used in this study, future experiments may require an estimate of the discrepancy of the reflection from a central focus.

The procedure for this study used a fixed stimulus interval, with a variable intertrial interval to prevent the possible occurence of temporal conditioning. Although this was a standard paradigm for habituation studies with infants in the 1960's, this methodology has fallen into disrepute. The major reason for this is by not linking stimulus onset to fixation of the screen by the infant, stimulus presentation trials can occur in which the infant does not fixate the stimulus for the entire presentation time. Primarily for this reason, Cohen (1973) and Horowitz (1975) strongly advocate the use of "infant control procedures". An example of this approach is described by Cohen (1973) where first the infant's attention is attracted by a flashing light; once the infant fixates the flashing light, the stimulus is presented contiguous to the light which goes out. If the infant then turns away, the flashing light reappears, and the cycle repeats itself. This method, while highly applicable for visual fixation responses, cannot be used for studies measuring physiological responses to stimulus onset since there also will be a physiological reaction to the onset of the flashing light to get the infant's attention. An alternative procedure is that used by McCall (1979). In the McCall study, after a fixed ITI, the stimulus was only presented when the infant was fixating the screen after the ITI interval was completed. However, in this study the stimulus was left on only while the infant fixated the stimulus (as in Cohen's approach). This approach was similarly rejected for the present study, since a fixed stimulus interval time was needed to yield equal intervals for variability analysis. For the present study, the decision was made to present the stimulus unlinked to any behavioral response. The infant seat used in the study was arranged such that when the infant was strapped in, it appeared almost certain he would be fixating the screen. It was predicted *a priori* that the change in ambient illumination in the experimental booth would be sufficient to attract the infant's attention, therfore obviating the possibility of excessively long intertrial intervals if the infant did not look at the screen. In a sense, this was viewed as a combination of a fixed trial procedure and the Cohen method; the change in illumination due to stimulus presentation was acting both as the attractant toward the stimulus, and the stimulus after orientation occurred. Personal experience from a previous study by the experimenter (Gitterman, Note 2) and in other studies in the laboratory (Ackles, Note 1) lent support to the decision to use this procedure. Although this proved correct for the majority of stimulus trials, trials did occur when the infant did not fixate the stimulus. The effects of this potential confound are discussed with the conclusions of this study.

CHAPTER 4

RESULTS

All analysis of variance tables for the main effects and interactions are contained in Appendix C. Calculations were done on the MSU Cyber 750 computer using either BMD (Dixon & Brown, 1979) or SPSS (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975). The analysis of variance results obtained via these programs, although allowing multiple independent factors, used a univariate dependent variable analysis of variance approach to repeated measures designs (see Keppel, 1973). As has been discussed by numerous authors (Bock, 1975; McCall & Applebaum, 1973; Richards, 1980), the univariate approach assumes homogeneity of the variance-covariance matrix, a situation that is rarely obtained in repeated measures designs. Heterogeneity of these matrices is especially probable when change in the variable of interest is part of the experimental treatment. Two alternatives to this problem have been proposed in the literature. The prefered solution is to use a multivariate approach with a multivariate analysis of variance (MANOVA) that makes no assumptions about the nature of the variance-covariance matrix. Although this was the approach the author intended to use for this analysis, statistical computer programs suited to this design were unavailable. The other alternative that has been discussed in the literature is the use of the Greenhouse-Geisser correction (Jennings & Wood, 1976; McCall & Applebaum, 1973) for the heterogeneity of the variance-covariance matrix. Essentially, this is an ad hoc correction that results in a reduced number of degrees of freedom for the F-ratio tests, thereby yielding a more conservative test of significance. The reduction in degrees of freedom with this correction can be very substantial, often causing significant tests to become clearly nonsignificant. McCall and Applebaum (1973) suggest doing all repeated measurse F-tests with 1 and k-1 degrees of freedom (k= the number of levels on the repeated factor) for the most conservative possible testing; alternatively, Jennings and Wood (1976) advocate a three-stage procedure wherein, if the normal test is significant, but the conservative test nonsignificant, the formula for an exact correction of the degrees of freedom based on the degree of heterogeneity of the variance-covariance matrix should be applied. If the unadjusted test is nonsignificant, there is no need for any further testing. The three-stage procedure was not done in the present analysis since BMD does not give the necessary figures for this calculation. However, given the borderline significance for many of the results that will be described, it is fairly certain that any, even small, correction of the F-test would cause it to become nonsignificant. (Heterogeneity of the variance-covariance matrices was tested by BMD program P2V for every analysis; in almost every case the data in the present study were heterogeneous (or nonsymmetric).) In those situations where the standard test is significant and the conservative test nonsignificant, McCall and Applebaum (1973) propose that the results be described as tentative (or "ambiguous"), erring on the side of nonsignificance. Situations where this occurred (almost every significant result) will be described below. The level of significance conventionally used for F-tests in psychological research is $p<.05$. However, given the small number of subjects in this study, it was thought that a more lenient criterion for significance would be appropriate, and a $p<.10$ was chosen for the F-tests that will be described.

Results for cardiac measures alone:

Before analysis, the interbeat intervals were converted to heart rate in units of beats per minute. An analysis of covariance was then performed using the prestimulus second as the covariate for the subsequent 18 second intervals. There was a significant main effect for trials ($F=1.86$, $df=9,242$, $p=.05$) with the uncorrected F test for the analysis of heart rate after stimulus onset for all 28 subjects. If the most conservative correction possible is applied (reducing the degrees of freedom to 1,17), the F test becomes nonsignificant ($p=.20$). However, as noted, this is the most conservative possible reduction in degrees of freedom. This result will be discussed further below; it is plotted as

Figure 3. There also was a significant main effect for seconds (F=6.73, df=17,459, p<.001). This result also was significant after testing with the conservative degrees of freedom (df=1,17, p=.02). The seconds main effect can be interpreted as evidence for an orienting response to stimulus onset by the entire sample, and the trials effect, although tentative, indicates evidence for habituation by the decline in the HR response to stimulus onset over successive trials. The nonsignificant interaction (p=.15, uncorrected) indicates relatively uniform change for the components of the orienting response over the stimulus trials. The seconds effect and the uncertain trials effect were both predicted and replicate previous studies.

There was no main effect for trials for the analysis of covariance on the variability measure. The main effect for periods (the four 4.5 sec. units after the prestimulus interval is covaried out) was significant before correction (F=3.84, df=3,81, p=.01). After correction, this result was nonsignificant (df=1,3, p=.16), but again the extreme reduction in the degrees of freedom for correction must be considered (Figure 4).

Analysis of behavioral data with cardiac measures:

Subjects were then grouped into habituator-nonhabituator groups using the criterion of 3 consecutive trials each having a total fixation at least 50% below the average of the two longest fixations of the first 5 trials. (However, due to the low number of habituators, one infant with a decline between 40% and 50% of the criterion was included.) This

Figure 3. Heart rate response for all 28 subjects to stimulus onset.

