



University of Nebraska at Omaha
DigitalCommons@UNO

Student Work

11-1979

Cardiac Changes During an Attention-Demanding Task in Mentally Retarded Adults

James M. Granfield

University of Nebraska at Omaha

Follow this and additional works at: <https://digitalcommons.unomaha.edu/studentwork>

 Part of the [Psychology Commons](#)

Recommended Citation

Granfield, James M., "Cardiac Changes During an Attention-Demanding Task in Mentally Retarded Adults" (1979). *Student Work*. 97.
<https://digitalcommons.unomaha.edu/studentwork/97>

This Thesis is brought to you for free and open access by DigitalCommons@UNO. It has been accepted for inclusion in Student Work by an authorized administrator of DigitalCommons@UNO. For more information, please contact unodigitalcommons@unomaha.edu.



42

Cardiac Changes During
an Attention-Demanding Task in
Mentally Retarded Adults

UNIVERSITY LIBRARY
UNIVERSITY OF NEBRASKA
AT OMAHA

A Thesis
Presented to the
Department of Psychology
and the
Faculty of the Graduate College
University of Nebraska

In Partial Fulfillment
of the Requirements for the Degree
Masters of Arts
University of Nebraska at Omaha

by
James M. Granfield

November 1979

UMI Number: EP72737

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



UMI EP72737

Published by ProQuest LLC (2015). Copyright in the Dissertation held by the Author.

Microform Edition © ProQuest LLC.

All rights reserved. This work is protected against unauthorized copying under Title 17, United States Code



ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

THESIS ACCEPTANCE

Accepted for the faculty of the Graduate College, University of
Nebraska, in partial fulfillment of the requirements for the degree
Masters of Arts, University of Nebraska at Omaha.

THESIS COMMITTEE

Name	Department
<u>Gaylon L. Oswald</u>	<u>Psychology Dept</u>
<u>Melton Knudsen</u>	<u>Psychology Dept.</u>
<u>J. Miguel Leheny</u>	<u>Psychology</u>
<u>Sharon G. Gallen</u>	<u>Special Education</u>

Gaylon L. Oswald
Chairman

Nov 6, 1979
Date

Acknowledgements

The author wishes to express his thanks to a great many people who contributed their time and effort over the course of this study. To Dr. Joseph LaVoie who, along with the Psychology Department, provided me with the heart rate monitoring equipment, to Jack Toukatly who demonstrated its use, and to Jim Leyman who directed its initial calibration. Thanks are also extended to Ron Fanto and to Bob Wilson for their excellent photography. Special thanks are in order for Al Schlegel and his staff for the remarkably creative job they did in ascertaining how I wanted the stimulus pictures mounted and then turning this concept into a reality.

Thanks are also extended Susan Monti for the excellent job of typing all manuscript drafts. I also wish to thank my wife, Carol, who, aside from being the research assistant in the study, persevered through its entire course and never once lost faith in my ideals. For this I am eternally grateful.

I should also like to extend my appreciation to the staff of Glenwood State Hospital-School for their efforts during the study, in particular, Ron Bales, Bob Wallace, Max Moore, Bob Tungland, and members of the Research Committee. Special thanks go to Harold Adams who support and trust in me during the entire course of this project was greatly appreciated. Additionally, to those individuals who participated in this research, I extend my thanks not only for the cooperation they displayed, but also for the genuine enthusiasm they demonstrated toward participating in a research project.

I also wish to thank the members of my Thesis Committee for their critical reading of the manuscript and helpful suggestions for its revisions. Special thanks go to its Chairman, Dr. Gaylon Oswalt for his guidance during all facets of the study. Dr. Oswalt's sincerity in his willingness to discuss this study with me at any time provided me with a foundation of trust in my own ideas which, in the end, proved to be the decisive factor in seeing this study to fruition.

Additionally, a special note of appreciation is extended to Stephen Porges at the University of Illinois for the dedicated use of his staff, his computers, and his technology. Dr. Porges' enthusiasm and assistance during my 3 day visit was matched only by his persistent desire to investigate the fundamental questions in Psychology.

Finally, this paper would not be complete until due recognition is given to Stephen Paige. As friend and colleague for the past 5 years, Mr. Paige was instrumental in guiding and, at times, reformulating many of the ideas presented in the study. His assistance in surmounting the numerous technical problems that arose during the study is greatly appreciated even the ones where both of us walked blindly. For these reasons, and many more, I can safely say that "the jig is not up".

J.M.G.

Table of Contents

	<u>Page</u>
Acknowledgements	i
Introduction	1
Method	13
Subjects	13
Dependent Variables	13
Apparatus	16
Procedure	18
Quantification of the Data	20
Results	21
Recognition Measures	21
Spontaneous Heart Rate Activity	23
Trial Data	26
Discussion	33
Reference Notes	37
References	38

List of Tables and Figures

	<u>Page</u>
<u>Table 1A</u> Subject Characteristics	14
<u>Table 1B</u> Medical Diagnosis	14
<u>Table 2</u> Subject Withdrawal	22
<u>Table 3</u> Mean Percent of Correct Quadrants Per Trial Per Group	22
<u>Figure 1</u> Number of Trials Completed Per Group In Less Than 25 Seconds	24
<u>Figure 2</u> Mean Heart Period Log Variance Per Group During 55-Second Pre-Baseline	25
<u>Table 4</u> Comparison of 55-Second Pre-Baseline With the Trial Baseline (Period 1)	27
<u>Figure 3</u> Heart Period Log Variance During Baseline (Period 1) and On-Task (Periods 2 & 3)	28
<u>Figure 4</u> Mean Square Successive Difference During Baseline (Period 1) and On-Task (Periods 2 & 3)	29
<u>Figure 5</u> Mean Square Successive Difference for the Fast Responders (25 Seconds) Vs. the Slow Responders (25 Seconds)	31
<u>Figure 6</u> Heart Period Log Variance Between and Within Trials for Slow and Fast Responders	32

Abstract

The relationship between physiological response patterns and intellectual deficiencies was investigated by examining heart rate changes during a sustained attention-demanding task with institutionalized mentally retarded adults classified into three different I.Q. levels. The task consisted of simple motor responses made to a visual display within which was "hidden" the stimulus cue of Santa Claus. The findings indicated that changes in the within-trial heart rate response were significantly different between groups. Consistent with previous research on retarded adolescents, the retarded adults in the present study were characterized by a significant increase in heart rate variability upon stimulus onset. However, the high I.Q. group (\bar{X} I.Q.=61) and the middle I.Q. group (\bar{X} I.Q.=48) displayed significantly less variability in heart rate within the trials than did the low I.Q. group (\bar{X} I.Q.=36) who remained well above their base rates. Moreover, measures of latency indicated that the high I.Q. group responded significantly faster to the stimulus cues than did the other two groups. The present findings are discussed in terms of viewing peripheral deficits as manifestations of central nervous system deficits paralleling I.Q.

Mentally retarded individuals have been characterized as exhibiting deficits in attention and attentional processes. A number of investigators have demonstrated that when compared to non-retarded individuals, the retarded display slower reaction times (Collman, 1959; Baumesiter & Kellas, 1968), exhibit shorter alpha-blocking time (Lindsley, 1957; Berkson, Hermelin, & O'Connor, 1961), require a longer time to inspect a stimulus (Lally & Nettlebeck, 1977), and exhibit general deficits in overall attentional performance (Zeaman & House, 1963; Heal & Johnson, 1973). Such attentional deficiencies in the retarded likely result in an inadequacy in obtaining relevant information from the environment. Indeed, it may be this attentional deficiency that prevents them from learning to adapt competently to changing environments.

One of the major difficulties encountered in studying attention, regardless of the population, is the lack of agreement among investigators as to the definition of the concept. Traditionally, measurements of attention have ranged from the assessment of physiological alterations due to abrupt changes in stimulation, i.e., gun shots, buzzers, (Landis & Hunt, 1939; Wallace & Fuhr, 1970) to the subtle instrumental behaviors associated with focused or sustained attention (Wachtel, 1967; Porges & Humphrey, 1977). James (1890), for example, distinguished between passive-reflexive and active-voluntary attention. Passive-reflexive attention was always involuntary and immediate and related to nothing but the object that impinged directly into the senses. Active-voluntary attention, on the other hand, was always derived from past experiences and related directly to the motivation and interests of the organism. It involved the voluntary selection of environmental stimuli which

functioned to associate events and to form ideas. Pavlov (1927) first introduced the term "orientational reflex" (OR) as the behavior elicited by a stimulus which resulted in an organism immediately adjusting its appropriate receptor organ in order to make "full investigation" of the stimulus quality which initially elicited the response. This orientational reflex is comparable to James' "passive reflexive attention." Sokolov (1964) has revised this approach and reserved "adjusting" reactions to simple receptor-directed changes in posture and "orienting" reactions to a general increase in excitation and overall mobilization of the sensory system, the latter being the most common view of the OR in the literature.

