CARDIAC AND SOMATIC CONCOMITANTS OF RESPONSE ACTIVATION AND RESPONSE INHIBITION

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ABSTRACT

CARDIAC AND SOMATIC CONCOMITANTS OF RESPONSE ACTIVATION AND RESPONSE INHIBITION

By

Terry Walter Allen

Recent research has found that patterns of cardiac and somatic change are related to performance in a reaction time task. However, studies which have examined the generalization of these relationships across different tasks have had limited success. The relationship between patterns of physiological change and reaction time was studied using an Activation Task and an Activation-Inhibition Task with male college students. In contrast to previous investigations, the type of preparatory interval (fixed or variable) was covaried with task. Magnitude of heart rate deceleration was found to be related to reaction time for Ss in both fixed preparatory interval Activation and Activation-Inhibition Task groups. Preperiod heart rate variance and Tonic heart rate variance reduction were related to reaction time for Ss in both variable preparatory interval Activation and Activation-Inhibition Task groups. Tonic muscle activity was related to reaction time for Ss in both fixed and variable preparatory interval Activation Task groups. In the fixed preparatory Activation-Inhibition Task, low Tonic muscle activity was related to successful response inhibition. Magnitude of Tonic heart rate variance reduction was related to successful response inhibition

for Ss in the variable preparatory interval Activation-Inhibition Task group. The results of this study were discussed in terms of their implications for a physiological basis of attention.

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By

Terry Walter Allen

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INTRODUCTION

Recent research has found that patterns of physiological change used to index an individual's attentional behavior are related to task performance. This relationship between physiological responding and performance has been most frequently examined using a reaction time task. In a reaction time task, a signal (warning signal) is presented, the purpose of which is to prepare S for a second stimulus (response signal), to which S must respond as quickly as possible. The time between the onset of the warning signal and the response signal is called the preparatory interval.

Using a reaction time task, investigators have been chiefly interested in studying relationships between cardiac and somatic activity and reaction time performance. Several investigators have found that a large heart rate deceleration just prior to the response signal was associated with a fast reaction time (Krupski, 1971; Lacey, 1967; Schwartz & Higgins, 1971). This relationship appears to be specific to those reaction time tasks employing a fixed preparatory interval in contrast to those employing variable preparatory intervals. In addition, Porges (1972) recently has examined heart rate variability as a component of attention and its relationships to reaction time performance.

In this study, it was found that mean heart rate variance reduction in anticipation to the response signal and mean pretrial variance were related to reaction time. However, this result was true only for Ss in a variable preparatory interval condition and not for Ss in a fixed preparatory interval condition.

In addition to these heart rate indexes of attention and subsequent reaction time performance, anticipatory muscle activity has been found to be related to reaction time performance. Using electromyographic (EMG) recording of chin muscle activity, Jennings, Averill, Opton, and Lazarus (1971) found that increases in muscle activity prior to responding were associated with faster reaction times. Grossman, Fitzgerald, and Porges (1971) also found that increases in forearm circumference for males (task relevant muscles) were correlated with fast reaction times. On the other hand, increases in forearm circumference were correlated with slow reaction times for females.

The results of these studies suggest that both heart rate deceleration and variability as well as muscle activity are useful indexes of attentional involvement and subsequent performance. However, investigators which have studied the generality of relationships between physiological and performance in variations of the reaction time task or other more complex tasks have reported little success. Jennings et al. (1971) examined the relationships between heart rate deceleration, muscle activity, and reaction time

under various task conditions in which Ss were required to perform more than one response or underwent stress. Although some relationship between muscle activity and reaction time was observed across tasks, relationships between heart rate deceleration and reaction time were limited. Moreover, Stroufe (1971) compared children's performance on a simple fixed preparatory interval reaction time task and on a task which required them to respond or not respond to a perceptual signal. In both tasks, Stroufe found that magnitude and temporal preciseness of heart rate deceleration were related to reaction time. However, Stroufe did not find a significant relationship between inhibition performance (errors) and heart rate deceleration.

The above findings have important implications for hypotheses which propose a physiological basis for attention. If heart rate deceleration or other physiological responses are to be regarded as a strong index of the organism's attention, then these responses should be related to performance in other tasks. In particular, the results of these studies suggest that heart rate deceleration may be limited in its value as an index of the individual attention when used in tasks other than the simple reaction time task. However, the failure to obtain this relationship between patterns of physiological change and performance across tasks may be due to a failure to consider the type of preparatory interval employed in a reaction time task or variations of this task. In all of the previous studies

reviewed, preparatory interval in combination with task demands has not been systematically varied. This is an important omission since previous research has shown that heart rate and somatic responses are affected considerably by the nature (fixed or variable) of the preparatory interval employed in the task (Krupski, 1971; Lacey, 1967; Porges, 1972). Consequently, a more conclusive test of generality of these responses as predictors of performance would be an experiment in which the effects of type of preparatory interval in conjunction with task demands on heart rate and somatic activity were examined.

The present experiment was designed to study the relationship between physiological response patterns (cardiac and somatic components of attention) and reaction times under various task conditions. Preparatory interval (fixed or variable) was covaried with task. Two tasks were used in the present study: a simple reaction time task (Activation Task) and an Activation-Inhibition Task patterned after the one employed by Luria (1961) in which S is required to respond to one signal and inhibit the same response to another signal. It was hypothesized that those cardiac and somatic response patterns related to reaction time performance in a simple reaction time task would also be related to successful response inhibition and reaction time for Ss in the Activation-Inhibition Task.

Method

Subjects

Subjects were 48 college-age-males acquired from the introductory psychology course offered at Michigan State University and from the East Lansing area. Subjects recruited from Michigan State University received extra course credit for their participation in the experiment while those obtained from the East Lansing community were paid. Six Ss were discarded because of mechanical failure of equipment.

Apparatus

Stimuli. The stimulus presentation apparatus consisted of a gray panel (12" x 12" x 6") on which amber, blue, and white 24v. lights were mounted. These lights were presented at a distance of 4 ft. from S at eye level. During the Activation task, onset of the amber light warned S to prepare to respond while its offset signaled S to respond. In the Activation plus Inhibition condition, the amber light onset signaled S to respond or inhibit his response. The onset of the blue or white lights was simultaneous with the offset of the amber light and signaled S to respond or not to respond. The presentation of these stimuli (stimulus duration and intertrial interval) was controlled by Hunter timers. The experiment was conducted in a sound-attentated room with a temperature of 70 degrees F. The ambient noise level was 51 db.

Response measurement. Reaction time (RT) was measured using a bulb connected to a vacuum switch (Grossman et al., 1970). Reaction time was registered in milliseconds on a Standard electric clock. Physiological responses were recorded on a four-channel Grass polygraph, Model P7. Beckman biopotential silver-silver chloride electrodes were used to record EKG and electromyographic activity while Beckman biopotential paste was used as the electrolyte. Heart rate (HR), unintegrated electromyographic responses (EMG), and forearm circumference (FC) were recorded. Heart rate was recorded with a Grass Model 7P4A tachograph. A Grass Wide-Band Preamplifier and Integrator, Model 7P3B, was used to measure EMG amplitude. Forearm circumference was recorded using a Parks Electronic four-inch mercury strain gauge (Grossman et al., 1970). Changes in circumference were measured by a Grass Low-Level DC Pre-Amplifier, Model 7P1A.

Procedure

Subjects were randomly assigned to Groups 1 through 6 when they arrived at the experimental room (See Table 1). The subject was seated and EKG and EMG recording sites were prepared. EKG electrodes were attached to the right leg near the ankle (±), to the left arm (+), and to the right arm (-). EMG electrodes were placed on the right forearm one-third the distance between the medial epicondyle of the humerus end the styloid process of the radius; and the second electrode was placed two inches in the distal

TABLE 1

A representation of the experimental design prior to analysis for color preference.

Group	Task	Preparatory Interval	Stimulus Color of Respond Signal
1	Activation	Fixed	White or Blue
2	Activation	Variable	White or Blue
3	Activation-Inhibition	Fixed	White Blue
4	Activation-Inhibition	Fixed (counterbalance)	Blue White
5	Activation-Inhibition	Variable	White Blue
6	Activation-Inhibition	Variable (counterbalance)	Blue White

direction from the first electrode along the same line (Venables & Martin, 1964). The ground electrode was located on the bicep of the same arm. The strain gauge was placed between the two EMG electrode sites on the forearm.

Following attachment of recording electrodes and the strain gauge, the task instructions were read to S. Subjects in Groups 1 and 2 were told to watch for the appearance of the amber light. When the amber light disappeared, Ss were told to respond as rapidly as possible when it disappeared and the blue light came on. Subjects were also told to not respond when the amber light disappeared and the white light came on. Subjects in Groups 4 and 6 were given the same instructions except that the Activation and Inhibition stimulus values used for Groups 3 and 5 were reversed. The polygraph was then calibrated. Following calibration, lights in the experimental room were dimmed and S was informed via an intercom that the experiment was about to begin. At the completion of the experiment, Ss were informed via the intercom that the experiment had ended.

Each S received twenty trials during the experimental session. For Groups 1 and 2, all twenty trials were Activation trials. During the experimental period for Groups 3 through 6, ten trials were Activation trials and ten trials were Inhibition trials. A predetermined random schedule ordered the appearance of the Activation and Inhibition trials. All groups had the same ITI which varied among 45, 60, and 75 seconds. The length of the

fixed ISI condition (Groups 1, 3, and 4) was 32 seconds. For the variable ISI condition, the ISI length varied among 16, 22, and 28 seconds (Groups 2, 5, and 6) with a mean of 22 seconds.