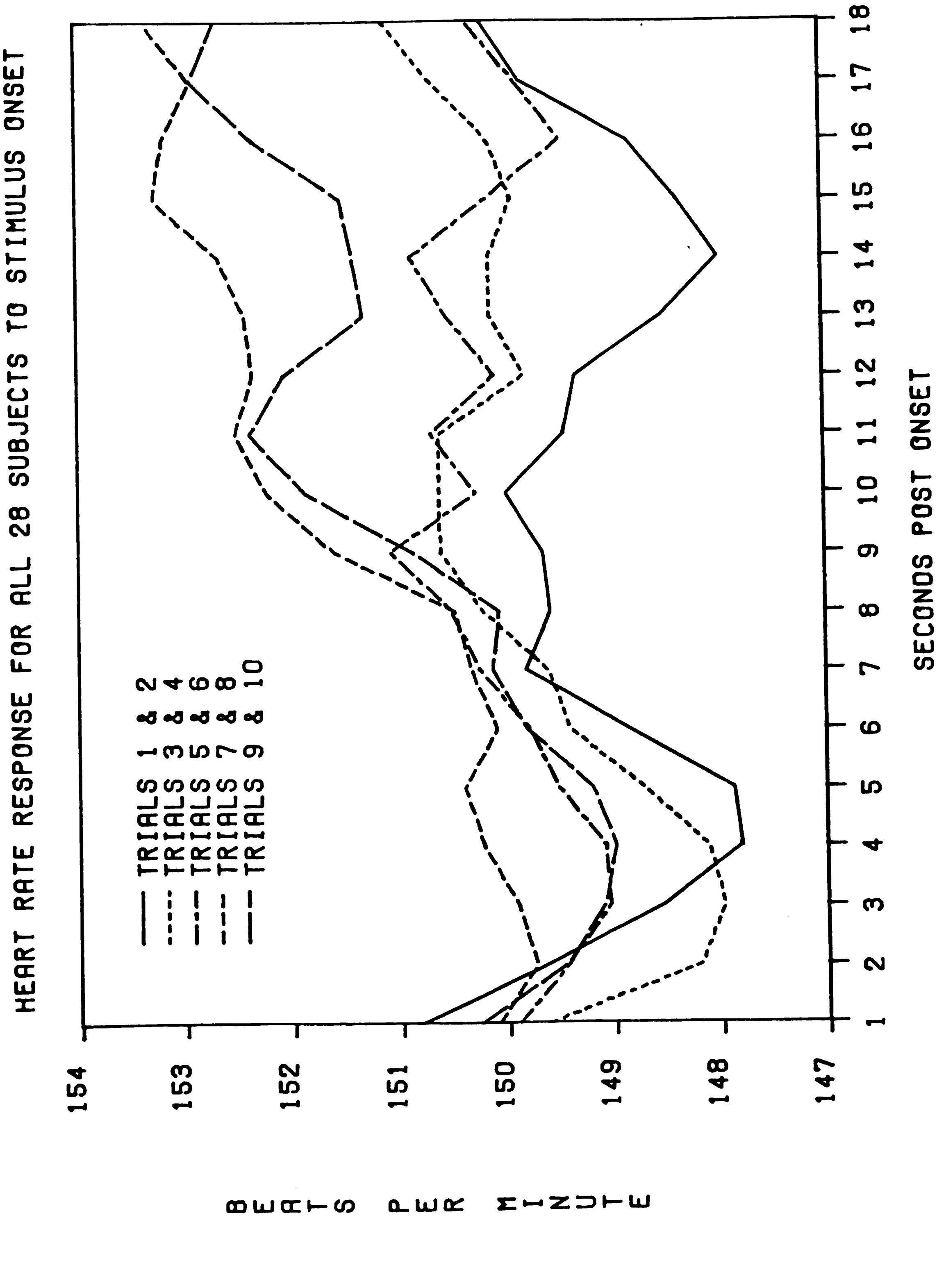
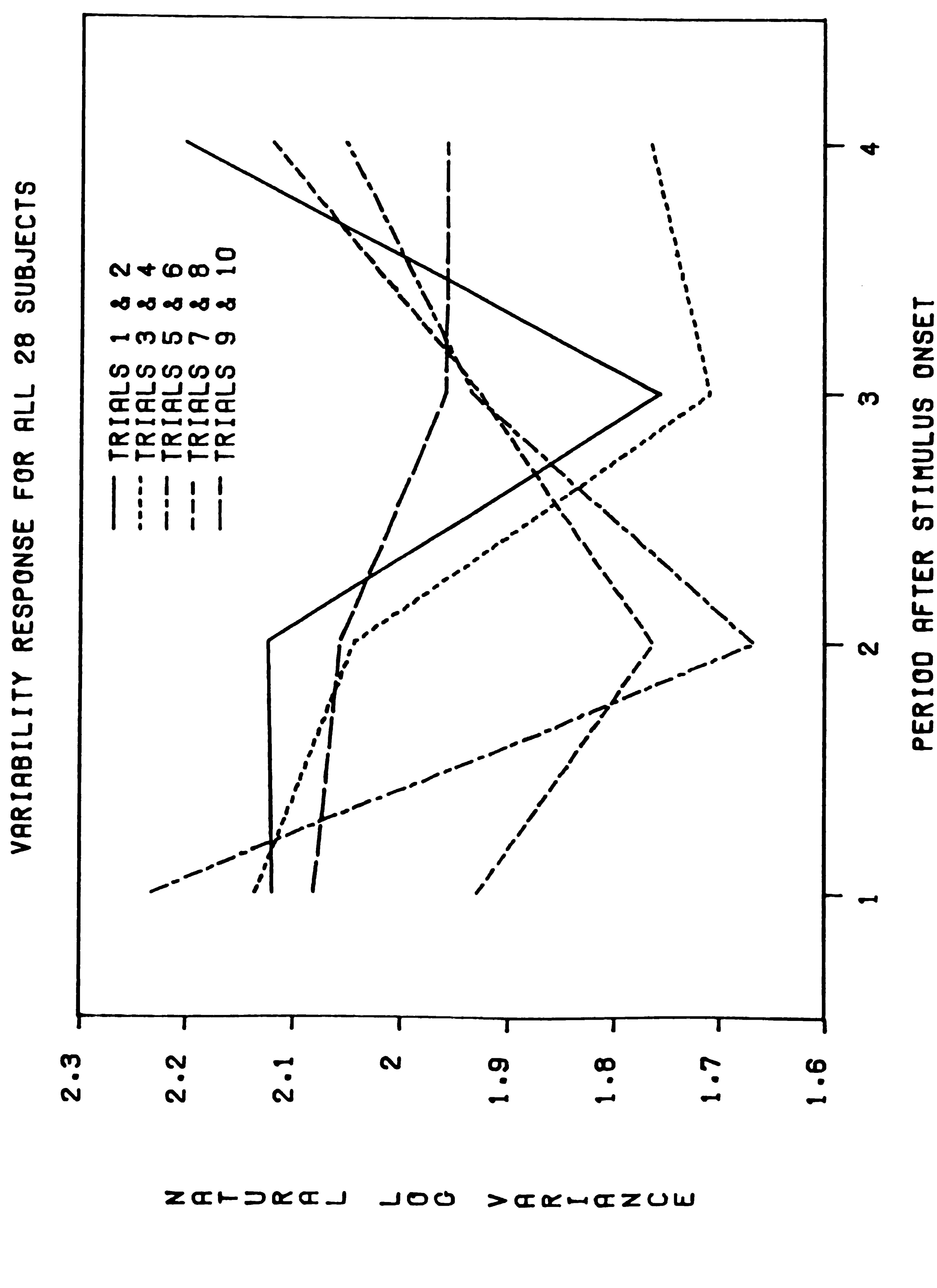

HEART RATE RESPONSE FOR ALL 28 SUBJECTS TO STIMULUS ONSET
TRIALS 1 & 2
TRIALS 3 & 4
TRIALS 5 & 6
TRIALS 7 & 8
TRIALS 9 & 10
BEATS PER MINUTE
154
153
152
151
150
149
148
147
SECONDS POST ONSET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Figure 4. Variability response for all 28 subjects to stimulus onset.


VARIABILITY RESPONSE FOR ALL 28 SUBJECTS
TRIALS 1 & 2
TRIALS 3 & 4
TRIALS 5 & 6
TRIALS 7 & 8
TRIALS 9 & 10
1
2
3
4
PERIOD AFTER STIMULUS ONSET
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
NATURAL LOG VARIANCE

yielded 6 habituators from the original sample. The low number of habituators from the original sample of 28 is probably a result of a number of factors, the most important being the methodological problem of not making presentation of the stimulus contingent on the infant facing toward the screen; this issue will be raised later in the discussion section. The average total fixation time for the habituation group used to calculate criterion levels (i.e., the average of the 2 longest total fixations for the first 5 trials) was 11.3 seconds (range 4.9-17.1). The minimum average fixation time of 4.9 seconds implies that inclusion in the habituation group was not an artifact of short initial fixations. The remaining 18 subjects not meeting the criterion for habituation were pared to a group of 6. Of the 12 subjects eliminated, 7 were eliminated either because they made no response on a majority of trials or showed response patterns that came close to habituation without meeting the criterion. This procedure should have discriminated maximally the resulting group from the habituation group on the behavioral dimension. Five additional subjects were also eliminated randomly from the nonhabituation group to yield equal group sizes. For the nonhabituation group, the average of the longest fixations was 15.5 secs. (range 12.5-18.2 secs.). A t-test comparing these two groups showed the two groups significantly different on this criterion measure [$t=1.93$, $df=6$, $p=.05$; test corrected for heterogeneity of variance (Winer, 1971)]. However, since the trial of longest total fixation was rarely the first trial, another t-test was done comparing the two groups on length of total fixation on the first trial on which fixation occurred. For this measure the means were 8.8 and 10.7 seconds for habituators-nonhabituators respectively, with a nonsignificant _t_-test ($t = .65$, $df = 8$, $p > .20$; test corrected for heterogeneiety of variance) indicating that the two groups did not differ significantly at the onset of fixating the screen. The fixation responses over trials are plotted in _Figure 5_ as a forward curve; _Figure 6_ represents the habituation group data plotted backward from the trial when the criterion for habituation was met. The importance of the difference in looking behavior will be discussed in the following section.

After grouping was done, analysis of covariance (ANCOVA) was applied to the heart rate and variability measures. In the analysis of covariance, the regression of the poststimulus measures on the prestimulus measurement (either heart rate or variability) is used to decrease error variance by removing differences in the data correlated with the covariate; in the present case the prestimulus level is used to covary out differences in initial level. In a repeated measures design with a nested factor, one of the assumptions of ANCOVA is that the regression of the covariate on the dependent measures is homogeneous for each level of the nested factor (Richards, 1980). Although there is a test of this assumption in standard texts (e.g., Keppel, 1973), a simpler approach taken here was to do a repeated measures ANOVA for the baseline period (the prestimulus period for trial 1, before any testing began) and the first post stimulus onset period. It was felt these would be most highly correlated (hence most linearly related) and free of any influence of the trials effect (in this case the experimental treatment). The 2x2

Figure 5. Total fixation response over trials by group.