This notion of an increase (or decrease) in excitation of the sensory or nervous system in response to stimulation is not new. The concept of modulated arousal has provided many investigators with a foundation upon which to make remarkable advances in demonstrating reliable relationships between specific brain areas and behavior (Moruzzi & Magoun, 1949; Olds, 1958; Hernandez-Peon, 1964). Such a relationship has been demonstrated between components of cardiac activity and different types of attention (Lacey, 1956; Lacey & Lacey, 1958; Obrist, 1963; Kagen & Rosman, 1964). Porges (1972) has postulated a two-component model of attention similar to James'. The first, a reactive component, involves a sudden reactive heart rate response to brief changes in stimulation the magnitude and direction of which is a function of the stimulus signal value. Orienting reactions and startle reflexes with corresponding heart rate decelerations occurring with the OR (novel or mild stimuli) and heart rate accelerations

occurring with the startle reflex (intense stimuli) are characteristics of this reactive phase of attention. Porges maintains that the effect is primarily vagally mediated through parasympathetic nervous system inhibition (heart rate acceleration) or activation (heart rate deceleration). The second component involves a gradual reduction in heart rate and heart rate variability (the inter-beat interval becomes more constant) and a generalized inhibition of respiratory and motoric activity. Physiologically, this effect can be characterized by an increase in parasympathetic activity which serves to attenuate sympathetic nervous system activity thereby facilitating the processing of information. This second component is associated with sustained attention and follows the reactive component by 5-6 seconds. Porges maintains that this response may persist for as long as the observer elects to attend.

Although Sokolov (1964) never directly addressed the issue of cardiac changes and their relationship to the OR, some investigators have maintained that they do play a role in his model (Graham & Clifton, 1966). In both the OR and defensive reactions, the latter being reactions to intense stimulation (Sokolov, 1964), heart rate tends to increase. However, in the OR, with repeated exposures, these increases become less and less pronounced (habituate) as the incoming stimuli are properly analyzed and compared to the internalized model.¹ Conversely, in

¹Sokolov has proposed that a novel stimulus evokes an OR mainly because the organism has no "internalized" representation of that stimulus. Upon repetition, the quality, intensity, frequency, and duration of the stimulus become internalized and all new stimuli are analyzed and compared to it. Habituation occurs when the stimuli matches all the dimensions of the model.

defensive reactions, heart rate remains elevated until the stimulus is removed and no habituation is demonstrated upon stimulus repetition.

The Laceys have investigated specific heart rate changes in response to complex environmental inputs requiring attention or internal problem-solving abilities (Lacey, 1956; Lacey & Lacey, 1958; Lacey, Kagen, Lacey, & Moss, 1963). Although both Sokolov and the Laceys emphasize the feedback within the autonomic nervous system and its role in amplifying or reducing the organism's sensitivity to environmental inputs, the Laceys maintain that heart rate decelerations accompany the OR and serve to mobilize the entire sensory system. Specifically, the Laceys hypothesize that a rise in heart rate and blood pressure stimulates the baroreceptors within the carotid sinus to produce impulses along Herings nerve resulting in inhibition of cortical and sensori-motor activity. They further hypothesize that since heart rate increases result in cortical inhibition and thus, to a reduction in sensitivity to environmental stimulation, it should facilitate a "rejection of environmental inputs." In situations involving pain or otherwise unpleasant stimulation or in situations where external distractions would interfere with internal problem-solving, the Laceys predict an increase in heart rate. Conversely, heart rate decreases should be associated with increased sensitivity to stimulation and should facilitate an "acceptance of environmental inputs." This should occur in situations involving attention to the environment where information from the environment is needed to complete a task.

Although the theories of Sokolov and the Laceys differ on a number of points, the major distinction for our purposes rests upon their emphasis of either tonic or phasic heart rate changes. Tonic rate, the primary method used by Sokolov, involves brief changes in heart rate

(1-2 seconds) in response to stimulation (the reactive component of attention in Porges' model). The Lacey's, on the other hand, utilize phasic heart rate involving heart rate changes over an extended period of time (up to 1 minute) in response to complex stimulation (the sustained attention component in Porges' model). The similarity of both approaches is not that the OR and attention are identical processes, although one may precede the other, but rather that both emphasize different directional heart rate changes in enhancing the sensitivity to environmental events.

One way to assess the relationship between heart rate and attention is to investigate a population which has demonstrated attentional deficits. As noted at the outset of this paper, attentional deficits have been reported in the mentally retarded population. Additionally, they also have demonstratable deficits in physiological activity as well.

Powazek and Johnson (1973) investigated the OR in normal and mentally retarded (\bar{X} I.Q. = 60) subjects. Half of each group received auditory signals (73dB buzzer at 1,000 Hz) and were instructed to listen for the tone. The remaining subjects were given the same auditory tone and instructed to press a lever to obtain an M&M. Heart rate was continually monitored throughout the task. The results showed that in the retarded group fewer OR's were elicited to the stimulus than in the normal group. Additionally, retarded subjects also displayed significantly higher heart rates across sessions. The authors maintained that the data are consistent with Sokolov's model in that the heart rate increases were indicative of a defensive reaction and not one of an OR since no habituation in heart rate was demonstrated upon stimulus repetition.

Luria and Vinogradova (1959)² have reported that the retarded exhibit OR's to words that are both similar in sound and meaning to previously shock-conditioned words. As I.Q. decreases, the similarity of the sound of the stimulus word to the key word are more effective (had a shorter latency) in eliciting an OR than are the synonymous words. Luria (1963) has found that stimuli of weak to mild intensity which produce OR's in normal children fail to produce OR's in retarded children. Luria maintains that stimuli of strong intensity will evoke an OR in retarded children and a defensive reaction in normal children.

Some support for this latter finding comes from investigations of the startle reaction in response to a gunshot (Pryor & Ellis, 1959). Galvanic Skin Responses (GSR) were recorded in a group of 60 males and female adult retarded persons for 12 minutes following stimulus presentation. The results indicated that only females with a relatively high I.Q. (\bar{X} I.Q. = 51.5) demonstrated a significant increase in GSR. Landis and Hunt (1939), also using a gunshot as the stimulus, found that the startle reaction in a group of mentally retarded was more pronounced (had a higher amplitude) on the GSR than it was for the normal group.

Although the OR was not the explicit mechanism under investigation, there are some studies that have emphasized the reactive component of it.

²The data from the Russian literature concerning the OR has, historically, been stimulating and provocative. However, too often they do not report information that is essential to the proper acceptance by Western scientists. They continually fail to specify the criteria for subject selection, the exact procedures employed in the methodology, the intensity and duration of stimulus presentation, etc. For this reason, caution should be exercised in reviewing their data.

Berkson, Hermelin, and O'Connor (1961) recorded resting levels of heart rate and SR among institutionalized retarded individuals and normals. Although no differences in resting levels were found between the mildly retarded group (\bar{X} I.Q. = 60) and the normal group, the moderately and severely retarded group (\bar{X} I.Q. = 33.5) displayed significantly higher resting levels on SR. The normal group was more responsive in GSR to brief visual stimuli displaying decreases whereas the retarded groups showed GSR increases. The normal group also displayed significantly longer alpha-blocking time than did the retarded group.

Karrer (1965) has suggested that the initial direction of heart rate change upon external stimulation is related to the purpose for which an organism interacts with its environment. He measured heart rate changes (R-R intervals) resulting from a brief auditory signal (56dB buzzer) in normal and retarded (\bar{X} I.Q. = 54.8) subjects. Results indicated that the normal subjects demonstrated an initial heart rate deceleration followed by a rapid heart rate increase. The retarded subjects also showed an initial heart rate decrease but failed to show a compensatory heart rate increase. Karrer concluded that the effect was a centrally-acting process and reflected a passive reception of sensory stimuli (facilitating environmental input) as contrasted with active attention (rejection of environmental inputs) displayed by the normal subjects.

Karrer and Clausen (1964), measuring resting levels on SR, heart rate, blood pressure, and finger volume in a group of institutionalized retarded individuals (\bar{X} I.Q. = 55) and normals, found only SR to be significantly different in the direction of increased skin conductance

(lower SR) for the retarded group. They also found, however, that the retarded had lower amplitude in heart rate and SR in response to the buzzer when compared to the normal group although they tended to exhibit a large but nonsignificant trend in blood pressure.

The above studies have been concerned with the reactive component of attention, i.e., responses to brief non-signal stimuli. There are a few additional studies that concern responses made to complex stimuli, i.e., sustained attention. Collman (1959) obtained SR responses in a large group of mentally retarded, normal, and bright subjects to a variety of pictures and words as well as responses to a verbal warning signal prior to each task. He found that the retarded (\bar{X} I.Q. = 70) and the dull (\bar{X} I.Q. = 80) tended to have higher resting SR levels than the average (\bar{X} I.Q. = 101) or the bright (\bar{X} I.Q. = 132) subjects. In response to stimulation, the dull and average subjects exhibited significantly greater SR decreases than did the retarded or bright subjects. Collman concluded that a curvilinear relationship exists between autonomic reactivity and I.Q. with the greatest reactivity around I.Q. 90. Vogel (1961) has essentially confirmed this curvilinear relationship.

Das and Bower (1973) investigated heart rate responses to a probability learning task in normal and retarded (\bar{X} I.Q. = 53) adolescents. The task required the subjects to predict the occurrence of a certain letter (X or Y) given prior knowledge of the probability of their association with the stimulus word. Heart rate was recorded during two phases; anticipation of results (lasting 4 seconds after the stimulus was removed), and feedback where the onset of a light signalled the subject that he was about to receive knowledge of the correctness of his responses. The results of the first phase (antici-

pation showed that heart rate tended to show an increase in rate across I.Q. such that the higher I.Q. group (\bar{X} I.Q. = 64) and the normals displayed heart rate accelerations whereas the lower I.Q. group (\bar{X} I.Q. = 42) displayed greater variability in heart rate with a non-significant tendency to decelerate. During the feedback phase, the higher I.Q. and normal subjects displayed significantly greater heart rate decelerations whereas the lower I.Q. groups remained variable in heart rate and continued to show a trend to decelerate. Das and Bower interpret the results as reflecting an internal cognitive integration of the responses during the anticipation phase which necessitated an inhibition of sensation from external stimulation on the part of the higher I.Q. and normal subjects. The lower I.Q. group displayed no such integration or inhibition of physiological activity. They hypothesize that during the feedback phase, the heart rate deceleration evidenced by the higher I.Q. and normal subjects reflects a facilitation of environmental inputs (knowledge of the correctness of his responses) necessary for the performance in a probability task.