Quantification of Data

Reaction time, HR, EMG, and FC were scored for each of the twenty trials during the experimental period. Each trial was divided into four periods for analysis (see Figure 1): (a) a Preperiod consisting of 8 seconds prior to the onset of the amber light (warning signal); (b) a Phasic period of 8 seconds immediately following the onset of the amber light; (c) a Tonic period consisting of 8 seconds prior to the onset of the blue or white lights; and (d) a Response period of 8 seconds immediately following the onset of the blue or white lights (see Porges, 1972).

Reaction time. Subjects' RT was defined as the latency between offset of warning signal and the bulb squeeze.

Response errors. Those inhibition trials in which S responds or those Activation trials in which S failed to respond--were recorded.

Heart rate. Subject's HR (beats per minute, bpm) was scored directly from the printed output from the polygraph. A HR score was obtained for each of the 8 seconds contained within the four periods of analysis. If more than one heart beat occurred during one second, only the last beat to occur was scored.

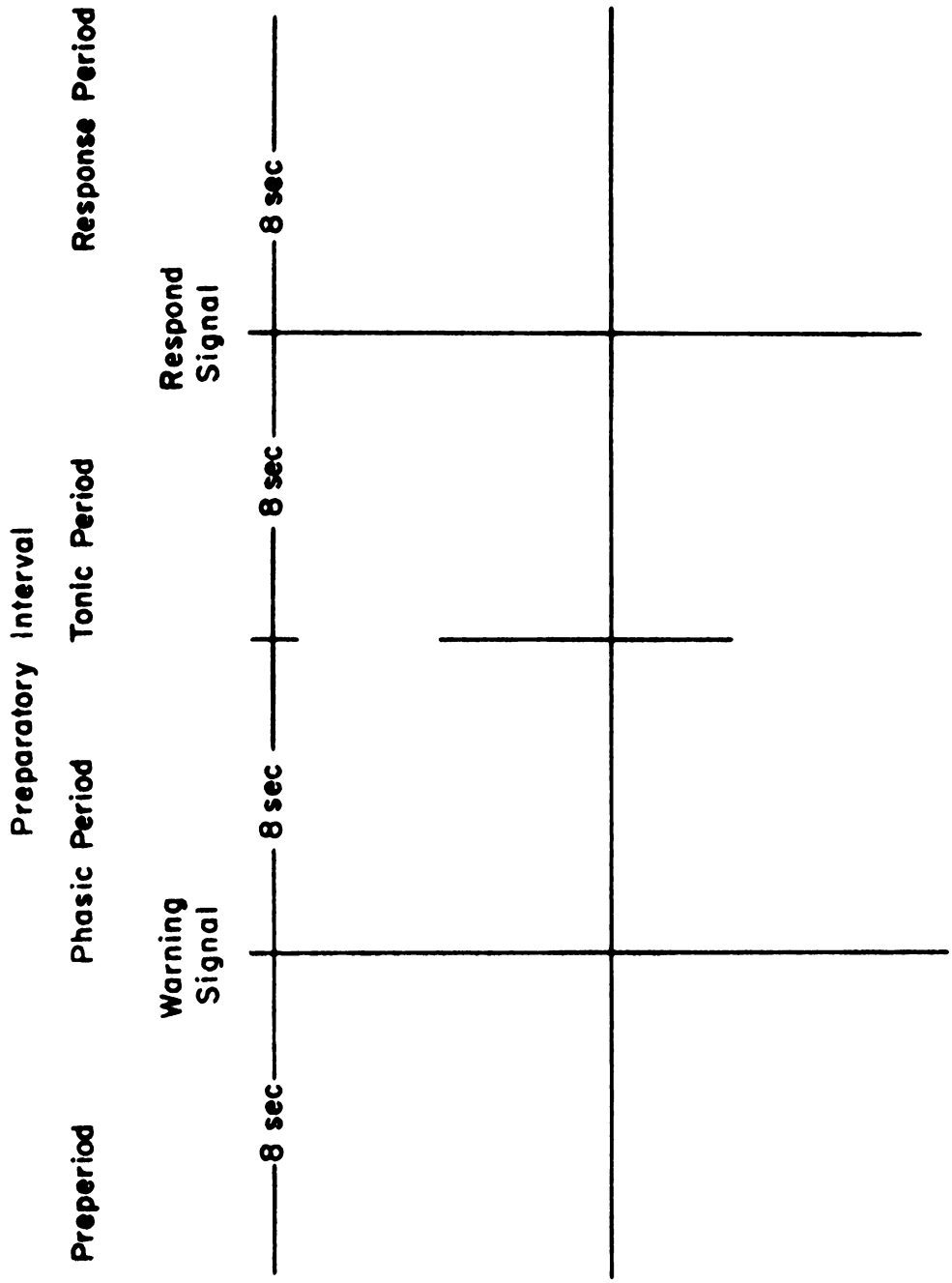

Figure 1. A representation of the reaction time paradigm.

EMG. EMG amplitude was computed by counting the number of spike potentials occurring during each of the four periods of analysis. A spike potential was defined as a change in polarity greater than or equal to 50 microvolts.

FC[1]. Changes in S's FC were obtained by measuring millimeters of pen deflection from base line for each second during the four periods of analysis.

Results

Analysis of the data was divided into three phases: (a) a reaction time phase; (b) a physiological activity phase; and (c) a relationship between physiological activity and RT phase. Analysis of reaction time consisted of examining the experimental effects on reaction time and error frequency. Experimental effects on heart rate and muscle activity were examined during the analysis of physiological activity. Finally, the relationship between physiological state and performance was examined for each experimental condition.

Before considering the results of these analyses, one preliminary analysis was done. Although there was no *a priori* reason to suspect that the color of the response signal would influence performance, the data were analyzed for possible color preferences. Reaction times to the blue light were compared with those to the white light yielding no significant differences as a function of response signal color ($t = 1.03$, $df = 718$, $p > 0.20$). Consequently for the

rest of the data analysis, Groups 3 and 4 were combined to form Group AI-FI and Groups 5 and 6 were combined to form Group AI-VI (see Table 2).

TABLE 2

A representation of the experimental design following the analysis for color preference.

Group	Task	Preparatory Interval
1 (A-FI)	Activation	Fixed Interval
2 (A-VI)	Activation	Variable Interval
3 + 4 (AI-FI)	Activation-Inhibition	Fixed Interval
5 + 6 (AI-VI)	Activation-Inhibition	Variable Interval

Reaction Time

Reaction time data for all conditions were plotted. The plotting of RT data for the Activation conditions appear in Figure 2 while those for the Activation-Inhibition conditions appear in Figure 3. An analysis of variance was performed on the RT data for the Activation groups while a separate analysis of variance was performed on RT data for the Activation-Inhibition groups. Results of this analysis (see Table 3) for Group A-FI and Group A-VI indicate that RT performance improved across trials. Results of the analysis of variance for Groups AI-FI and AI-VI (see Table 4) also indicated that RT performance improved across trials.

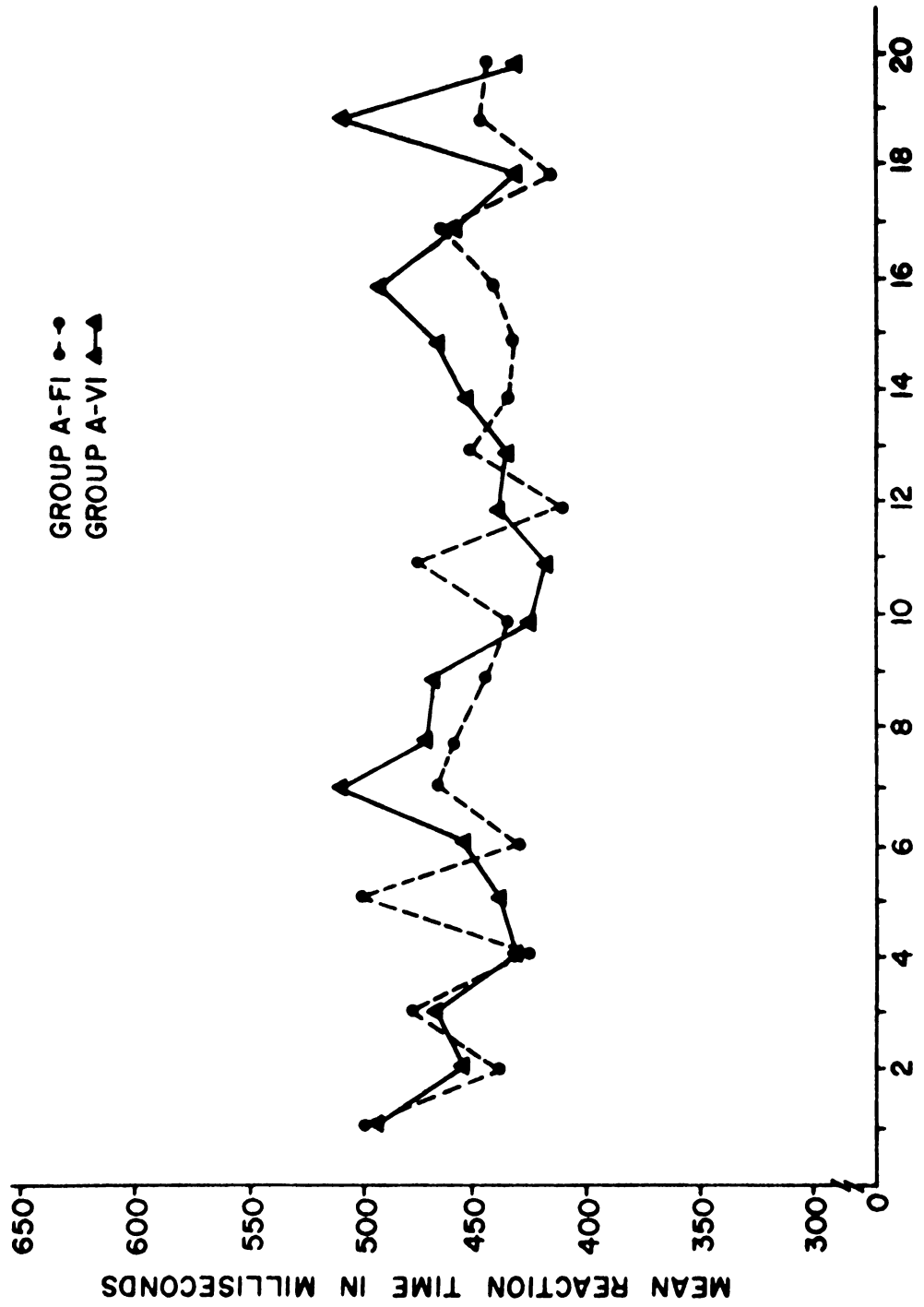

Figure 2. Mean reaction times on each trial for Ss in Activation groups A-FI and A-VI.

