PHASIC CARDIAC RESPONSES IN REACTION TIME AND MENTAL ARITHMETIC TASKS: THE DOMINANT INFLUENCE OF MENTAL TASK PERFORMANCE ON HEART-RATE IN ADOLESCENTS

R.J.M. Somsen, M.W. van der Molen *), D.I. Boomsma, and J.F. Orlebeke

Department of Psychology
Free University
Amsterdam, The Netherlands

ABSTRACT

Task related and individual specific phasic heart rate responses were studied in monozygotic and dizygotic twins. In this report the task related results are presented. Lacey and Lacey (1974) suggest that two integrated tasks evoke intermediate tonic heart rate (HR) responses but that a non-integrated combination of a mental arithmetic and perceptual task do not evoke intermediate tonic HR responses. In this study two different tasks (choice reaction time and mental arithmetic) were carried out separately as well as in a combined form. Twenty two twin pairs participated in the experiment. In one condition they performed reaction time (RT) trials. In the other condition trials were presented which consisted of either an RT task, or a mental arithmetic (MA) task, or a task in which RT and mental arithmetic was combined. Phasic heart rate and reaction time was measured. The results showed that MA performance has a powerful effect on HR and dominates the HR curve that usually occurs in RT trials. RT trials that immediately followed a MA trial showed greatly enhanced anticipatory deceleration. It is argued that different patterns of vagal and sympathetic activity may have controlled the differential heart rate responses.

---

*) Department of Psychology, University of Amsterdam.

INTRODUCTION

Different tasks that are presented under controlled stimulus and response conditions can evoke conflicting heart rate (HR) responses. Lacey, et al. (1963) have shown that tasks requiring internal mental elaboration --like mental arithmetic (MA)-- induce tonic heart rate (HR) acceleration while tasks that require environmental intake --like reaction time (RT) tasks-- are related to HR deceleration. They hypothesized that environmental rejection (acceleration) and intake (deceleration) evoke these opposing HR responses. When (opposing) demands for attention and mental work were integrated in one task (learning Rules of the Game), tonic HR was intermediate between the responses in pure intake and pure rejection tasks (Lacey and Lacey, 1974). It was concluded that a 'vectorial resultant' cardiac response occurred in an integrated task situation. However, when two non-integrated tasks --a signal detection and an MA task-- were performed simultaneously, cardiac activity was not intermediate but appeared to be dominated by the MA task: Tonic HR acceleration was somewhat (non-significantly) greater in this combined task compared to a single MA task. This dominance of MA over signal detection on HR occurred in spite of the fact that the MA task was purposely made much easier than the signal detection task.

Lacey and Lacey (1970) also studied the well-known three-phasic HR reaction pattern in two stimuli (S1-S2) tasks: This pattern consists of a small initial deceleration, followed by acceleration, and deceleration that lasts until S2 onset. When different S1-S2 situations are compared in a mixed design changing task instruction and/or nature of the S2 from trial to trial in a random fashion, reliable variations in this basic three-phasic HR pattern can be observed (Somsen, van der Molen, and Orlebeke, 1983). In this study two main types of S1-S2 task were investigated: an RT condition and an unavoidable shock (US) condition. Under RT and US conditions the anticipatory HR responses in the S1-S2 interval differed significantly in amplitude. Shock anticipation evoked relatively lesser HR acceleration and much more HR deceleration than anticipation of a RT stimulus. The two tasks were also presented as a non-integrated combination (anticipating an imperative signal and a shock simultaneously). The HR responses in this combined task were intermediate between the responses induced by the separate tasks. This implies that in a non-integrated combination of a stressful shock and a non-stressful perceptual-motor task the corresponding HR response is not dominated by the most stressful shock task. In the study of Lacey et al. (1974) a perceptual task and a task that required mental problem solving was applied. The crucial factor that determines dominance in the HR response of one task over another is, probably, the presence of higher cognitive activity and mental stress.

