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# Autonomic Profiles During Stress and Cognitive Activity

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AUTONOMIC PROFILES DURING STRESS AND COGNITIVE ACTIVITY

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Dissertation Submitted to the Graduate School of Loyola  
University in partial fulfillment of the requirements of  
the Degree of Doctor of Philosophy

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## INTRODUCTION

The purpose of the dissertation was to systematically investigate by means of an intensive individual analysis the effects of a physiological stressor, heat, and a cognitive task, problem solving, which included an additional element of psychological stress; namely, an unsolvable problem, on a battery of autonomic measures. Included in this battery are heart rate, diastolic and systolic blood pressure, and measures of change in blood volume in selected body areas. With this approach, detailed below, an autonomic profile was obtained which will relate bodily response to problem solving and levels of stress. Further, since these measures, excepting blood pressures, will be taken continuously for each session, momentary variations in arousal during the problem solving process itself were obtained. Systolic and diastolic pressure was monitored at approximately five minute intervals.

The emphasis of the dissertation was directed toward the study of consistent patterns of change between cognitive activity and physiological response, not toward the testing of any specific set of hypotheses. This is reflected in the

extensive use of curve fitting techniques and trend analyses rather than inferential statistics; although t-tests are used where applicable for completeness.

As an adjunct to the principal problem, the subjects were pretested for level of anxiety and the relation of this variable to the study is presented.

### Review of the Related Literature

In the past few years classical activation theory has undergone some revisions. Freeman (1940), Hebb (1955), Malmo (1957, 1958), and Stennett (1957), initially presented evidence that an inverted U-shaped relation existed between performance and autonomic activity. That is, autonomic "tension" was facilitating up to an optimum level. Beyond that level, further increase in "tension" became detrimental to performance. It was further implied by Duffy (1962) and Malmo (1959) that autonomic arousal and behavioral arousal since they occur in near simultaneity were always positively related. The simplicity of this notion has recently been challenged, Malmo (1966), and Lacey (1967). Lacey contended that the degree of attention required of the problem may play a central role in the level of autonomic response. In fact, in test situations which require simple environmental input, cardiac deceleration and blood pressure decrease may occur. Obrist (1968) demonstrated that anticipation of an unconditioned stimulus was accompanied by cardiac deceleration and a concomitant decrease in somatic responses such as eye movements, blinking, and



electromyographic activity. Steele (1968) indicated that cardiac response to arithmetic tasks was acceleration, the increase being significantly greater with distraction.

Early, Darrow (1929) concluded that stimuli requiring little cognitive integration resulted in cardiac deceleration; whereas, associative activity produced the opposite effect. Duffy (1951) postulated that autonomic arousal was positively related to task difficulty. Schnore (1959) found autonomic responsivity higher in a difficult situation with distraction than under reverse conditions. Blatt (1961) analyzed cardiac change at specific points in the process of problem solving. He found significant increases in heart rate at those stages corresponding to periods of sufficient information for solution, transition from analytic to synthetic questions, and the time corresponding to the solution of the problem. Rimoldi and Meyer (1963) found that the degree of increase in heart rate was related to the difficulty of the test situation. They monitored cardiac change to problems described as "abstract" and "concrete" and concluded that greater arousal accompanied the latter condition. Meyer (1963) found an increase in heart rate when a subject attempted to incorporate and assimilate

information during problem solving. Hess and Polt (1964) suggested that autonomic arousal accompanying thought processes may be related to various periods within the process. Kahneman and Beatty (1966) found that increases in pupillary constriction were a function of the amount of information presented to the subject. Daly (1967) using the Rimoldi thought problems found definite patterns of arousal as assessed by pupillary response corresponding to critical points in the problem solving process.

Contrary results have also appeared in the recent literature. Lober (1968) claimed the curve of mean heart rate was not sensitive enough to discriminate between various levels of mental effort such as monotonous adding, concentrating on division problems, and sitting idly for a forty-five minute control period. Burdick (1968) questioned whether resting heart rate and variability alone are reliable measures of arousal since these appear to be principally affected by conditions which are usually controlled in the usual methods of experimentation. Synder (1968) demonstrated that a conditioned vasoconstriction response can be obtained which is independent not only of the typical somatic measures, respiration rate

for example, but of heart rate as well.

The present study attempted to extend this line of investigation by employing a more extensive sampling of measures of autonomic arousal, by introducing different levels of stress to see if these function as distractors and hence influence the degree of attention, and proceeding through intensive investigation of a small number of subjects. In regard to this last point, the search for intersubject autonomic relatedness has recently been questioned (Lazarus et al. 1963), Mardkoff (1964), and Lazarus (1965a). Schnore (1959) and Lacey (1953) argued that intraindividual change rather than an investigation of intersubject autonomic patterning has produced more valid measurements. The low intersubject correlation of autonomic measures is similarly documented by these individuals; hence, it seemed that intraindividual investigation would be potentially fruitful and indicated in the present research.

In regard to the way in which stress was applied in the present study, it is to be noted that Teichner (1968) in an extensive treatment of stress and behavioral change claimed that, "Very few experiments involving symbolic stressors have been done which have studied the interaction between the state

of the organism at the time of stimulation and the stress reaction. Most investigations have imposed stimulation while the organism was in an otherwise normal state of environmental exposures. We have postulated that during unusual environmental exposures, the effect of strong symbolic stimulation would be to prolong the ongoing direction of regulatory activity or, if associated with a high data-processing ratio, to reverse it. This leads to the conclusion that increased muscular and decreased skin blood flow are not necessary stress reactions; but rather, are compensatory reactions whose direction of change is determined by existing levels of flow." Cited as illustrative findings are Fencil et al. (1959), who found an increase in blood flow through the forearm muscle with mental arithmetic but a decrease in skin flow when the "normal" level was high. When skin flow was "normally" low, the arithmetic task increased it. Teichner and Levine (1968) reported that when subjected to heat, subjects responded to a conditioned stimulus with vasodilation in the periphery, but vasoconstricted in a digit; however, when cooled, the subjects vasoconstricted in the periphery and dilated in the digit as the conditioned response. The

design of the present study allowed both the comparison from the "normal" state and an "unusual environmental exposure" in an information processing situation. Skin flow and muscle flow were also monitored, hence Teichner's proposed model of autonomic reactivity can be tested.

The relationship between anxiety and autonomic arousal has received much attention in the literature but the findings are anything but certain. Baler and Taylor (1954), Berlyne (1961), and Learmouth, Ackerly, and Kaplan (1959) all found positive correlations between arousal and psychological reactivity. More recently, Koepke and Pribram (1967) indicated that habituation of vasoconstriction was a function not only of stimulus duration but anxiety levels as well. Jackson (1967) postulated that a high level of arousal in an anxious subject may interfere with his processing of the stimulus and hence effect his physiological response in its presence. Oetting (1966) reported different patterns of physiological response between anxious and non-anxious subjects in a test taking situation. The present study used a measure of anxiety as an adjunct to the primary problem and its use is treated in the discussion section.

## PROCEDURE

Subjects: Four subjects, all male students from the undergraduate division of St. Louis University were tested. All subjects were pretested with the Nicolay-Walker Personal Reaction Schedule and the Raven's Progressive Matrices, sets A, B, C, D, and E, to assess base levels of anxiety and general aptitude respectively.

Testing materials: The thought problems used were developed and analyzed according to the method developed by Rimoldi (1955, 1961, 1963). This method studies the problem solving process by analyzing the questions asked by a subject in order to reach the solution to a problem. Rimoldi (1964) using this technique demonstrated that an analysis of problem solving behavior based on norms pertaining to the logical scheme of a problem rather than group norms is more sensitive. Hence, as with the physiological measures, an individual analysis of cognitive activity was chosen. Rimoldi (1967) suggested the application of several scoring procedures to the problems. One termed the "schema pulling out" method, assigns values to

the questions used in terms of their relevancy and order asked. Hence irrelevant questions used in the solution to a problem are eliminated from an observed tactic, and the subject is penalized for irrelevant questions asked in computing his total score. Since the Rimoldi technique analyzes the ongoing activity rather than merely a final product, it is ideally suited to the continuous autonomic measures used in the present study. The unsolvable problem (USP) employed merely gave a redundant piece of information to the last question in a particular tactic; hence, the USP had no exact solution but could be scored as the rest of the problems. A complete listing of the problems is contained in the APPENDIX.

Autonomic measures: During the experimental periods, the subject's physiological responses were monitored through a six channel Grass recorder. Using the polygraph and photocell transducers, three channels of information concerning blood volume were obtained from the toe, calf, and forehead. Kelly (1967) and numerous other investigators have presented data establishing blood flow as a valid and reliable index of arousal. The method used in this research to measure blood

volume depends on the amount of light reflected back to a photocell from a restricted body area. When blood flow is high, as during vasodilation, more light is reflected back to the photocell and appears as an increase in amplitude on the channel being monitored. Reduced blood flow results in more light passing through tissue, hence less reflectance, and therefore pressure pulses of a reduced amplitude result. The particular positioning of the transducer was chosen to reflect any shunting of blood, due to vasoconstriction or dilation, from peripheral to central structures and to reveal the specific pattern of vascular response within the general state of arousal. More specific information as to the function and placement of the transducers for various applications may be obtained from Senay et al. (1961).

The heart rate was determined by counting each pressure pulse for one minute's time. The pressure pulses from the toe, calf, and forehead were sampled and their average height compared to a standard calibration factor which was checked at about ten minute intervals. Calibration was accomplished by shutting off the light to a transducer momentarily and recording the no light situation as a baseline. The no light



condition would correspond to the complete absence of blood in the area being monitored. All changes in volume were then expressed as per cent change from this baseline. In addition, a pressure cuff and stethoscope were attached to the arm of the subject so that blood pressure could be remotely recorded. The subjects were all tested while lying on a wire mesh grounded bed in a climate chamber. The bed was adjustable so that the subject could read the problems which were presented on a board in front of him. The climate chamber in which the subjects were tested was a room approximately 9' X 12' with a one way mirror. All recording was done remotely and the temperature and humidity of the chamber were accurately controlled.

Method: All the subjects had been pretested the day before SESSION I on a thought problem of rather simple structure in order to familiarize them with the testing technique. The climate chamber was shown to them and the method of recording the physiological measures was demonstrated in order to allay possible fears. Briefly, as to the thought problems, each subject was told that he would be asked to solve a series of

problems, some simple, some more complex. Each subject was instructed that he was to read the problem and the accompanying questions. Next, they were told that the statement of the problem did not contain enough information to be solved; consequently, they were to choose from among the questions presented those which they felt were necessary to arrive at a solution to the problem. It was also noted that time was not a critical factor within reasonable limits, and that they should therefore work at their own pace.

In reference to the design of the experiment proper, there were three SESSIONS. On day one of testing, SESSION I consisted of the administration of two Rimoldi thought problems, 3IA and 3IB, with no heat stress. The subjects were tested in the climate chamber lying on the grounded bed with all physiological measures except the calf being monitored. The total time of this session averaged about 75 minutes for all the four subjects. At the beginning of the session ample time, about 15 minutes, was given for the physiological indices to stabilize and this period served as the control baseline preceding problem 3IA. After the problem had been solved a similar period of control time was allowed in order to assess recovery time.