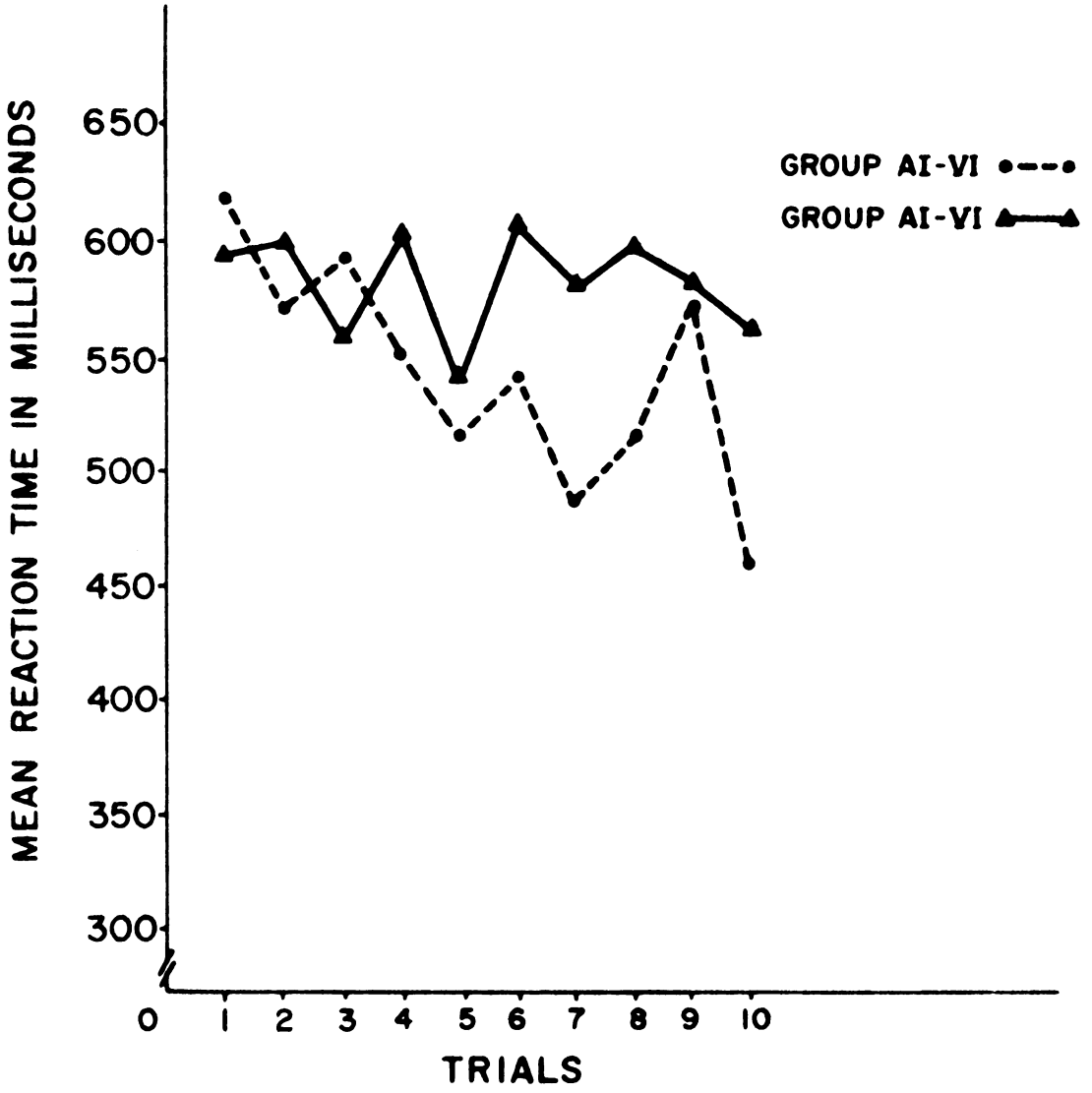

Figure 3. Mean reaction time on each Activation trial for Ss in Activation-Inhibition groups AI-FI and AI-VI.

TABLE 3

Summary of the analysis of variance of reaction time as a function of preparatory interval (PI) and trials for Ss in the Activation groups.

Source	SS	df	MS	F	p
PI	5333.33	1	5333.33	0.08	<0.20
Error	1568604.66	22	71300.21		
Trials	185824.76	19	9727.62	1.92	<0.05
Trials x PI	107514.15	19	5658.64	1.12	<1.20
Error	2115324.69	418	5060.59		
Total	3981601.59				

TABLE 4

Summary of the analysis of variance of reaction time as a function of preparatory interval (PI) and trials for Ss in the Activation-Inhibition groups.

Source	SS	df	MS	F	p
PI	88051.70	1	88051.70	1.54	< 0.20
Error	1259548.96	22	57252.23		
Trials	187241.51	9	20804.61	2.00	< 0.05
Trials x PI	399590.05	9	44398.89	4.28	< 0.001
Error	2055870.75	198	10383.19		
Total	3990302.96				

In addition, a significant interaction effect between Preparatory Interval (PI) and Trials indicated that RTs for Ss in the AI-FI group decreased more than the RTs for Ss in the AI-VI group.

In order to make task and PI comparisons, mean RTs were computed for each task condition and PI condition. These were then compared using t-tests. The Activation Task group was composed of Groups A-FI and A-VI combined while the Activation-Inhibition Task group was composed of Groups AI-FI and AI-VI combined. The Fixed PI group was composed of Groups A-FI and AI-FI while the Variable PI group was made up of Groups A-VI and AI-VI. The means for these groups and the results of the comparisons are presented in Table 5.

TABLE 5

The mean reaction times in milliseconds for each Task group and Preparatory Interval (PI) group with their subsequent t-values.

Group	Mean	S.D.	t	df	p
Activation	457.31	101.40	12.49	718	<0.001
Activation-Inhibition	565.39	126.79			
Fixed PI	500.10	125.52	2.37	718	<0.02
Variable PI	522.59	102.68			

As indicated in Table 5, Ss in the Activation-Inhibition Task had slower reaction times than did Ss in the Activation Task. This outcome suggests that the Activation-Inhibition Task was the more difficult task. Results of the analysis comparing mean performance for the PI groups showed that Ss in the Fixed PI group performed more rapidly than Ss in the Variable PI group. This result suggests that the Variable PI condition was more difficult than the Fixed PI condition. However, this latter outcome must be qualified in light of the results obtained from the analysis of variance of the reaction time data. If both of these analyses are considered together, they would suggest that the difference between the Fixed and Variable PI groups is largely due to the difference between Groups AI-FI and AI-VI. This interpretation is borne out by subsequent comparisons made between PI groups contained within each Task. The only significant difference obtained was with comparisons of the mean RTs of the AI-FI group and the AI-VI group ($t = 2.37$, $df = 238$, $p < 0.02$). Comparisons of RT performance between interval groups contained within the Activation Task were nonsignificant ($t < 1$).

Response Errors. The frequency of response errors was computed for each block of five trials for each experimental group. In this case, a response error refers to the S's failure to inhibit a response on an inhibition trial. Other types of response errors (e.g., failure to respond) did not occur.

These error frequencies are presented in Table 6.

TABLE 6

Error frequencies across five trial blocks (trial block = trials 1 - 5) for each experimental group.

Group	Block 1	Block 2	Block 3	Block 4	Total
A-FI	0	0	0	0	0
A-VI	0	0	0	0	0
AI-FI	8	3	2	3	16
AI-VI	5	1	3	0	9

Since there were no errors in the Activation groups, the analysis of variance was used to examine error frequencies occurring in the Activation-Inhibition groups over trial blocks. This analysis is summarized in Table 7 and indicates that the number of errors decreased across trial blocks.

Physiological Activity

Mean heart rate. A mean HR score was computed for each period for all Ss. An analysis of variance was used to compare these means across all experimental conditions. The results of that analysis are given in Table 8. As indicated in Table 8, Ss in the Variable PI groups had higher mean heart rates than Ss in the Fixed PI groups. In general, mean heart rate decreased across trials for all Ss. However, as illustrated in Figure 4, this decrease was greater for Ss in the Activation Task than in the

TABLE 7

Summary of the analysis of variance of error frequency as a function of preparatory interval (PI) and trial blocks for Ss in the Activation-Inhibition groups.