It is well known that the performance of a mental arithmetic task induces sympathetic excitation and massive phasic heart rate acceleration (cf. van der Molen, Somsen, and Orlebeke, in press; Jennings, 1983). Most experimenters have applied this task solely as a 'mental stressor' to induce increases in sympathetic activation, while only few were interested in the relationship between HR and cognitive activity itself (e.g. Kahneman et al., 1969; Tursky, Schwarz, and Crider, 1970; Jennings, 1975). In contrast, perceptual-motor tasks, that are almost exclusively controlled by vagal changes (Obrist, et al., 1974) have been widely studied. The current experiment used these two types of tasks to study the relative effects on phasic cardiac responding of sensorimotor and stressful mental activity. RT and MA trials were presented separately and combined as a double task in a mixed design. This method of mixed presentation of separate and combined tasks was adopted from a previous study (Somsen et al., 1983).

METHOD

Subjects

Forty four paid subjects (Ss) between the age of 15 and 18 years participated in the experiment. Half of them were monozygotic twin pairs (6 female and 5 male) and the other half were dizygotic twins pairs (6 female and 5 male). Twins were used as subjects because the purpose of the experiment was to study both task related and genetic influences on cardiac activity in the same data set. The results of the individual HR responses are reported by Somsen, Boomsma, Orlebeke, and van der Molen (this volume). All subjects had normal heart functions. They were paid a fixed sum for their participation and a bonus of 5c for each correct addition in the MA task.

Apparatus

Each trial started with the onset of a warning set (S1) consisting of colored lights (yellow and/or red) and a three digits display that contained a number. The imperative signal (S2) was a tone of 80 dBA and 1000 or 3000 Hz that lasted 500 ms.

In the blocked RT condition four interstimulus interval (ISI) lengths were used (2, 3, 4, and 5 sec). Intertrial intervals lasted 9, 10, 11, and 12 sec, respectively. The S1 consisted of a red light and a number in the display, indicating the duration of the ISI. Ss had to press a key with their right hand to a 1000 Hz tone and a left key to a 3000 Hz tone or vice versa.

In the mixed condition the warning combination consisted of a

Table 1. Relationship between warning combination and task instruction in the blocked and mixed conditions.

Warning combination display	light	Description of task demands
2,3,4,5	red	BLOCKED CONDITION Choice RT task, ISIs vary between 2 to 5 sec
		MIXED CONDITION
0	red	RT(ISI 3) Single RT task, ISI is 3 sec
0	yellow	RT(ISI 5) Single RT task, ISI is 5 sec
20-70	red and yellow	MA Single addition task
20-70	red	MA+RT(ISI 3) Combined Addition and RT(ISI 3)
20-70	yellow	MA+RT(ISI 5) Combined Addition and RT(ISI 5)

red, yellow or red and yellow light, and a zero (for RT trials) or a starting number between 20 and 70 (for MA trials) in the display. When Ss had to perform mental arithmetic three other numbers (between 2 and 9) appeared in the display after respectively 1750, 3500, and 5250 ms. The starting number and the three following numbers had to be added. Depending on the current task instruction the display was set off after 3, 5 (single RT tasks), or 7 sec (MA tasks). At display offset Ss had to give the solution of the addition task. Intertrial intervals lasted 10, 12, or 14 sec, respectively. Table 1 summarizes the stimuli presented at warning onset, that determined the task.

Procedure

In the blocked RT condition each ISI length was replicated 20 times; the resulting 80 trials were randomized and presented without replacement in four blocks of trials. Between blocks Ss were informed about their performance. Each block started with four warming-up trials, that were omitted from analysis. Before the blocked condition started Ss worked through four blocks of practice trials. Both speed and accuracy of responding was emphasized.

In the mixed condition five different task types were randomly presented: single RT tasks with an interstimulus interval of 3 or 5 sec, a single MA task, and double tasks in which a MA and RT (ISI 3) or a MA and RT (ISI 5) task was performed simultaneously. Stimuli and time intervals in the RT trials of the mixed condition were identical to stimuli and time intervals used in the blocked condition (ISI 3 and 5 sec). Each condition was replicated 16 times; these 80 trials were randomized and presented without replacement in four blocks of trials. Between blocks Ss were informed about their performance. Each block started with two warming-up trials, that were omitted from analysis. Before the mixed condition started Ss worked through about 25 practice trials.

Each twin pair was tested during the same experimental session; when one subject was tested the other waited elsewhere. Both twins were first tested in one condition and then in the other. Order of blocked and mixed conditions was counterbalanced across twin pairs.