Porges (1974) notes that although the directionality of the heart rate response has generated much research, the variability component of it has been relatively neglected. Heart rate variability can be defined as the beat-by-beat changes in heart rate during a specified amount of time. It contrasts with heart rate acceleration and deceleration which reflect an abbreviation or elongation of the interbeat interval (heart period). Porges maintains that heart rate variability combined with measurements of respiration, represent the fluctuating state changes found within the autonomic nervous system and as such

merit further investigation as a measure of sustained attention (Porges & Raskin, 1969; Porges, 1972; Porges, Walter, Korb, & Sprague, 1975; Cheung & Porges, 1976).

Porges and Humphrey (1977) investigated the effects of a sustained visual attention task on heart rate in normal and mentally retarded (M.A. = 3-8 yrs.) subjects. All subjects were seated in front of a visual display board which was divided into equal quadrants upon which were projected four separate pictures with the "Snoopy" cartoon character hidden in some of the pictures. Each quadrant was outlined in a different color. The subjects were instructed to search each quadrant for the hidden Snoopy characters. Subjects were to press the "on" button located on the panel before them. This illuminated the corresponding colored quadrant on the display screen in which the Snoopy appeared. The task was completed when the subject pressed the "all-done" button indicating that he had identified all the characters. During each trial period, heart rate and respiration were monitored. Analysis of the results indicated that the normal subjects were characterized by a suppression in heart rate variability and respiration whereas the retarded group displayed not a suppression but a significant increase in heart rate variability and respiration across sessions. Since heart rate variability has been associated with parasympathetic responding, Porges and Humphrey suggest that the retarded may have deficits in parasympathetic nervous system responding as manifested by their inability to suppress the variability in heart rate.

Although Porges and Humphrey have provided us with an alternate view of the psychophysiology of the retarded, there are limitations to their

study. For example, the "attention-demanding" task may have been less salient for the retarded subjects than for the normal subjects since they may have had less exposure to or less appreciation for the Snoopy character than did the normal subjects. This factor may have accounted, at least in part, for the more correct responding on the part of the normal subjects. Heart rate increases in the retarded subjects, then, could have been in response to the anxiety associated with not knowing what to respond to. Additionally, the small sample size of the retarded group ($n = 16$) may have limited the results to the specific M.A. range studied. Thus, any general conclusions drawn concerning the retarded seems unjustified.

In summary, it is apparent from the research presented, that the mentally retarded exhibit differences with respect to normals on a variety of psychophysiological measures. There are trends in the literature that show, for example, that the retarded exhibit higher resting skin resistance levels than normals, exhibit fewer OR's than normals, and display a heart rate acceleratory response where normals display a heart rate deceleratory response to an attentional cue. There are some indications that these differences are related to the degree of retardation (cf. Collman, 1959; Vogel, 1961; Das and Bower, 1973). There also appears to be adequate support for the notion of a heart rate change in response to any attention-demanding situation. Although the literature is, at best, cautious in elucidating the mechanisms of such changes, there does appear to be strong support for a heart rate deceleratory response accompanying an attentional process.

The research of the Laceys presents a rather appealing theory as to the mechanisms of this response, however, vital aspects of the theory are, at present, beyond direct investigation in humans, i.e., role of the baroreceptor reflex. Moreover, some investigators have emphasized the importance of the overall organization of the nervous system to concepts such as attention and to advise that others not limit their investigations to specific directions a response system takes (Porges, Bohrer, Keren, Cheung, Drasgow, & McCabe, Note 1).

The present research was designed to investigate the differential relationship between heart rate variability and I.Q. Extending the methodology of Porges and Humphrey (1977), sample size has been increased, the range of I.Q. extended, and the stimulus figure has been changed from Snoopy to Santa Claus in an attempt to make it more salient. Taking Porges and Humphrey's premise that the ability to maintain attention is a function of the ability to attenuate ongoing sympathetic nervous system activity, then within the population of mentally retarded where different degrees of attention-maintaining skills are manifested in different rates of learning, it is likely that different levels of retardation will exhibit a differential attenuation of sympathetic nervous system activity. Two hypotheses were generated: First, that recognition of the stimulus cue would improve as I.Q. increased and; Second, that heart rate would be less variable as I.Q. increased.

Method

Subjects

Forty-five subjects, free of gross sensory, motor, and cardiac deficits as determined by a physician, were voluntarily selected from a large population of mentally retarded individuals residing in an institution in the Midwest. All subjects met the following criteria: a) were between the ages of 16 and 35, b) had a measured or extrapolated I.Q. of from 25 to 70, c) had been psychologically evaluated within 3 years of the start of the experiment, d) had been evaluated on the same testing instrument (WAIS). All subjects were assigned to one of the three groups based upon I.Q.: Group 1 (15 subjects) had an I.Q. from 25-40; Group 2 (15 subjects) had an I.Q. from 43-55; Group 3 (15 subjects) had an I.Q. from 58-70. Table 1 (a + b) provides a summary of subject characteristics. For reasons stated below, only information on 33 subjects is presented.

Dependent Variables

In order to more accurately detect differences in heart rate variability, two measures of it were used in the present study. Heart period log variance represents the natural log of the overall variability in heart rate. It is based on the simple variance, $\frac{\sum(X - \bar{X})^2}{n}$ of the beat to beat intervals in a specific time period. The second measure of variability used is the Mean Square Successive Difference statistic (Leiderman & Shapiro, 1962). This is a time series statistic used to assess sequential points along a continuously changing function, i.e., heart period. Mathematically, a time series may be described as a

Table Ia
Subject Characteristics

	I.Q. Range	\bar{X} I.Q.	S.D.	\bar{X} Chronological Age	Sex	
					M	F
Group 1	32-39	36	2.1	26.1	7	4
Group 2	45-54	48	3.0	20.3	8	3
Group 3	58-70	61	6.0	25.7	8	3

Table Ib
Medical Diagnosis

	Uncertain Cause	Encephalopathy	Birth Injury	Hypothyroidism	Hydrocephaly	Post-Natal Injury	Prader-Willi Syndrome	Craniosostenosis
Group 1	7	2	0	1	1	0	0	0
Group 2	6	1	2	0	0	2	0	0
Group 3	6	0	1	1	1	0	1	1

string of random variables that are sequentially indexed;

$$X_t + X_{t+1}, X_{t+2}, \dots, X_{t+n}$$

where t represents time and X is the measure under consideration. The Mean Square Successive Difference (δ^2), then, can be defined as:

$$\delta^2 = \frac{\sum (X_t - X_{t+1})^2}{n-1}$$

Whereas, the log variance measure describes the overall central tendency of the series and the variability associated with it, the δ^2 describes the trend around which successive points vary.

Since it is important for the reader to fully understand the difference between these two measures, the following example is presented. Suppose measurement of heart period yielded the following series:

830 816 809

the Mean (\bar{X}) of this series is 818.34 and the variance is 114.3. The δ^2 is calculated to be 122.5. Now using the same heart period but altering its trend

816 830 809

yeilds the same \bar{X} and variance but the δ^2 is now calculated at 318.5. From this example, we can see that the variance does not detect the trend in the heart period, whereas, the change in heart period is detected by an increase in δ^2 . In general, if the trend is linear, the variance and δ^2 will be low and similar. If the trend is non-linear, the δ^2 will change and increase in respect to the variance regardless of whether the trend in heart period is acceleratory or deceleratory. Thus, it is possible to have significant differences on one measure of variability and not the other.

The reasons for choosing two measures of variability rests upon methodological as well as statistical grounds. The measure used in the Porges and Humphrey (1977) study was log variance and thus, to facilitate discussion, this measure has been obtained. However, Porges et. al. (note 1) maintains the variance measure may not be statistically independent of the mean. Thus, different rhythmic patterns in heart period representing fluctuations within the autonomic nervous system may go undetected thereby artificially lowering the actual variability in heart period. Thus use of the Mean Square Successive Difference statistic should avoid this problem.

Apparatus

An experimental room (5m.X5m.) was used for all testing sessions and was chosen so as to minimize auditory and visual distractions. A 40 watt light bulb provided illumination. In the room were two chairs, a small table, the response panel, and the display screen. The response panel (83cm.X83cm.) contained five toggle switches. Four of the switches were colored and wired directly to the corresponding color on the display screen (red, green, blue, or yellow). A fifth switch ("all done switch") was colored black and was wired directly to an interval timer. The display screen (83cm.X83cm.) was fastened to the end of the response panel and was perpendicular to it. The projection area of the screen (76cm.X76cm.) was divided into four equal viewing areas (quadrants). All of the borders surrounding each quadrant were colored according to the colors of the switch wired to it. Additionally, four small colored light bulbs were positioned directly over or under the middle of each viewing area and were illuminated when the proper color switch was activated. Stimuli were presented on a Kodak Carousel slide projector located 3.66m. behind the display screen.