Source	SS	df	MS	F	p
PI	0.51	1	0.51	1.65	<0.20
Error	6.73	22	0.31		
Trials	2.62	3	0.87	3.48	<0.025
Trials x PI	0.44	3	0.15	0.60	<0.20
Error	16.19	66	0.25		
Total	26.49				

TABLE 8

Summary of the analysis of variance of mean heart rate as a function of task (T), preparatory interval (PI), Trials (Tr), and period (Per) for Ss in all experimental groups (Groups A-FI, A-VI, AI-FI, AI-VI).

Source	SS	df	MS	F	p
T	367.43	1	367.43	0.06	0.81
PI	53249.10	1	53249.10	8.19	0.006
T x PI	1318.07	1	1318.07	0.20	0.66
Error	286049.98	44	6501.14		
Tr	21566.29	19	1135.07	16.69	0.0005
T x Tr	3175.90	19	167.15	2.46	0.001
PI x Tr	819.45	19	43.13	0.63	0.88
T x PI x Tr	251.38	19	13.23	0.19	1.00
Error	56860.99	836	68.02		
Per	4863.39	3	1621.13	125.25	0.0005
T x Per	1389.91	3	463.30	35.79	0.0005
PI x Per	51.99	3	17.33	1.34	0.25
Tr x Per	1859.10	57	32.62	2.52	0.0005
T x PI x Per	75.04	3	25.01	1.93	0.12
T x Tr x Per	490.62	57	8.61	0.67	0.98
PI x Tr x Per	731.12	57	12.83	0.99	0.50
T x PI x Tr x Per	746.21	57	13.09	1.01	0.45
Error	34170.84	2640	12.94		
Total	468036.83				

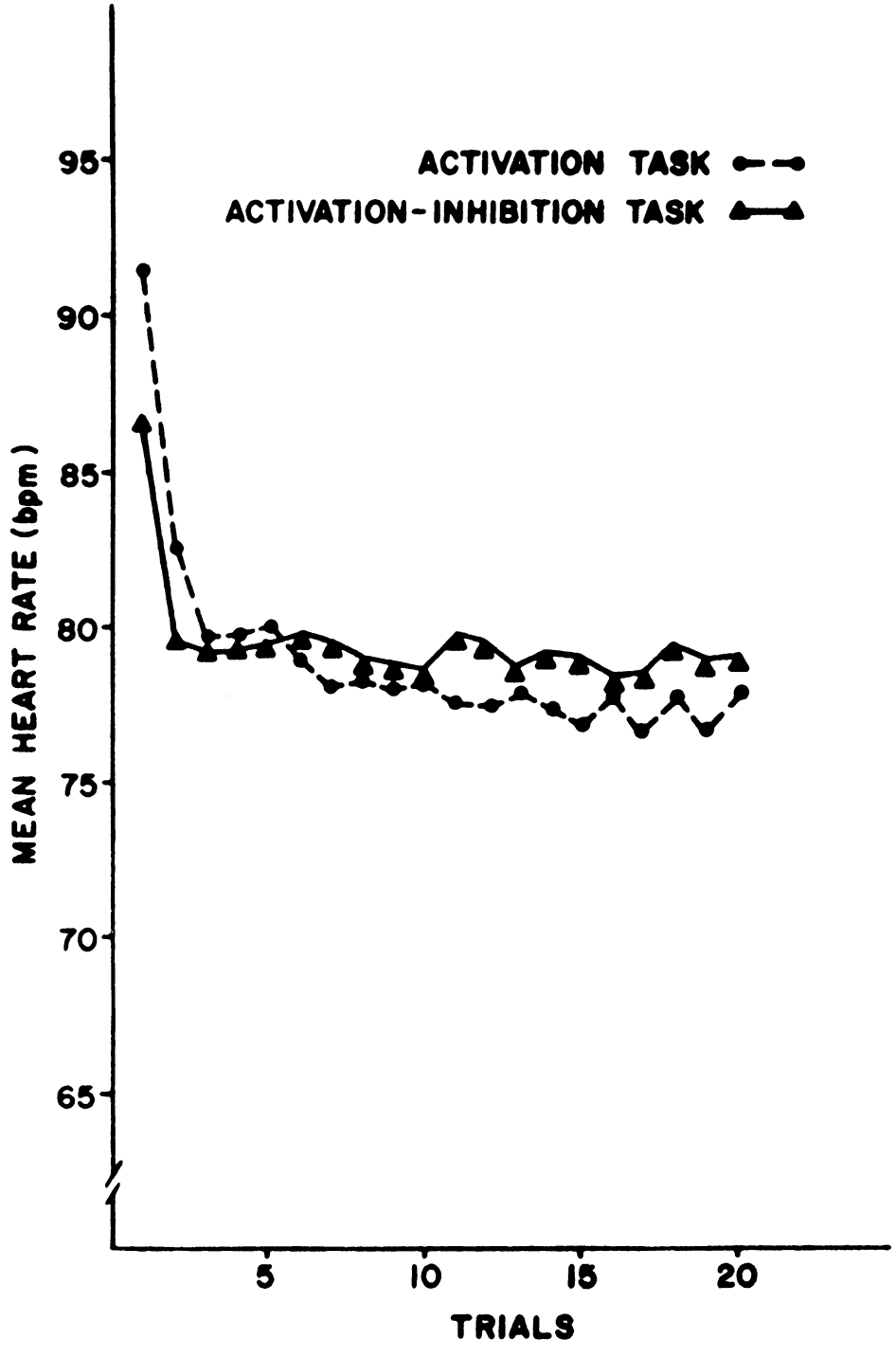

Figure 4. Mean heart rate on each trial for Ss in Activation and Activation-Inhibition tasks.

Activation-Inhibition Task.

The data revealed than mean heart rate varied significantly across the four periods within a trial. Mean heart rate increased during the Phasic period from the Preperiod level. This acceleration in heart rate was followed by a deceleration during the Tonic period; a sharp acceleration occurred in the Respond period. The significant Task x Period interaction effect indicated in Table 8 suggests that the Activation and Activation-Inhibition Tasks contributed differently to this pattern of heart rate change. As shown in Figure 5, this interaction effect can be attributed to the occurrence of a greater acceleration of heart rate during the respond period for the Activation Task than for the Activation-Inhibition Task. Finally, a significant Trials x Period effect depicted in Figure 6 indicates that there were greater changes in heart rate for some of the periods than for others; decreases in heart rate were greater for the Tonic period than for the remaining periods.

In order to examine heart rate changes in greater detail, second-by-second heart rate was examined using an analysis of variance statistic for each of the four experimental groups. Results of this analysis are shown in Table 9 for the A-FI group. Since there was an overall Trials effect obtained from the previous analysis of mean heart rate, it was not surprising that a significant Trials as well as Period effect was obtained.

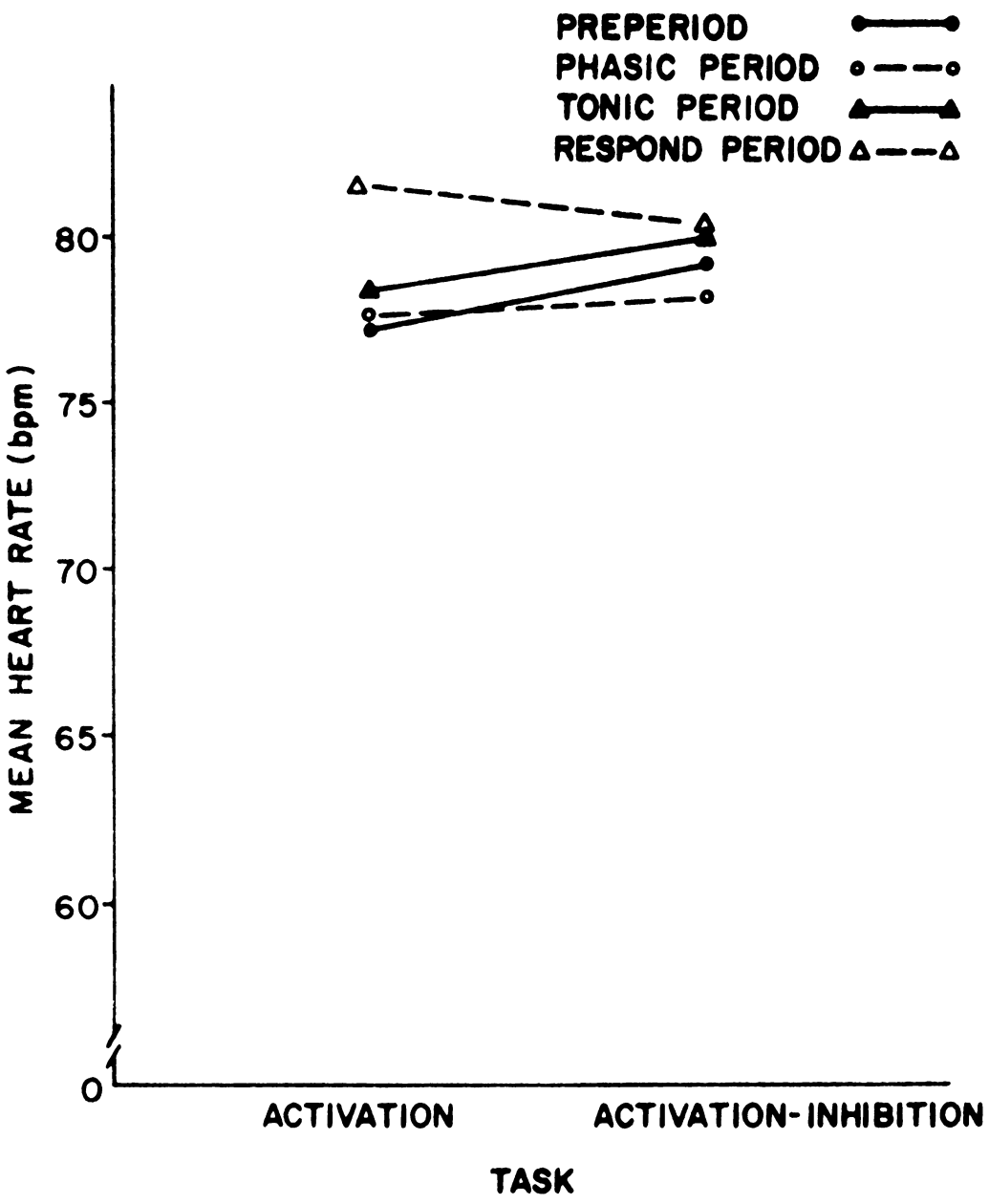

Figure 5. Mean heart rate during each period for Ss in Activation and Activation-Inhibition tasks.