RESULTS

Reaction times

Two pairs (one MZ and one DZ) were not included in the analyses of the task effects because one of their members made more than 25% RT errors. In both the blocked and mixed conditions the remaining 40 subjects made 17% RT choice errors; these trials were omitted from further analyses. Subjects made 25% addition errors (wrong solutions); these trials were not omitted. Sign tests showed that subjects made less RT errors and addition errors in the RT (15%) and MA (21%) tasks than in the RT+MA tasks (21% RT errors and 29% addition errors). Thus, as judged from the relatively high error rates, time pressure and double task requirements made the mixed condition relatively stressful for the subject.

In the blocked condition mean RT was 331 ms. An analysis of variance (ANOVA) showed that ISI length did not significantly influence the speed of responding ($F(3/117)=1.82$). (All effects reported are significant at the $p = .05$ level or beyond, unless indicated otherwise.)

In the mixed condition mean RT (544 ms) in MA+RT trials significantly differed from mean RT (381 ms) in single RT trials ($F(1/39)=255.47$). Comparison of RT trials of the blocked (ISI 3 and 5) and mixed (ISI 3 and 5) conditions showed that RT in the blocked condition was significantly faster (about 50 ms) than in the mixed condition ($F(1/39)=31.86$).

Heart Rate

Heart periods were converted to rate per half second format from 2 sec before warning onset until 4.5 sec after warning offset.

The blocked condition

Figure 1 shows the HR changes in the four ISIs of the blocked condition. Except for ISI 2 and 3 the curves in the S1-S2 intervals are clearly three-phasic. Several analyses of variance (ANOVAs) were performed on three HR components that were selected as follows: In ISI 2 one time point in which averaged acceleration (A1), and averaged deceleration (D2) was maximal and two time points in which post-S2 acceleration (A2) was maximal; in the remaining ISIs two subsequent time points in which A1, D2, and A2 was maximal were selected. Pre-warning time points did not show a significant change or interaction with ISI conditions. As recommended by Bohlin and Kjellberg (1979), the HR components were first analyzed relative to pre-warning base level.

The A1 component showed a significant increase with ISI length ($F(3/117)=4.96$), but the D2 component only marginally increased ($F(3/117)=2.12$; $p< 0.10$), while no conditions effect was present for the A2 ($F<1$). The amount of deceleration was also assessed relative to the preceding acceleration (peak to valley). In this case there was a highly significant effect of ISI length ($F(3/117)=12.43$).

The mixed condition

Figure 2 shows the HR curves of the mixed condition in which Ss were doing mental arithmetic. Pre-warning time points showed significant deceleration for all five conditions, while no interaction of conditions and time points occurred. The amount of initial HR acceleration that occurred during mental arithmetic did not differ under single and double task conditions. Reacting to a tone during MA first induced a small dip followed by a HR acceleration that seemed to be superimposed on the single MA pattern. This ef-

