Cardiovascular Response to a Mentally Stressful Stimulus

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SUMMARY

The purpose of this study was to investigate multivariable cardiovascular responses to a non-mathematical mental task. Fifty-two subjects, 8 to 69 years of age, were monitored at rest and while attempting to solve a Raven’s matrix test without prodding or pressure from the experimentors. Adults (≥18 years) had higher blood pressures (BP) and longer pre-ejection periods (PEP) at rest than did the children. Women had higher resting heart rates (HR) than men. The task induced significant increases in systolic and diastolic BP and HR in adults and children, with the adults exhibiting larger BP responses. During the stressful stimulus significant decreases in left ventricular ejection time occurred in men and women, and significant increases in forearm blood flow occurred in men. The stability in PEP during the stressful period when both BP and HR were increased is evidence of enhanced contractility brought on by the stress. In general, men and women responded similarly. Thus, even a mild, non-mathematical stress of short duration elicits the multiple cardiovascular responses, including increases in BP, HR, muscle blood flow, and contractility, which are observed with more threatening tasks.

Additional Indexing Words:
Arterial pressure   Systolic time intervals

CARDIOVASCULAR responsiveness to repeated stressful episodes may be linked to hypertension and other cardiovascular diseases. The strong cardiovascular response elicited by acute, intense emotional stimulation, such as mental arithmetic problems performed under very restrictive time limitations and/or constant prodding by the investigator, is well documented.1–7 In many investigations, moreover, the invasive techniques of

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cardiovascular monitoring may add significantly to the level of stress,\textsuperscript{1,2,8} Most individuals, however, are customarily engaged in tasks which are only mildly challenging and without constant prodding, but little research is reported on cardiovascular response to this type of task. Furthermore, investigations are typically limited to one or two cardiovascular variables and do not present a comprehensive view of cardiovascular response to mentally stressful stimuli.

The purpose of this study was to comprehensively assess by noninvasive techniques cardiovascular responses to a mild, non-mathematical mental stress. Heart rate, systolic and diastolic arterial pressure, systolic time intervals, and forearm blood flow were monitored; and the data were examined for responses to the stressful stimulus as well as sex and age effects and associations with resting blood pressure.

\section*{Methods}

\textit{Subjects}

Fifty-two male and female subjects between the ages of 8 and 69 years volunteered for this study. All subjects were members of a single large kindred ascertained through one adult male with essential hypertension.\textsuperscript{9} The proband was not included in this analysis; none of the subjects included had hypertension or other cardiovascular disease, as determined from a history and physical examination, and none were on antihypertensive medication.

\textit{Apparatus and variables monitored}

Electrocardiogram (ECG), phonocardiogram, and carotid pulse contour

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{Sample trace of simultaneously recorded electrocardiogram, phonocardiogram, and carotid pulse contour at a paper speed of 100 mm/sec. Sample measurements of Q-Q interval from the electrocardiogram, electromechanical systole (EMS), and left ventricular ejection time (LVET) are indicated. Pre-ejection period (PEP) = EMS − LVET. PEP/LVET is calculated.}
\end{figure}
were simultaneously recorded with an Electronics for Medicine (E for M) VR-12 photographic recorder at a paper speed of 100 mm/sec. E for M PS1B microphones were used in obtaining the phonocardiogram and carotid pulse contour. These traces were used to determine heart rate (from Q-Q interval of ECG) and systolic time intervals, including electromechanical systole (EMS), left ventricular ejection time (LVET), pre-ejection period (PEP), and PEP/LVET, as shown in Fig. 1.

Forearm blood flow (FABF), monitored by venous occlusion plethysmography using a Hg-in-silastic Whitney strain gauge10 on the left arm, was recorded on an E for M VR-6 photographic recorder at 5 mm/sec. Arterial pressure was obtained using a Narco programmed electrosphygmomanometer and recorded on the VR-6 as shown in Fig. 2.

The mental task consisted of attempting to solve a Raven’s Matrix picture puzzle1. Although puzzles were individually chosen so as to be challenging to each participant, the threat frequently elicited by mathematical problems was avoided, and participants were not harrassed or hurried during the 30-sec period allowed for solving the puzzle.

![Fig. 2. Sample trace of simultaneously recorded forearm blood flow and arterial pressure at a paper speed of 5 mm/sec at rest (A) and during the mental task (B). Systolic pressure (SP) and diastolic pressure (DP) are indicated. Each horizontal line represents 20 mmHg. Slope of forearm blood flow traces are indicated.](image)

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1 Psychological Corporation, 757 Third Avenue, New York, New York 10017.
Experimental protocol

During their first visit, subjects provided detailed medical history data; a physical examination by a physician and numerous other laboratory tests were performed, and four resting, seated blood pressure determinations were made by a highly trained observer using random zero and standard mercury sphygmomanometers. Siervogel and associates9) have reported details of the protocol as well as replicability data. Participants were then shown a videotape of the laboratory and the mental task procedures which would be performed during their second visit, to occur within a week.