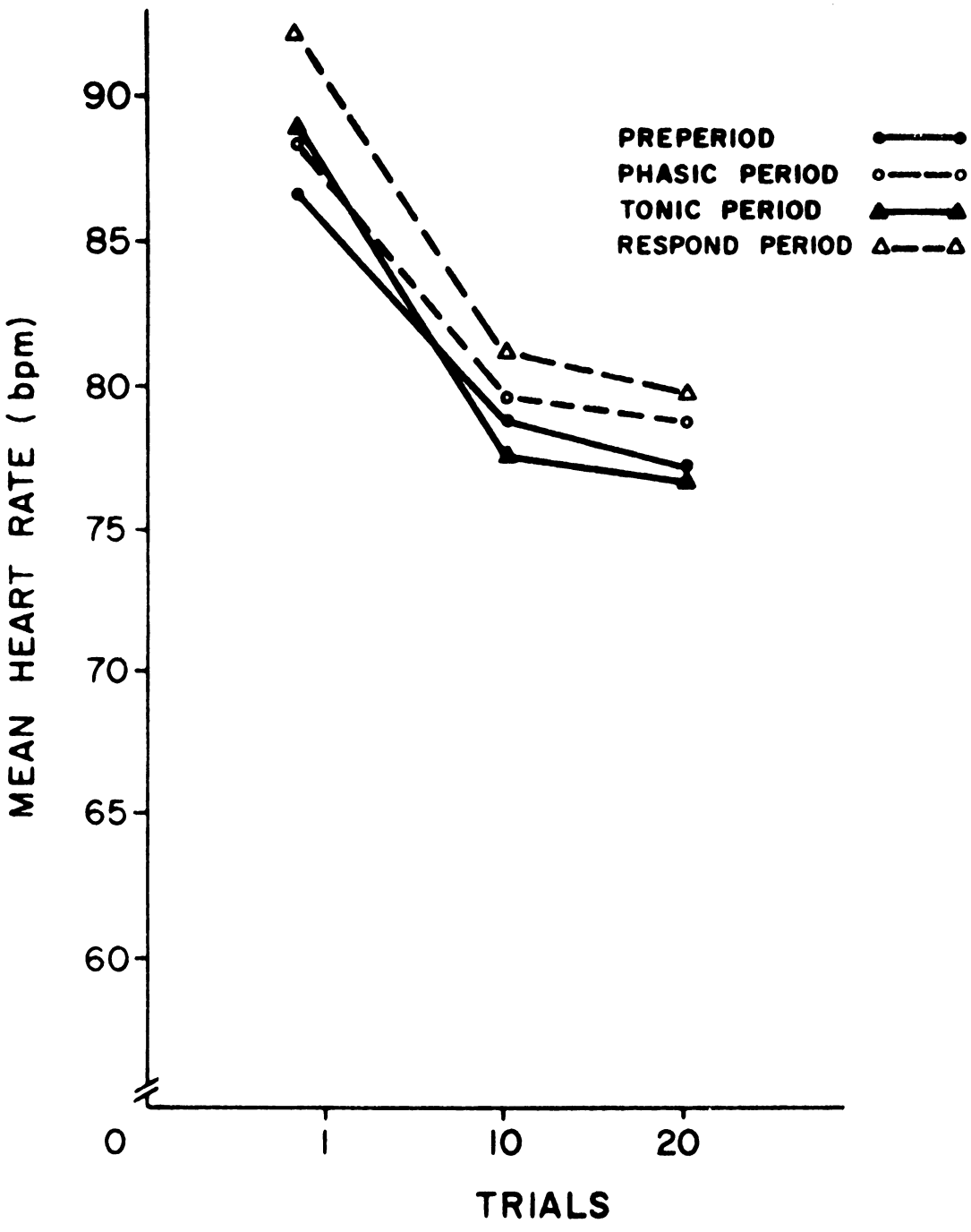

Figure 6. Mean heart rate during each period for Ss in all experimental groups for trials 1, 10, and 20.

TABLE 9

Summary of the analysis of variance of heart rate as a function of trials (Tr), period (Per), and seconds (Sec) for Ss in Group A-FI.

Source	SS	df	MS	F	p
Tr	84873.06	19	4467.00	2.57	0.001
Error	382631.83	220	1739.24		
Per	26943.01	3	8981.00	68.15	0.0005
Tr x Per	5788.27	57	101.55	0.77	0.89
Error	86972.86	660	131.78		
Sec	4786.32	7	683.76	27.06	0.0005
Tr x Sec	4317.32	133	32.47	1.28	0.016
Per x Sec	9040.04	21	430.48	17.03	0.0005
Tr x Per x Sec	8597.61	399	21.55	0.85	0.98
Error	155668.94	6160	25.27		
Total	769619.87				

In addition, Seconds and Period x Seconds effects were significant indicating that heart rate varied across seconds during the experimental task. The Seconds effect does not indicate anything about changes in heart rate during a trial, since the respective heart changes are based on sums across periods and trials. However, the Period x Seconds effect shows that second-by-second heart rate varied significantly across periods within a trial. This effect can be attributed to the acceleration and deceleration of heart rate during the Phasic period and the acceleration in heart rate during the Respond period. The interaction effects shown in Table 9 indicate that second-by-second heart rate decreased across trials.

Results of the analysis for the A-VI group are given in Table 10. For this condition, heart rate did not change significantly across trials although it did vary significantly across periods. A significant Trials x Period interaction indicated that heart rate decreased more during the Tonic Period across trials than during the other periods. A significant Seconds effect occurred indicating changes in heart rate across seconds. The significant Period x Seconds effect shows more specifically that the seconds effect was due to changes in heart rate during the Phasic and Respond periods within a trial.

Table 11 summarizes the results of the analysis for the AI-FI group. There was no significant Trials main effect or interaction effect although the Period effect was significant.

TABLE 10

Summary of the analysis of variance of heart rate as a function of trials (Tr), period (Per), and seconds (Sec) for Ss in Group A-VI.

Source	SS	df	MS	F	p
Tr	76837.77	19	4044.09	1.01	0.45
Error	883275.29	220	4014.89		
Per	16558.15	3	5519.38	65.32	0.0005
Tr x Per	9901.05	57	173.70	2.06	0.0005
Error	55767.81	660	84.50		
Sec	5727.41	7	818.20	43.81	0.0005
Tr x Sec	2716.31	133	20.42	1.09	0.22
Per x Sec	8385.72	21	399.32	21.38	0.0005
Tr x Per x Sec	7135.75	399	17.88	0.96	0.72
Error	115043.59	6160	18.68		
Total	1181348.86				

TABLE 11

Summary of the analysis of variance of heart rate as a function of trials (Tr), period (Per), and seconds (Sec) for Ss in Group AI-FI.

Source	SS	df	MS	F	p
Tr	24789.96	19	1304.73	0.57	0.92
Error	500881.99	220	2276.74		
Per	4624.93	3	1541.64	14.12	0.0005
Tr x Per	6669.69	57	117.01	1.07	0.34
Error	72084.48	660	109.21		
Sec	2595.71	7	370.82	16.91	0.0005
Tr x Sec	2483.71	133	18.67	0.85	0.89
Per x Sec	4715.44	21	224.54	10.24	0.0005
Tr x Per x Sec	8044.29	399	20.16	0.91	0.87
Error	135058.19	6160	21.93		
Total	761948.38				

This outcome suggests that the pattern of Period changes in heart rate depicted in Figure 7 were established very early during the experimental task. As was observed for the previous experimental conditions, a significant Seconds and Period x Seconds effect was obtained. Again, these effects can be attributed to the second-by-second changes in heart rate occurring during the Phasic and Tonic periods.

In the AI-VI groups, a significant Period and Trials x Period effect was obtained (see Table 12). Period variations in heart rate reflect the same pattern noted earlier, i.e., an acceleration in heart rate during the Phasic period followed by a deceleration in heart rate during the Respond period. The Trials interaction effect was due primarily to the greater decrease in heart rate occurring during the Tonic period. A consistent finding throughout the analysis has been the occurrence of significant Seconds and Period x Seconds effects. As noted before, these effects may be attributed to the second-by-second variations in heart rate during the Phasic period and Respond period.