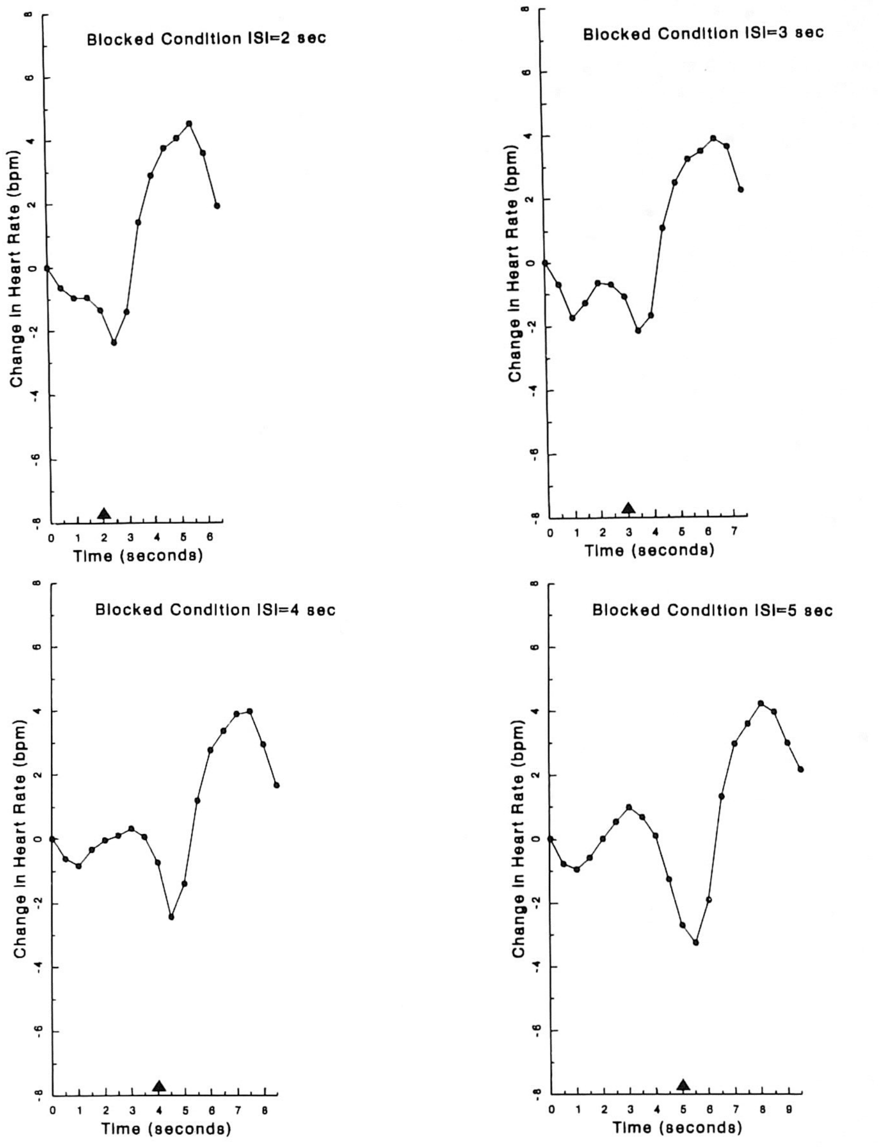

Figure 1. Mean HR changes in the blocked condition plotted over 6.5 (panel A), 7.5 (panel B), 8.5 (panel C), and 9.5 (panel D) sec from warning onset. From panel A to D inter-stimulus interval length was respectively 2, 3, 4, and 5 sec. Filled arrow heads indicate the moment that the reaction stimulus was presented.

Blocked versus mixed condition

In the ISI 3 and ISI 5 trials of the blocked condition HR acceleration followed by deceleration was present. HR deceleration was greater in ISI 5 (4 bpm below pre-stimulus level) than in ISI 3 (2 bpm). In the corresponding RT trials of the mixed condition a steep and sustained HR deceleration occurred in the interstimulus interval (4 bpm in ISI 3 and 6.5 bpm in ISI 5). Two types of RT trials were selected from the latter condition: RT trials that were preceded by another RT trial (RT-after-RT) and RT trials that were preceded by an MA or MA+RT trial (RT-after-MA).

Figure 3 illustrates the difference between RT trials with an ISI of 5 sec in the blocked condition and the corresponding RT-after-RT and RT-after-MA trials of the mixed condition. The figure shows that following an MA trial pre-warning HR level is much higher than following an RT trial. Nevertheless, subsequent cardiac deceleration is increased to such extend that it attains the level of the other RT trials at S2 onset. ANOVAs with blocked RT,

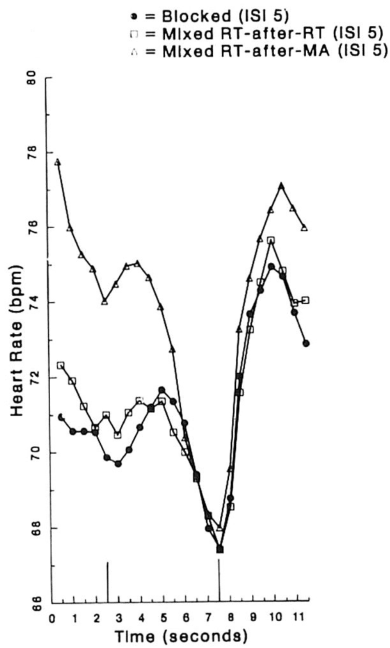

Figure 3. Mean heart rate responses in the blocked condition and RT-after-MA and RT-after-RT (ISI 5) trials of the mixed condition plotted over 11.5 sec from 2 sec before to 9.5 sec after warning onset.