When the physiological indices again stabilized, problem 318 was administered, and recovery time was again allowed after its solution. These periods of stable response served as the baselines from which both arousal and recovery are plotted. As mentioned previously, the total time of SESSION I was about 75 minutes per subject. SESSION II on day two of testing consisted of five hours of heat stress at 110 degrees Fahrenheit and the administration of a single thought problem, 31C, late in the session. This long period of heat stress without cognitive "stress" served as the control session or baseline heat stress from which arousal and recovery due to 31C were plotted. This baseline heat stress was also compared to baseline no heat stress in order to assess the magnitude of the physiological stressor. SESSION III contained the same level of heat stress as in SESSION II but here three thought problems, 31D, 42, 33A, and a single unsolvable problem were given spaced throughout the session. During this third day of testing, as with the previous SESSIONS, ample control time and recovery time was allowed around each problem and these periods served as the baseline for the proper problem being analyzed. Further, all subjects were put in the climate chamber one hour before

monitoring was begun for SESSIONS II and III, in order that their body temperature would be at a fairly stable level for testing.

The data was analyzed both descriptively and inferentially. Firstly, for each subject, an autonomic profile was obtained for the problem solving segments of each session. This profile presents actual heart rate and pressure and mean scores from the volume measures for successive five minute periods for each experimental session and hence reflects changes from baseline conditions as well as recovery time. Both a trend analysis and curve fitting procedures were performed on this data. The trend analysis used herein followed the format outlined by Winer, Statistical Principles in Experimental Design pp. 132-135.

This technique is designed to evaluate data from experiments involving the use of repeated measures and does so through an analysis of blocks of mean scores. A block is composed of the means for all subjects for a given treatment level. By applying the proper set of weights to these means, coefficients of orthogonal polynomials, the amount of total variance attributable to linear, quadratic, cubic, etc., trends is extracted. In this study all trends were analyzed to the fourth degree. A

restriction imposed by this technique is that the blocks of means be composed of equal units. Therefore, since the trend analysis necessarily involved a summing through all subjects for each block analyzed in order to estimate error variance, and since each subject typically had different problem solving times, the series of trend analyses were applied to the long control period preceding problem 31C in SESSION II, where equal blocks of time could be established for all the subjects. The value of this analysis is that the stability of a period, which is assumed to be a control condition can thereby be assessed. That is, if the analysis reveals that the direction of change of the physiological measures for all the subjects is essentially flat, lack of significant trends, then this period is established as a baseline from which to plot problem change under heat stress. A total time of ninety minutes, three blocks of thirty minutes each, was selected for analysis. Specifically, BLOCK ONE consisted of each physiological measure taken separately for all the subjects from time 65 minutes to 90 minutes into SESSION II. BLOCK TWO encompassed time 145 minutes to 170 minutes, and BLOCK THREE time 225 to 250 minutes.

The curve fitting involved the use of a least squares

polynomial procedure. Each physiological measure for each subject for each problem was analyzed up to the fourth degree since it was felt that further analysis would neither be physiologically nor psychologically meaningful. By following the development of the equations for the cubic form, one can arrive at the equations for the general case of the LEAST SQUARES POLYNOMIAL:

$$Y' = a_0 + a_1X + a_2X^2 + a_3X^3 \quad (1)$$

the individual deviation  $d_i$ :

$$d_i = Y_i - a_0 - a_1X_i - a_2X_i^2 - a_3X_i^3 \quad (2)$$

$D$ , the sum of the squared deviations:

$$D = \sum_{i=1}^N d_i^2 = \sum (Y_i - a_0 - a_1X_i - a_2X_i^2 - a_3X_i^3)^2 \quad (3)$$

Minimizing the function with respect to the four constants,  $a_0$ ,

$a_1$ ,  $a_2$ ,  $a_3$ :

$$\frac{\partial D}{\partial a_0} = -2\sum (Y_i - a_0 - a_1X_i - a_2X_i^2 - a_3X_i^3) = 0$$

from which:

$$\sum Y_i = Na_0 + a_1\sum X_i + a_2\sum X_i^2 + a_3\sum X_i^3 \quad (4)$$

Successive equations as (4) can be obtained for constants

$a_1$ ,  $a_2$ , and  $a_3$ .

Expressing the general form of these equations in matrix form yields:

$$\begin{bmatrix}
 N & \sum X_i & \sum X_i^2 & \sum X_i^3 & \dots & \sum X_i^n \\
 \sum X_i & \sum X_i^2 & \sum X_i^3 & \sum X_i^4 & \dots & \sum X_i^{n+1} \\
 \sum X_i^2 & \sum X_i^3 & \sum X_i^4 & \sum X_i^5 & \dots & \sum X_i^{n+2} \\
 \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
 \sum X_i^n & \sum X_i^{n+1} & \sum X_i^{n+2} & \sum X_i^{n+3} & \dots & \sum X_i^{2n}
 \end{bmatrix}
 \begin{bmatrix}
 a_0 \\
 a_1 \\
 a_2 \\
 \vdots \\
 \vdots \\
 a_n
 \end{bmatrix}
 =
 \begin{bmatrix}
 \sum Y_i \\
 \sum X_i Y_i \\
 \sum X_i^2 Y_i \\
 \vdots \\
 \vdots \\
 \sum X_i^n Y_i
 \end{bmatrix}$$

number of  
pairs of  
observations

The matrix system is then solved for the unknown constants using a least squares method. The actual analysis was done on an IBM 360 system using the POLFIT program to obtain the least squares polynomials. This program yielded an index of fit which approaches one as the goodness of fit increases as well as the value of the constants for each degree evaluated.

t tests for correlated means were run on mean heart rate for each problem period and its preceding control or base-line period in order to establish the magnitude of each problem effect. Similar analysis was done on the control periods

of SESSIONS I, II, and III, in order to establish the effect of the heat stress, comparison baselines SESSION I versus SESSION II, and to analyze the amount of day to day variability of the autonomic indices under heat stress, comparison baselines SESSION II versus SESSION III. The formula used was obtained from Guilford, Fundamental Statistics in Psychology and Education, pp. 177-180:

Table II presents the results of  $t$  tests using the formula from successive five minute periods from the session period covered by each of the five heat stress periods. The formula is as follows:

$$t = \frac{M_D}{\sqrt{\frac{\sum x^2 d}{N(N-1)}}}$$

where  $N$  = number of pairs of observations

The  $t$  test is a statistical test of the null hypothesis that there is no difference between the means of two groups of observations. In this case, the null hypothesis is that there is no difference between the means of the two groups of observations, the heat stress and the control. The results of the  $t$  test are presented in Table III. It is concluded that there is a significant difference between the two groups of observations, the heat stress and the control, in the autonomic indices.



## RESULTS

Table I presents the results from the Nicolay-Walker Personal Reaction Schedule. The total anxiety score and the four subscales are presented for each subject. Although there is a fair amount of diversity among these scores, the small number tested restricted generalizations from this particular type of data.

Table II presents the results of t tests using mean heart rate from successive five minute periods from the control period preceding each problem and the mean heart rate obtained within each problem period. Strong significance can be noted for problems 3IC and the unsolvable problem (USP).

Table III contains the results of the comparison among the control periods of SESSIONS I, II, and III. This analysis of mean heart rate from successive five minute periods indicates significance for the comparison of control SESSION I and control SESSION II. The second comparison among the two sessions with heat stress does not reach significance. It can be concluded that the heat stress was an effective and consistent physiological stressor.

TABLE I  
PERSONAL REACTION SCHEDULE SCORES

Subject 1:	Motor = 2	
	Object = 7	
	Personal = 3	
	K-scale = 10	
	Total = 12	
Subject 2:	Motor = 8	
	Object = 3	
	Personal = 9	
	K-scale = 19	
	Total = 20	
Subject 3:	Motor = 6	
	Object = 2	NORMS: Motor - 10.96 ± 4.17
	Personal = 2	Object - 9.16 ± 4.23
	K-scale = 24	Personal - 11.03 ± 4.30
	Total = 10	K-scale - 13.85 ± 4.06
		Total - 31.16 ± 10.26
Subject 4:	Motor = 14	
	Object = 11	
	Personal = 8	
	K-scale = 13	
	Total = 33	

TABLE II

MEAN DIFFERENCES, STANDARD DEVIATION OF THE DIFFERENCE BETWEEN MEANS, NUMBER OF SUBJECTS, AND  $t$  VALUES OF MEAN HEART RATE FOR CONTROL VERSUS PROBLEM PERIODS.

	$M_D$	$S_{D_M}$	N	$t$
Control I-3IA	-2.65	2.26	4	-1.17
Control I-3IB	-4.70	1.84	4	-2.55
Control II-3IC	-11.00	1.23	4	-8.94**
Control III-3ID	-6.08	1.96	4	-3.10*
Control III-42	-3.58	2.09	4	-1.71
Control III-33A	-4.56	2.93	4	-1.56
Control III-USP	-11.31	1.52	4	-7.44**

\* Significant

\* Significant beyond .05 level

\*\* Significant beyond .01 level

TABLE III

MEAN DIFFERENCES, STANDARD DEVIATION OF THE DIFFERENCE BETWEEN MEANS, NUMBER OF SUBJECTS, AND  $t$  VALUES OF MEAN HEART RATE FOR CONTROL PERIODS, SESSION I, II, AND III.

	$M_D$	$S_{M_D}$	N	$t$
Control I vs. Control II	-12.00	2.45	4	-4.90*
Control II vs. Control III	2.25	1.93	4	1.17

\* Significant beyond .05 level

Although all the data from the four subjects was scored, analyzed, and graphed in order to derive the autonomic profiles, because of the bulk of this data only representative findings are presented for each of the three sessions. A complete set of graphs and tables for the profiles as well as the curve fitting data was done using an IBM II30 and 360 computers and is available for inspection.

Figures I through I4 contain data for the problem periods for each physiological measure. In each case, the data from Subject one is presented. Inspection of the data from all the subjects revealed that a very consistent pattern of change was present for all the conditions. In order to be parsimonious and consistent, Subject one was chosen as representative of the changes observed in all the subjects.

Figures I to 4 represent the change in heart rate for each problem through the successive daily sessions.

Figures 5 to 8 present change in systolic blood pressure for each problem period for SESSIONS I, II, and III.

Figures 9 to I2 present changes in toe blood volume for each problem, again through all three sessions.

Figure I3 presents graphically the change in blood volume

in the calf for problems 310 and 42 in SESSION III.

Figure I4 presents the change in forehead blood volume for problems 310 and 42 in SESSION III.

The consistent elevation of heart rate and systolic blood pressure through each problem period can be readily observed in these figures. The toe is seen to be a consistent constrictor, while blood volumes in the calf and forehead do not exhibit such consistent change.

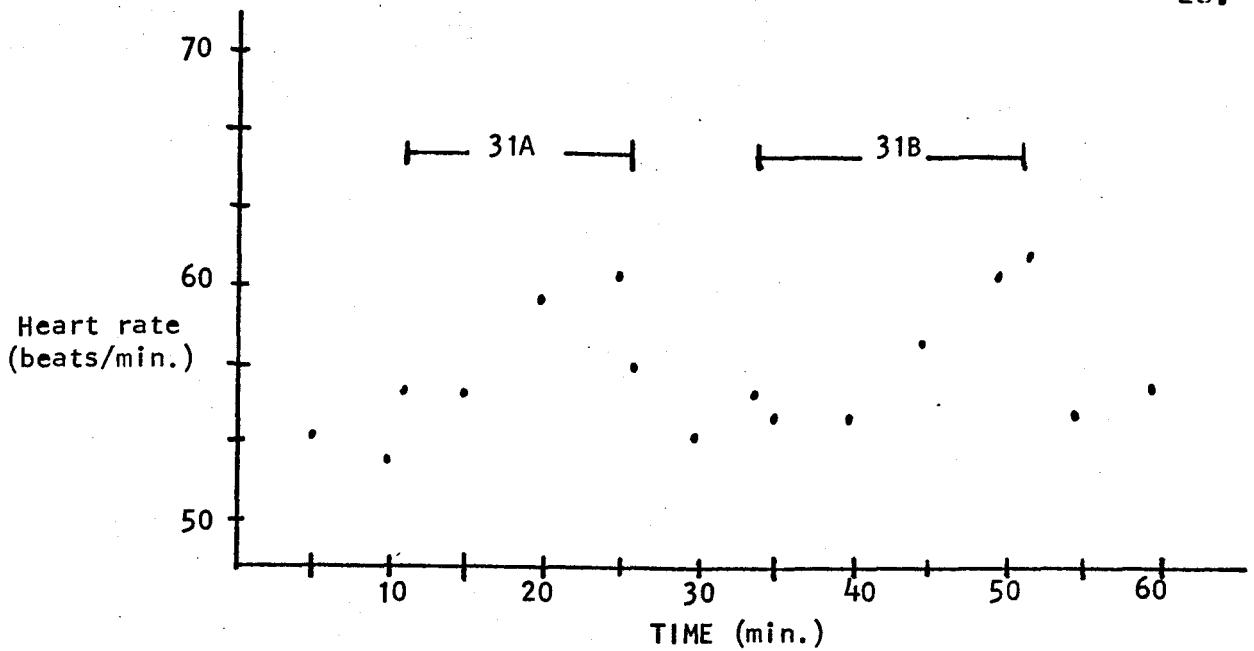


Figure 1. Subject 1: Heart rate change, Session 1, Problems 31 A and 31B.