Heart rate variance. A heart rate variance score was computed from the 8 seconds occurring during each period. A 2(Task) x 2(PI) x 20(Trials) x 4(Period) analysis of variance was used to evaluate these heart rate variance scores. The results of this analysis are shown in Table 13. As was observed for mean heart rate, significant Period and Task x Period effects were obtained. Changes across periods shown in Figure 8 indicate an increase in heart rate

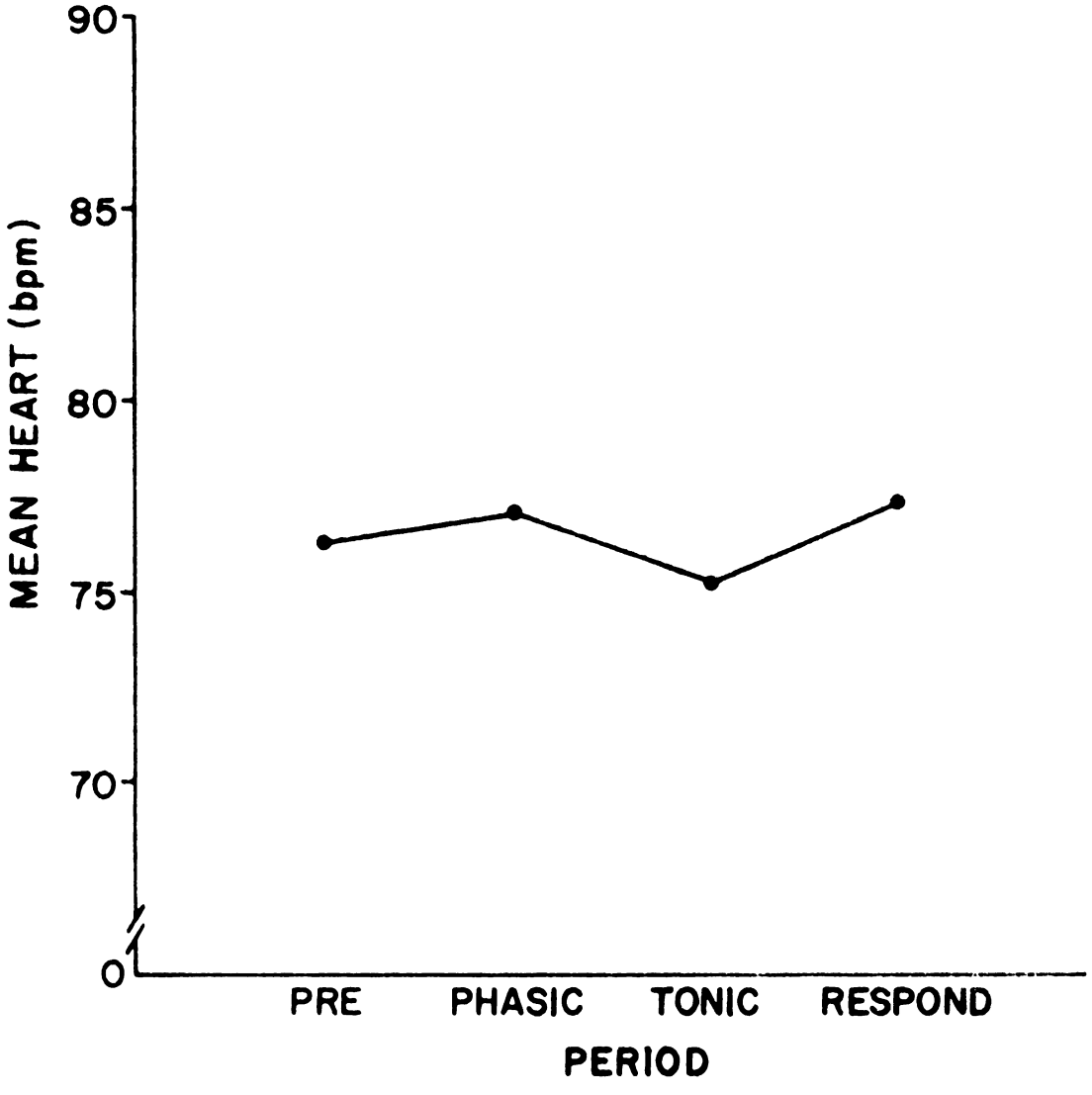

Figure 7. Mean heart rate during each period for Ss in Group AI-FI.

TABLE 12

Summary of the analysis of variance of heart rate as a function of trials (Tr), period (Per), and seconds (Sec) for Ss in Group AI-VI.

Source	SS	df	MS	F	p
Tr	19986.72	19	1051.93	0.24	1.00
Error	976529.21	220	4438.77		
Per	2923.36	3	974.45	10.98	0.0005
Tr x Per	8256.35	57	144.85	1.63	0.003
Error	58551.73	660	88.71		
Sec	2351.37	7	335.91	17.06	0.0005
Tr x Sec	2144.28	133	16.12	0.82	0.94
Per x Sec	5467.94	21	260.38	13.22	0.0005
Tr x Per x Sec	8060.24	399	20.20	1.02	0.35
Error	121292.00	6160	19.69		
Total	1205563.20				

TABLE 13

Summary of the analysis of variance of mean heart rate variance as a function of task (T), preparatory interval (PI), trials (Tr), and period (Per) for Ss in all experimental groups (Groups A-FI, A-VI, AI-FI, and AI-VI).

Source	SS	df	MS	F	p
T	4533.53	1	4533.53	0.39	0.53
PI	17256.88	1	17256.88	1.52	0.22
T x PI	4725.94	1	4725.94	0.42	0.52
Error	500262.39	44	11369.60		
Tr	12374.45	19	651.29	0.75	0.77
T x Tr	12242.21	19	644.33	0.74	0.77
PI x Tr	14690.03	19	773.16	0.89	0.59
T x PI x Tr	25119.08	19	1322.06	1.53	0.07
Error	723445.90	836	865.37		
Per	106936.04	3	35645.35	43.11	0.0005
T x Per	7418.88	3	2472.96	2.99	0.03
PI x Per	1452.58	3	484.19	0.59	0.63
Tr x Per	40114.77	57	703.77	0.85	0.78
T x PI x Per	1823.78	3	607.93	0.74	0.53
T x Tr x Per	37979.56	57	666.31	0.81	0.85
PI x Tr x Per	36984.22	57	648.85	0.78	0.88
T x PI x Tr x Per	57131.73	57	1002.31	1.21	0.13
Error	2182694.49	2640	826.78		
Total	3787186.48				

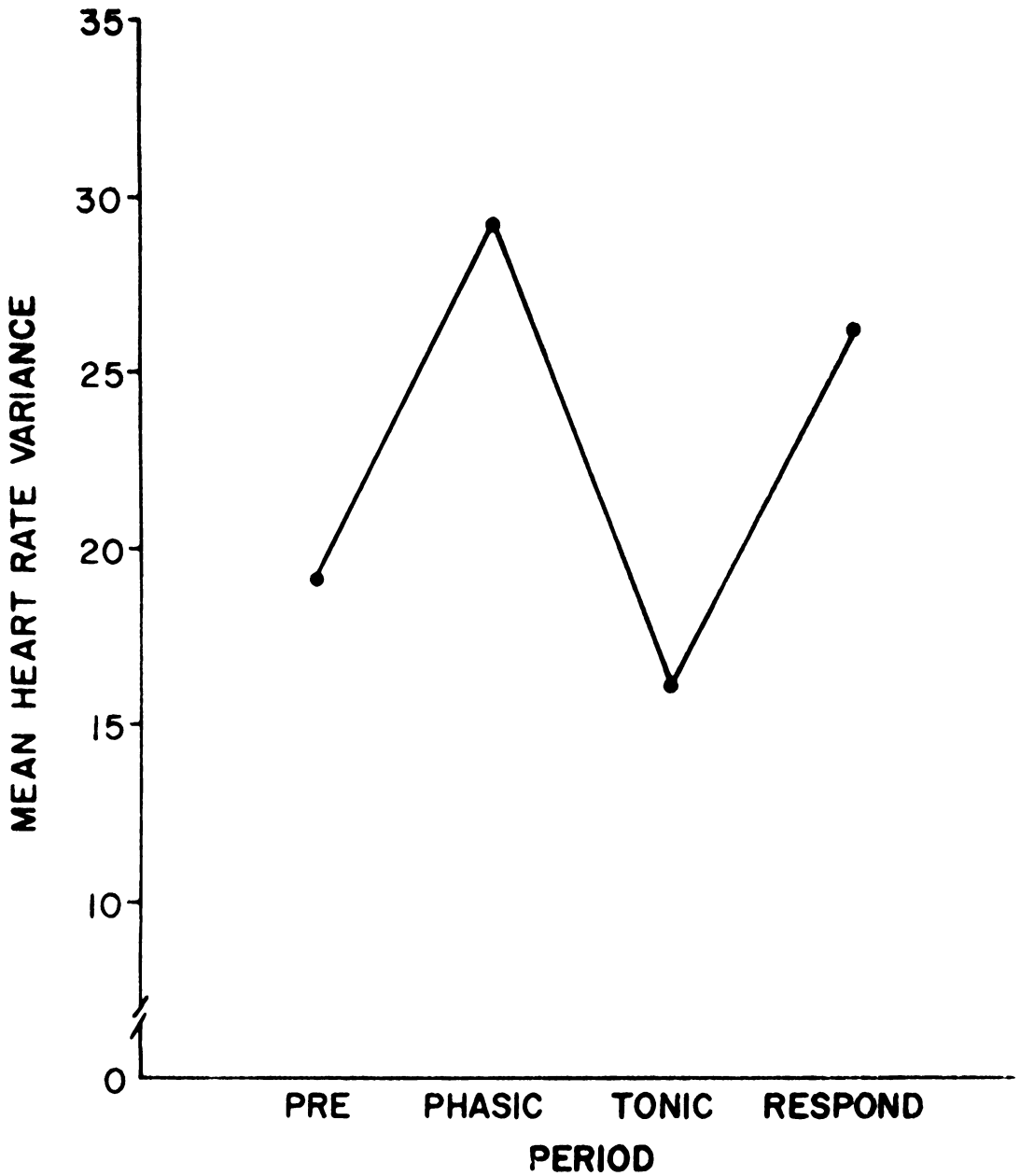

Figure 8. Mean heart rate variance during each period for Ss in all experimental groups.

variability from the Preperiod level to the Phasic period. This increased variability was followed by a reduction in variability during the Tonic period with a subsequent increase in variability occurring during the Respond period. In regard to the Task x Period interaction, inspection of Figure 9 shows that this interaction was due to a higher heart rate variability of Ss in the Activation-Inhibition Task occurring during the Preperiod. This outcome was reversed for the remaining periods.