RT-after-RT, and RT-after-MA conditions (3) and pre-warning time points (4) as factors showed highly significant main effects and interactions. Table 2 shows the results of post-hoc ANOVAs which compare blocked RT with RT-after-RT and with RT-after-MA, separately. The table shows that HR significantly decelerated before the warning signal in the RT-after-MA trials as compared to the blocked trials, while no such difference was present between the blocked and RT-after-RT trials. Further post-hoc analyses showed no significant change in the blocked pre-warning time points for ISI 3 and ISI 5 and significant deceleration before warning in RT-after-RT (ISI 5) and RT-after-MA (ISI 3 and ISI 5) trials. Because of the differences in pre-warning HR only trend analyses were done on the phasic HR responses in the S1-S2 intervals of the blocked, RT-after-RT, and RT-after-MA trials. Quadratic and cubic trends were greatest in the blocked condition, while trends were predominantly linear in the mixed conditions (see table 3). In the RT-after-MA trials more variance was explained by the linear trend than in the RT-after-RT trials. These results indicate that HR deceleration in the interstimulus interval of the RT-after-MA trials was considerably enhanced compared to RT-after-RT trials.

Table 2. Post-hoc ANOVA results of pre-warning HR for the blocked, and RT-after-RT and for the blocked and RT-after-MA trials.

	BLOCKED and RT-AFTER-RT		BLOCKED and RT-AFTER-MA	
ISI 3	71.8 bpm	71.8 bpm	71.8 bpm	74.6 bpm
Conditions (2):	F<1		F(1/39)=6.69*	
Conditions (2) * Time Points (4):	F(1/39)=4.04 1)		F(1/39)=7.20* 1)	
ISI 5	70.6 bpm	71.5 bpm	70.6 bpm	76.0 bpm
Conditions (2):	F<1		F(1/39)=17.76*	
Conditions (2) * Time Points (4):	F(1/39)=1.25 1)		F(1/39)=5.01* 1)	

* $p < .05$

1) Dfs adjusted for repeated-measures factor (cf. Jennings and Wood, 1976)

Table 3. F values and percentages of variance explained by linear, quadratic, and cubic trends in the HR curves for the blocked (ISI 3 and 5) and mixed RT-after-RT and RT-after-MA (ISI 3 and 5) trials.

BLOCKED CONDITION	ISI 3		ISI 5	
F-linear	3.50	11%	41.72	22%
F-quadratic	6.18	19%	127.13	66%
F-cubic	19.0	59%	6.78	4%

MIXED CONDITION	RT-AFTER-RT ISI 3		RT-AFTER-MA ISI 3		RT-AFTER-RT ISI 5		RT-AFTER-MA ISI 5	
F-linear	14.47	56%	26.48	63%	51.46	65%	328.06	81%
F-quadratic	9.00	35%	14.42	34%	25.00	30%	54.96	13%
F-cubic	2.07	8%	0.82	2%	0.30	0%	15.73	4%

DISCUSSION

Different types of task related HR responses are demonstrated in the perceptual-motor and mental arithmetic tasks. In the shortest ISI of the blocked condition hardly any task related HR acceleration and deceleration is present. Both HR acceleration and HR deceleration increase as interstimulus interval lengthens. The three-phasic HR pattern occurs in the interstimulus intervals of 4 and 5 sec. This finding replicates Bohlin and Kjellberg (1979) and van der Molen and Orlebeke's (1980) results. It is noteworthy that post-S2 HR acceleration is not influenced by ISI length. Whether or not anticipatory deceleration differs just before the S2 does not affect subsequent acceleration. Brunia and Damen (this volume) reported evidence that post-S2 HR acceleration is related to type of motor response. In their study HR acceleration after the S2 was smaller with voluntary eye blink and verbal responses than with finger and foot movement responses. In the present experiment the same fingerflexion response was made in all ISI conditions which may have been the main determinant of the (identical) post-S2 accelerations.

The simultaneous performance of non-integrated MA and RT tasks induces a significant decline in the speed of responding to the tone and an increase in the number of choice RT errors and addition errors. This result replicates the findings of Lacey and Lacey (1974). The cardiac results show that before the S2 phasic HR acceleration in the MA+RT trials does not differ from HR acceleration in the single MA task. Acceleration and deceleration associated with RT-only tasks is completely overshadowed. In contrast, cardiac changes that occur after S2 onset induce a small (decelerative) dip and a pronounced subsequent acceleration which seem to be superimposed on the (MA-related) HR response. The results suggest that a MA task dominates the anticipatory HR responses when a MA and a RT task are simultaneously performed, while HR changes following stimulus onset (stimulus-induced deceleration and subsequent acceleration associated with motor response execution) constitute a 'vectorial resultant' with the MA related HR changes.