Trial stimuli consisted of individually-presented slides with each slide divided into four equal quadrants. Four scenes of the institution grounds with five pictures of each scene were randomly selected such that during each trial, a different scene was projected into each quadrant. During subsequent trials, the scenes shifted to a different quadrant. Of the five pictures of each scene, four contained the stimulus cue of Santa Claus in different locations within each scene. The fifth picture was identical to the other four except Santa Claus was not in it. During the test sessions with a projected picture size of 38.1 cm. square, the Santa ranged in height from 1.91 cm. to 3.81 cm. Location of Santa Claus varied from scene to scene, but the topography of his presence remained unchanged. For example, in one scene, Santa was poking his head out from behind a tree whereas in another scene, he was poking his head out from a doorway. For the testing sessions, the slides contained either 0, 1, 2, 3 or 4 Santas with no more than one Santa per quadrant. The order of slide presentation was held constant across all groups.

For the pre-test slides, recognition of the Santa was "faded" into the task. Thus, the first three slides contained a picture of Santa Claus standing alone (26.67 cm. high). The next three slides contained Santa (16.51 cm. high) standing in front of a tree. The last four slides contained Santa (8.89 cm. high) leaning out from behind a tree.

The programming equipment, located outside the experimental room, consisted of timers and relay circuitry which provided for the occurrence and timing of stimulus events. Heart rate was monitored with a Hewlett-Packard telemetry system utilizing a H-P transmitter (#78100A) and a H-P electrocardiographic receiver (#1500B) affixed with heat-

sensitive EKG tape. Although paper tracings were not obtained during the trials, baseline tracings were obtained to confirm appropriate amplitudes of the waveforms. All the heart rate analogue data was then fed into a Vetter's 4-Channel FM tape recorder (model C-4) for analysis on a PDP-11 computer.

Procedure

Each subject was escorted into the testing room and introduced to a female research assistant who was in the room during all sessions. Each subject was allowed to look around the room for five minutes. In cases of non-verbal subjects, the experimenter pointed to the various items in the room. After this adaptation period, the subject was asked to sit in front of the response panel. The heart rate recording sites were located on the subject's back approximately 5.08 cm. on either side of the spinal column and at the lower level of the shoulder blades. A third recording site was approximately 8.89 cm. below the first sites and just to the left of the spine. All recording sites were cleaned with a 70% ethanol solution prior to the application of Beckman biopotential silver-silver electrodes that were filled with Beckman electrode paste and attached with self-adhesive collars.

Prior to the start of the experiment, a 55-second pre-baseline was taken on heart rate so as to insure proper placement of the electrodes and as a measure of spontaneous heart rate. The task consisted of 10 pre-test trials and 15 test trials. After the pre-baseline had been taken, the experimenter demonstrated the correct procedure for responding to each subject. A sample slide was projected onto the display screen. Santa Claus appeared in one of the quadrants while the remaining three quadrants remained the color of their respective

quadrants. The experimenter activated the proper colored switch on the response panel that illuminated the colored light over the quadrant in which the Santa appeared. This procedure was followed for 3 slides with Santa appearing in different locations in each slide. The subject was then told, "Now you try it." The same 3 slides were presented to the subject and he was required to make the responses himself. After this was completed, the experimenter left the room and the pre-test trials began.

The pre-test trials consisted of 10 individually-presented slides. The first three slides contained only Santa. The middle three slides contained Santa but with some background. The last four slides contained Santa hidden almost completely in the picture. During the last four slides, all three pre-test Santas appeared in different quadrants. The criterion for recognition was 100% correct responding to the last four slides. When this criterion was met, the testing session began.

Each testing session consisted of 15 test trials. Each trial lasted a maximum of one minute. Between the end of each trial was an inter-trial interval of 15 seconds. Each trial began with the onset of slide presentation.

Four picture, one in each quadrant of the screen, were presented during each trial. The subject pushed the "on" button located on the response panel that illuminated the corresponding color on the display screen and the quadrant in which Santa was seen. If the Santa was not in a particular quadrant, the corresponding light was not activated. If the subject illuminated a quadrant in which a Santa did not appear, it was scored as an incorrect response only when that

particular trial was terminated. Subjects were allowed to change a choice if desired simply by pulling down on the switch. This was allowed, however, only during that particular trial. When the subject felt he had identified all the Santas in that trial, he pushed the "all done" button terminating that trial.

Quantification of the Data

Each of the 15 test trials were divided into five 5-second sequential periods for heart rate analysis: Period 1 (5-seconds prior to stimulus onset); Period 2 (first 5-seconds after stimulus onset); Period 3 (second 5-seconds after stimulus onset); Period 4 (third 5-seconds after stimulus onset); Period 5 (fourth 5-seconds after stimulus onset). The mean heart period (time between successive beats), heart period log variance, and the Mean Square Successive Difference statistic were computed for each of the 5 periods on each trial for each subject. So as to convert these beat-by-beat measures into time-based data, successive 1-second windows were established within each trial. The weighted mean heart period for each 1-second window was computed as the sum of the heart periods that occupied a specific 1-second window multiplied by the proportion of the window that the heart period occupies. The editing of the heart rate data after it was digitized was accomplished by plotting each 1-second heart period and summing or dividing successive points, if necessary, in order to bring each point into the "best fit" trend of the points preceding and following them.

Results

From the 45 subjects originally selected, data on 33 subjects (11 per group) were submitted to statistical analysis. Table 2 provides the reasons for subject withdrawal. Additionally, due to the persistent problem of heart rate artifacts, it was impossible to analyze all 15 trials. In order to obtain the maximum amount of data, the number of trials where heart rate measures were obtained were noted for each subject. The total number of trials suitable for analysis across all subjects was 12. Data from Trials 8, 9, and 15 were not analyzed. Thus, data was analyzed on 33 subjects across 12 trials. Moreover, since a number of subjects ended some of the trials within 15 seconds, only data from periods 1, 2, and 3 were submitted to analysis.

Recognition Measures

A two-way analysis of variance with repeated measures was performed on the percent of quadrants correct per trial for all three I.Q. groups (Table 3). Although there was a distinct upward trend in correct recognition as I.Q. increased, except during Trials 2 and 4, the analysis revealed no statistically significant differences between the groups on recognition of a stimulus figure Santa Claus ($F(2,30)=2.31$, $p \geq .05$). Moreover, the complexity of each trial, defined as the number of Santas in each picture, did not reveal any group differences as demonstrated by a nonsignificant group X trial interaction ($F(22,30)=1.00$, $p > .05$). However, a one-way analysis of variance on the response latency measures did yield significant differences among groups in latency to end each trial ($F(2,30)=7.27$, $p < .003$). A post-hoc Tukey multiple range test ($\alpha .05$) performed on the latency data revealed

Subject Withdrawal

	Refused to continue once trials began	Seizure during trials	Did not meet pre-test criteria	Heart rate not analyzable	N=
Group 1	1	0		1	11
Group 2	1	0		2	11
Group 3	0	1	0	3	11
					N=33

Table 3
Mean percent of correct quadrants per trial per group

Groups	T R L A I												\bar{X}
	1	2	3	4	5	6	7	8	9	10	11	12	
1	81.8	86.4	75.5	95.5	76.6	79.5	93.2	81.8	80.3	90.9	86.4	71.2	83.3
2	90.9	81.8	81.8	84.1	94.0	81.8	95.5	93.2	87.1	95.5	87.9	86.5	88.1
3	100.0	77.3	84.1	95.5	77.0	81.8	95.5	81.8	85.7	95.5	100.0	100.0	93.3

that Group 3 accounted for this difference by terminating more trials faster (within 25 seconds) than either Group 1 or Group 2. This effect reflects the different response latencies seen in Figure 1. In summary, although the groups did not differ significantly in the number of correct identifications, the high I.Q. group responded much faster than the other two groups.

Spontaneous Heart Rate Activity

Since spontaneous heart rate activity has been used as a measure of the lability of the autonomic nervous system, the 55-second pre-trial baseline was submitted to a one-way analysis of variance to test for group differences in heart period, heart period log variance, and mean square successive difference. Although Group 1 demonstrated an elevation in heart period ($\bar{X} = 838.3\text{msec.}$) when compared with Group 2 ($\bar{X} = 698.1\text{msec.}$) and Group 3 ($\bar{X} = 774.5\text{msec.}$), this difference was not significant ($F(2,30)=1.00, p > .05$). Likewise, the analysis performed on mean successive difference measures yielded a nonsignificant group effect ($F(2,30)=1.08, p > .05$). However, the analysis of heart period log variance did yield a significant group effect ($F(2,30)=3.53, p < .05$). As can be seen in Figure 2, this effect was characterized by a greater amount of overall variability in heart period as I.Q. decreased.

To insure the validity of heart rate activity during each trial baseline (Period 1), the 55-second pre-trial baseline was compared to the trial baseline. The results parallel those obtained during the analysis of the 55-second baseline. There was no statistically significant differences between the groups in baseline heart period scores ($F(1,19)=2.48, p > .05$) or in baseline mean successive difference scores ($F(1,19)=3.41, p > .05$). However, there was a significant group effect for heart period log variance ($F(1,19)=19.42, p < .001$).