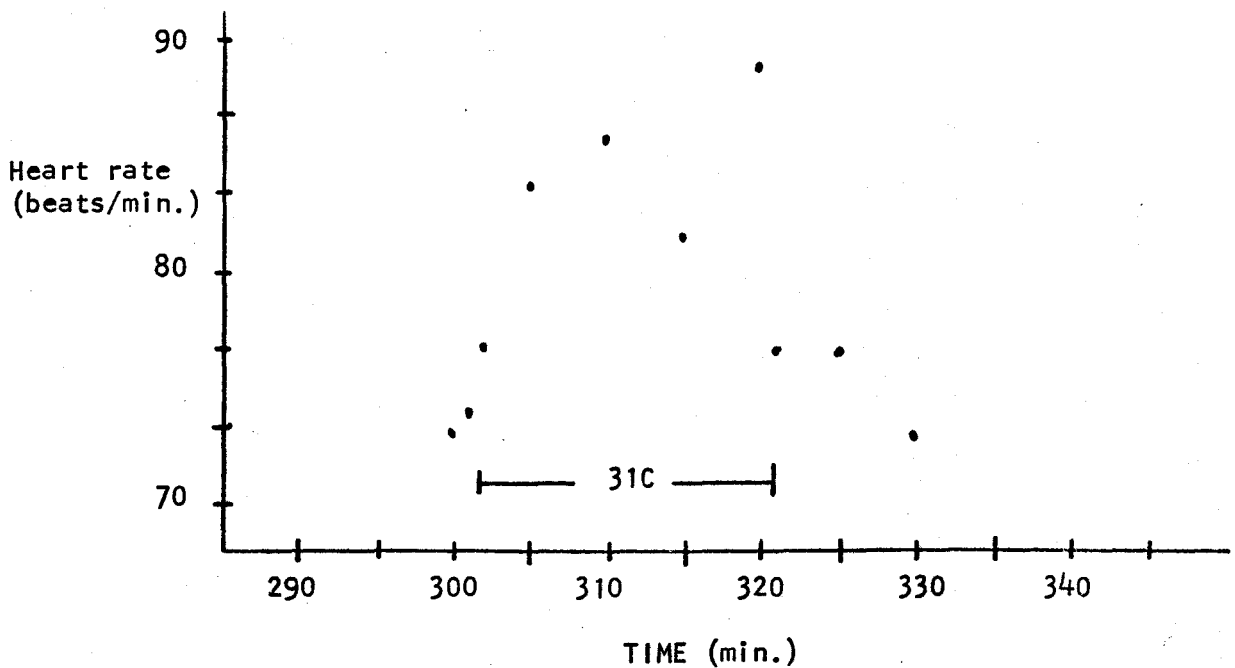


Figure 2. Subject 1: Heart rate change, Session II, Problem 31C.

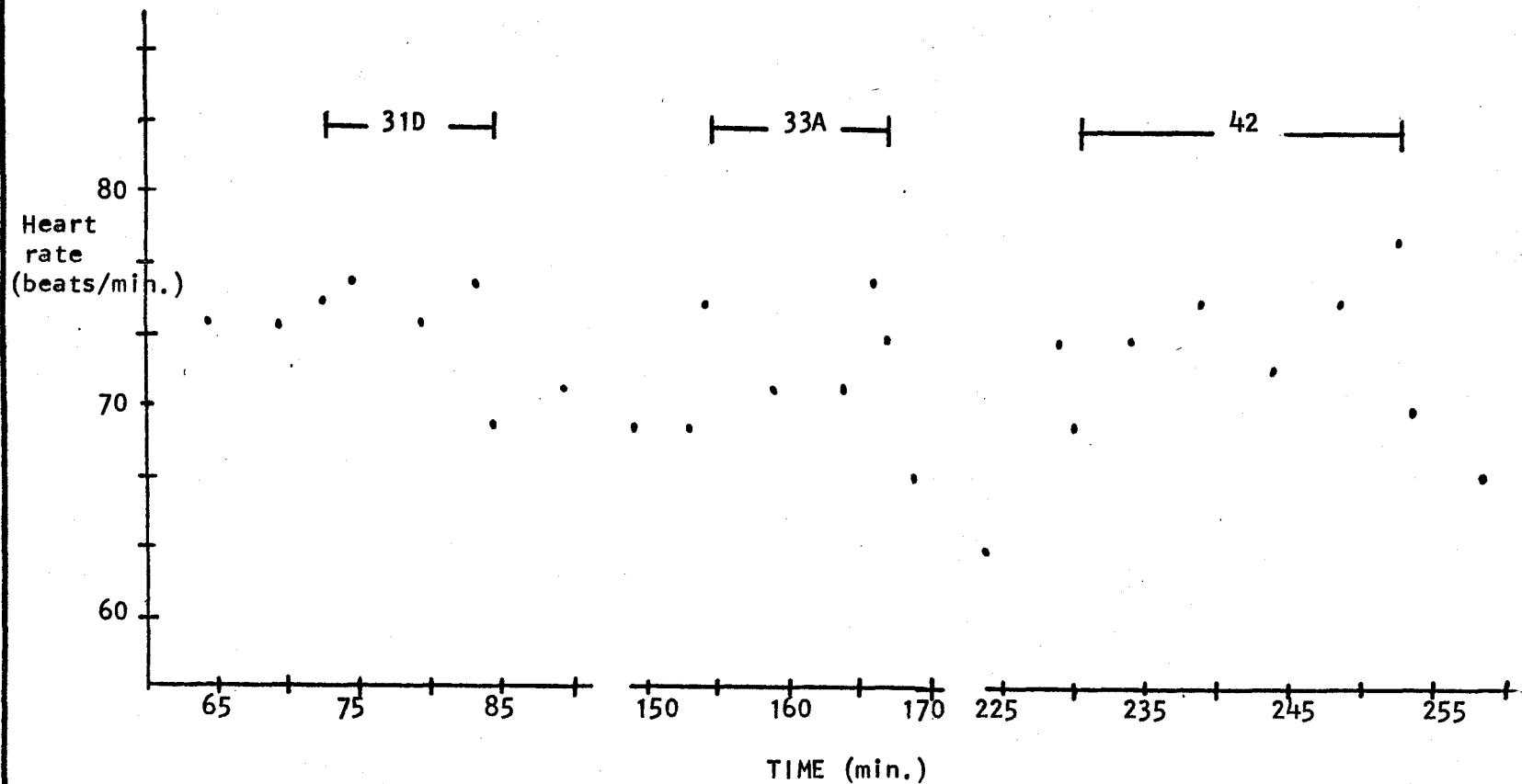


Figure 3. Subject 1: Heart rate change, Session III, Problems 31D, 33A, and 42.



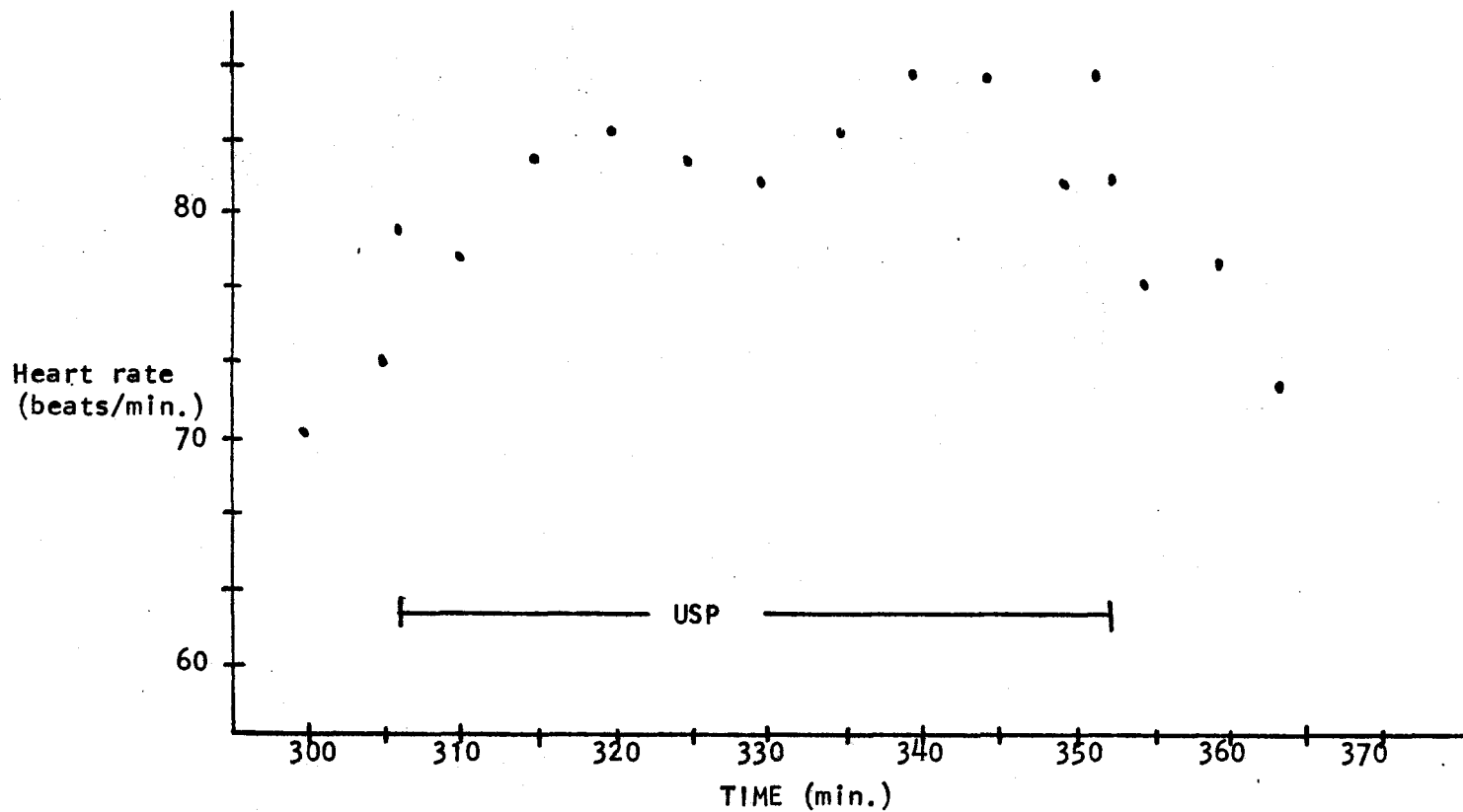


Figure 4. Subject 1: Heart rate change, Session III, Problem USP.