EMG activity. An EMG frequency score was obtained for each period for all Ss. A 4-way analysis of variance was performed on the data. A significant Trials effect ($F = 2.61$, $df = 19/220$, $p < 0.001$) occurred indicating that EMG activity decreased across trials. A significant Task x Period interaction effect ($F = 3.21$, $df = 3/2640$, $p < .03$) shows that EMG activity was greater during the Respond period for Ss in the Activation Task than for Ss in the Activation-Inhibition Task. A significant Trials x Period interaction ($F = 2.43$, $df = 57/2640$, $p < 0.0005$) revealed that this general decrease in activity across trials was primarily due to a decrease in muscle activity occurring during the Respond period. A significant Period effect was also obtained ($F = 38.95$, $df = 3/2640$, $p < 0.0005$) indicating that muscle activity varied significantly across periods. This effect was due to the large amount of muscle activity occurring during the Respond period relative to the preceding periods.

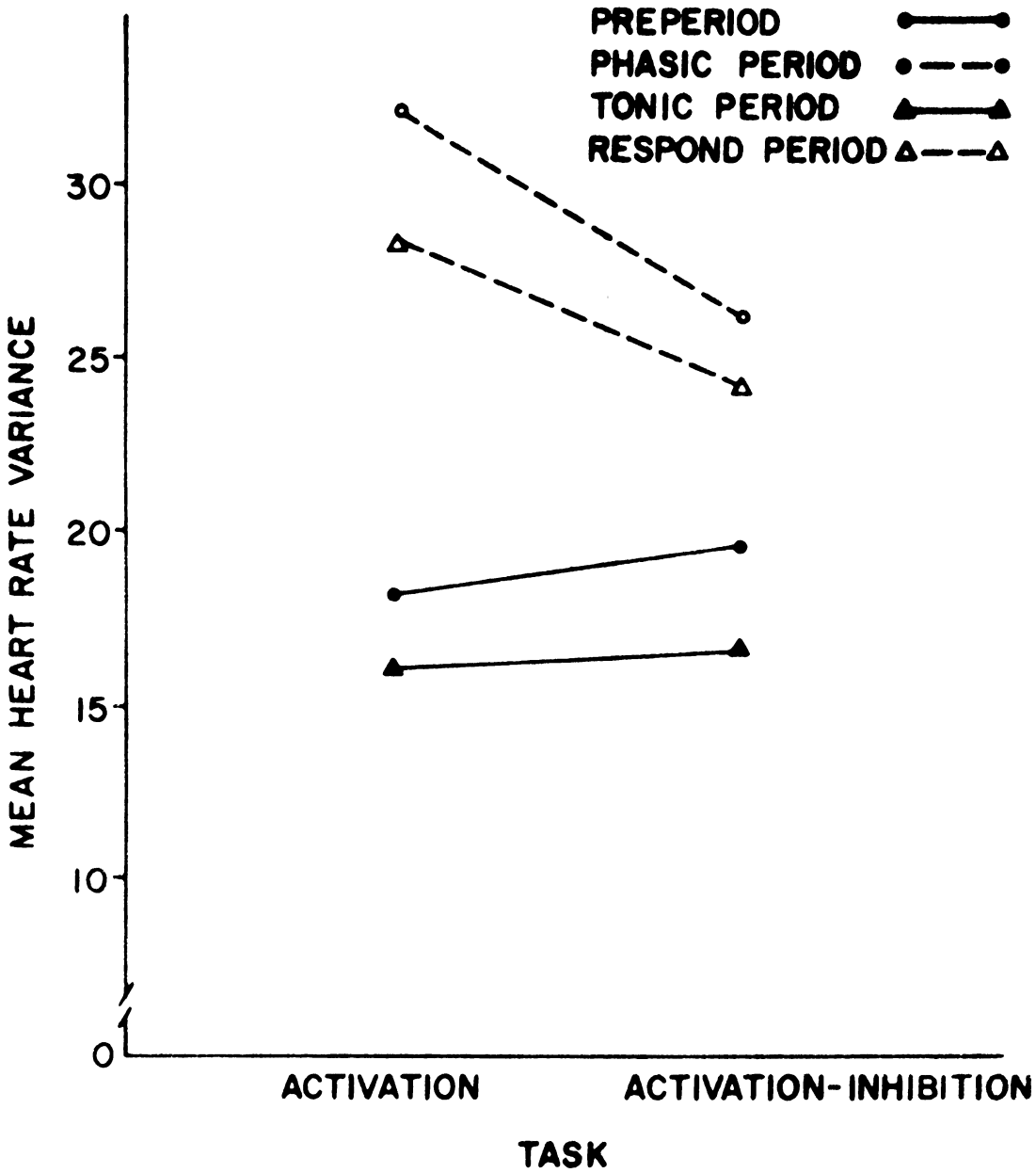

Figure 9. Mean heart rate variance during each period for Ss in Activation and Activation-Inhibition tasks.

Physiological Correlates of Reaction Time

The preceding sections have dealt with performance and corresponding physiological activity occurring during the various experimental conditions. This section presents data directly related to the question posed earlier, i.e., what is the relationship between S's physiological activity prior to the reaction time response and his actual reaction time. In order to examine this relationship, five measures of physiological activity were related to reaction time: (a) Preperiod heart rate variance; (b) Tonic-variance reduction; (c) heart rate deceleration I; (d) heart rate deceleration II; and (e) Tonic EMG activity. Preperiod variance score was computed for each trial from heart rate on each of the 8 seconds prior to the warning signal onset (Porges, 1972). A Tonic-variance reduction score was computed by subtracting the Tonic period heart rate variability score from the Preperiod heart rate variability score (Porges, 1972). Heart rate deceleration I score was recorded as the lowest heart rate to occur during the last three seconds of the Tonic period and the first two seconds of the Respond period (Krupski, 1971). Heart rate deceleration II score, reflecting both the magnitude of deceleration as well as temporal preciseness of the deceleration, was scored by recording heart rate occurring at the time of warning signal offset (Krupski, 1971). Finally, a Tonic EMG activity score was computed by counting the frequency of muscle potentials (= 50 microvolts) occurring during the Tonic period.

Each of the heart rate scores were correlated with RT during the last 10 trials for each S in the Activation Task conditions. For the Activation-Inhibition Task conditions, each score was correlated with each of the activation trials for each experimental group. In order to correlate EMG Tonic activity with RT, a point-biserial correlation was used to relate RT with occurrence-nonoccurrence of activity during the Tonic period. The results of this analysis are presented in Table 14.

For the A-FI group, heart rate deceleration I score was significantly related to RT performance. This relationship means that the lower the heart rate during the last seconds of the Tonic period, the faster the RT. Moreover, this relationship between magnitude of heart rate deceleration and RT was even greater for the heart rate deceleration II score. In addition to these heart rate correlates of RT, Ss who tensed or activated their forearm muscles (task relevant) during the Tonic period had faster RTs.

Within the A-VI group, both Preperiod variance and Tonic-variance reduction scores were related to RT. On the one hand, the higher the Preperiod heart rate variability, the faster the RT obtained. On the other hand, the greater the reduction of this variability from Preperiod to Tonic period, the faster the RT observed. As in the A-FI group, Tonic period muscle activity was associated with faster RTs.

In the AI-FI group, both the heart rate deceleration scores were significantly related to RT performance although

TABLE 14

Summary of correlational analysis in which antecedent physiological activity was correlated with reaction time performance for each experimental group.

Group	Preperiod Heart Rate Variance	Tonic Variance Reduction	Heart Rate Deceler-ation I	Heart Rate Deceler-ation II	Tonic EMG Activity
A-FI	0.04	0.00	0.23*	0.41***	0.36***
A-VI	-0.19*	-0.28**	-0.06	-0.02	0.33***
AI-FI	-0.11	0.00	0.25**	0.24**	-0.15
AI-VI	-0.35***	-0.36***	-0.17	-0.13	-0.34***

*p <0.05
**p <0.01
***p <0.001

not as strongly as was the case with the A-FI group. Again, larger heart rate decelerations were associated with faster RTs. However, Tonic period muscle activity was not related to performance in this experimental group.

As was observed with the A-VI group, both Preperiod variance and Tonic-variance reduction scores were related to RT. For the AI-VI group, higher Preperiod variance was related to faster RTs; the greater the Tonic-variance reduction, the faster the RT. Tonic muscle activity was shown to be related to slower RTs.

Correlates of response errors. A correlational analysis was done to discover what relationships, if any, existed between antecedent physiological activity and failure to inhibit a response. Since the Ss in Activation Task conditions made no errors, this analysis was performed on the relevant data for Activation-Inhibition groups only. The same physiological scores were used since their use would indicate whether or not comparable physiological preparatory states observed for RT would also be observed for successful response inhibition. A point-biserial correlation statistic was used to relate these two scores, since this analysis would involve correlating a continuous variable (heart rate and EMG scores) with a dichotomous event (successful response inhibition or failure to inhibit a response).