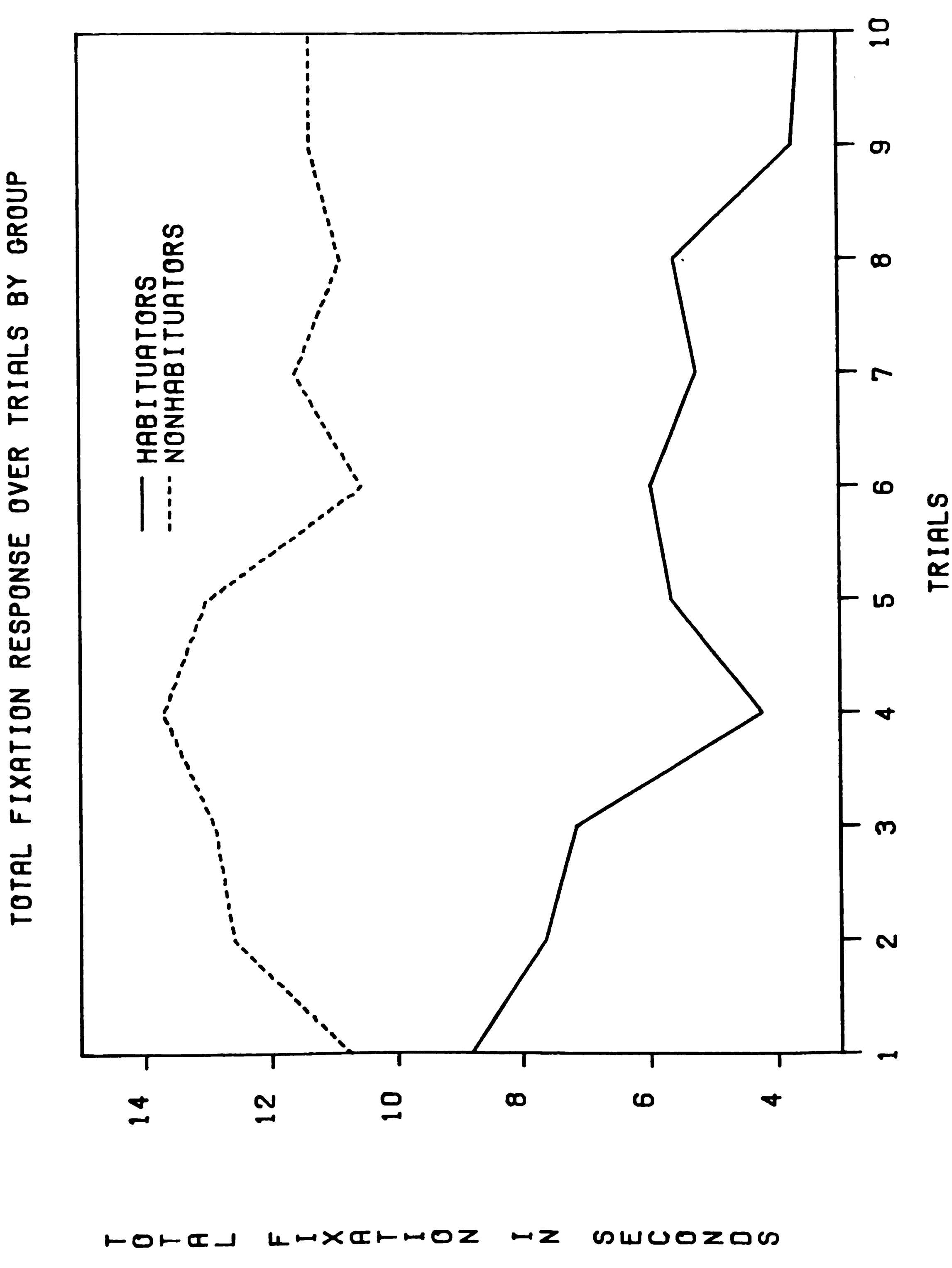
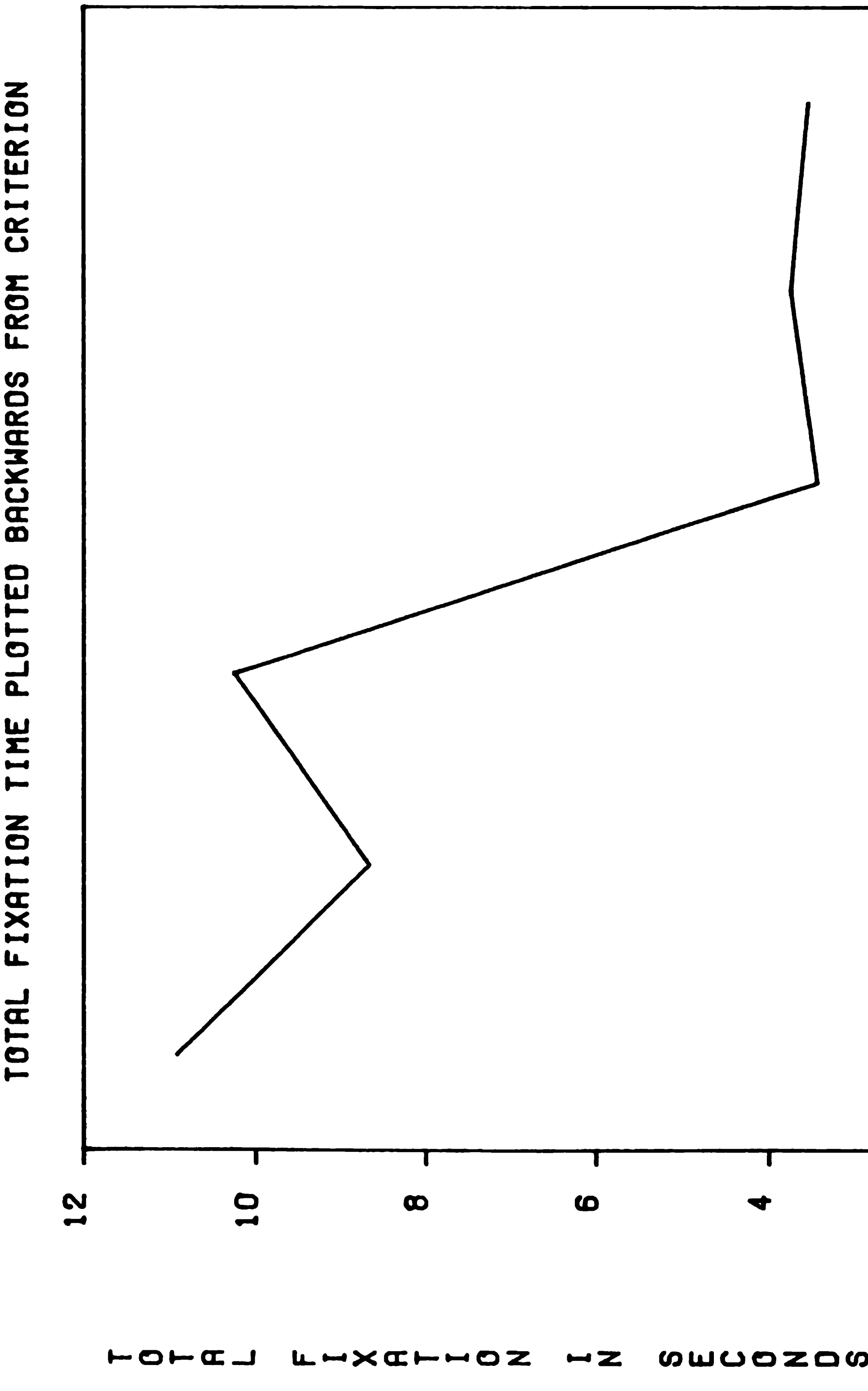

TOTAL FIXATION RESPONSE OVER TRIALS BY GROUP
HABITUATORS
NONHABITUATORS
TRIALS
1
2
3
4
5
6
7
8
9
10
TOTAL FIXATION IN SECONDS
4
6
8
10
12
14

Figure 6. Total fixation time plotted backwards from criterion.


TOTAL FIXATION TIME PLOTTED BACKWARDS FROM CRITERION
TOTAL FIXATION IN SECONDS
12
10
8
6
4
2
-3
-2
-1
CRITERION
+1
+2
HABITUATION TRIALS

ANOVA (group by period) was nonsignificant for group or trial. The period by group interaction was very close to significance (p=.12); given the low power of the small sample size, this result was interpreted as indicating heterogeneity of the regression slopes. The means for these two periods are displayed in Figure 7. In addition, examination of the beta weights after the analyses were done showed that the beta weights for the two groups were substantially different. Therefore, for the variability analysis, separate analyses were done for the habituation and the nonhabituation groups. A similar test for the heart rate measure was nonsignificant, so an ANCOVA containing all three factors (group by trial by second) was done here.

For the heart rate results, there was no main effect for habituation group or trials, although the uncorrected seconds effect remained significant (F=2.51, df=17,170, p=.001). This result was also nonsignificant when the more conservative test was done (df=1,17, p=.15). Although, the trials effect was nonsignificant, the trials by seconds interaction was significant (F=1,18, df=153,1530, p=.07) uncorrected, but it was clearly nonsignificant with the conservative test. The results for this analysis are plotted separately by group (Figures 8 and 9). The three way interaction (group by trials by seconds) was nonsignificant. After these tests for the entire 10 trials, a test was made comparing HR responses on the first trial that was used to classify habituators into the habituation group and the trial preceding it (essentially comparing the trial before and after habituation). The effect for trials in this comparison [a 2 (trials) by

Figure 7. Prestimulus period versus poststimulus period for trial 1.

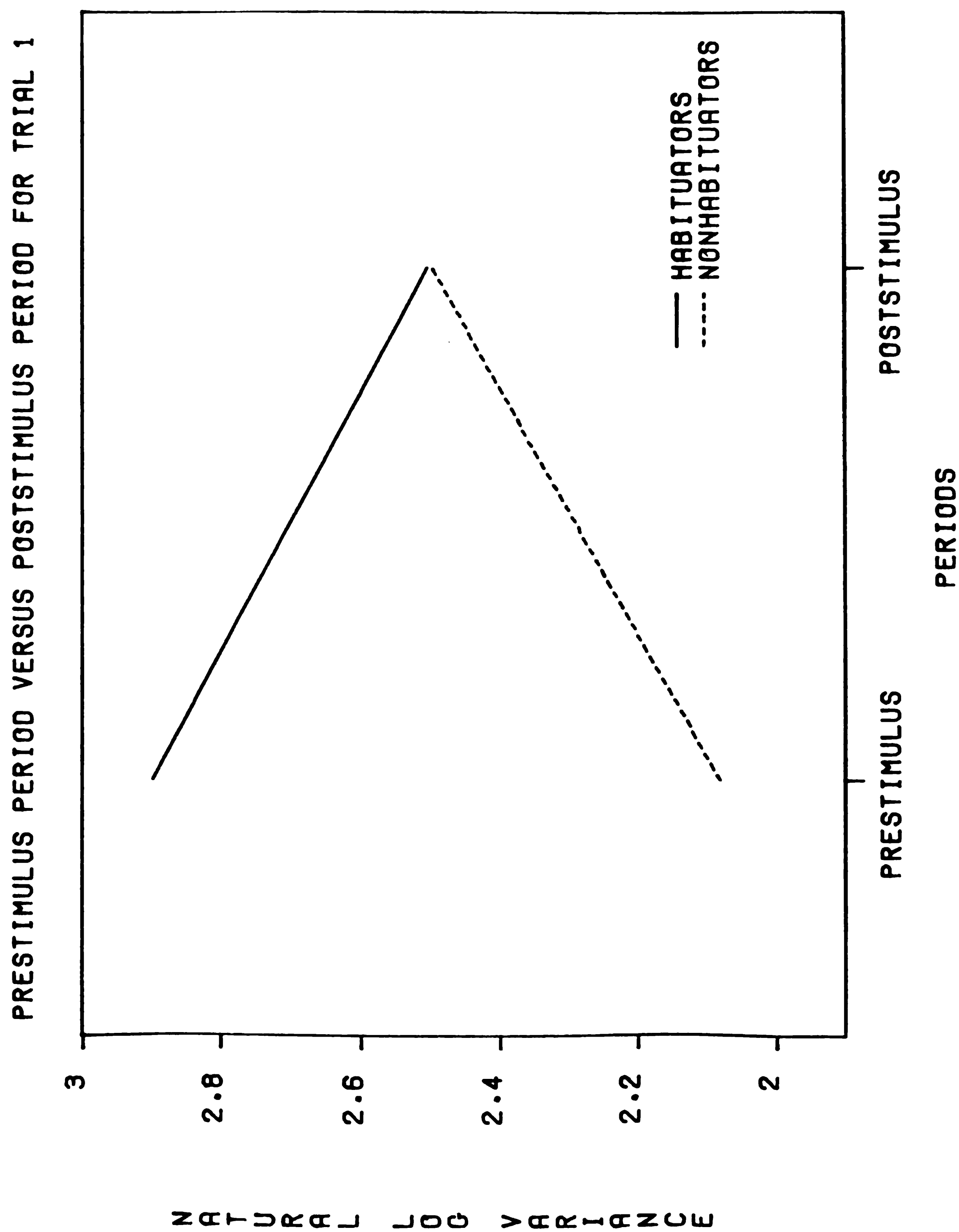

PRESTIMULUS PERIOD VERSUS POSTSTIMULUS PERIOD FOR TRIAL 1
HABITUATORS
NONHABITUATORS
PRESTIMULUS
POSTSTIMULUS
PERIODS
3
2.8
2.6
2.4
2.2
2
NATURAL LOG VARIANCE

Figure 8. Heart rate response for habituators.