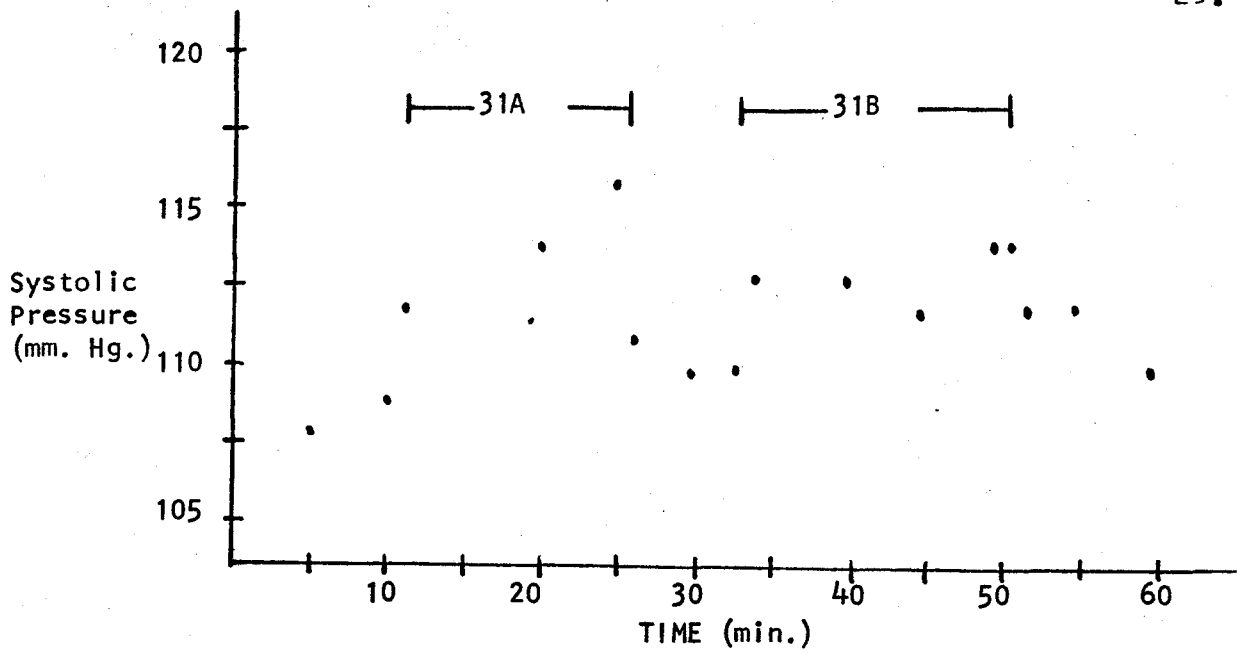


Figure 5. Subject 1: Systolic pressure change, Session 1, Problems 31A and 31B.

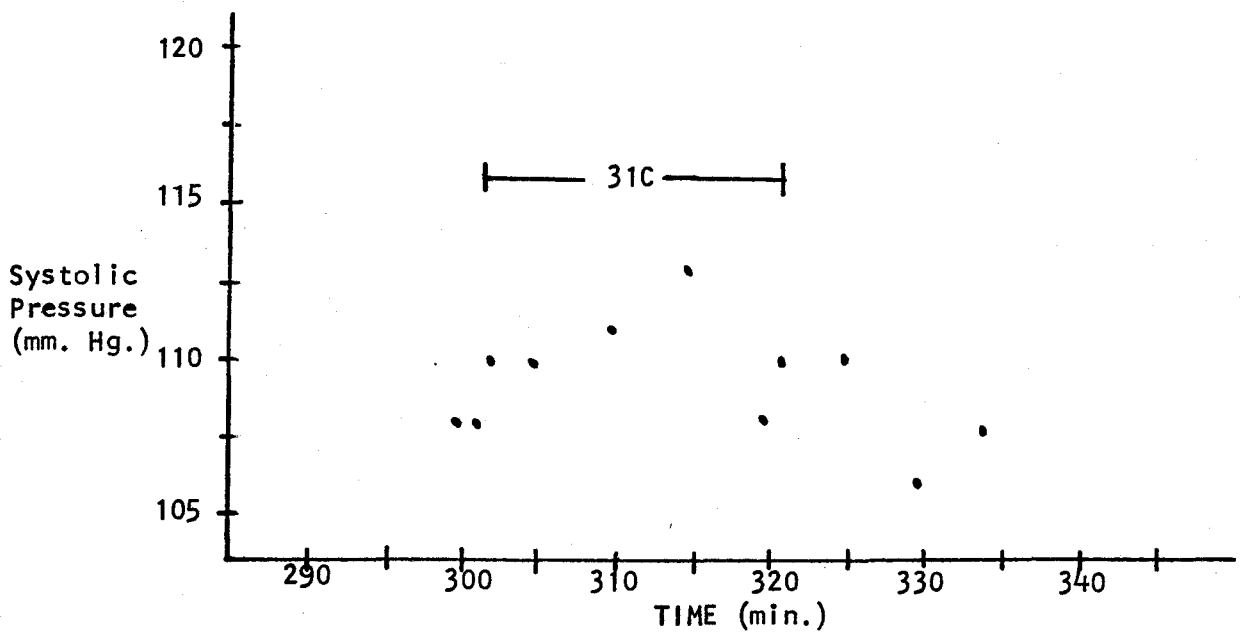


Figure 6. Subject 1: Systolic pressure change, Session II, Problem 31C.

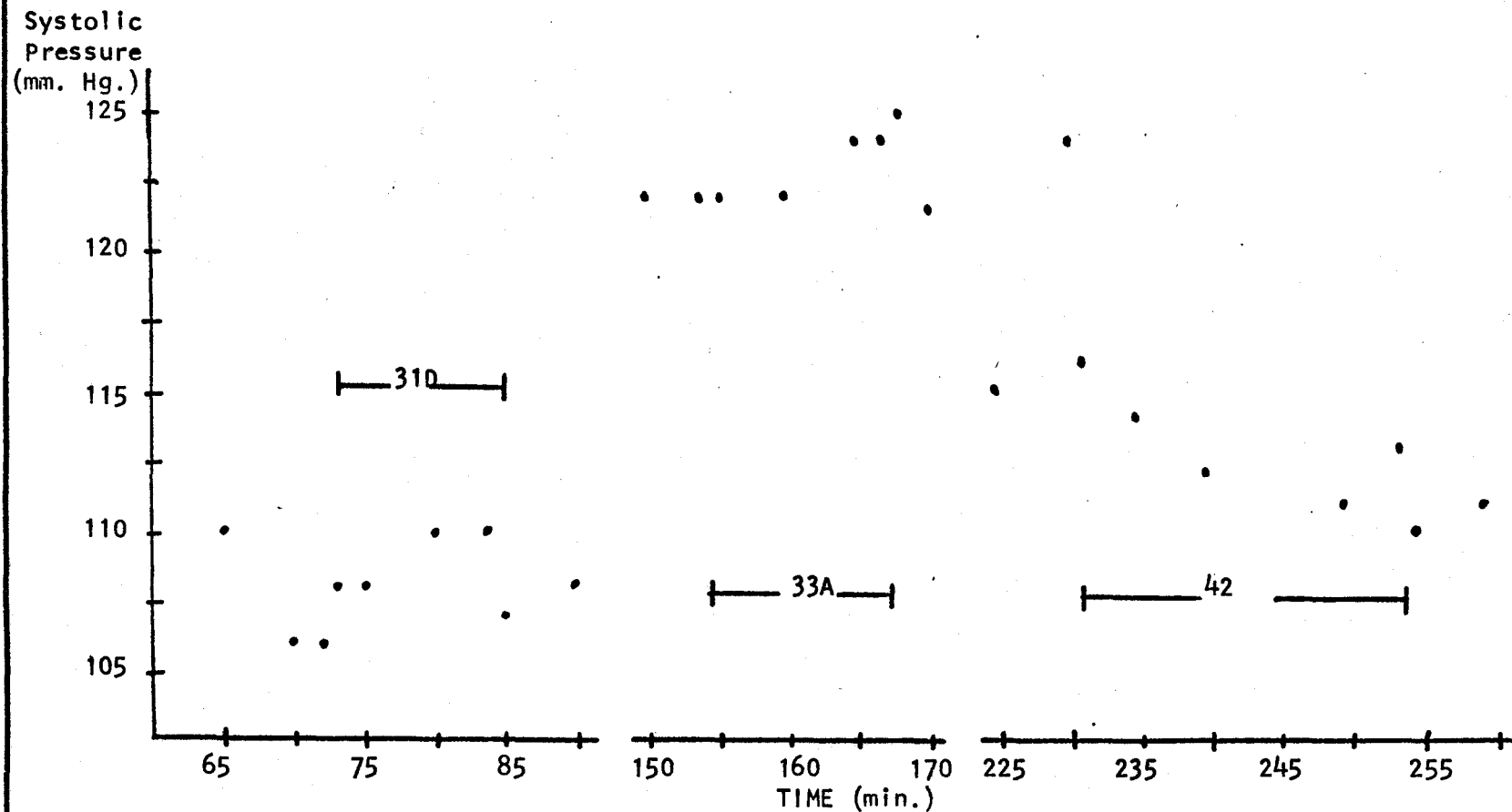


Figure 7. Subject 1: Systolic pressure change, Session III, Problems 31D, 33A, and 42.

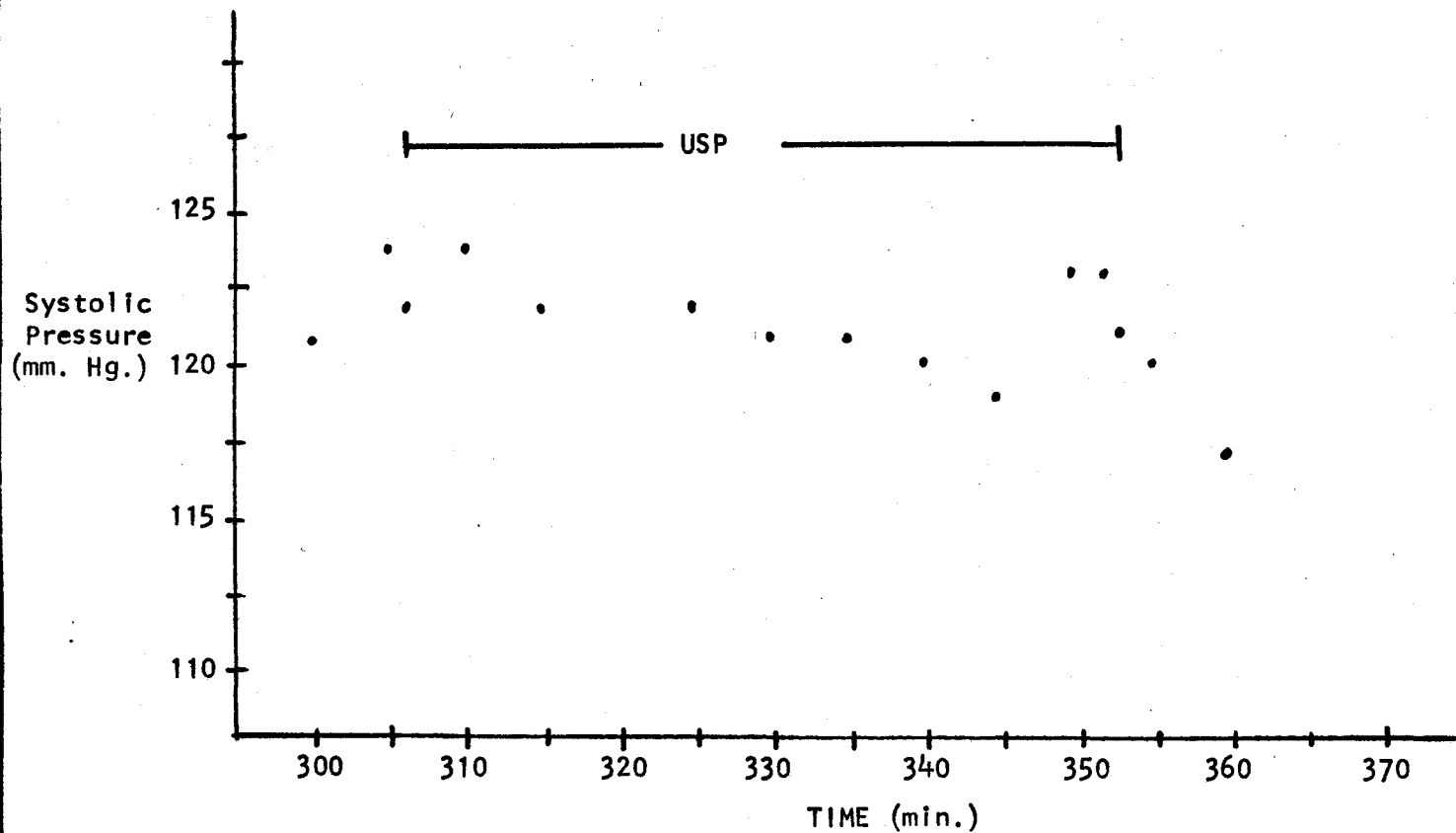


Figure 8. Subject 1: Systolic Pressure change, Session III, Problem USP.