Jennings (this volume) who also investigated HR changes in double (MA and RT) tasks reported results that do not parallel the present findings: Phasic HR changes in a double task differed from the response in a single MA task but did not differ from the response in a single RT task. MA problems were presented either one second before or one second after the presentation of the imperative signal. Jennings suggests that the RT task dominates the MA task because the former is paced and the latter was not. The opportunity to postpone problem solving until after the speeded motor reaction, presumably has caused the predominant influence of the RT task on HR. In the present study both MA and RT tasks were paced, therefore, a more reliable comparison of the relative influence of RT and MA performance on HR was possible.

Two decelerative responses may be distinguished: anticipatory (dominated by MA) and primary (superimposed on MA curve) deceleration. This distinction was made previously by the Laceys (Lacey and Lacey, 1980), who studied primary bradycardia in relation to cardiac cycle time effects. It was found that stimuli which are relevant for the subject and occur relatively close to the preceding R-wave of the EKG induce relatively more primary deceleration than later occurring stimuli (see van der Molen, et al.; Coles and Strayer; Jennings, respectively, this volume). The present results (and similar results of van der Molen and Orlebeke, 1980) suggest that primary deceleration may occur in the absence of anticipatory deceleration in short ISIs (ISI 2 and 3). Thus, it appears that the nature of primary deceleration differs from anticipatory deceleration, because it may occur without previous anticipatory deceleration, it is controlled by the onset of the imperative stimulus, and because it is superimposed on (not dominated by) heart rate changes associated with other mental operations such as mental arithmetic performance.

Why has mental task performance such a powerful effect on heart rate? It is known that vagal changes predominantly control the HR response in RT tasks, (Obrist, et al., 1974; Somsen et al., 1983) but the relative contribution of vagal and sympathetic neural activity during mental arithmetic is unclear. Results of Ulrych (1969) showed that increase in various cardiovascular indices such as stroke volume, arterial pressure, and cardiac output, was strikingly similar in response to quiet conversation and MA performance. Only HR acceleration was much greater during MA compared to conversation. Blockade of beta-adrenergic activity during conversation reduced activity in most sympathetic cardiovascular measures but did not affect HR. It was suggested that HR acceleration mainly resulted from decreased vagal activity. Unfortunately, it was not investigated whether this was also true for the MA task. The strikingly similar cardiovascular responses in the two situations suggest that next to increased sympathetic tone, vagal inhibition may have influenced HR acceleration during MA. Results of Brooks, et al. (1978) also suggest that vagal inhibition may occur during mental arithmetic. They reported reduced sensitivity of the (vagally controlled) baroreceptor reflex in an MA task as compared to a control condition i.e., heart rate was less readily adjusted to changes in blood pressure during MA performance.

Increase in sympathetic tone may explain the increased amplitude of the phasic cardiac responses during and following mental arithmetic and the gradual return to lower levels that is visible in the pre-warning HR of RT-after-MA and RT-after-RT trials. The substantially increased amplitude of anticipatory HR deceleration in RT trials that closely followed an MA trial (figure 3) may have resulted from the mechanism of accentuated antagonism which has been observed in animal studies (cf. Levy and Martin, 1979). Accentuated antagonism implies that the impact of vagal impulses becomes greatly enhanced when they occur against a background of an increased level of sympathetic stimulation. Thus, the performance of mental arithmetic may have induced elevated sympathetic tone which was still present during the RT-after-MA trials and which may have enhanced anticipatory vagal HR deceleration before the S2.

Complex autonomic interactions may influence heart rate during and adjacent to mental arithmetic performance. Increased sympathetic tone together with vagal inhibition may have occurred in the MA trials. In addition, enhanced effects of vagal reactivity may have induced the increased deceleratory HR response in the RT-after-MA trials. However, the relative influences of vagal and sympathetic activity on phasic HR during MA performance have not been studied directly. The present results only indicate that different interactions between vagal and sympathetic activity may have induced the dominance of MA over RT tasks. Further clarification of these interactions and their relationship with mental stress and attentional processes is needed. Selective pharmacological blockade of the two branches of the autonomic nervous system or the simultaneous registration of vagal and sympathetic indices (cf.