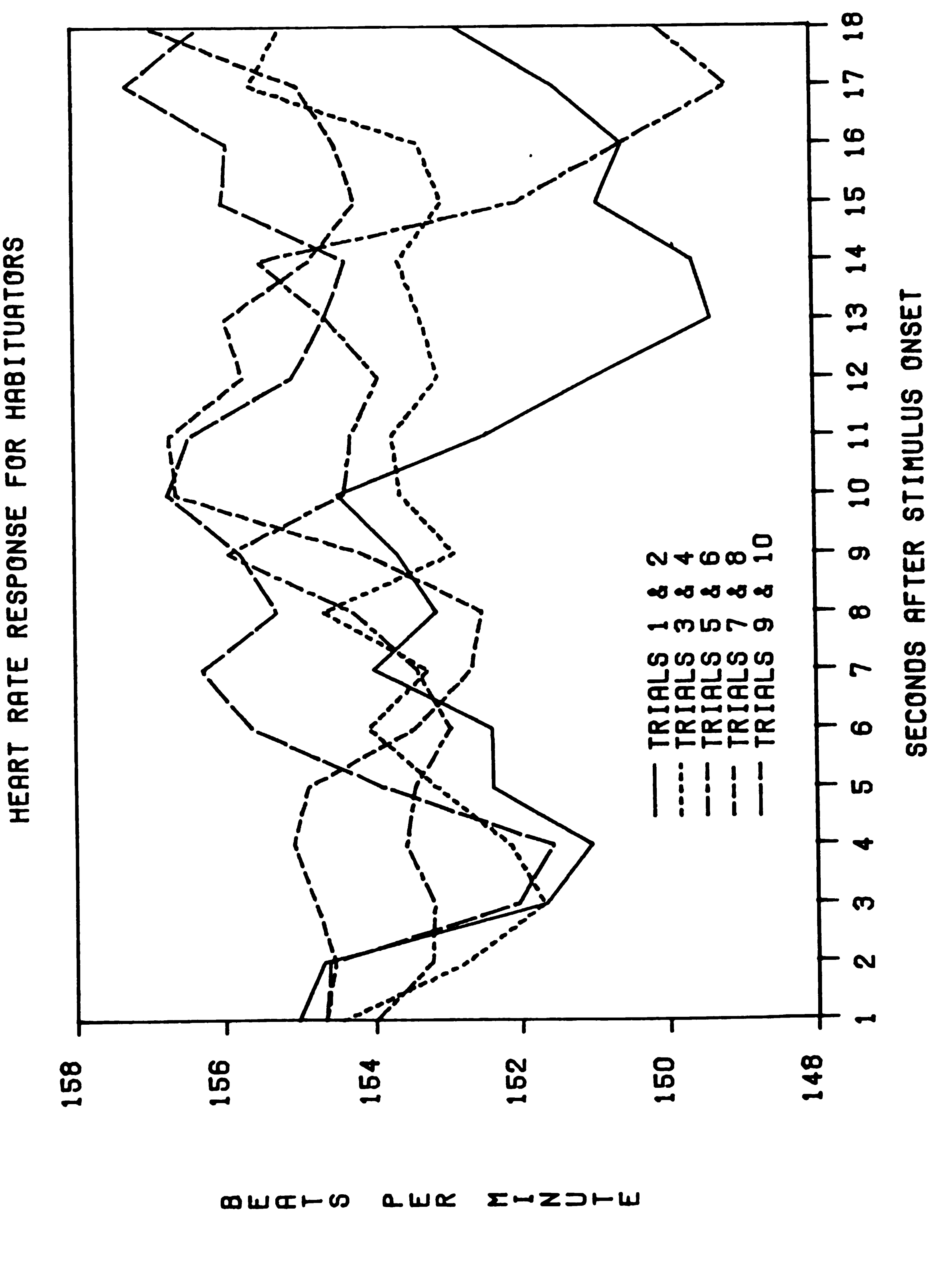
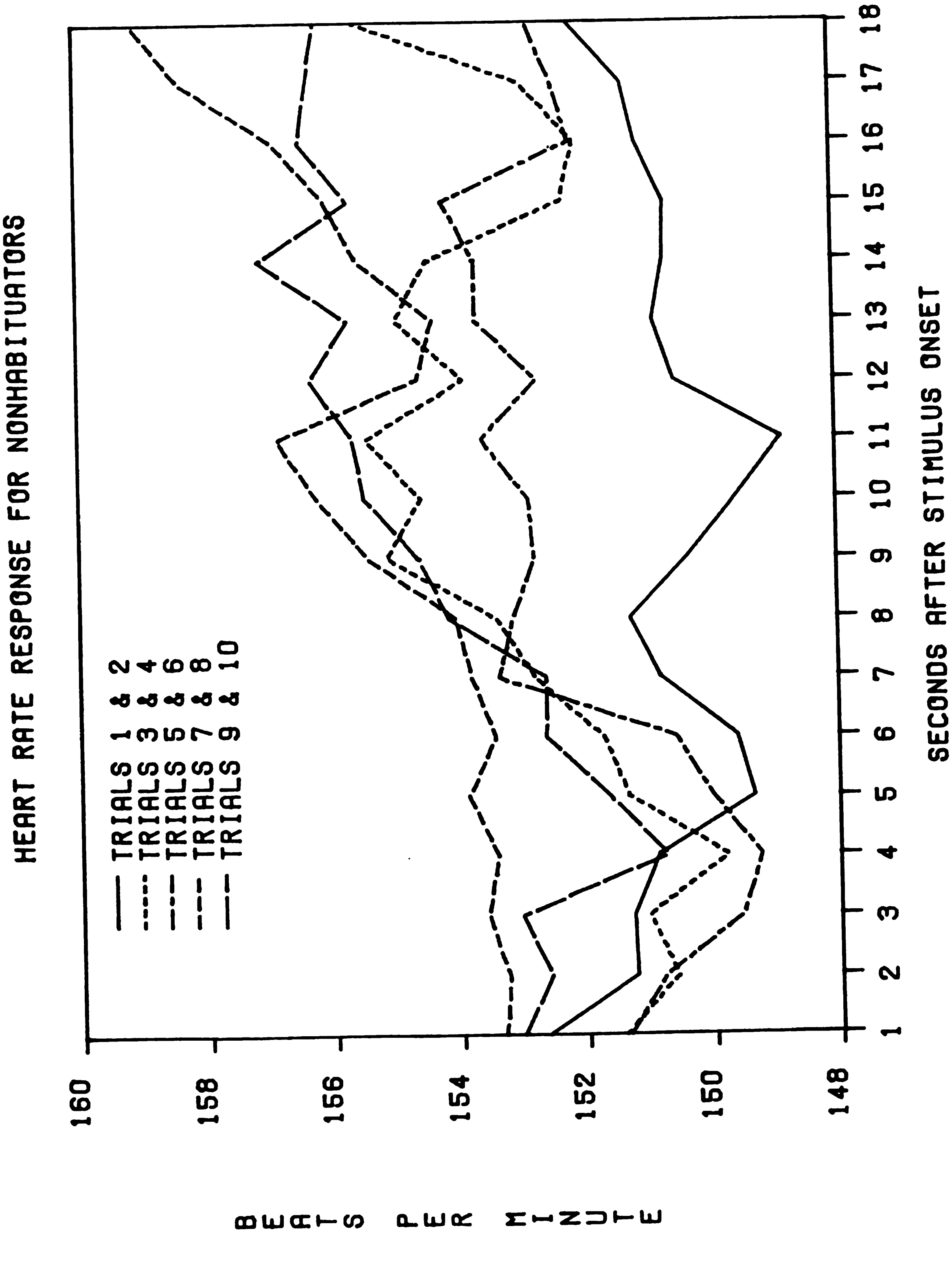

HEART RATE RESPONSE FOR HABITUATORS
TRIALS 1 & 2
TRIALS 3 & 4
TRIALS 5 & 6
TRIALS 7 & 8
TRIALS 9 & 10
SECONDS AFTER STIMULUS ONSET
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
BEATS PER MINUTE
158 156 154 152 150 148

Figure 9. Heart rate response for nonhabituators.


HEART RATE RESPONSE FOR NONHABITUATORS
TRIALS 1 & 2
TRIALS 3 & 4
TRIALS 5 & 6
TRIALS 7 & 8
TRIALS 9 & 10
BEATS PER MINUTE
160
158
156
154
152
150
148
SECONDS AFTER STIMULUS ONSET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

18 (seconds)] analysis of covariance was nonsignificant.

For the variability measure, prestimulus variabilty was covaried out in the analysis of covariance with the four 4.5 second periods post stimulus as the dependent variables. As described above, a separate analysis was done for each group. For the habituators, the trials effect was nonsignificant ($F=1.31$, $df=9,44$, $p=.26$). The uncorrected effect for periods was marginally significant ($F=2.95$, $df=3,15$, $p=.07$), but clearly nonsignificant if the conservative test is applied ($df=1,3$, $p=.20$). The interaction was also nonsignificant ($p=.20$), but in the proper direction. The response of the habituators over trials is plotted (in blocks of 2 trials) as Figure 10 . For the nonhabituators the trial effect was nonsignificant ($p>.25$), as was the period effect ($p>.25$). There was an uncorrected significant interaction (see Figure 11) for trials by periods ($F=1.57$, $df=27,135$, $p=.05$). When tested conservatively, this interaction was again nonsignificant ($df=3,9$, $p>.25$).