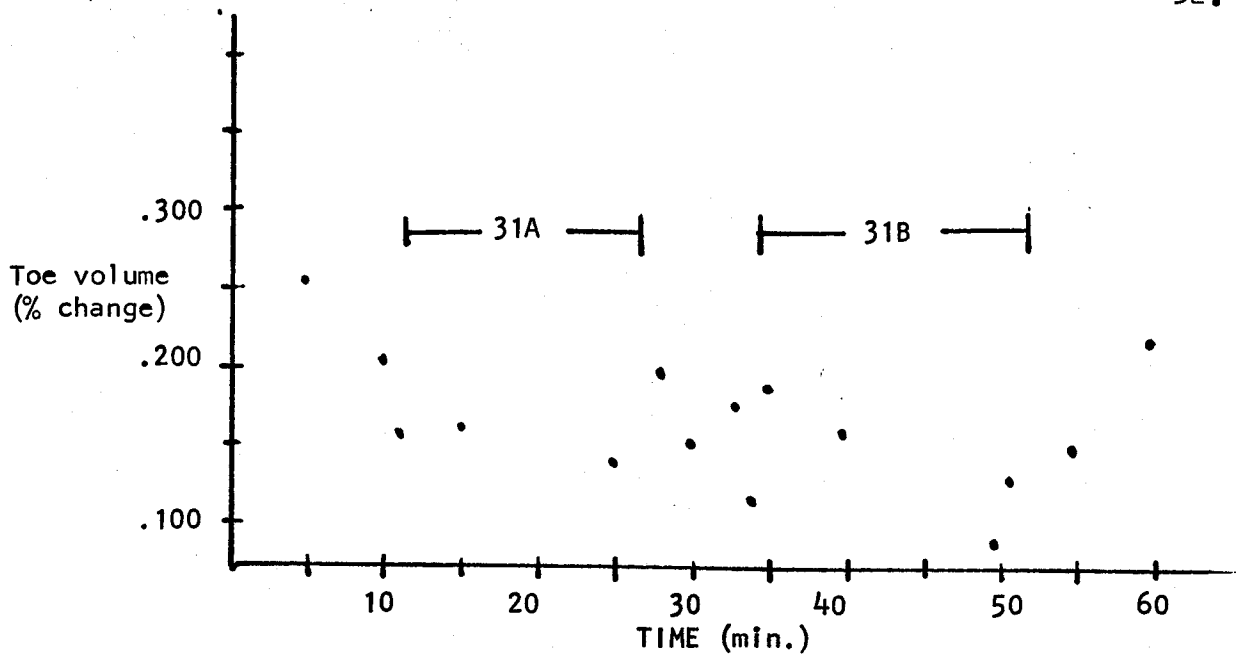


Figure 9. Subject 1; Toe volume change, Session I, Problems 31A and 31B.

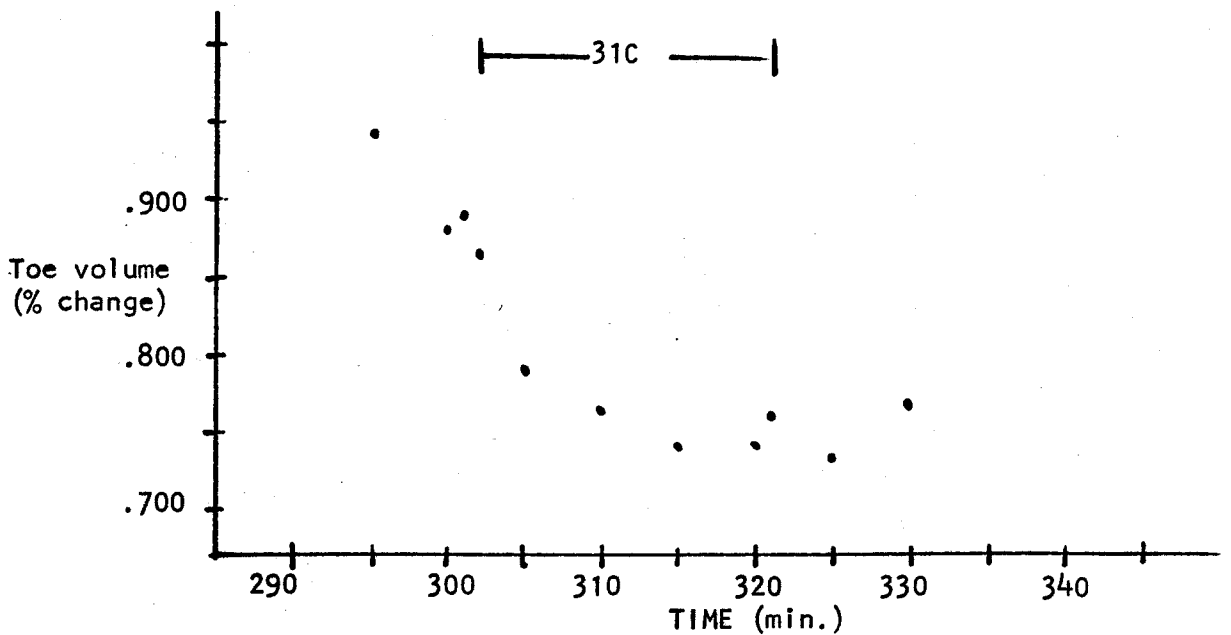


Figure 10. Subject 1; Toe volume change, Session I, Problem 31C.

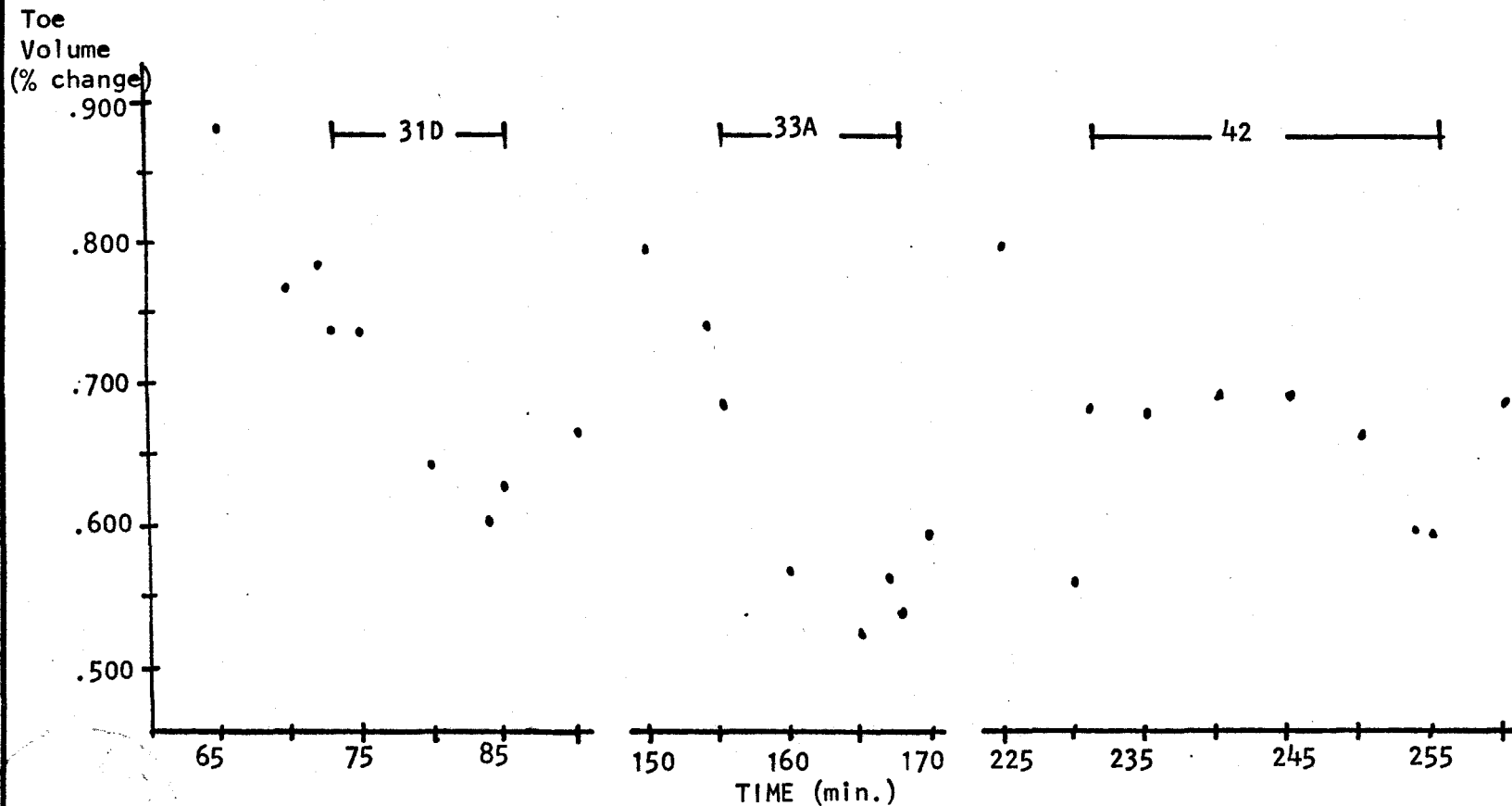


Figure 11. Subject 1: Toe volume change, Session III, Problems 31D, 33A, and 42.

