Cardiovascular Reactivity to Behavioral Stress in Young Males With and Without Marginally Elevated Casual Systolic Pressures

Comparison of Clinic, Home, and Laboratory Measures

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SUMMARY Heart rate (HR), systolic (SBP), and diastolic (DBP) blood pressure levels were compared in 60 young males during various resting and stressful conditions. Subjects included 29 who had and 31 who had not shown occasional casual SBP readings \( \geq 135 \) mm Hg under low stress conditions. These groups were further divided into those who showed above-average and below-average HR increases at onset of a stressful shock-avoidance task (high vs low HR reactors). High HR reactors, who were equally distributed in both casual SBP groups, also showed higher SBP than low reactors during avoidance, and higher HR and SBP during a pre-stress rest period and two other stresses, the cold pressor test and viewing an erotic film (p's < 0.01). During less stressful conditions (relaxation in the laboratory, family doctor readings, and self-determinations at home), no HR, SBP, or DBP differences were seen between high and low HR reactors. Subjects with casual SBPs \( \geq 135 \) showed higher mean SBP than those with casual SBPs < 135 under all resting and stressful conditions (p's < 0.05) and generally higher DBP as well. Highest mean SBP levels during prestress rest and later stresses were shown by subjects with both casual SBPs \( \geq 135 \) and high HR reactivity to the avoidance task, and lowest by subjects with neither trait. Incidence of parental hypertension was greater among high than low HR reactors, and greatest among high reactors with casual SBPs \( \geq 135 \), suggesting that HR reactivity to stress may help predict future hypertension. (Hypertension 2: 802-808, 1980)

KEY WORDS • behavioral stress • family history of hypertension • borderline hypertension • beta-adrenergic nervous system • heart rate reactivity

B EHAVIORAL or psychological stress is one of many factors which could contribute to the development of essential hypertension in susceptible individuals. Prolonged exposure to certain stresses, such as overcrowding\(^1\) and demanding shock-avoidance tasks\(^2,3\) has been directly related to the onset of sustained hypertension in animal models. In humans, however, evidence on the role of behavioral stress in the etiology of hypertension is less conclusive. Under real life conditions, higher blood pressure (BP) levels have been associated with occupations which are unusually demanding\(^4,5\) with living in poorer, higher crime neighborhoods,\(^6\) and job loss\(^7,8\) and with life-threatening experiences such as war\(^9\) and massive explosions.\(^10\) Under the more controlled conditions of the laboratory, many studies have confirmed that exposure to difficult cognitive and psychomotor tasks or emotionally arousing events can lead to substantial transitory increases in BP and heart rate (HR).\(^11,12\) However, when these behavioral stresses end, the cardiovascular changes subside, and their relationship to any subsequent pathology remains unverified.

Although conclusive evidence is still lacking, a number of studies have demonstrated that hypertensive patients show greater increases in BP and HR during behavioral stresses than normotensive individuals.\(^13,14\) These observations have led to the suggestion that cardiovascular responses to stress in persons who have not yet developed sustained BP elevations could help predict risk of future hypertension. However, an equally plausible interpretation is that high cardiovascular reactivity to stress is a consequence rather than an antecedent condition of hypertension. The hypothesis that high reactivity to stress might help predict future hypertension can only be confirmed by long-term prospective studies, but it would be reinforced by demonstrating that: 1) high

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cardiovascular reactivity to behavioral stress can be evoked in some young individuals who do not yet have hypertension; 2) the characteristic of high reactivity is a stable one; that is, the same individuals will show above-average cardiovascular responses under many different stressful conditions; 3) high cardiovascular reactivity to stress provides novel information about the subject, and is not merely a correlate of other measures which can be more easily obtained, i.e., elevated resting BP or HR; 4) high reactivity to stress can be shown to be associated with established risk factors, such as family history of hypertension. The present study was directed at providing this evidence.