Results for dishabituation testing:

The results for behavioral dishabituation were different for the two groups. For the habituation group, a paired samples *t*-test between trials 10 and 11 (the last habituation trial and the dishabituation trial) was very close to significance, with an increase of looking time at the dishabituation stimulus ($t=-1.88$, $df=5$, $p=.08$, one-tailed test; Figure 12). For the nonhabituators, the fixation response on the dishabituation trial was nonsignificantly different from the last

Figure 10. Variability response of habituators over trials.

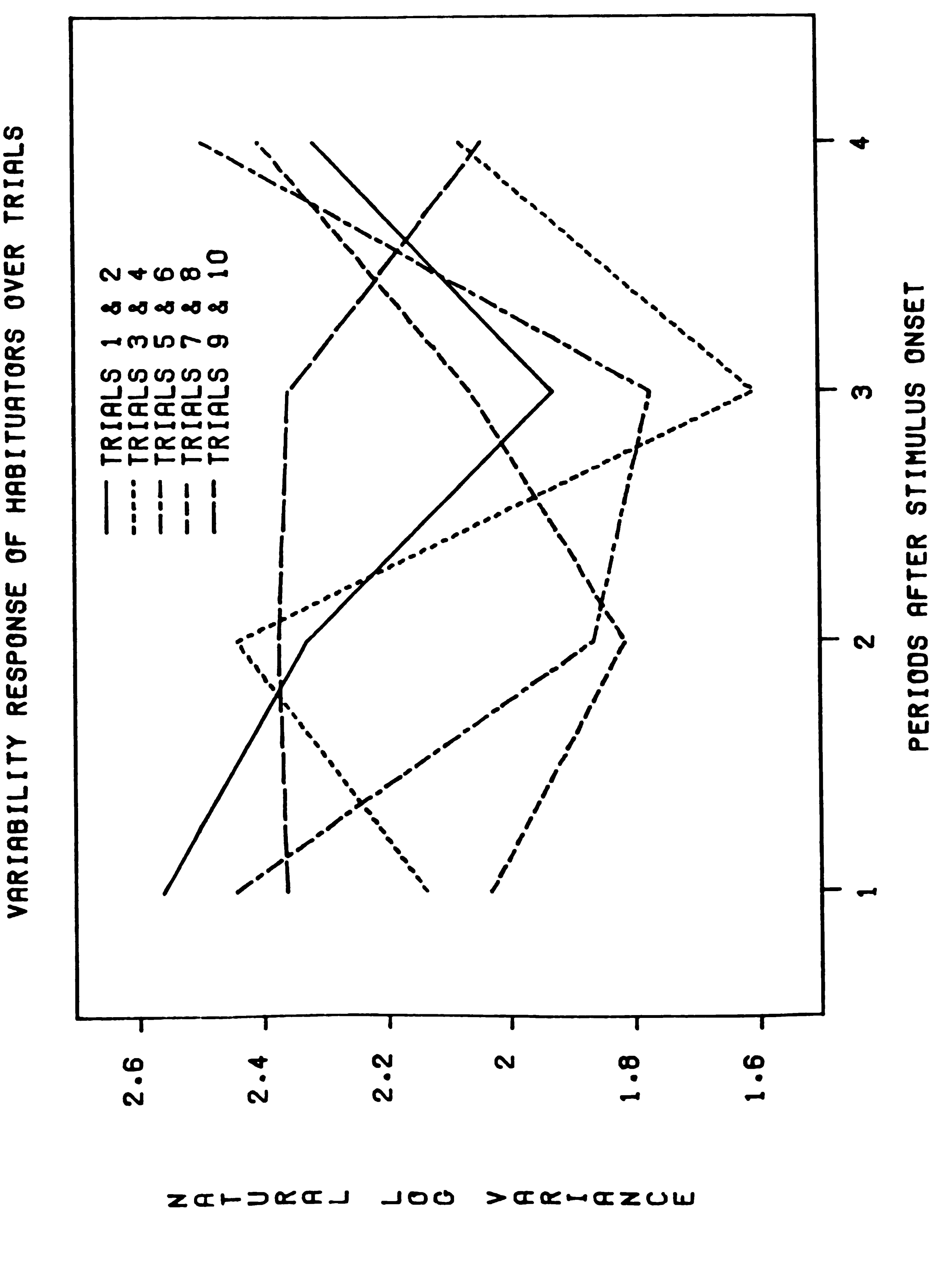

VARIABILITY RESPONSE OF HABITUATORS OVER TRIALS
TRIALS 1 & 2
TRIALS 3 & 4
TRIALS 5 & 6
TRIALS 7 & 8
TRIALS 9 & 10
NATURAL LOG VARIANCE
2.6
2.4
2.2
2
1.8
1.6
PERIODS AFTER STIMULUS ONSET
1
2
3
4

Figure 11. Variability response of nonhabituators over trials.

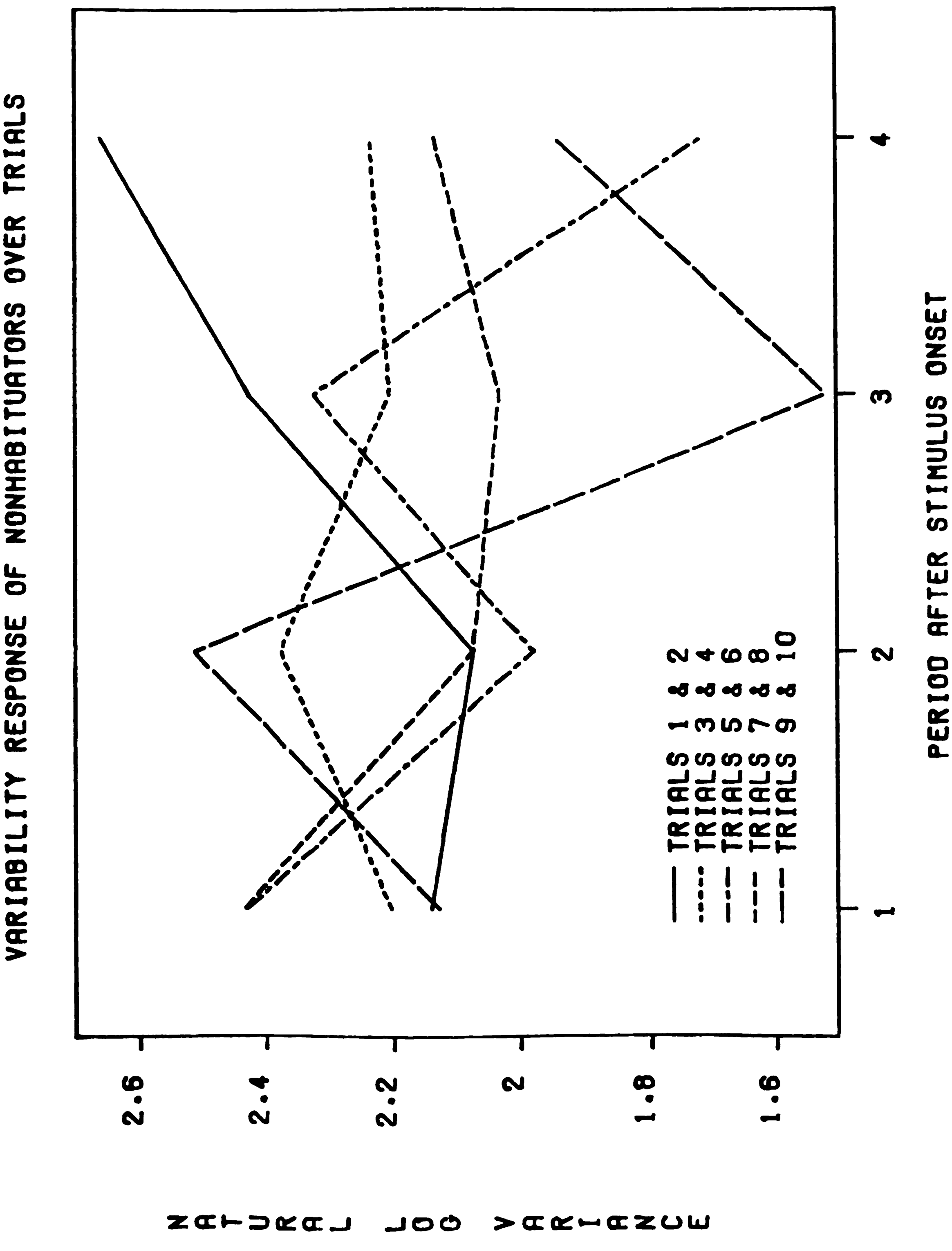
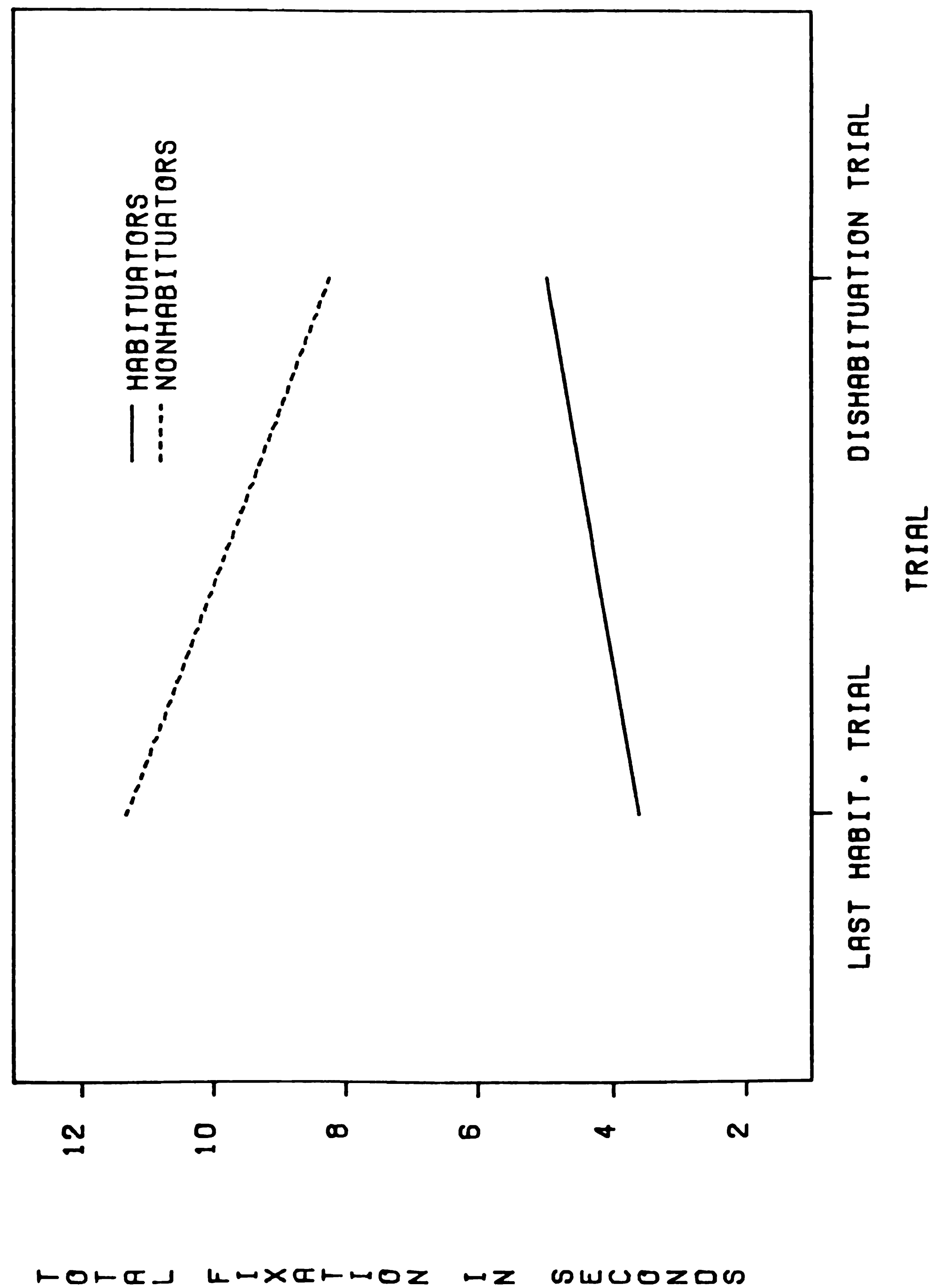