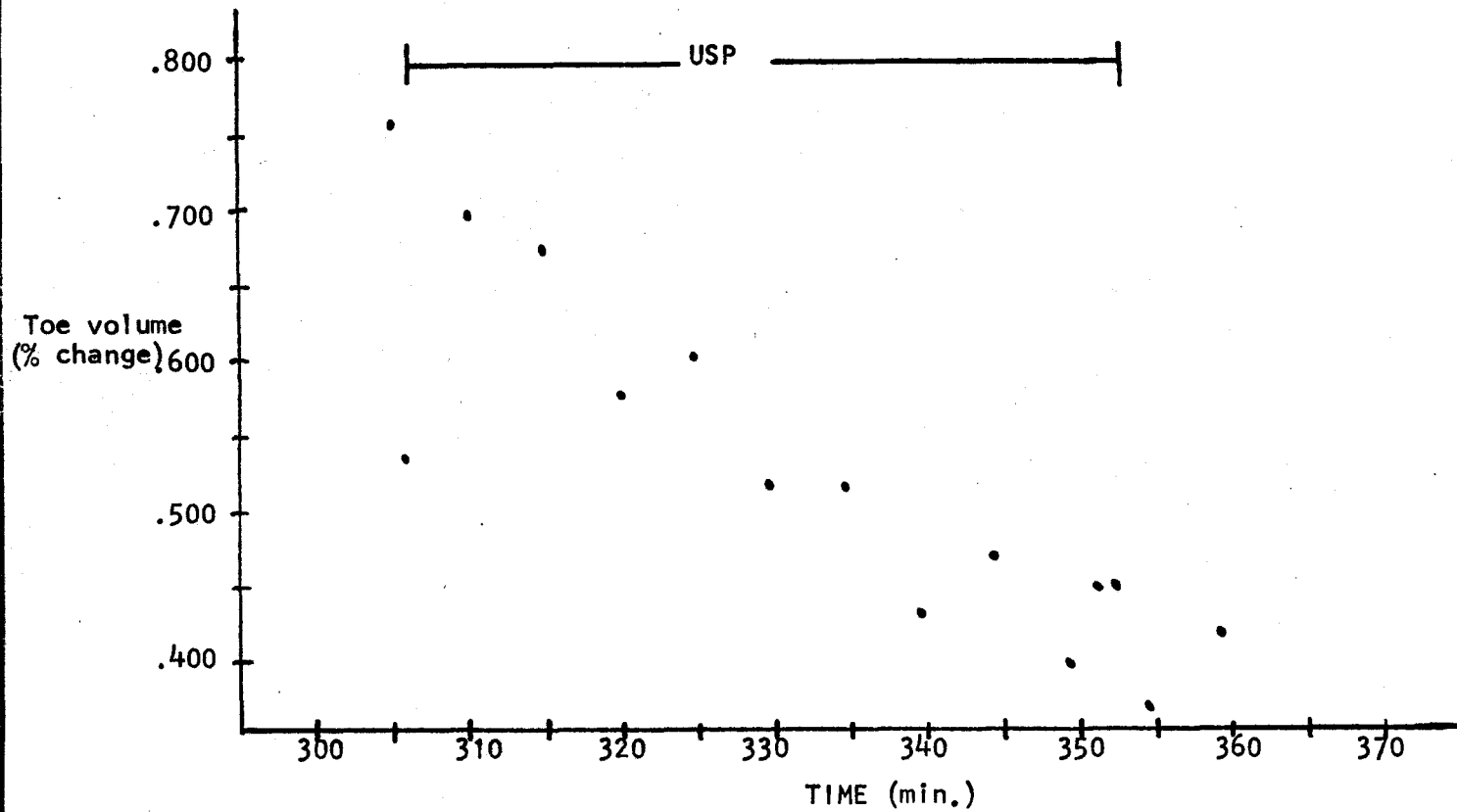


Figure 12. Subject 1: Toe volume change, Session III, Problem USP.

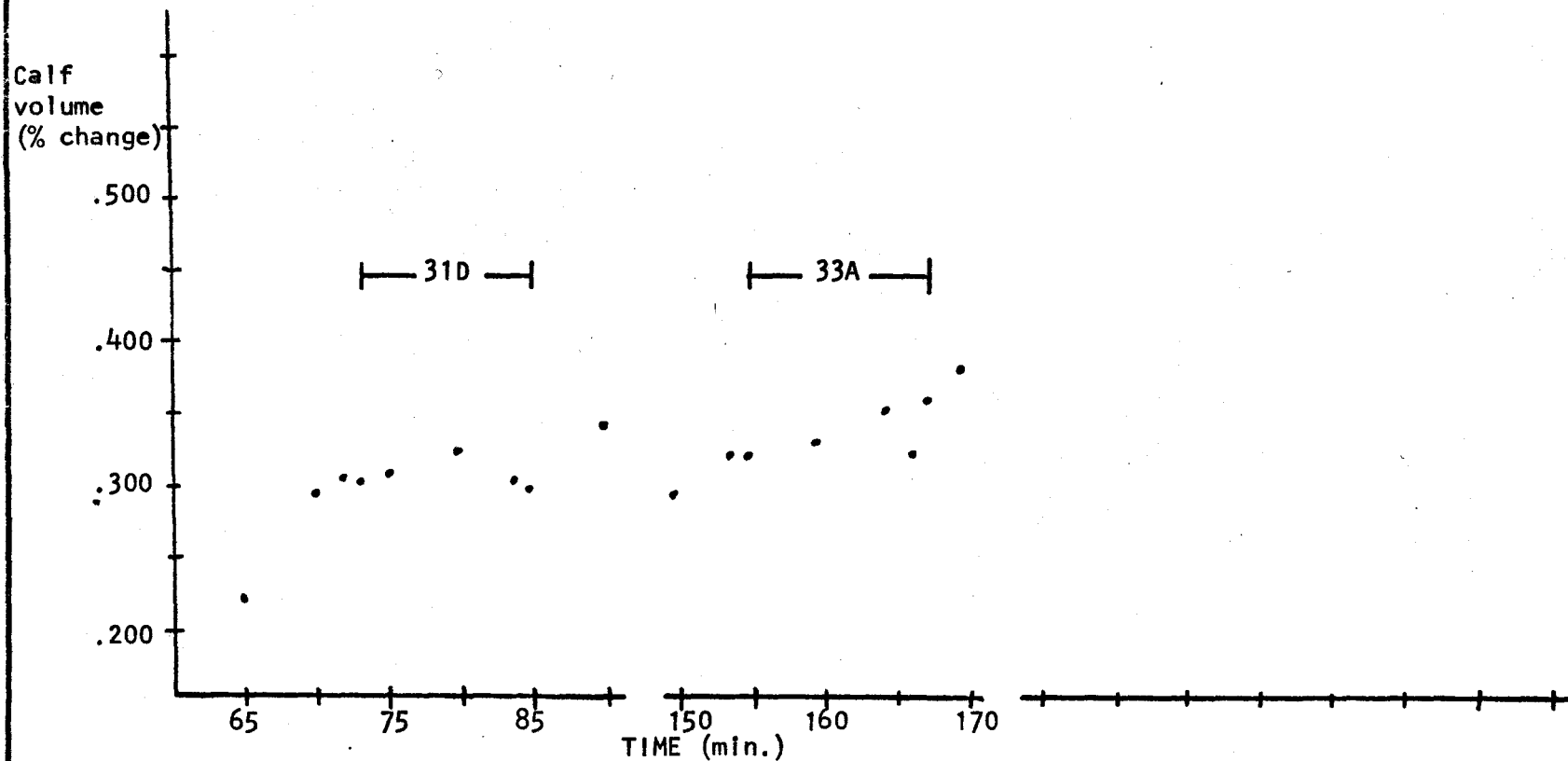


Figure 13. Subject 1: Calf volume change, Session III, Problems 31D and 33A.



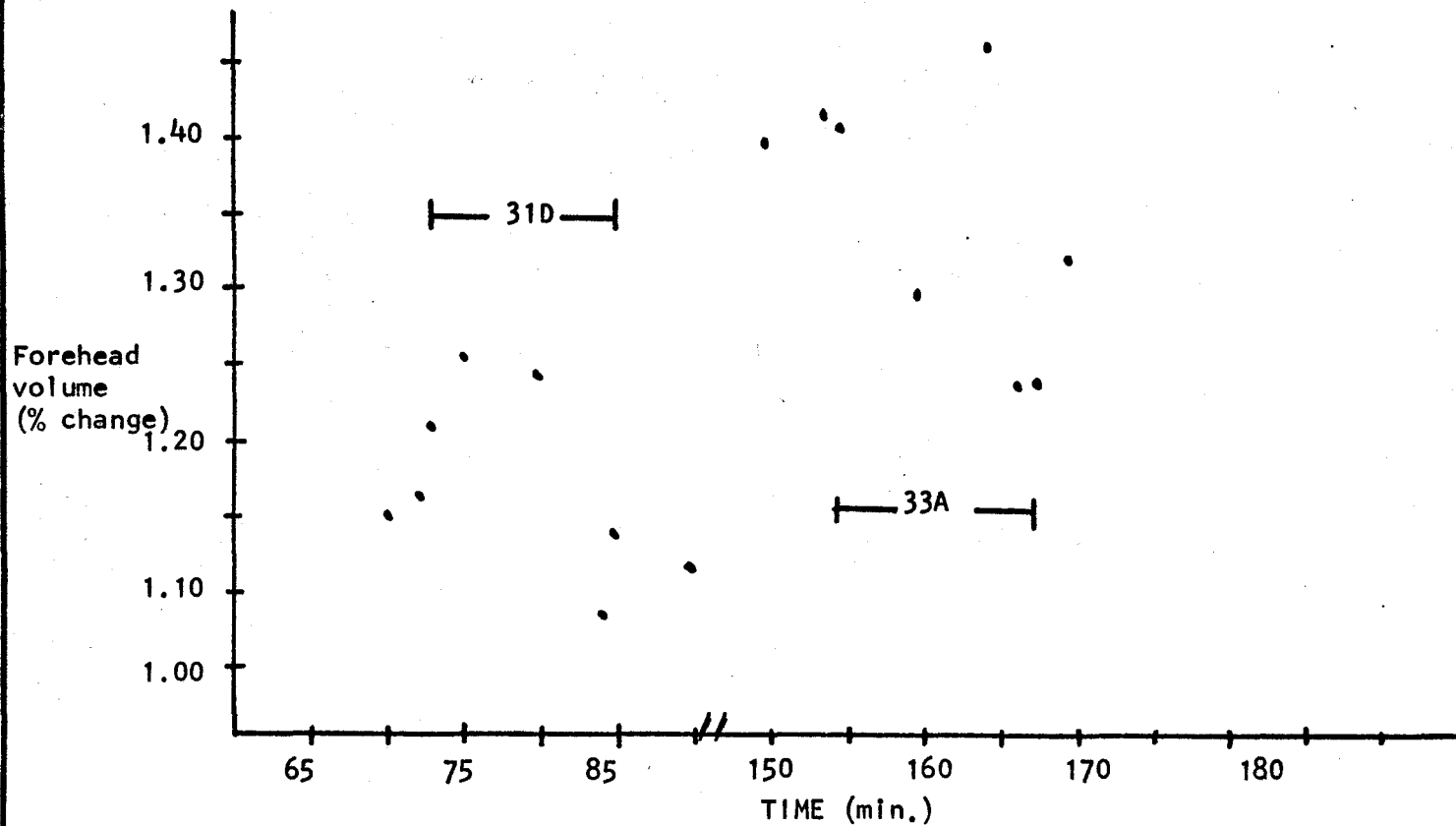


Figure 14. Subject 1: Forehead volume change, Session III, Problems 31D and 42.

Tables IV, V, VI contain the results of the trend analysis of the three blocks of time chosen from the control period of SESSION II. Each block contains each physiological measure, analyzed separately, for all the subjects for the thirty minute segment studied. The F-ratios presented indicate the absence of any significant trend in heart rate and blood volume; whereas, the calf volume exhibits significant linear trends in all three thirty minute segments. The forehead volume shows significance only in the first block.

## TABLE IV

## BLOCK ONE

TREND ANALYSIS OF CONTROL PERIOD, SESSION II, FOR ALL SUBJECTS  
FOR EACH PHYSIOLOGICAL MEASURE. F RATIOS PRESENTED.