For the AI-FI group, only Tonic muscle activity was associated with the commission of a response error

($r_{pb}(120) = 0.69$, $p < 0.001$). This indicated that the successful inhibition of responding on an inhibition trial was related to the non-occurrence of muscle activity during the Tonic period. Within the AI-VI group, magnitude of the Tonic-variance reduction was related to response errors; large Tonic-variance reduction was associated with successful response inhibition ($r_{pb}(120) = -0.27$, $p < 0.01$).

Discussion

The reaction time findings can be summarized as follows. Subjects in the Activation Task conditions had faster times than Ss in the Activation-Inhibiton Task conditions. The slow reaction times of Ss in the Activation-Inhibition Task can be attributed to S's uncertainty as to whether he would be required to respond or not respond on each trial. This pattern of performance has also been reported by investigators (Jennings et al., 1971; Stroufe, 1971) who have compared Ss' performances on both simple and complex reaction time tasks. In addition, the increased uncertainty of Ss in the Activation-Inhibition Task conditions resulted in the commission of response errors (failure to inhibit). Although there was a trend toward a higher error rate for Ss in the A-FI group, it was not significant.

Heart rate changes occurring during a trial for Activation and Activation-Inhibition Task conditions were similar. These changes suggest a four-phase pattern of

responding. Second-by-second heart rate accelerated from the Preperiod level during the Phasic period. Following this acceleration, heart rate decelerated sharply during the remainder of the Phasic period. Subsequently, during the Tonic period, heart rate increased slightly and then decreased just prior to respond signal onset. However, task conditions affected this general pattern of mean heart rate differently. Heart rate was higher for Ss in the Activation-Inhibition Task than for Ss in the Activation Task across all periods except the Respond period. Greater heart rate acceleration occurred during the Respond period for Ss in the Activation Task than for Ss in the Activation-Inhibition Task. This difference in magnitude of heart rate may be due to the difference in task requirements. Subjects in the Activation-Inhibition Task were required to respond only on half of the trials while Ss in the Activation Task were required to respond on all of the trials. Obrist, Webb, Sutterer, and Howard (1970) have shown that increased muscle activity is associated with higher heart rate due to the increased metabolic requirements of the muscles. Consequently, the lesser muscle activity observed for Ss in the Activation-Inhibition Task during the Respond period would produce lower heart rates.

Heart rate variability also changes across periods within a trial. Heart rate variability increased during the Phasic period from the variability level during the Preperiod; a subsequent reduction in heart rate variability occurred during the Tonic period followed by an increase in

variability during the Respond period. In general, heart variability was higher for Ss in the Activation group across periods except for the Preperiod. Subjects in the Activation-Inhibition Task had a higher heart rate variability.

An additional finding of interest was concerned with the rapidity in which the anticipatory decelerative heart rate response during the Tonic period was established. For the fixed PI groups, this directional response appeared in nine trials. This same response for Ss in the variable PI groups began to occur on the 15th trial. This finding has important implications for the study of Tonic heart rate variability and specific Tonic responses (Preperiod variance and Tonic-variance reduction). A primary reason for using a long and variable PI has been to prevent phasic heart rate responding (decelerative and accelerative directional responses) from masking or interfering with the appearance of Tonic response characteristics. If a long series of trials are used, results of the present study suggest that the characteristics of the tonic responses will be affected by the appearance of phasic responses on the later trials. Moreover, the strength of the relationship between tonic heart rate activity and performance will be affected by phasic responses occurring on the later trials. Consequently, the magnitude of correlations between Tonic activity and performance will be attenuated if computed over the last series of trials. (A practice commonly done with phasic heart rate activity and performance).

EMG or muscle activity was most affected by Task and Trials. Muscle activity decreased across trials. There was also more activity during the Respond period for Ss in the Activation task which was to be expected. In this task, Ss were expected to squeeze a bulb on every trial while Ss in the Activation-Inhibition Task were required to respond only on one-half of the trials. Although there was a slight increase in muscle activity for Ss in the A-FI group during the Tonic period, this trend was not significant. The failure of a conditioned anticipatory muscle response to occur consistently may have been due to the long PIs used in the present experiment.

Reaction time was found to be significantly related to phasic heart rate activity (magnitude of heart rate deceleration) for Ss in the Fixed PI groups and tonic heart rate activity (Preperiod variance and Tonic-variance reduction) for the Variable PI groups. Conditioned anticipatory heart rate deceleration was found to be significantly related to reaction time performance. This result replicates the general finding reported by other investigators using a fixed PI (Krupski, 1971; Obrist et al., 1970; Schwartz & Higgins, 1971; Stroufe, 1971) in that the greater the heart rate deceleration, the faster the reaction time. In addition, the tonic heart rate correlates of reaction time for Ss in Variable PI groups replicated the results reported by Porges (1972). Greater Preperiod heart rate variance and Tonic-variance reduction was associated with faster reaction times.

The strength of this relationship was not as great as reported by Porges. Two reasons may account for the difference between Porges' results and those of the present study. First, Porges correlated mean Preperiod variance and mean Tonic-variance reduction with mean reaction time over the first ten trials. In the present study, this correlation was computed on a trial-by-trial basis over the last ten trials. Future investigators will need to specify the basis for correlational analysis explicitly before the strength of the relationship between two events can be evaluated. Second, phasic responses which had begun to occur on the later trials affected tonic heart rate activity. As a result, the magnitude of the relationship between tonic heart rate activity and reaction time was reduced.

Tonic muscle activity was found to be related to reaction time for both Fixed and Variable PI conditions within the Activation Task. Although the relationship between Tonic muscle activity and reaction time for Ss in the A-VI group was unexpected (see Grossman et al., 1971; Jennings et al., 1971), the basis for this relationship for Ss in the A-VI group may be different than for Ss in the A-FI group. The point-biserial correlation was computed on the basis of 120 pairs of Tonic muscle scores and reaction times. For Ss in the A-VI group, Tonic muscle activity was observed on only 61 of those trials. However, on those trials where Tonic muscle activity occurred, reaction times were faster.

This finding suggests that those trials represent occasions when S was correctly able to "guess" when the respond signal was to occur. Nevertheless, these correct guesses (and consequently, increased Tonic muscle activity) led to better performance. In contrast, Ss in the A-FI group showed increased Tonic muscle activity on 87 trials. The higher frequency suggests that Ss were learning to estimate with greater accuracy the time period (PI length); consequently this led to a more optimal state of attention and improved performance. In any event, these findings support the conclusion that increased task relevant muscle activity just prior to responding facilitates performance. Anticipatory task relevant muscle activity was found to interfere with reaction time performance for Ss in the Activation-Inhibition Task conditions.

The question of particular interest for the present study was concerned with identifying whether or not an attentional state was associated with response inhibition. The present study provides support for the conclusion that certain physiological responses are associated with successful response inhibition. For the AI-FI group, decreases in Tonic muscle activity were associated with the successful inhibition of responding. The failure to find any relationship between phasic heart rate activity and inhibition performance replicates the results obtained by Stroufe (1971). However, for Ss in the AI-VI group, greater Tonic-variance reductions were associated with the successful inhibition of a response.

Support was not obtained for the hypothesis that those responses or preparatory states associated with reaction time are also related to response inhibition.

In conclusion, the present study provides evidence which indicates that Ss attentional state is related to response activation and inhibition performance. Moreover, the findings suggest that under certain conditions, Tonic muscle activity and heart rate variability may be more reliable indicators of S's attentional state than heart rate deceleration. The procedures and results of the present study may provide a useful approach for studying and consequently for obtaining a better understanding of the physiological concomitants of attention and their relationship to performance.

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Footnote

[1]FC data were not subjected to further analysis since the results of data scoring revealed that during PI, there was no change from baseline. Although this finding suggests that there was an equipment malfunction, this does not appear to be the case. Large changes in FC occurred during the Respond period which seems to rule out equipment malfunction. Contrary to the findings reported by Grossman et al. (1971), FC did not prove to be a sensitive index of preparatory state in this experiment.

APPENDIX

Appendix

Instructions for the Activation Task. The pickup leads I have attached will record changes in heart rate and muscle activity. They are very sensitive to movement, so try not to make any unnecessary movements. Your task will be to watch the amber light on the left of the panel appear and to squeeze the bulb as quickly as possible when the amber light disappears and the blue or white light appears (simultaneously). Remember not to make any unnecessary movements and to respond as rapidly as possible when the amber light disappears. You will receive a series of trials and the experimental session will last for approximately 30 minutes. I will announce over the intercom when the experiment begins and when it ends. At the end of the experiment, please remain seated until I come back and remove the electrodes. Do you have any questions? Take a couple of practice squeezes with the bulb. I am now going into the other room to calibrate the equipment, when I return I will close the chamber door. Remember to relax and to make as few body movements as possible.

Instructions for the Activation-Inhibition Task. The pickup leads I have attached will record changes in heart rate muscle activity. They are very sensitive to movement, so try not to make any unnecessary movements. Your task will be to watch the amber light on the left of the panel appear and to squeeze the bulb as quickly as possible when the amber light disappears and the blue (white) light comes on (simultaneously).

You are <u>not</u> to squeeze the bulb when you see the amber light disappear and the white (blue) light appear. Remember not to make any unnecessary movements and to respond as rapidly as possible when the amber light disappears and the blue (white) comes on. Do <u>not</u> respond when the amber light disappears and the white (blue) light appears. You will receive a series of trials and the experimental session will last approximately 30 minutes. I will announce over the intercom when the experiment begins and when it ends. At the end of the experiment, please remain seated until I come back and remove the electrodes. Do you have any questions? Take a couple of practice squeezes with the bulb. I am now going into the other room to calibrate the equipment; when I return, I will close the chamber door. Remember to relax and to make as few body movements as possible.

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