VARIABILITY RESPONSE OF NONHABITUATORS OVER TRIALS
NATURAL LOG VARIANCE
2.6
2.4
2.2
2
1.8
1.6
1
2
3
4
PERIOD AFTER STIMULUS ONSET
TRIALS 1 & 2
TRIALS 3 & 4
TRIALS 5 & 6
TRIALS 7 & 8
TRIALS 9 & 10

Figure 12. Comparison of final habituation trial and dishabituation trial.

COMPARISON OF FINAL HABIT. TRIAL AND DISHABITUATION TRIAL



habituation trial (t=4.86, df=5, p>.20, one-tailed test); however, this nonsignificant result was due to the nonhabituators significantly decreasing their looking time to the novel stimulus (p=.005 if a two-tailed test is used). This result is puzzling. The fact that looking times were higher on trial 10 for the nonhabituators would lead to the anticipation of a nonsignificant t-test due to ceiling effects, but not a significant decline.

For the physiological measures, separate repeated measures ANCOVAs were done comparing the habituation and dishabituation trials for each group on both the HR variable and the variablility measures. For habituators, none of the main effects or interactions (for both heart rate and variability) was significant. For the nonhabituators, the heart rate analysis showed no significant main effects; nor was the interaction significant (although the expected main effect for seconds was significant (F=1.71, df=17,85, p=.06), but again nonsignificant when corrected). For the variability measure, none of the F-tests was significant.

CHAPTER 5

DISCUSSION

The findings of this study replicated previous results in the literature that described infant orienting responses to stimulus onset. Unfortunately, the results of the variability tests that were the primary focus of analysis were inconclusive. Although these results support the exponentially decaying model of infant habituation superficially, my opinion is that drawing this conclusion is unwarranted. The pattern of habituation in infancy is probably still best considered an unresolved issue. For both conceptual and methodological reasons, I do not believe there is any unequivocal way to interpret these data so as to permit a definitive statement on the true course of habituation. In addition, I believe that the data collection was influenced by a number of methodological problems that occurred during the experiment. I feel that these problems, each of which will be discussed below, essentially vitiate any conclusions to be drawn from this experiment.

The results for heart rate orienting responses replicate many prior studies that have elicited a deceleratory response in infants in response to a relatively benign stimulus (see Berg & Berg, 1979). Similarly, the decline of this deceleratory response over trials, intuitively interpretable as habituation of the orienting reflex, also has often been reported in the literature. The lack of a difference between the habituation trial and the dishabituation trial for either group is puzzling, especially in context of the significant difference in looking behavior by both groups to the dishabituation stimulus. The small sample size (n=6) in each ANCOVA comparing the two trials is most probably the cause of this nonsignificant difference; nevertheless it weakens the utility of simple heart rate as an indicator of cognitive process. The results for orienting, showing a main effect for both seconds and trials, offer little other than verification of previous studies and an indication that, based on this one measure, the present sample did not differ significantly from others that have been used in psychophysiological paradigms.

The results for the variability response were disappointing and somewhat unexpected. The nonsignificant trials effect, or trials by periods interaction for the habituators was especially discouraging, as both models of habituation predict a change in the response pattern over trials for the habituators. If the 'tentative' period effect (i.e., nonsignificant after conservative F-testing) is assumed to be truly significant, this would argue that the infants did differ reliably in response after stimulus onset and that the variability response was measuring a response to prolonged stimulus presentation. Therefore, the lack of change in this response is doubly disappointing, as it would indicate that when the variability does change it reflects a significant reaction within trials that does not change as behavioral habituation occurs. The plot of the mean responses over periods does seem to show a general decline in variability over the first three periods with an increase in the fourth period (as the Porges model would predict). However, the small number of subjects makes any statement tenuous in the absence of replication. (Although the curve appears to show a significant habituation by comparison of trial block 9 & 10 with the earlier trial blocks, it is more an artifact of combining trials 9 & 10 rather than a true difference. Examination of the separate trial means bears this out.) The nonsignificant difference between the dishabituation and preceding habituation trial also strongly argues against the utility of measuring variability as an index of cognitive processes. The same can be said for the nonsignificant result when the two trials assumed to be pre- and post- habituation were compared. The effect for trials was assumed a priori to be present only in the habituation group, so the negative results for the nonhabituation group add little to the discussion of habituation in infancy. The significant interaction of trials by period for nonhabituators (also a 'tentative' result) was unexpected, and in context of the previous results defies easy interpretation or categorization.

As mentioned earlier in this section, the issue of the nature of habituation is still best considered unresolved; obviously the results described offer little insight into the comparison of decremental vs. all-or-none habituation models. The reasons this study has failed to adequately test its major hypotheses can be broadly dichotomized as either methodological or conceptual problems. The latter will be discussed first.

The most disagreeable result for testing the hypothesis concerning the nature of habituation was the nonsignificant trend over trials of habituation for the habituation group (evidenced by the nonsignificant periods by trials interaction). It is difficult to describe the progress of habituation using a dependent measure which does not show habituation. A strong possibility is that the use of variability is a poor measure of sustained or active attention. Porges et al. (1980), when discussing spectral analysis, refer to variability as only a "crude measure of attentional response". If HR variability does have validity as a measure of sustained attention, the strength of this effect is not sufficiently great to yield significant results with the extremely small group sizes obtained in this study. (Although no formal power calculations were done post hoc, it is not unreasonable to assume that power with an _n_ of is undesirably low, especially with dependent variables measured with much error). One possibility often cited to explain behavioral-physiological dissociation (in the present case, behavioral habituation but no variability response difference) is the degree of unreliability in the measurement of the dependent variables. As reliability of either (or both) measures decreases, there is less and less expectation that both will covary appropriately enough to show coincident response patterns in both systems. This does not appear to be true in the present study, as no effect at all over trials was noted. A better alternative appears to be the lack of construct validity in the use of variability as a measure of sustained response. The support for variability measures as an index for sustained attention is far from overwhelming, and (especially in infants) stems almost entirely from Porges's laboratory. Even a recent paper by Porges et al. (1981) describes variability responses in subjects contradictory to the predictions of his theory. The choice of this measure to examine the course of habituation thus appears to have been a poor one (although the original expectation was to have used spectral analytic measures as the dependent variable). It does, however, comment on the possible lack of utility of this variable for monitoring cognitive responses and should raise questions about its use in future studies. It must be noted, however, that the description of variability used in this study is not synonomous methodologically with other uses of this term in the literature; a 4.5 second interval was chosen to subdivide the post stimulus period into intervals of reasonable size; some of the earlier work with infants by Porges used longer intervals (approx. 30 seconds; Porges, Stamps, & Walter, 1974), which might be more stable over time and reflect true tonic changes in variability. (As a check, a post hoc analysis of variability calculated for the entire 18-second interval over trials was done for each group. These results here also showed no main effect for trials or interactions for either group (see Appendix C). As such, it appears this study ultimately evolved into more of a test of the validity of the use of variability as a measure of sustained attention rather than a true study of habituation. The single analysis that probably bears most on the utility of the use of variability measures is the nonsignificant comparison of the habituation and dishabituation trials. As was noted previously, the nonhabituators and habituators showed opposite responses to the dishabituation stimulus, with the nonhabituators showing the odd result of significantly ($p<.01$) decreasing their fixation behavior to the novel stimulus. An appropriate test of the validity of the variability measure is the comparison of the last habituation trial and subsequent dishabituation trial. This test was nonsignificant for the trial and second main effects (and the second by trial interaction) for each group separately. Again, a nonsignificant finding is not surprising, given the small sample size ($n=6$ for each group) and concomitant low power. This is underscored by the F's being below 1, most likely indicating significant heterogeneity of variance. Although significant results would have important bearing on the question of habituation, the nonsignificant results cannot be used to make any definitive statements due to the many possible causes of this outcome.