TREND	PHYSIOLOGICAL MEASURE			
	TOE	CALF	FRHD.	HT. RT.
LINEAR	.001	32.99*	13.68*	.092
QUAD.	.007	.001	3.21	1.45
CUBIC	.910	1.46	.911	1.07
QUARTIC	.700	.905	1.70	.230

\* Significant beyond the .01 level

TABLE V  
BLOCK TWO

TREND ANALYSIS OF CONTROL PERIOD, SESSION II, FOR ALL SUBJECTS  
FOR EACH PHYSIOLOGICAL MEASURE. F RATIOS PRESENTED.

TREND	PHYSIOLOGICAL MEASURE			
	TOE	CALF	FRHD.	HT. RT.
LINEAR	.984	13.78*	.347	.465
QUAD.	.319	7.80	2.65	.292
CUBIC	1.06	.114	.959	1.33
QUARTIC	.014	1.04	.855	1.49

\* Significant beyond the .01 level

## BLOCK THREE

TREND ANALYSIS OF CONTROL PERIOD, SESSION II, FOR ALL SUBJECTS FOR EACH PHYSIOLOGICAL MEASURE. F RATIOS PRESENTED.

TREND	PHYSIOLOGICAL MEASURE			
	TOE	CALF	FRHD.	HT. RT.
LINEAR	.394	9.17*	.539	.077
QUAD.	1.84	4.55	.098	.005
CUBIC	1.07	.011	1.94	.615
QUARTIC	1.87	1.54	.078	.001

\* Significant beyond the .01 level

Tables VII, VIII, IX, X, and XI present the results of the Least Squares Polynomial fit for each physiological measure for all the problem periods, SESSIONS I, II, and III. Presented are the highest index of fit and the index value for the second degree. These values reflect the performance of a representative subject and were obtained by analyzing for each problem the baseline - problem - baseline change. The values reflect, therefore, the form of the best fitting equation or pattern of change for each problem given. Inspection of the index values reveals several close fits among the various physiological measures but no apparent over all consistency.

Empty cells indicate that either not enough points were available to obtain a fit or that the autonomic measure was not fully monitored at that time.

## TABLE VII

## HEART RATE

INDEX OF FIT FOR PROBLEM PERIODS, SUBJECT NUMBER ONE. BOTH THE BEST FIT OBTAINED AND THE SECOND DEGREE PRESENTED. BEST FIT PRESENTED FIRST AND DEGREE IDENTIFIED. WHEN QUADRATIC IS BEST FIT, IT IS PRESENTED ALONE.

PROBLEM	I/F
31A	.999 - 3 <sup>0</sup>
	.787
31B	
	.337
31C	
	.625
31D	.548 - 1 <sup>0</sup>
	.426
42	.369 - 3 <sup>0</sup>
	.172
33A	
	.741
USP	.795 - 3 <sup>0</sup>
	.720

TABLE VIII  
 SYSTOLIC PRESSURE

INDEX OF FIT FOR PROBLEM PERIODS, SUBJECT NUMBER ONE. BOTH THE BEST FIT OBTAINED AND THE SECOND DEGREE PRESENTED. BEST FIT PRESENTED FIRST AND DEGREE IDENTIFIED. WHEN QUADRATIC IS BEST FIT, IT IS PRESENTED ALONE.

PROBLEM	I/F
31A	
31B	
31C	
	.544
31D	
	.333
42	.125 - 1 <sup>0</sup>
	-.270
33A	.470 - 3 <sup>0</sup>
	.420
USP	
	.450



TABLE IX  
TOE VOLUME

INDEX OF FIT FOR PROBLEM PERIODS, SUBJECT NUMBER ONE. BOTH THE BEST FIT OBTAINED AND THE SECOND DEGREE PRESENTED. BEST FIT PRESENTED FIRST AND DEGREE IDENTIFIED. WHEN QUADRATIC IS BEST FIT, IT IS PRESENTED ALONE.

PROBLEM	I/F
31A	
	.844
31B	.880 - 3 <sup>0</sup>
	.365
31C	
	.884
31D	
	.863
42	.930 - 3 <sup>0</sup>
	.720
33A	.061 - 1 <sup>0</sup>
	-.024
USP	.054
	-.020

TABLE X  
CALF VOLUME

INDEX OF FIT FOR PROBLEM PERIODS, SUBJECT NUMBER ONE. BOTH THE BEST FIT OBTAINED AND THE SECOND DEGREE PRESENTED. BEST FIT PRESENTED FIRST AND DEGREE IDENTIFIED. WHEN QUADRATIC IS BEST FIT, IT IS PRESENTED ALONE.

PROBLEM	I/F
3IA	
3IB	
3IC	$.507 - I^0$
	.466
3ID	$.414 - I^0$
	.230
42	$.979 - I^0$
	.976
33A	
	.650
USP	$.501 - 3^0$
	.474

TABLE XI  
FOREHEAD VOLUME

INDEX OF FIT FOR PROBLEM PERIODS, SUBJECT NUMBER ONE. BOTH THE BEST FIT OBTAINED AND THE SECOND DEGREE PRESENTED. BEST FIT PRESENTED FIRST AND DEGREE IDENTIFIED. WHEN QUADRATIC IS BEST FIT, IT IS PRESENTED ALONE.

PROBLEM	I/F
31A	.980 - 3 <sup>0</sup>
	.970
31B	.860 - 3 <sup>0</sup>
	.850
31C	
	.550
31D	
	.170
42	
	.250
33A	
	.560
USP	
	.445

## DISCUSSION

The results of the t tests presented in TABLE III clearly indicate that in relation to heart rate, the physiological stressor, heat, was effective in raising the baseline of autonomic activity. Since the baseline SESSION II versus baseline SESSION III means were not significantly different, it follows that any day to day changes in rate were minimal under heat stress. On the other hand, since the control SESSION I versus control SESSION II means were different beyond the .05 level, the heat stress would seem to be the causative factor. Hence the problem periods will reflect physiological response to cognitive activity both under "normal" and unusual" environmental conditions. The conclusions drawn from the data therefore will have some bearing on the theoretical model of autonomic change proposed by Teichner (1968). More immediately, it can be concluded from this data that a meaningful physiological change did occur in response to the stressor, that the heat did function as a stressor, and that this change could be accurately monitored.

The t tests of heart rate change during the problem periods presented in TABLE II indicate that in terms of magnitude of change that problems 3IC and the unsolvable problem (USP) provoked the greatest amount of arousal. Although the emphasis of this study is not directed toward significant differences, this finding helps to direct one's attention to these problems and it will be seen that other data relative to these two problems are equally interesting. More immediately, it would seem that problem 3IC provoked a large autonomic response because of its position in time in SESSION II. Each subject had been subjected to about five hours of continuous heat stress before the problem was given, hence it would seem logical that not only were the subjects "on edge" but that the problem functioned as a novel stimulus in the sense that it was a change in the environment. Simply giving the subject something to do was apparently sufficient to provoke a change in autonomic arousal. That is, the mental activity involved in the attempt to solve problem 3IC quite probably represented a break in the tedium of this session. The subjects were now called upon to both focus their attention on a specific task and to expend energy in order to obtain the solution to this

problem. The focusing of attention and the mental activity are inseparably bound together in one continuous process. The result of this process is the observed autonomic response. Note that the trend analyses of heart rate in TABLES IV, V, and VI indicate no significant trend in rate during the periods, blocks, preceeding problem 3IC. Since the degree of attention required of a task has been implicated in the magnitude of autonomic response, Malmo (1966) and Lacey (1967), it readily follows that 3IC was an adequate stimulus for arousal and required an increase in attention and cognitive activity.

The unsolvable problem, superficially, would seem to be an effective stressor simply because it was frustrating to the subject. However, in view of the relatively stable problem periods preceeding the USP - no significant change in heart rate due to problems 3ID, 33A or 42 - it would appear that habituation of both physiological and cognitive response may have been occurring during SESSION III. It has been pointed out by Rimoldi et al. (1962) that training in problem solving results in greater efficiency and the selecting of fewer questions to solve a problem as long as they require similar solutions. I believe that a physiological correlate of this

occured during SESSION III; namely, that the subject's initial attention to the problem was great and hence maintained, then with increasing efficiency and/or mere experience, arousal began to habituate. The USP would presumably present a new situation to the subject, a new "solution" is called for, and hence a greater degree of attention would be necessary and this in turn would be reflected in the physiological indices. It would seem logical that as time passed the stress due to the frustration encountered with the problem itself would become effective and serve to maintain the level of arousal. It must be noted that this conclusion is based on an analysis of mean performances of control period to problem period. It is not claimed that the subject is immediately aware of the new situation, only that the overall effect for the USP period is significantly different from its baseline condition. It seems probable that the subject would gradually become aware of the changed situation, expend additional energy to cope with the changed pattern as if he were approaching a novel task, persist in his attempts even after the last logical question had been asked, and then experience frustration when no solution could be derived. Hence the total effect of the entire sequence

would yield a significant degree of arousal above baseline conditions.

The autonomic profiles contain several interesting results. Relative to heart rate and systolic blood pressure, each problem invariably serves as a stimulus for acceleration of these measures. The heart rate response to problem 42 in Figure 3 is a good example of the consistent pattern of acceleration at the beginning of a problem and the decrease in rate with the solution. Note also the general pattern of response in the toe volume. Figures 9 and II show consistent patterns of vasoconstriction encountered in the periphery due to the problems. The results pertaining to change in calf volume from the trend analysis and the autonomic profiles present an interesting situation as well. The entries in TABLES IV, V, and VI show a clear linear trend in calf volume while the other indices remain stable. One possible explanation is that the tibial artery is a major vessel and hence much larger relative to the other areas monitored. Hence the time course of thermoregulation is revealed. The other indices would regulate rapidly and remain stable since no cognitive activity was being imposed during the control period of SESSION II, while the calf was



still undergoing changes associated with temperature regulation. Inspection of the autonomic graphs shows clearly, for example, that the toe, heart rate, and systolic blood pressure do react rather quickly to the problems; whereas, Figure I3 reveals the gradual linear trend of change in calf volume.

In regard to the autonomic graphs, problem 3IC seems to present an ideal case. Note in Figures 2 and 6 that heart rate and systolic blood pressure both rise. The systolic pressure is not as labile as the heart rate and therefore it requires a longer time to reach its maximum level of arousal. While these indices are increasing, the toe volume is undergoing a dramatic decrease, indicating a general vasoconstriction of the periphery, Figure IO. This shunting of the blood serves to partially explain the rise in systolic pressure, the increase in rate being another factor. Hence a clear total pattern of arousal may be observed. Since these changes occurred during a period of "above normal" reactivity, they would seem to refute Teichner's contention that a compensatory reversal in the autonomic system with cognitive activity should occur. In relation to the USP, Figures 4 and I2 show equally consistent changes in heart rate and toe pulse respectively;

although, the systolic pressure, Figure 8, does not exhibit such a clear trend it nevertheless maintains an increased level.

Does the notion of the inverted U-shaped function hold for the data? Teichner (1968) and others have maintained that the U-shaped function is dependent on the task. Simple identification tasks may not therefore show decrements in performance short of very high levels of arousal; whereas, more complex tasks may show decrements at low activation levels. Although the present study was not designed to systematically manipulate task complexity, it is possible to get some information from the curve fitting data. In relation to heart rate and systolic pressure it is evident in TABLES VII and VIII that a quadratic function does indeed yield the best fits for problems 3IC and the USP. The toe pulse for problem 3IC yields a very close fit although a linear equation would seem to reduce the error more for the unsolvable problem (USP). Note the strong linear trend for the calf pulse in problem 3IC confirming the previous analysis. In conclusion therefore, since problems 3IC and USP would seem to rate as "complex tasks", the inverted U-shaped function is the most tenable description

of the present data. As previously discussed, the explanation of this function would appear to involve both attentional and cognitive mechanisms.