Figure 1

Number of trials completed per group
in less than 25 seconds

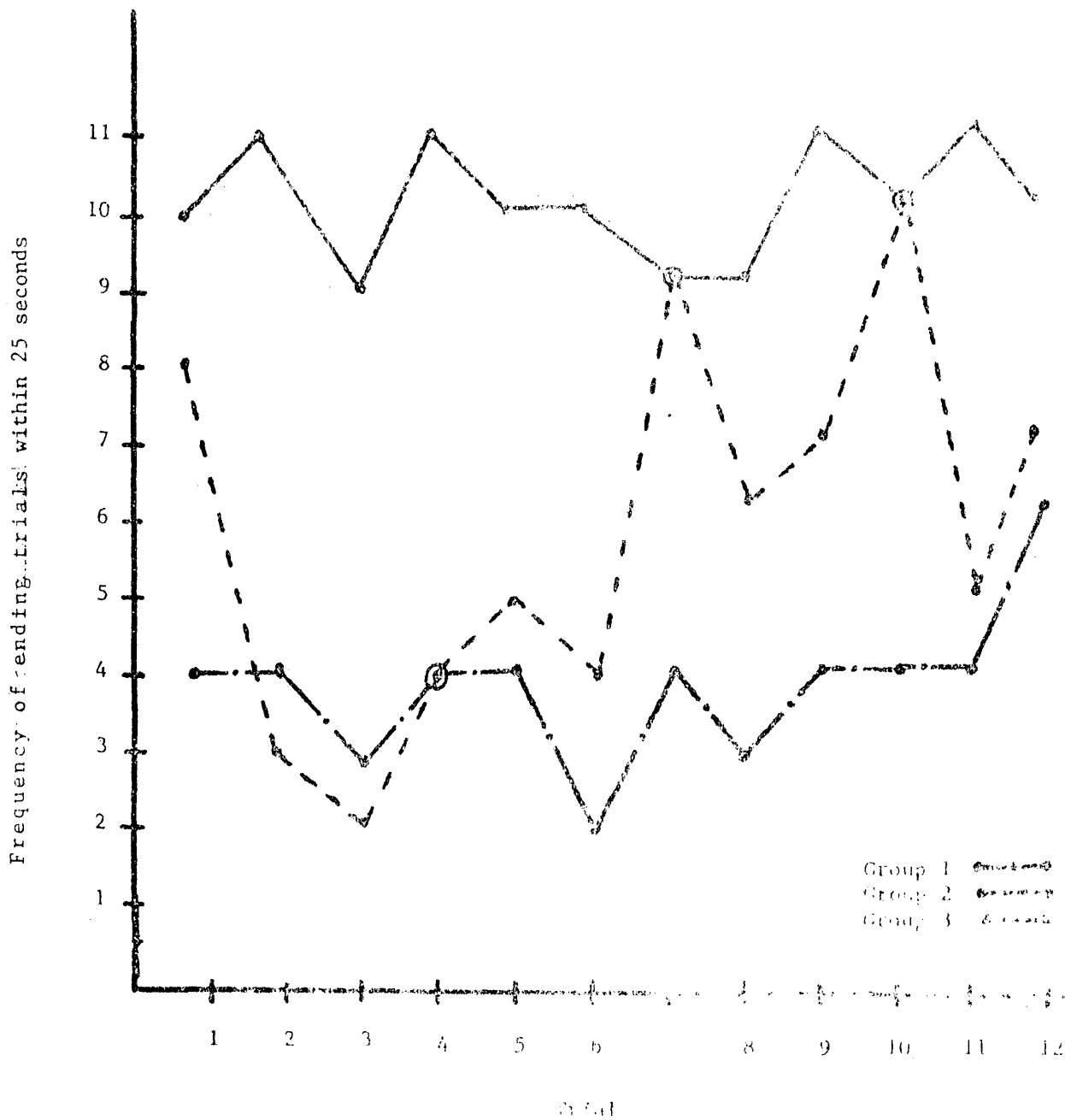
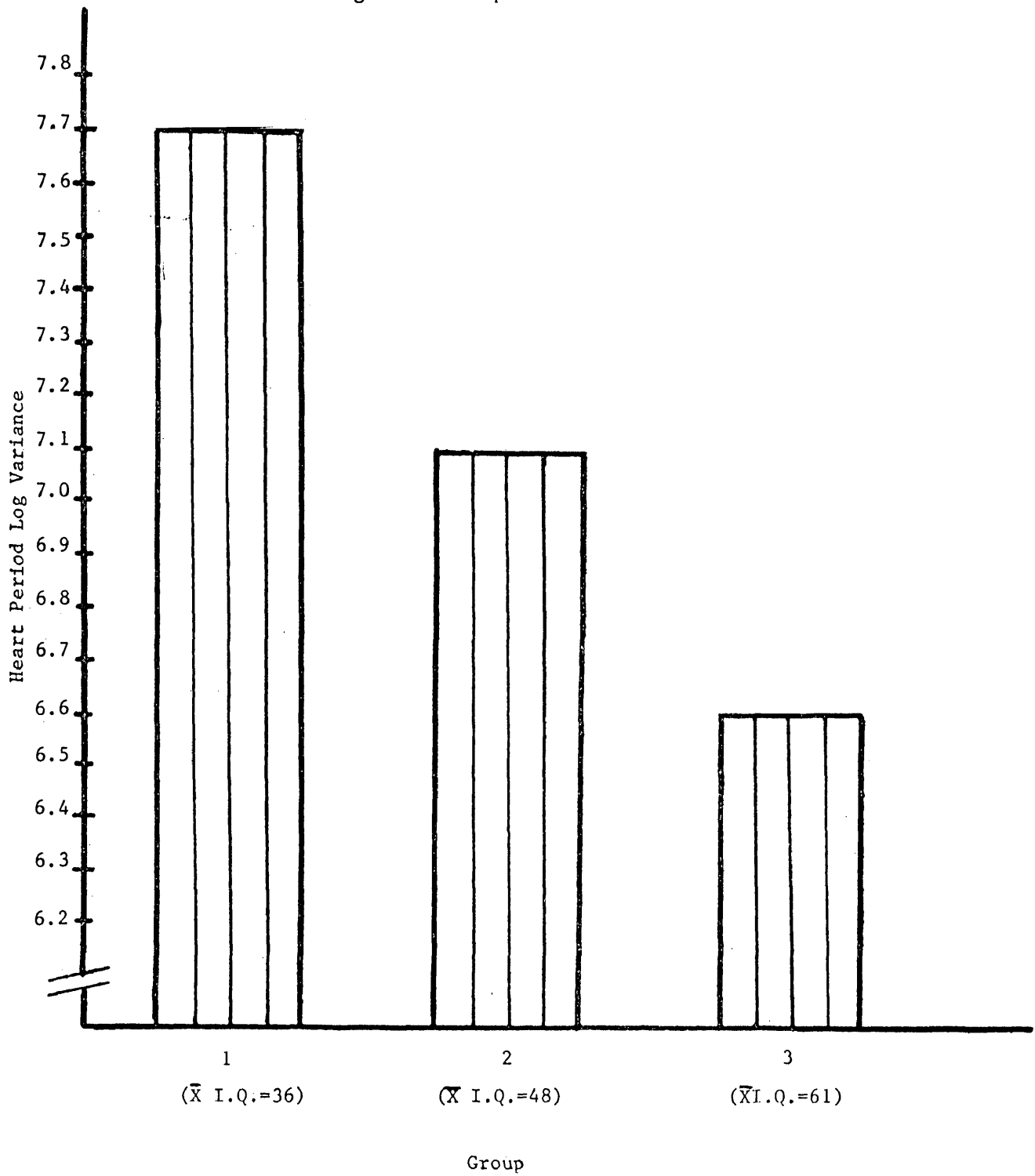


Figure 2

Mean Heart Period Log Variance per group
during 55-second pre-baseline



Inspection of Table 4 reveals that although there appears to be a group effect for mean successive difference, this relationship was characterized by a lack of a significant trend in variability. The effect observed for log variance reflects the difference in total variability between the groups. Thus, the beat-to-beat changes in heart period for the 55-second pre-baseline and Period 1 indicates no differences between the three I.Q. groups. In contrast, there was a difference between the groups on the two baselines using log variance as a measure of the overall variability in heart period.

Trial Data

Repeated measures analysis of variance over the three within-trial periods were performed on all three groups across all 12 trials. Heart period log variance changed significantly during the three periods ($F(2,60)=3.25, p < .05$). As illustrated in Figure 3, this period effect was characterized by an increase in variability during Period 2. Moreover, the levels of variability for Group 1 remained above the pre-trial levels during Period 3. A 3 X 3 analysis of variance comparing all three groups across the three within-trial periods on the mean successive difference measures yielded a significant period effect ($F(2,60)=4.20, p < .02$) and a significant group effect ($F(2,30)=6.25, p < .01$). An inspection of Figure 4 reveals that Group 1 was characterized by a greater amount of change in the trend of the heart period across each trial when compared to the other two groups.