From the preceding discussion, it is clear that deriving any conclusions about the pattern of infant habituation from this study is problematic. After examination of the important hypotheses, the problem of interpreting the odd dishabituation result remained. The first explanation that was considered was that this effect was secondary to age; age-related changes in visual preference during infancy are well documented (Fantz, Fagan, & Miranda, 1975). This was immediately discounted because the two groups did not significantly differ in age at time of testing. The second possibility entertained was that the groups differed on some other individual difference characteristic. No obvious descriptive characteristic differentiated the groups; this was expected, since participation in the study was contingent on the infant being healthy and having no history of pre- or post- natal insult. The next area of inquiry was analysis of both the baseline and prestimulus variability. Porges (1974) has reported differential conditionability in newborns correlated with baseline variability prior to stimulus onset. Other studies have been reported describing behavioral differences between groups differentiated on the basis of autonomic activity (e.g., Cousins (1976) and vanHover (1974) for heart rate; Ingram & Fitzgerald (1975) for skin conductance), but no study has been described replicating the Porges work with newborns. A *t*-test comparing the two groups on the 4.5 second period before the first stimulus period (i.e., during the end of the baseline period) was suggestive of possible differences between the two groups ($t=1.48$, $df=10$, $p=.17$). As this was too small an interval to consider differences between the groups as real, a reanalysis was done comparing the variability between the two groups for the final 10 seconds of the baseline period; the means for the two groups on this measurement were essentially equivalent ($t=.38$, $df=10$, $p>.25$).

The foregoing has focused primarily on the conceptual problems in interpreting results from this study. As was previously mentioned, I feel strongly that methodological problems severely affected the collection of data. It is necessary at this point to include a full discussion of these problems in this experiment as I feel that they influenced the outcome of this study. Moreover, recent ideas from other branches of psychology that are now being applied in psychophysiology call for a different way of conceptualizing psychophysiological variables and change in physiological systems. Although some of these ideas were incorporated in the proposal for this research, the same methodological problems obviated any approach to analysis other than the analysis of variance comparison between groups that was done.

The most obvious problem is a statistical one arising from the small number of infants in the habituation group. The primary reason for this low number was the use of a design that did not tie stimulus presentation to having the infant look at the rear-projection screen where the slides were displayed. Although various authors have discussed this problem for over a decade (e.g., Cohen, 1973; Horowitz, 1975), for previously discussed reasons I decided to present the slide without requiring the infant to be looking at the screen. The raw data clearly indicated that this is not a suitable alternative to the more commonly used linking procedure. Of the 28 subjects whose physiological records were sufficiently error-free to be usable, the literature suggests that 6 is an underestimate of habituators. Although the six subjects who formed the habituation group (obviously selected before analyses of the physiological data were accomplished) were felt to be reliable examples of habituators, the small n makes the power of detecting significant differences between the pre- and post- habituation trials exceedingly small. Another reason for the small number of habituators was the small number of subjects with physiologically acceptable heart rate records. This is mostly due to circumstances unique to the present study. Although infant psychophysiological research usually suffers an experimental loss of approximately 40% of subjects, the present study suffered a loss of 67% of the subjects tested. In habituation research the same stimulus is presented repeatedly and habituation results in the increased likelihood of a state change (or movement artifact) occuring. This is not as much a problem in studies where different stimuli are presented that maintain an infant's interest. Also implicit in the design of a habituation paradigm is that presentations cannot be stopped and restarted as in other studies where the parameter of interest is the physiological response to the stimulus.

A further cause of subject loss was the use of the laboratory computer for timing the interbeat intervals from the electrocardiographic record. As previously mentioned, this was the first use of the computer for this task, an almost unbearably tedious job when done by hand. All the data were collected and stored on audio tape before the programs were written to perform the analysis. When the programs were used it was discovered that baseline shifts are an important source of error during computer analysis of heart rate, and little can be done if they are already present in the EKG record. To solve this problem, the laboratory program has been adjusted so that the experimenter has an auditory feedback signal occuring with each heart beat during the experimental procedure to indicate that computer analysis of the polygraph record is acceptable, and if not, the experimenter can adjust the signal recorded to the appropriate levels. The loss of over 1/3 sample completing the experimental procedure (16 of 44) is unacceptably high for this type of research; future studies in this laboratory should not suffer as greatly from this problem. Of the 72 infants in the original sample who came to the laboratory, 44 completed the experimental session. The 61% completion rate is in accordance with previously cited studies (e.g., Olson, 1976).

Though the methodological difficulties were severe in the present experiment, the question of whether the approach taken in this study is the best for investigating the relationship between psychophysiological and behavioral events remains salient. In the time since the study was first proposed, two significant developments in psychophysiology have occurred. The first is the advocacy of multivariate techniques in analyzing the relationships both between physiological measures and between subjects (Kircher, 1981; Porges, 1981). This involves clustering subjects into groups based either on behavioral or physiological criteria, and then differentiating between the groups. This method was applied successfully by McCall (1979) to the same problem that the present experiment addressed. Although McCall was unsuccessful in demonstrating a relationship between behavioral and physiological responses, conceptually the approach he used holds great promise for future research in this area. Had there been a sufficient number of subjects in the present experiment, this would have been the preferred statistical technique. It allows the distinct advantage of forming statistically post hoc groups of subjects that demonstrated either of the two contrasting habituation patterns behaviorally (and in McCall's study, a third group showing idiosyncratic patterns), and then allowing comparison with physiological measures. These groups are defined solely by response pattern, thereby avoiding the necessity of forcing subjects to meet an arbitrary criterion definition of habituation.

A second important advance in psychophysiology has been the use of time series and spectral analytic procedures for analyzing cardiac data (for a review, see Kitney & Rompelman, 1980). Porges and his associates (e.g., 1976; Porges et al., 1980) appear to be the most ardent American supporters of this methodology, though they have not yet described any experimental studies where this approach has been used with infants, although in a recent paper, Porges (1979) described its potential use for monitoring fetal distress in high risk deliveries. Richards (1980), in his review of statistics for analyzing infant heart rate data, also advocated the potential utility of this and other time series approaches to infant heart rate analysis. However, the application of this procedure absolutely requires a minimum number of equidistant points, and although conventionally used time units can be subdivided to increase the number of intervals (e.g., 1-second units can be subdivided into four 250 msec. units [Porges et al. (1981); but see Wastell (1980)], there still is the requirement of a minimum number of points for analysis, with increasing reliability as the number of points increases. To apply this to the present study would require 35 seconds of stimulus presentation to obtain 150 points, which is much too long for this and most infant paradigms. However, the application of spectral analysis offers the very significant practical and conceptual advantage of being able to estimate the amount of shared variance between the two processes from analysis of the cross coherence between two rhythmic measures (in this instance, heart rate and respiration). In Porges's work with hyperactive children the coherence measure has been used as the dependent variable. This has been used to test his hypothesis that one of the causes of hyperactivity is an inappropriate balance of inhibitory neuronal forces that can be measured as the degree of coherence between respiration and heart rate. Other applications have used spectral analysis to partial out the variability in heart rate records due to concurrently occurring respiratory and blood pressure changes; what remains is a far cleaner estimate of the variability due to the experimental manipulation, although in the Porges example, use of coherence directly is appropriate, since his manipulation (administration of Ritalin) affects both HR and respiration and especially the relationship between them. For this reason, Porges has described heart rate variability as only a crude measure of sustained attention. This is underscored in the discussion of the general application of spectral analysis by Porges et al. (1980) where two variables have the same mean and variance but no relationship in the time domain.

Given the preceding discussion of both multivariate grouping of subjects and spectral analytic analysis of cardiac data, there are many possible ways this approach could be applied profitably to questions about habituation. One possible study would use a design exactly the same as that used in this study, except that stimulus presentation would be linked to viewing the slide image. Subjects would be monitored on line until they reach a criterion of habituation, and at that point the computer could be programmed to present the stimulus again. However, on this trial it would be presented for a longer duration sufficient to obtain enough points for spectral analysis. These subjects would then be paired with nonhabituators who would receive the prolonged stimulus presentation after the equivalent number of trials but without having habituated. (Obviously a study of this nature would require many controls and subtleties not mentioned here; this brief paragraph is meant only to convey that designs using this approach are not inconceivable. Clearly much research demonstrating the validity of spectral analytic interpretation of physiological data is needed.)

In summary, while the overall results of this study are inconclusive, they are entirely congruent with an unpublished thesis by Ackles (Note 1), conducted in the same laboratory which found little relationship between variability and infant attention. The recent developments in psychophysiological methodology are allowing more sophisticated experimental designs in psychophysiological studies. Perhaps they will shed more light on the nature of habituation. However, more critical at the present juncture are intensive studies to establish the validity and strength of psychophysiological measurements in a variety of situations and paradigms; only then can they be used to answer questions in other areas.

APPENDICES

APPENDIX A

Forms

Permission Form for Testing Infant

Date:_______

Dear Parent(s):

This form is to request permission for us or our staff to examine your infant in tests of attention, and to observe your infant during a short period of sleep.

You may withdraw permission at any time simply by informing us or our staff members that you wish to do so. The information collected is confidential; it will only be available to qualified personnel, and information on any individual infant will be identified by number only. If you have any questions about the procedure to be used, please feel free to ask. The tests will not disrupt the infant, or in any way be harmful; however, participation in the study will not guarantee you or your infant any beneficial results.

Your signature on this form verifies that the specific tests and procedures to be used with your infant have been explained to your satisfaction, and that you have voluntarily agreed to allow us to test your infant. If at any time you wish to have the data for your baby withdrawn from the study, simply advise us and we will destroy all records relevant to your child.

None of the background information will be used in any form, other than to ascertain that the infant has met the criteria for participation in this study. Any reference to this information will also be by number only, after which these records will be destroyed.

Thank-you again for your help and participation.

Sincerely,

Steven R. Gitterman
Experimenter

Hiram E. Fitzgerald
Professor of Psychology

Parents signature ______________________

Experimenters signature ____________________ .

MICHIGAN STATE UNIVERSITY

Department of Psychology East Lansing, Michigan 48824
Snyder Hall

Developmental Psychobiology Laboratory
Infant Learning Unit

Dear Parent(s):

For the past several years we have been studying the young infant's ability to pay attention to and learn from his or her environment. Over the next few months, we will be continuing our work by examining the abilities of three-month old infants to pay attention to certain picture presentations.