As to the anxiety data presented in TABLE I, it would seem that in regard to this particular data, that the small size of the sample severely limits any conclusions. Such tests should be incorporated in studies of this kind, however, if only to serve as a screening device for highly anxious and reactive subjects.

## SUMMARY

An intensive analysis of the effects of cognitive activity, with and without heat stress, was performed on a battery of physiological measures in order to investigate the total pattern of autonomic arousal. The interaction of the physiological measures during heat stress and cognitive activity was presented in graphical form, and also discussed in relation to the U function hypothesis and a model of autonomic action proposed by Teichner. A least squares curve fitting procedure and several trend analyses were employed to analyze the data and to support the conclusions drawn from it; namely, that the U shaped relationship is teneable, and autonomic compensatory reversal does not appear to occur when cognitive activity is imposed on a physiologically "aroused" subject.

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APPENDIX

PROBLEM 3IA

I.

At Spencer High School, the annual fall dance is about to be held. A dance committee has been selected to make the necessary arrangements. Both boys and girls are on the committee. A part of the committee is to take care of the refreshments for the evening and another part will look after the sale of the tickets for the dance. The list of the girls on the dance committee involved in the sale of tickets has been lost. From the other information available, which you will find in the questions, your object will be to discover the number of girls involved in the sale of tickets.

- 
- |   |                 |
|---|-----------------|
| 1. Is Spencer High School the only co-educational school in the city?                   | 1. No           |
| 2. How many boys are on the dance committee?  | 2. Ten          |
| 3. How many boys attend Spencer?  | 3. 240 boys     |
| 4. Are there more girls than boys at this school?                                       | 4. Yes          |
| 5. How many students on the dance committee are assigned to supplying the refreshments? | 5. Fourteen     |
| 6. What is the total number of students on the dance committee?                         | 6. Twenty-five  |
| 7. How much time would the committee as a whole spend in preparation for the dance?     | 7. 275 hours    |
| 8. How much time would the average committee member contribute?                         | 8. Eleven hours |
| 9. How many boys on the committee are involved in the sale of tickets?                  | 9. Six boys     |
| 10. How many girls are on the refreshment part of the dance committee?                  | 10. Ten girls   |

Solution: 5

PROBLEM 318

II.

We have a certain number of objects: M, a part of which, for lack of a better name, will be called C's. The C's are composed of B's and G's. Each of this latter two types is divided into R's and T's. From the other information available which you will find in the questions, your object will be to discover the number of G's that are also T's.

- 
- |   |                |
|---|----------------|
| 1. Are there C's that are not B's and G's?    | 1. No          |
| 2. How many B's are C's?                      | 2. Thirty      |
| 3. How many B's are M's?                      | 3. 120         |
| 4. How many C's are R's?                      | 4. Thirty-five |
| 5. Are there more G's than B's among the M's? | 5. Yes         |
| 6. What is the value of k times the C's?      | 6. 550         |
| 7. What is the total number of C's?           | 7. Fifty       |
| 8. How many B's that are C's are also T's?    | 8. Ten         |
| 9. How many G's that are C's are also R's?    | 9. Fifteen     |
| 10. What is the value of k?                   | 10. Eleven     |

Solution: 5

## PROBLEM 31C

Assume that X, A, D, P, and S represent properties among F objects. Not X, not A, not D, and so on represent lack of these properties. The not X's are composed of not A's and not D's. Each of these latter is divided into not P's and not S's. From the other information available, which you will find in the questions, your object will be to discover the number of not D's that are also not S's.

- 
- |   |                |
|---|----------------|
| 1. Are there not X's that are A's and D's?              | 1. No          |
| 2. How many not A's are F's?                            | 2. 100         |
| 3. Are there more not D's than not A's among the F's?   | 3. Yes         |
| 4. How many not A's are not X's?                        | 4. Fourteen    |
| 5. What is the total number of not X's?                 | 5. Forty       |
| 6. How many not X's are not P's?                        | 6. Twenty-four |
| 7. What is the value of 1 times the not X's?            | 7. 440         |
| 8. What is the value of 1?                              | 8. Eleven      |
| 9. How many not D's that are not X's are also not P's?  | 9. Twenty      |
| 10. How many not A's that are not X's are also not S's? | 10. Ten        |

Solution: 6

## PROBLEM 310

From R objects L has been selected. These L objects are divided into A's and B's. Each of these letter types is divided into M's and N's. From the other information available, which you will find in the questions, your object will be to discover how many N's are also B's.

- 
- |   |                    |
|---|--------------------|
| 1. How many A's are R's?                      | 1. W               |
| 2. What is the total number of L's?           | 2. $E+F+H+I=P+Q=L$ |
| 3. How many L's are M's?                      | 3. $E+F=X$         |
| 4. How many A's are L's?                      | 4. $E+H=P$         |
| 5. Are there more B's than A's among the R's? | 5. Yes             |
| 6. Are there L's that are not B's and A's?    | 6. No              |
| 7. How many B's that are L are also M?        | 7. F               |
| 8. How many A's that are L are also N?        | 8. H               |
| 9. What is the value of K?                    | 9. T               |
| 10. What is the value of K times the L's?     | 10. Z              |

Solution: I

PROBLEM 33A

V.

A drug store owner received different types of magazines that have different prices. Some cost less than 25¢, some cost more than 25¢. You are to find out how many mystery magazines cost more than 25¢.

- 
- |  |                                |
|--|--------------------------------|
| I. What kinds of magazines does the store receive?                 | I. Mystery, sports, mechanical |
| 2. Has the store more magazines about mechanics than sports?       | 2. No                          |
| 3. Has the store more magazines about mechanics than mysteries?    | 3. Yes                         |
| 4. How many different prices do the magazines have?                | 4. Three                       |
| 5. What is the total number of magazines which the store receives? | 5. Sixty                       |
| 6. How many cost 25¢ or more?                                      | 6. 52                          |
| 7. How many mechanics magazines cost less than 25¢?                | 7. Five                        |
| 8. Do all the sports cost less than 25¢?                           | 8. No                          |
| 9. How many sports magazines and mechanics cost less than 25¢?     | 9. Six                         |
| 10. Do all the sports cost less than 25¢?                          | 10. No                         |
| 11. How many sports magazines are received?                        | 11. Thirty                     |
| 12. How many mechanics are received?                               | 12. Twenty                     |
| 13. How many mystery magazines are received?                       | 13. Ten                        |



## PROBLEM 42

This figure is composed of 24 areas. The numbers in the areas are merely for the purpose of identifying a particular area and have no bearing on the solution of the problem.

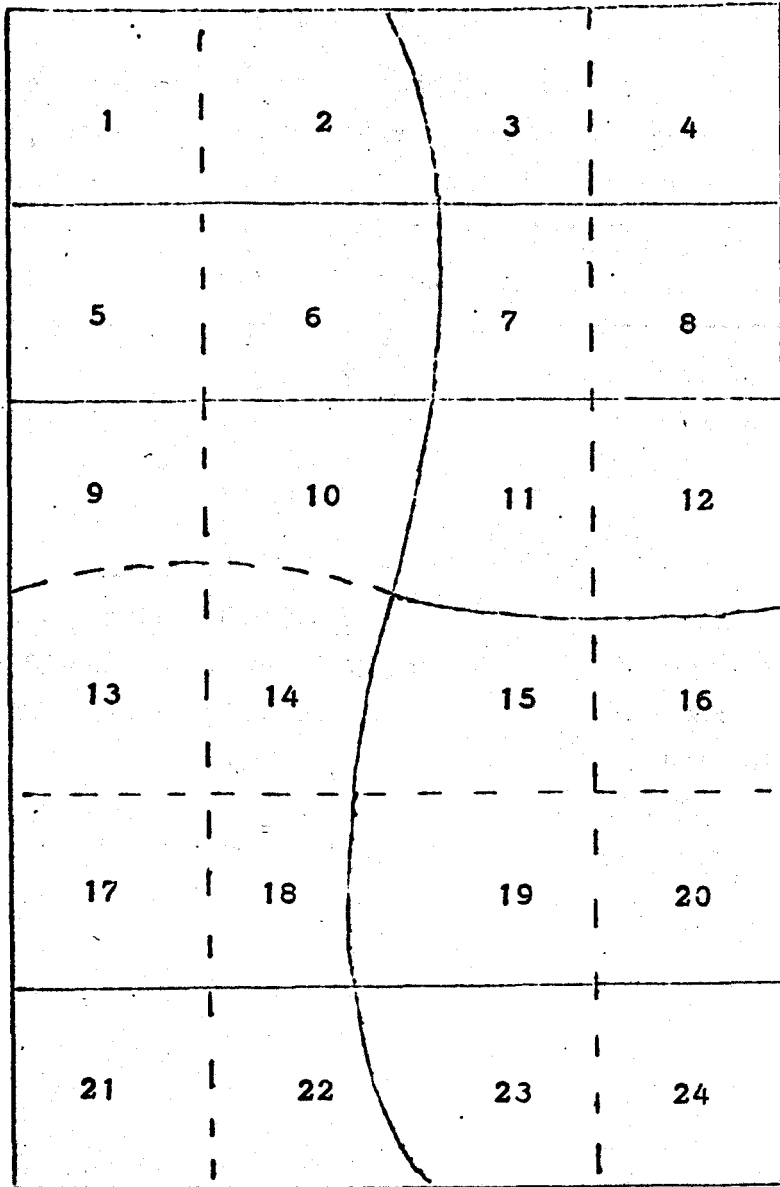
One of the areas has been selected. Your task is to discover the selected area. You may discover this area by using any of the questions you like to arrive at the answer.

- 
- |  |        |
|--|--------|
| 1. Is it above the unbroken curve line?  | 1. No  |
| 2. Does it have two curved lines as borders?   | 2. No  |
| 3. Is it to the right of the vertical curve line?  | 3. Yes |
| 4. Does it have two continuous straight lines and two broken lines as borders?                     | 4. No  |
| 5. Does it have 2 broken straight line borders?  | 5. No  |
| 6. Does it have any combinations of 2 broken and 2 curved sides?                                   | 6. No  |
| 7. Is it below the dotted curve line?  | 7. No  |
| 8. Does it have three continuous straight lines and one broken straight line as borders?           | 8. No  |
| 9. Does it have a broken curve line as a border?   | 9. No  |
| 10. Does it have at least one continuous straight line and two continuous curved lines as borders? | 10. No |

Solution: 23

PROBLEM 42

VII.



## PROBLEM USP

We have a certain number of objects, X, which are composed of A's, B's and C's. The A's have as components D's, E's, and F's. The same is true for the B's and C's; that is, they have D's, E's, and F's as components. Your task is to find out the number of F's that are also C's.

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- |                                   |                 |
|-----------------------------------|-----------------|
| 1. Are there more E's than F's?   | 1. No           |
| 2. How many F's are A's?          | 2. Eleven       |
| 3. Are there more B's than A's?   | 3. No           |
| 4. What is the number of X's?     | 4. 75           |
| 5. How many D's are also A's?     | 5. Six          |
| 6. What is the number of A's?     | 6. Twenty-five  |
| 7. How many D's and F's are C's?  | 7. Twenty-three |
| 8. What is the number of B's?     | 8. Twenty-five  |
| 9. How many E's are there?        | 9. Twenty-two   |
| 10. How many E's are C's?         | 10. Two         |
| 11. How many E's are A's and C's? | 11. Ten         |
| 12. How many F's are B's and C's? | 12. Fourteen    |

No Solution

APPROVAL SHEET

The dissertation submitted by Bernard J. Harney, has been read and approved by members of the Department of Psychology.

The final copies have been examined by the director of the dissertation and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the dissertation is now given final approval with reference to content and form.

The dissertation is, therefore, accepted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Jan 10/70  
(Date)

W. J. Harney  
(Signature of advisor)