A post-hoc analysis was applied in order to investigate the relationship between heart rate variability and response latency. Total number

Table 4

Comparison of 55-second pre-baseline
with the trial baseline (Period 1)

	Heart Period (msec)		Log Variance *		Mean Square Successive Difference	
	55-Second	Period 1	55-Second	Period 1	55-Second	Period 1
Group 1	838.3	856.6	7.7	6.8	1190.7	1135.7
Group 2	698.1	708.7	7.1	6.1	402.7	411.5
Group 3	774.5	792.2	6.6	6.0	563.5	439.4

* $P < .05$

Figure 3

Heart Period Log Variance during
baseline (Period 1) and on-task (Periods 2 & 3)

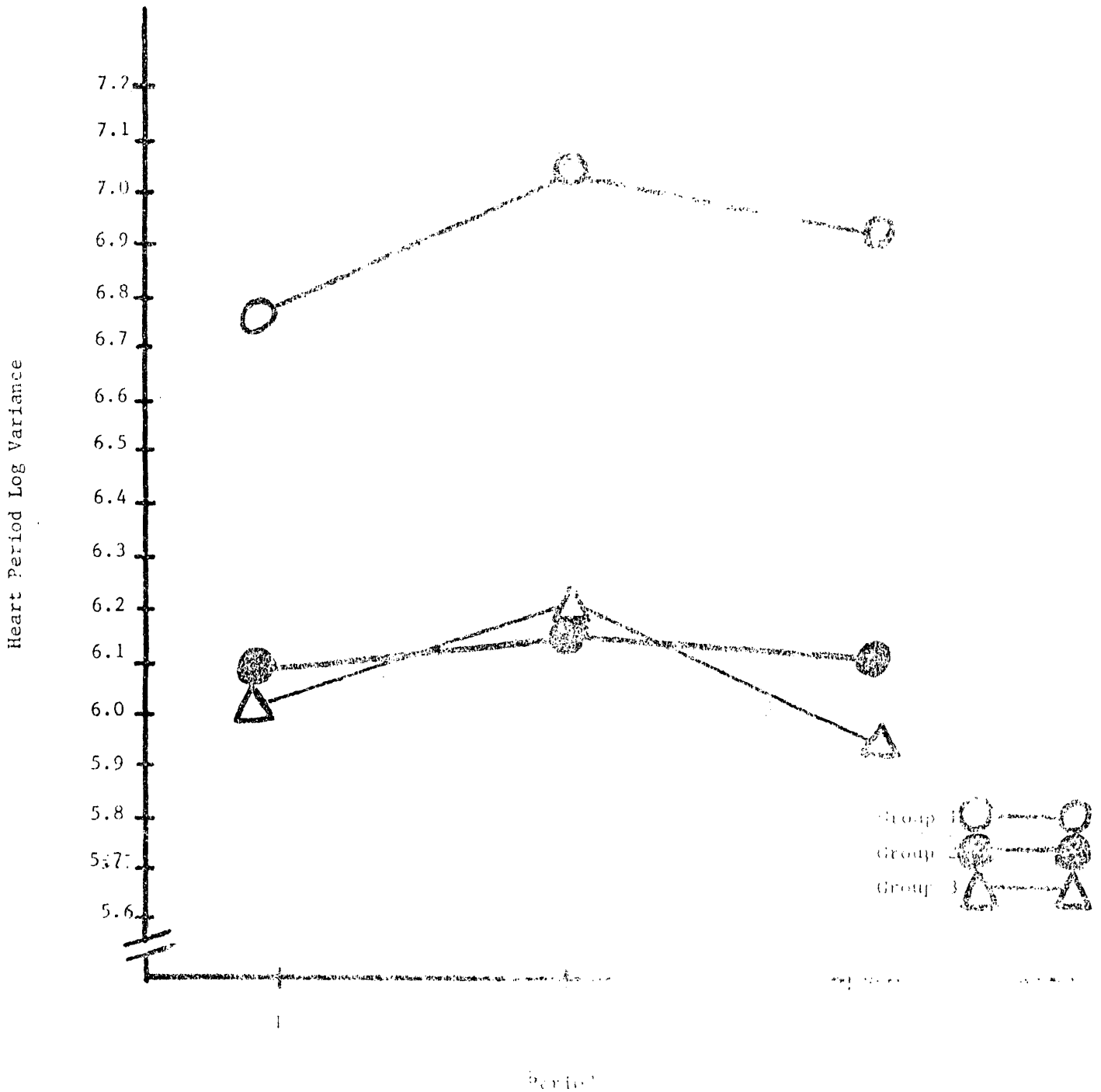
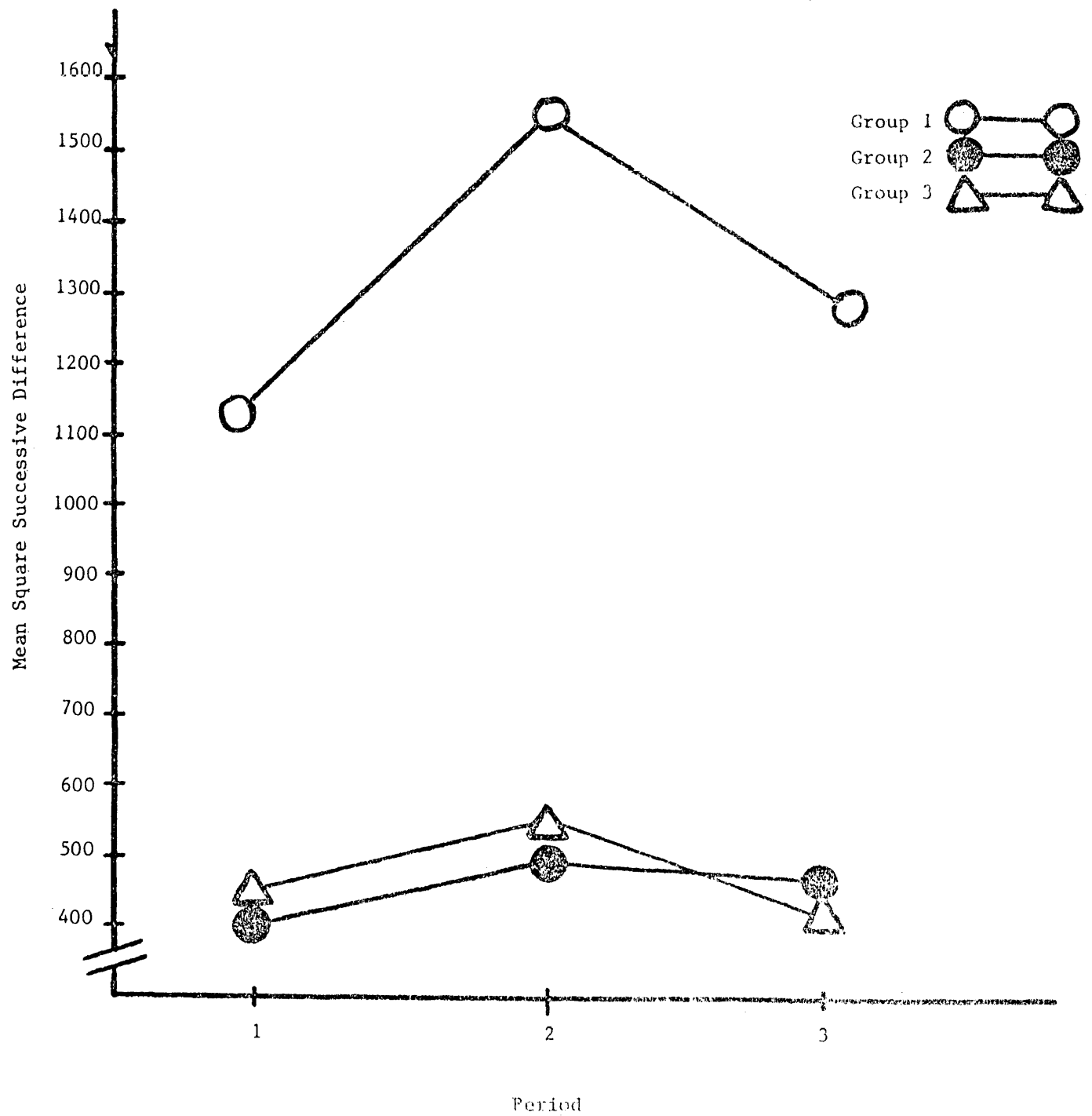