All participants were tested in the Human Physiology Laboratory at Cox Heart Institute in the morning between 8:00 and 11:30 a.m. to eliminate diurnal variations in cardiovascular parameters. The laboratory was softly lit, and restful background music encouraged participants to relax. After transducers were applied, subjects reclined on a comfortable mattress for 15 min. Supine control data were then recorded including a 30-sec recording on the VR-12, one or two arterial pressure measurements, and 5–7 forearm blood flow measurements.

A laboratory technician then showed a simple Raven's Matrix puzzle to the participant and thoroughly explained how the problem was solved. When the participant indicated understanding, the "actual" more difficult puzzle was held at a visually comfortable height above his or her eyes. When the subject indicated the puzzle was "solved", data collection was immediately terminated. If the subject did not solve the puzzle, cardiovascular variables were monitored for 30 sec. Three laboratory technicians participated in the experiments: one to monitor the tracings and record data on the VR-12, one to record arterial pressure and forearm blood flow, and the third to explain and present the mental task.

Scoring and analysis of data

All recorded beats, throughout all respiratory phases, where the traces were cleanly recorded and the landmarks were clearly evident, were used in the calculation of heart rate and systolic time intervals for each subject. These intervals were measured with the assistance of a computer-digitizer system similar to that described by Frey and Kenney.11) Mean values were determined for each subject at rest and during the mental task.

The blood pressure recordings for each subject during control and task periods were deciphered as shown in Fig. 2. Forearm blood flow was calculated from the equation of Whitney,10) using the slope of the venous-occlusion plethysmogram (Fig. 2). Mean values for FABF were determined for each subject using all well-recorded traces during control (usually 5–7) and during the mental stress period (usually 1–2).
Results

Sex, age, and resting seated blood pressures of the subjects are described in Table I. The boys were slightly younger than, and had slightly lower resting seated arterial pressures than, the girls. Mean age and blood pressure of the men and women were similar, and their pressures were higher than those of the children. Table II provides means and standard deviations for all cardiovascular variables for men, women, and children at rest and during the stressful stimulus period and for the responses to stress. Response to the mental stress was measured as the mean value of a specific variable during the test minus the mean value at rest. Thus, a positive response indicates an increase in the variable due to the stressful stimulus, while the converse is true for a negative response. In each group of subjects, for each of the variables a paired t-test was used to determine if the response to the mental task was significantly different from baseline (shown with asterisks in Table II). The mental task caused a significant increase in SBP, DBP, and HR in each group. In addition, both men and women showed a significant decrease in LVET and an increase in FABF (significant to p<0.05 in only the men). The increase in the PEP/LVET ratio was significant only in the women.

Using the entire sample, age and sex effects in control levels, levels after mental task, and response to mental task were examined by analysis of variance for each of the variables. All of the relationships noted in the analysis of variance are discernible by examining the data presented in Table II, but one should ignore the asterisks as they refer to the significance level of the responses. Significant age effects were present for SBP, DBP, and PEP and sex effects for HR during control and mental task. These effects were significant whether age was treated as a quantitative variable or as an age group dichotomy. Men and women had significantly higher SBP, DBP, and PEP than youths, and women had a faster heart rate than men (Table II).

Response to the mental task also showed significant age effects for SBP and DBP, with men and women exhibiting larger responses than youths.

| Table I. Age and Resting Seated Blood Pressure Levels in Children (<18 Years) and Adults (≥18 Years) |
|---|---|---|---|
| | N | Age Mean ± S.D. | Systolic B.P. Mean ± S.D. | Diastolic B.P. Mean ± S.D. |
| Children | Boys | 12 | 12.7 ± 2.9 | 94.6 ± 11.3 | 57.9 ± 7.3 |
| | Girls | 6 | 14.1 ± 2.5 | 97.3 ± 12.1 | 60.8 ± 10.0 |
| Adults | Men | 18 | 32.8 ± 13.3 | 112.5 ± 9.8 | 72.1 ± 8.0 |
| | Women | 16 | 34.4 ± 13.6 | 110.0 ± 14.9 | 71.1 ± 8.9 |
Table II. Cardiovascular Variables in Youths (<18 Years), Men, and Women

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Sample size, means, and standard deviations of systolic blood pressure (SBP), diastolic blood pressure (DBP), forearm blood flow (FABF), heart rate (HR), left ventricular ejection time (LVET), pre-ejection period (PEP), and the PEP/LVET ratio recorded under control conditions, CS (resting supine), and during mental task, MT. Responses to mental task (i.e., R=MT-CS) are also summarized for children aged <18 years and men and women aged ≥18 years. Significance levels (asterisks) are shown for the paired t-test of the hypothesis that response equals zero.

* 0.01 < p ≤ 0.05, ** p ≤ 0.01.