Jennings and Choi, 1981) seem to be most appropriate for this purpose.

ACKNOWLEDGEMENTS

This study was supported by a grant from the Society of Pure Scientific Research in the Netherlands.

REFERENCES

Bohlin, G. and Kjellberg A., 1979, Orienting activity in two stimulus paradigms as reflected in heart rate, in: "The orienting reflex in humans", H.D. Kimmel, E.H. van Olst, and J.F. Orlebeke, eds., Lawrence Erlbaum Associates Publishers, Hillsdale, New Jersey.

Brooks, D., Fox, P., Lopez, R., and Sleight, P., 1978, The effect of mental arithmetic on blood pressure variability and baroreflex sensitivity in man, J. of Physiol., 280:75.

Jennings, J.R., 1975, Information processing and concomitant heart rate changes in the overweight and underweight, Physiol. Psychol., 3:90.

Jennings, J.R. and Wood, C.C., 1976, The e-adjustment procedure for repeated-measures analyses of variance, Psychophys., 13:277.

Jennings, J.R. and Choi, S., 1981, Type A components and psychophysiological responses to an attention demanding performance task, Psychosom. Med, 43:475.

Jennings, J.R., 1983, Attention and coronary heart disease, in: "Handbook of Psychology and Health, vol 3, Cardiovascular disorders and behavior", D.S. Krantz, A. Baum, and J.E. Singer, eds., Erlbaum, Hillsdale, New Jersey.

Kahneman, D., Tursky, B., Shapiro, D., and Crider, A., 1969, Pupillary, heart rate, and skin resistance changes during a mental task, J. of exp. psychol., 79:164.

Lacey, J.I., Kagan, J., Lacey, B.C., and Moss, H.A., 1963, The visceral level: Situational determinants and behavioral correlates of autonomic response patterns, in: "Expressions of the emotions of man", P.H. Krapp, ed., International University Press, New York.

Lacey, J.I. and Lacey, B.C., 1970, Some autonomic central nervous system interrelationships, in: "Physiological correlates of emotion", P. Black, ed., Academic press, New York.

Lacey, B.C. and Lacey, J.I., 1974, Studies of heart rate and other bodily processes in sensorimotor behavior, in: "Cardiovascular Psychophysiology", P.A. Obrist, H.H. Black. J. Brener, and L.V. DiCara, eds., Aldine Publishing Company, Chicago.

Lacey, B.C. and Lacey, J.I., 1980, Cognitive modulation of time dependent primary bradycardia, Psychophys., 17:209.

Levy, M.N. and Martin, P.J., 1979, Neural control of the heart, in:

"Handbook of Physiology, section 2, The Cardiovascular System", R.M. Berne, N. Sperelakis, and S.R. Geiger, eds., Am. Physiol. Soc., Bethesda Md, 581-620.

Molen, M.W. van der, and Orlebeke, J.F., 1980, Phasic heart rate change and the U-shaped relationship between choice reaction time and auditory intensity, Psychophys., 17:471.

Molen, M.W. van der, Somsen, R.J.M., and Orlebeke, J.F., in press, The rhythm of the heart beat in information processing, in: "Advances in psychophysiology", P.K. Ackles, J.R. Jennings, and M.G.H. Coles, eds., JAI press, Greenwich.

Obrist, P.A., Lawler, J.E., Howard, J.L., Smithson, K.W., Martin, P.L., and Manning, J., 1974, Sympathetic influences on the heart in humans: Effects on contractility and heart rate of acute stress, Psychophys., 11:405.

Somsen, R.J.M., Molen, M.W. van der, and Orlebeke, J.F., 1983, Phasic heart rate changes in reaction time, shock avoidance, and unavoidable shock tasks: Are hypothetical generalizations about different S1-S2 tasks justified? Psychophys., 20:88.

Tursky, B., Schwartz, G.E., and Crider, A., 1970, Differential patterns of heart rate and skin resistance during a digit transformation task, J. of exp. Psychol., 83:451.

Ulrych, M., 1969, Changes in general haemodynamics during stressful mental arithmetic and non-stressing quiet conversation and modification of the latter by beta-adrenergic blockade, Clinical Science, 36:453.