Figure 4

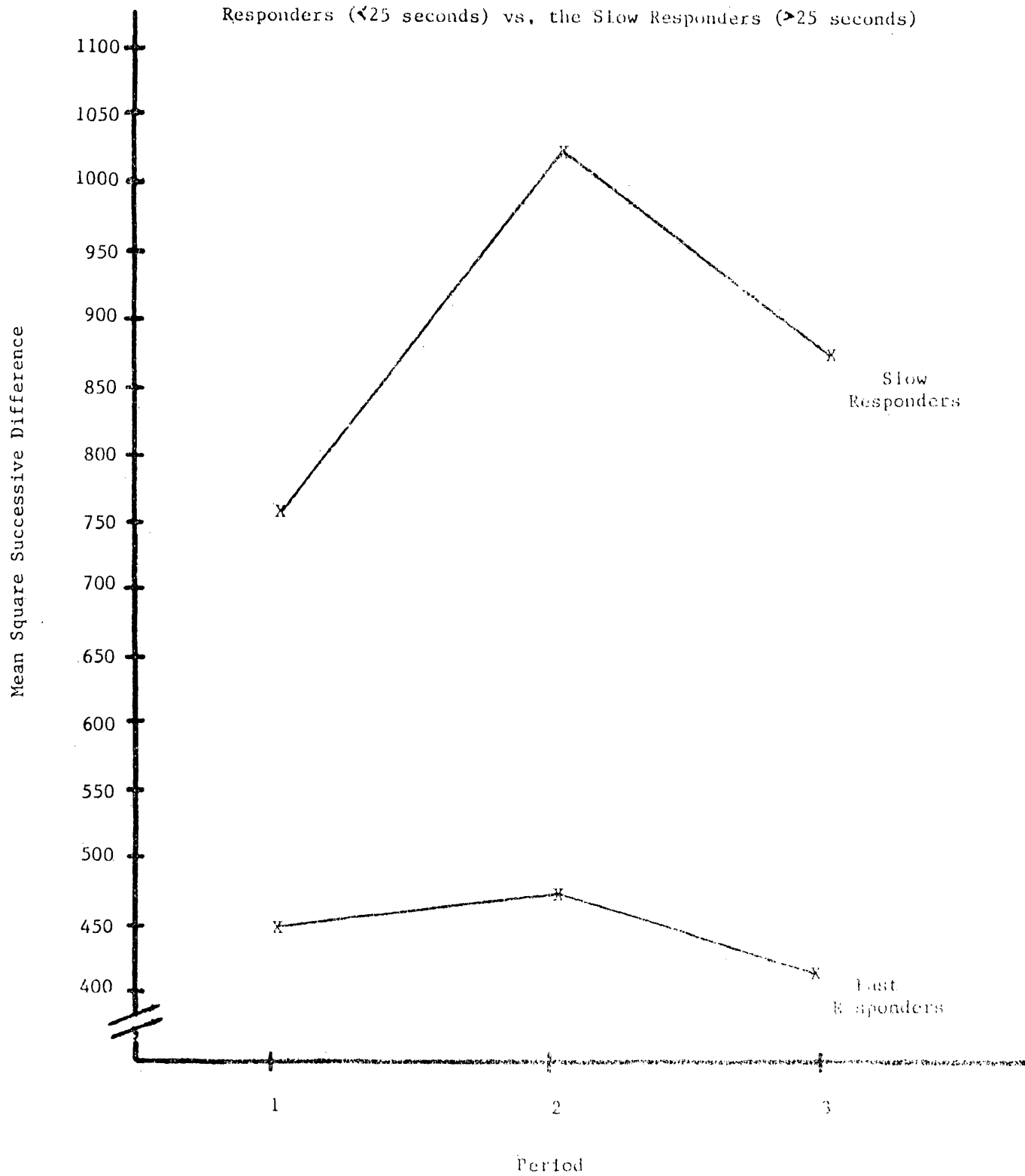
Mean Square Successive Difference during
baseline (Period 1) and on-task (Periods 2 and 3)



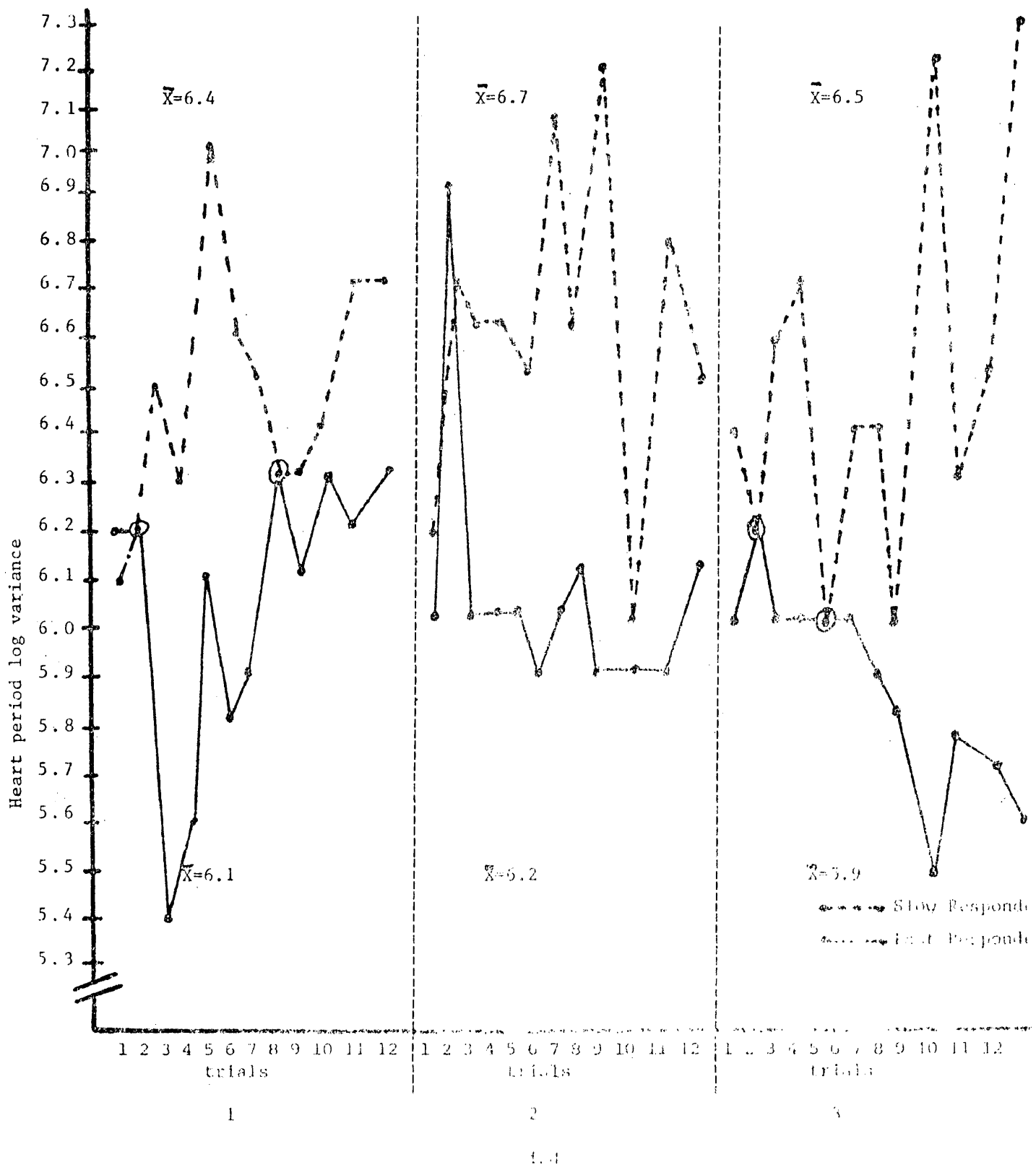
of trials that were responded to in less than 25 seconds were determined for each subject. They were then rank ordered and split at the median to obtain a "fast responders" group and a "slow responders" group. The heart rate data were then submitted to a two way analysis of variance with repeated measures. These results yielded a significant group effect ($F(1,30)=5.39, p < .05$) and a significant period effect ($F(2,60)=3.91, p < .02$) on mean successive difference. As can be seen in Figure 5, the fast responders were less reactive (as measured by changes in Period 2) than were the slow responders. As the trial progressed (Period 3), the fast responders suppressed variability to below base levels whereas the slow responders continued to demonstrate levels of variability well above base rates.

The analysis of heart period log variance found that although no group or period effect was displayed, there was a significant trial X period interaction ($F(22,660)=1.55, p < .05$) and a significant group X trial X period interaction ($F(22,660)=2.09, p < .01$). As can be seen in Figure 6, the fast responders were characterized during Period 1 by a slow increase in variability over the trial, by a leveling off of variability during Period 2, and by a steady decrease in variability during Period 3 of all trials. In sharp contrast, the slow responders were characterized not by a suppression in variability as trials progressed, but rather by a significant increase in variability between and within trials.

Mean Square Successive Difference for the Fast Responders (<25 seconds) vs, the Slow Responders (>25 seconds)



Heart period by variance between and within trials for slow and fast responders



Discussion

The findings of this investigation support the view that during tasks demanding sustained attention individuals of different I.Q. levels exhibit differential variability of cardiac activity. These data are consistent with other research findings indicating that decreases in heart period variability reflect the ability to sustain attention to a task (Porges, in press) and that such decreases are related to I.Q. (Porges & Humphrey, 1977). The present findings may potentially shed some light onto the etiology of mental retardation by accounting for individual differences based upon a relatively noninvasive measure of physiological activity.

A common theme of this area of psychophysiological research is that fluctuations within the autonomic nervous system may function to enhance or attenuate the reception of a stimulus array. Such fluctuations are said to reflect differences in sustained attention (Lacey, 1967; Porges, 1976). Porges (1976) maintains that fluctuations in heart period variability are mediated by the parasympathetic nervous system and, as such, can be used as an index of an attentional response. In the present study, the high I.Q. group ($\bar{X} = 61$) and the middle I.Q. group ($\bar{X} = 48$) suppressed variability significantly faster and to a greater extent than did the low I.Q. group ($\bar{X} = 36$). This suggests that individuals with different I.Q. levels possess different degrees of parasympathetic control. Whereas Porges and Humphrey (1977) concluded that deficits in parasympathetic functioning characterize the retarded population, the present findings allow the qualification that progressive deficits exist in parasympathetic activity as a function of different I.Q. groupings.

The relationship between heart period variability and attention is less clear since no reliable differences in recognition were demonstrated between the groups despite differences in heart period variability. However, with the significant latency effect between the group, it is possible to argue that the lower I.Q. group was not attending to the stimulus in the same way as the high I.Q. group was thus accounting for their slower response times. Even though it took them longer to respond, they did eventually respond correctly. It is speculated that if more accurate response-dependent measures of latency had been obtained, the relationship between heart period variability and latency would have been consistent among the groups.

Zeaman and House (1963) have shown that the performance deficits seen in the retarded are a function of the latency of the initial attentional response. Although not in total agreement with their model, the present data suggest that there is an initial "attentional lag" as I.Q. decreases, but that with sufficient time, an attentional response is displayed. This attentional lag may parallel the increase in heart period variability seen in Group 1 over the first 10 seconds of the trial. Only additional research can confirm whether the disappearance of this "lag" is paralleled by a suppression of heart period variability. This possibility appears likely since the data from the present study demonstrated that the fast responders exhibited a suppression in heart period variability over the trials whereas the slow responders did not exhibit such decreases in variability.