The procedure that will be used is quite simple. The infant will be seated in an infant seat in front of a movie screen (either parent, or anyone you wish, will be seated directly next to the infant throughout this procedure). Your baby will be shown a picture of a checkerboard for a minimum of 3 minutes, but in no case longer than 12 minutes (in fact, the responses by your baby will determine how long the checkerboard appears). While your baby is watching, we will be monitoring his or her heart rate, breathing, and whether he or she is looking at the screen. We are interested primarily in how your infant changes his or her looking behavior over time, a question that has been asked frequently in infant research but will be analyzed differently in this particular study.

In order to measure heart rate, it will be necessary to place three small surface electrodes on your baby's chest. To measure breathing, we will place a small rubber bellows around the baby's chest. These standard methods are completely safe and involve no discomfort to the child. The entire session usually lasts no longer than an hour. In order to have your baby feel as comfortable as possible, we ask that one parent remain with the infant throughout the study. if necessary, there are private areas where you can change and feed your baby if you wish. If at any time during the study you desire to stop, we will do so at once. If you are interested in participating in this project, or learning more about it before making your decision to participate, please sign and mail the enclosed card. When we receive a signed permission card, we will call you to make an appointment and to answer any additional question you might have. Be assured that your participation is wholly confidential, and we assign each participant a number to preserve anonymity. As a result, parents will be unable to receive information of their own infants performance, but a summary of the group results will be sent to all parents in the future. Please feel free to call us at the phone numbers listed below if you wish any additional information.

Thank you for your time and interest. We look forward to hearing from you in the near future.

Sincerely,

Steve Gitterman, M.A.
Project Coordinator (353-1651)

Dr. Hiram E. Fitzgerald
Professor of Psychology (353-3933)

SRG/hp

BACKGROUND INFORMATION SHEET

The information requested in this form will be used only to report the general characteristics of the infants used in our research. Only group results will be reported, and the identity of individual infants will remain anonymous. All information you provide on this form will remain strictly confidential.

Infant number _______ Stimulus number _______

Date of testing ______ Time of testing _______

Tape number and loc ____

____

Parents:

Date of birth ____________________ Sex ______________________
mo day year

Place of birth ____
City or town State

Weight at birth _________________ Weight now _______________
lbs oz. lbs. oz.

Height at birth _________________ Height now _______________
inches inches

Due date _________________________
mo day year

Any complications during pregnancy ?_____ If so, please briefly describe them.

Was any anesthetic used during labor and/or delivery (for example, local anesthetic, gas, saddle block)?____ If so, please describe briefly.

Has your infant received any medication since birth?___ If so, please briefly describe.

Is your infant, ____ bottle fed, ____ breast fed, or ___ some combination, with bottle feeding __75%, __50%, __5%.

Is this your first child ? ___. If no, how many other children do you have ___.

Any special problems with ( )colic ( )rashes ( )feeding ( )sleeping. If so, please briefly describe.

Is there anything else special about your infant that you feel it would be important for us to know about for this project ? If so, please describe.

Thank you very much for your time.

APPENDIX B

Subject Characteristics

Habituators

Subject number	age (days)	Sex
1	119	F
2	118	M
3	92	F
4	114	F
5	157	M
6	131	M

Non-habituators

Subject number	age (days)	Sex
1	107	M
2	167	F
3	146	M
4	113	F
5	122	M
6	102	M

Other subjects

Subject number	age (days)	Sex
1	128	M
2	137	M
3	148	M
4	109	F
5	114	M
6	143	F
7	149	M
8	114	F
9	118	M
10	119	M
11	113	F
12	114	F
13	148	F
14	141	M
15	109	M
16	113	F

APPENDIX C

Analysis of variance tables

TABLE 1

Analysis of Covariance of heart rate response to stimulus onset over trials for all 28 subjects.

Source	df	MS	F	p	con. df*	p**
Trials	9	622.088	1.86	.06	1,8	.20
error	242335.171					
Seconds	17	190.211	6.73	<.001	1,17	.02
error	459	28.262				
T by S	153	26.244	1.12	.15		
error	4131	23.463				

*con. df = degrees of freedom for conservative test of effect
**probability of conservative test

TABLE 2

Analysis of covariance of variability response to stimulus onset for all 28 subjects over trials.

Source	df	MS	F	p	con. df	p
Trials	9	1.197	.87	.55		
error	242	1.371				
Periods	3	3.101	3.84	.01	1,3	.17
error	81	.807				
T by P	27	.969	1.16	.26		
error	729	.835				

TABLE 3

T-test comparing habituation and nonhabituation groups on average of two longest fixations during first five trials.

T-TEST

Variable	number	mean	Standard deviation	Standard error
habituators	6	9.8	4.41	1.80
nonhabituators	6	15.5	2.23	.87

pooled variance estimate			separate variance estimate		
T-value	df	2-tail prob.	T-value	df	2-tail prob.
-2.83	10	.018	-2.83	7.20	.025

TABLE 4

T-test comparing habituation and nonhabituation groups on duration of first fixation time.

T-TEST

Variable	number	mean	Standard deviation	Standard error
habituators	6	8.82	6.62	2.51
nonhabituators	6	10.73	3.38	1.54

pooled variance estimate			separate variance estimate		
T-value	df	2-tail prob.	T-value	df	2-tail prob.
-.65	10	.529	-.65	8.32	.533

TABLE 5

Analysis of variance comparing variability response for prestimulus and poststimulus seconds on trial 1 by habituation group.

Source	df	MS	F	p	con. df	p
Group	1	1.024	.53	.48		
error	10	1.918				
Period	1	.007	.00	.96		
P by G	1	.982	2.93	.12		
error	10	.335				

TABLE 6

Analysis of variance comparing heart rate response for prestimulus and poststimulus seconds on trial 1 by habituation group.

Source	df	MS	F	p	con. df	p
Group	1	51.041	.16	.70		
error	10	326.229				
Period	1	.327	.03	.87		
P by G	1	15.360	1.24	.29		
error	10	12.428				

TABLE 7

Analysis of covariance for heart rate responses to stimulus onset by habituation groups over trials and over seconds.

Source	df	MS	F	p	con. df	p
Group	1	181.394	.31	.59		
error	9	583.851				
Trials	9	730.040	1.42	.19		
T by G	9	124.732	.24	.98		
error	89	515.310				
Seconds	17	79.272	2.51	<.01	1,17	.15
S by G	17	40.236	1.27	.22		
T by S	153	34.560	1.18	.07	9,17	>.25
T by S by G	153	19.508	.66	.99		
error	1530	29.343				

TABLE 8

Analysis of covariance of heart rate responses on trial preceding and trial of habituation for habituation group.

Source	df	MS	F	p	con. df	p
Trials	1	.011	.00	.95		
error	4	2.218				
Period	3	.303	.24	.86		
error	15	1.247				
T by P	3	.125	.19	.90		
error	15	.648				

TABLE 9

Analysis of covariance of variability response for habituation group to stimulus onset over trials and over periods.

Source	df	MS	F	p	con. df	p
Trials	9	1.959	1.31	.26		
error	44	1.492				
.B 1						
Periods	3	1.579	2.95	.07	1,3	.21
error	15	.535				
T by P	27	1.142	1.25	.20		
error	135	.91				

TABLE 10

Analysis of covariance for nonhanbituation group variability response to stimulus onset over trials and over periods

Source	df	MS	F	p	con. df	p
Trials	9	.626	.39	.93		
error	44	1.622				
Period	3	.321	.62	.61		
error	15	.517				
T by P	27	1.013	1.57	.05	3,9	>.25
error	135	.644				

TABLE 11

T-test comparing habituators fixation response on last habituation trial and dishabituation trial.

T-TEST

Variable	number	mean	Standard deviation	Standard error
last hab. trial	6	3.55	2.81	1.76
dishabituation	6	5.30	4.24	1.73

Difference	Standard deviation	Standard error	cor	T-value	df	2-tail prob.
-1.75	2.28	9.3	.86	-1.88	5	.119

TABLE 12

T-test comparing nonhabituators fixation response on last habituation trial and dishabituation trial

T-TEST

Variable	number	mean	Standard deviation	Standard error
last hab. trial	6	11.33	4.055	1.656
dishabituation	6	8.25	4.446	1.815

Difference	Standard deviation	Standard error	corr.	T-value	df	2-tail prob.
3.08	1.55	6.35	.937	4.86	5	.005

TABLE 13

Analysis of covariance comparing habituators heart rate response on last habituation and dishabituation trials.

Source	df	MS	F	p	con. df	p
Trials	1	99.493	.60	.48		
error	4	165.420				
Seconds	17	7.535	.25	.99		
error	85	29.586				
T by S	17	13.522	.30	.99		
error	85	44.866				

TABLE 14

Analysis of covariance comparing habituators variability response on last habituation trial and dishabituation trial.

Source	df	MS	F	p	con. df	p
Trials	1	.011	.00	.99		
error	4	2.019				
.B 1						
Periods	3	.303	.24	.86		
error	5	2.218				
T by P	3	.125	.19			
error	15	.648				

TABLE 15

Analysis of covariance comparing nonhabituators heart rate response on last habituation and dishabituation trials.

Source	df	MS	F	p	con. df	p
Trials	1	203.819	.42	.55		
error	4	488.890				
.B 1						
Seconds	17	42.930	1.71	.06	1,17	.22
error	85	25.090				
T by S	17	16.324	.55	.91		
error	85	29.660				

TABLE 16

Analysis of covariance comparing nonhabituator variability response on last habituation and dishabituation trials.

Source	df	MS	F	p	con. df	p
Trials	1	.059	.08	.79		
error	4	.722				
Periods	1	.199	.28	.84		
error	15	.721				
T by P	3	.822	2.02	.15		
error	15	.406				

TABLE 17

Analysis of variance for groups over trials with the variability of the entire 18 second stimulus presentation as dependent variable.

Source	df	MS	F	p	con. df	p
Group	1	.407	.14	.71		
error	10	2.966				
Trials	9	.408	.85	.57		
T by G	9	.406	.85	.58		
error	90	.480				

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