While not quite significant at the 0.05 level, FABF and HR showed similar age trends. Finally, in the overall sample, there was a significant age-by-sex interaction for HR, which reflects the significant sex difference in HR response in adults (men showed a larger increase in HR in response to the mental task than did women) that is not present in youths. There were no other significant age or sex effects for any of the other variables.

Correlations between resting blood pressures or blood pressure response and the other cardiovascular responses to the mental task were also examined. Although no significant correlations existed between resting blood pressure and the cardiovascular responses in this normotensive population, systolic
blood pressure response correlated with heart rate response \( (r=+0.5, \ p<0.01) \) and with LVET response \( (r=-0.5, \ p<0.01) \).

**DISCUSSION**

This investigation has provided a multivariable examination of cardiovascular response to a mentally stressful stimulus, demonstrating that even a short, minimally stressful, nonmathematical mental task without extreme time pressures will elicit significant cardiovascular responses in men, women, and youths.

The increases in arterial pressure observed in this study are in agreement with—although in some cases of lesser magnitude than—the increases observed by other investigators during more severely stressful tasks using both invasive\(^1\),\(^2\),\(^8\) and noninvasive\(^3\),\(^4\),\(^7\) techniques. The lesser magnitude of the arterial pressure response in this study probably resulted from the milder nature of the stress as well as the short duration of the task, since in the present study pressures were monitored during only a 30-sec period. Falkner et al\(^3\) have shown that pressures continually increase through several minutes of a mental arithmetic task. Female subjects studied by Nyberg\(^6\) were an exception to other studies in that they did not experience an increase in SP during mental stress. Our adult female subjects demonstrated an increase in SP which was of smaller magnitude than that of the males. The small significant blood pressure increase (4.4 mmHg) exhibited by our youths is consistent with the changes observed by Falkner et al\(^3\) in nonhypertensive adolescents performing very stressful mental arithmetic tasks.

The increase in forearm blood flow during this mildly stressful task, which represents muscle blood flow, also mimics responses to more stressful mental arithmetic tasks.\(^2\) This redistribution of blood flow during the mental task involves reduction of blood flow to the skin\(^2\),\(^4\),\(^5\) and other organs and prepares an individual for heightened performance under stressful situations.

The increased heart rate in all subject groups is also consistent with that reported during more stressful tasks.\(^1\),\(^3\),\(^5\)–\(^7\) The short time span of this test, however, did not allow the return of heart rate toward control values during the stress period as reported by Falkner et al,\(^6\) a response which may be attributed to baroreceptor reflex mechanisms. The shortening of LVET in all groups during the mental task was primarily due to the increase in heart rate; the inverse relationship between LVET and heart rate is well established.\(^13\)

Ventricular contractility is reportedly enhanced during mental stress in primates\(^13\) and in humans.\(^14\) In this investigation we have used the non-
invasively determined PEP as a measure of ventricular function. Duration of the PEP, however, is influenced by other factors as well as “contractility” or inotropic influence which tend to shorten its duration. An increase in arterial pressure has the effect of prolonging PEP, since the ventricle must develop a greater pressure during isovolumic contraction before ejection can commence. A reduction in filling, such as occurs with venous pooling or an increased heart rate would also prolong PEP, because the Starling forces would be reduced. PEP/LVET is reported to correlate with ejection fraction and perhaps to be another index of “contractility”. Neither PEP nor PEP/LVET were changed during the mental task in this study, however. Although not immediately apparent, these data support an enhancement of contractility during this mild stress, a conclusion which is drawn as follows. During the mental task, arterial pressure, and more specifically diastolic pressure, is increased. Concomitantly, heart rate is significantly increased, which reduces ventricular filling time. Both of these events would prolong PEP in the absence of an offsetting increase in contractility. Thus, the lack of change in PEP is strong evidence of increased contractility. The changes in PEP/LVET correspond exactly with the change in PEP, substantiating this conclusion.

This report supports the contention that, in general, men and women exhibit similar cardiovascular responses to mild non-mathematical mental stress. This corroborates Brod et al who report no difference between male and female patients during a 10 min mental arithmetic stress; however, Nyberg did observe a sex difference. The adults in the present study responded more vigorously than the youths in both arterial pressure and heart rate; however, correlational analysis revealed no effect of age on cardiovascular response within the adult group, which is in agreement with Brod et al.

**CONCLUSION**

In conclusion, it appears that even a mental task which is of short duration and designed to be mildly stressful will elicit multiple significant cardiovascular responses, including elevated arterial pressure, which are similar to those experienced during severe stress. Many individuals, from childhood on, spend a significant portion of their waking hours hours performing tasks at a comparable level of stressfulness to the picture puzzle presented in this investigation. Thus, if morbidity results from the cumulative effects of recurring elevations of blood pressure with stress, these results should be considered when investigating stress as a cause of cardiovascular disease.
REFERENCES