The concept of heart period variability has been discussed in the Introduction. Two measures of it were employed in the present study; one emphasizing the relative difference of each heart period to the

overall heart period for the group (log variance), and one emphasizing the relative difference of each successive heart period between subjects within each group (means square successive difference). The inability of both measures to predict group differences in variability may point out subtle individual differences in attention. Since the mean square successive difference is a time-series statistic, it may be more sensitive to changes in discrete waveforms that are thought to parallel the initiation and maintenance of an attentional response. Lacey and Lacey (1978) have reported that the R-R interval can be abbreviated or lengthened (thereby accelerating or decelerating heart rate) depending upon where in the cardiac cycle the stimulus first appeared. These authors maintain that this phenomenon is associated with vagal stimulation, not sympathetic action, and must be mediated by cortical events. In Porges' two-component model of attention, fluctuations within the autonomic nervous system determine the quality of an attentional response. These fluctuations are best represented by a time-series statistic which reflects the changes in trend in the heart period over time. At present, Porges is investigating the use of cross-spectral analysis as a method of quantifying the rhythms found within the autonomic nervous system and partitioning these into constituent sinusoidal functions of different frequencies (Porges, et. al., Note 1). This method will permit an assessment of the extent to which one physiological system influences another.

The implications of the present findings possess both theoretical and practical significance. The relationship between cardiac activity and the brain suggests the possibility of developing a noninvasive technique of assessing autonomic dysfunctions that may parallel central

nervous system deficiencies associated with mental retardation. Such an instrument could lead to early detection of infants "at-risk" with subsequent treatment being initiated sooner. Bradley-Johnson and Travers (1979) have found, for example, that non-retarded infants (16 months) display heart rate deceleration to a moderate intensity auditory tone whereas retarded infants (16.5 months) display no such changes in cardiac activity.

The possible manipulation of cardiac activity thereby facilitating an attentional response is theoretically plausible. Such manipulations have already been accomplished with the administration of methylphenidate (Ritalin) to suppress heart rate variability in hyperactive children (Porges, Walter, Korb, & Sprague, 1975). Another procedure, left virtually untouched in the literature, concerns the use of biofeedback as a method of altering physiological response systems to improve attention. Katz, McAllister, & Bregman (Note 2) have conducted preliminary but encouraging investigations with severely retarded adults attempting to manipulate attention by increasing alpha-blocking time.

Such approaches to the understanding of mental retardation will continue to shed light on the mechanisms responsible for delayed development. The results of such research will necessarily provide suggestions based upon physiological data that will provide possible strategies for the amelioration of attentional deficiencies in the mentally retarded.

Reference Notes

1. Porges, S.W., Bohrer, R.E., Keren, G., Cheung, M.N., Drasgow, F., & McCabe, P. A new time-series statistic for detecting rhythmic co-occurrences in the frequency domain: The weighted coherence and its application to psychophysiological research. Unpublished manuscript, University of Illinois at Champaign-Urbana, 1979.

2. Bregman, N.J. Personal communication, November 29, 1978.

References

- Baumeister, A.A. and Kellas, G. Reaction time and mental retardation. In N.R. Ellis (Ed.) International Review of Research in Mental Retardation. Vol. 3. New York: Academic Press, 1968.
- Berkson, G., Hermelin, B., and O'Connor, N. Physiological responses of normals and institutionalized mental defectives to repeated stimuli. Journal of Mental Deficiency Research. 1961, 5, 30-39.
- Bradley-Johnson, S. & Travers, R.M. Cardiac change of retarded and nonretarded infants to an auditory signal. American Journal of Mental Deficiency. 1979, 83 (6), 631-636.
- Collman, R.D. The galvanic skin responses of mentally retarded and other children in England. American Journal of Mental Deficiency. 1959, 63, 626-632.
- Das, J.P. and Bower, A.C. Autonomic responses of retarded adolescents during anticipation and feedback in probability learning. Journal of Mental Deficiency Research. 1973, 17, 171-175.
- Graham, F.K. and Clifton, R.K. Heart rate changes as a component of the orienting response. Psychological Bulletin. 1966, 65, 305-320.
- Heal, L.W. and Johnson, J.T. Inhibition deficits in retardates learning and attention. In N.R. Ellis (Ed.) International Review of Research in Mental Retardation. Vol. 8. New York: Academic Press, 1973.
- Hernandez-Peon, R. Attention, sleep, motivation, and behavior. In R.G. Heath (Ed.) The Role of Pleasure in Behavior. New York: Hoeber, 1964.
- James, W. Principles of Psychology. New York: Holt, 1890.

- Kagan, J. and Rosman, B.L. Cardiac and respiratory correlates of attention and an analytic attitude. Journal of Experimental Child Psychology. 1964, 1, 50-63.
- Karrer, R. Comparison of autonomic activity of mental defectives and normals: A sequential analysis of the heart rate response. Journal of Mental Deficiency Research. 1965, 9, 102-108.
- Karrer, R. and Clausen, J.A. A comparison of mentally deficient and normal individuals upon four dimensions of autonomic activity. Journal of Mental Deficiency Research. 1964, 8, 149-163.
- Lacey, J.I. The evaluation of autonomic responses: Toward a general solution. Annals of the New York Academy of Sciences. 1956, 67, 123-164.
- Lacey, J.I. and Lacey, B.C. Verification and extension of the principle of autonomic response stereotypy. American Journal of Psychology, 1958, 71, 50-68.
- Lacey, J.I. and Lacey, B.C. Two-way communication between the heart and the brain. Significance of time within the cardiac cycle. American Psychologist. 1978 (February), 99-113.
- Lacey, J.I. and Kagan, J., Lacey, B.C., and Moss, H.A. The visceral level: Situational determinants and behavioral correlates of autonomic response patterns. In P.H. Knapp (Ed.) Expression of the Emotions in Man. New York: International University Press, 1963.
- Lally, M. and Nettlebeck, T. Intelligence, reaction time, and inspection time. American Journal of Mental Deficiency. 1977, 82(3), 273-281.
- Landis, C.A. and Hunt, W.A. The Startle Pattern. New York: Rhinehart, 1939.

- Leiderman, P.H. and Shapiro, D. Application of a Time Series Statistic to Physiology and Psychology. Science. 1962, 138, 141-142.
- Lindsley, D.B. Psychophysiology and motivation. In M.R. Jones (Ed.) Nebraska Symposium on Motivation. Lincoln Nebraska Press, 1957.
- Luria, A.R. The Mentally Retarded Child. New York: Macmillan, 1963.
- Luria, A.R. and Vinogradova, O.S. An objective investigation of the dynamics of semantic stimuli. British Journal of Psychology. 1959, 50, 89-105.
- Moruzzi, G. and Magoun, H.W. Brain stem reticular formation and activation of the EEG, Electroencephalography and Clinical Neurophysiology. 1949, 1, 455-473.
- Obrist, P.A. Cardiovascular differentiation of sensory stimuli. Psychosomatic Medicine. 1963, 25, 450-459.
- Olds, J. Self-stimulation experiments and differentiated reward systems. In H.H. Jasper, L.D. Proctor, R.S. Knighton, W.C. Noshay, and R.T. Costello (Eds.) Reticular Formation of the Brain. Boston: Little, Brown. 1958.
- Pavlov, I.P. Conditioned Reflexes. London: Oxford University Press, 1927.
- Porges, S.W. Peripheral and Neurochemical parallels in psychopathology: A psychophysiological model relating autonomic imbalance in hyperactivity, psychopathology, and autism. In H.W. Reese (Ed.) Advances in Child Development and Behavior. Vol. 11, New York: Academic Press, 1976.
- Porges, S.W. Individual differences in attention: A possible physiological substrate. In B.K. Keogh (Ed.) Advances in Special Education, in press.

- Porges, S.W. and Humphrey, M.N. Cardiac and somatic responses during visual search in nonretarded children and retarded adolescents. American Journal of Mental Deficiency. 1973, 78, 286-291.
- Porges, S.W., Walter, C.F., Korb, R.J., & Sprague, R.L. The influence of methylphenidate on heart rate and behavioral measures of attention in hyperactive children. Child Development. 1975, 46, 727-733.
- Powazek, J. and Johnson D. Acquisition and extinction of the orienting response in normal and retardates to novel and signal stimuli. American Journal of Mental Deficiency. 1973, 78, 286-291.
- Pryer, R.S. and Ellis, N.R. Skin conductance and autonomic lability as a function of intelligence in mental defectives. American Journal of Mental Deficiency. 1959, 63, 835-838.
- Sokolov, E.N. Perception and Conditioned Reflex. New York: Academic Press, 1963.
- Vogel, W. The relationship of age and intelligence of autonomic functioning. Journal of Comparative and Physiological Psychology. 1961, 54, 133-138.
- Wachtel, P.L. Concepts of broad and narrow attention. Psychological Bulletin. 1967, 68 417-438.
- Wallace, R.M. and Fehr, F.S. Heart rate, skin resistance, and reaction time of Mongoloid and normal children under baseline and distraction conditions. Psychophysiology. 1970, 6, 722-731.
- Zeaman, D. and House, B.J. The role of attention in retardates discrimination learning. In N.R. Ellis (Ed.) Handbook of Mental Retardation. New York: McGraw-Hill, 1963.