Methods

Equipment and Procedures

The subjects were 60 male undergraduate and graduate students aged 18–29 years who had never been diagnosed as hypertensive. Of these, 22 were recruited from psychology classes; to obtain more subjects with higher BP levels, another 38 were recruited through a BP screening booth set up on campus. The protocol was approved by both the UNC Department of Psychology and North Carolina Memorial Hospital committees for the protection of human subjects. After giving informed consent in writing, all subjects first underwent monitoring in the laboratory during a stress session involving procedures modeled after Obrist et al. The HR, systolic (SBP), and diastolic (DBP) blood pressure (all BP determinations were made in the sitting position) were monitored during a 3-minute prestress rest period and three stressful events: 1) the cold pressor, where one foot is immersed in ice water for 90 seconds; 2) viewing a 4-minute segment of a film explicitly depicting normal heterosexual activity; 3) 14 minute of a simple reaction time task in which subjects were told that any time they did not react quickly enough, there was a chance they would be given a mild electric shock. All subjects received a sample shock before the task, and were asked if they wished to end the study; none did so. During the 34 trials of the avoidance task, most subjects received only 2 shocks (range 1–4).

Following the stress session, all subjects returned to the laboratory on 2 later days when they were not exposed to any stressful events, but instead relaxed in a comfortable chair in a quiet, dimly lit room while HR, SBP and DBP were monitored for 15 minutes. From these two sessions, average values for relaxation onset (based on the first 4-minutes of each session) and relaxation end (based on the last 3 minutes) were generated. Also, as an approximation of basal state levels, lowest relaxation values were generated by averaging the lowest 2 consecutive minutes of HR and the lowest six consecutive readings for SBP and DBP obtained during either relaxation session.

During all laboratory sessions, HR in bpm was obtained continuously using ECG electrodes and a cardiograph. SBP and DBP were obtained independently from occlusion cuffs on each arm; piezoelectric microphones in these cuffs (Parke-Davis BPI2200) were placed over the brachial artery for the detection of Korotkoff (K) sounds. The inflation-deflation cycles were adjusted so that the cuffs inflated rapidly (2–5 sec) to a level close to that obtained on the previous reading and deflated rapidly and totally (1–2 sec) after each new reading. In this way, from 3–6 SBP and 4–8 DBP readings per minute were achieved. Data obtained using these systems have been validated against BP recorded directly from a radial catheter in 16 subjects, and the correlations between direct and indirect readings obtained were typically very high (median r's = +0.86 for SBP and +0.90 for DBP). Thus, readings from these indirect recording systems have been demonstrated to mirror changes in BP quite accurately. (For further details, see Light and Obrist.) In addition to laboratory measures, BP and HR determinations made by family doctors prior to college entrance were obtained for 55 of these 60 subjects by authorized access to student health files. Also, following campus BP screening, several BP recording systems designed for self-determinations (Lumitronics, Inc., NY) became available. These systems were then used by the 38 subjects recruited at that time to monitor variations in BP occurring during the normal events of a two-day period spent on campus and at home. Like our laboratory systems, these manually-inflated BP systems contain a transducer in the cuff for detection of K-sounds, which are then indicated by light flashes and beeping sounds. The subjects were told to make two consecutive determinations of SBP and DBP in the sitting position ten times per day, every 1–3 waking hours, and to include occasions both high and low in stress. Before each reading, subjects wrote down the time of day and listed their most recent activity. After excluding values obtained following exercise, the remaining readings were averaged to generate mean home values.

Design and Data Analysis

The HR, SBP and DBP levels were thus obtained under three highly stressful conditions (cold pressor, erotic film, shock avoidance) and six less stressful conditions (onset, end and lowest relaxation, prestress rest, family doctor, mean home; no HR levels were obtained in the home environment.) With the exception of the family doctor measures, all levels obtained were averages of repeated determinations made over a period of from 2–4 minutes. During the most prolonged event, the avoidance task, averages obtained from min 1–2, 3–4, 8–9 and 12–14 were analyzed separately in order to reveal the pattern of changes shown over that task's duration.

Subjects were divided into four groups. First, they were divided into those who had and had not shown at least one marginal SBP elevation under low stress conditions. Those with marginal elevations included 21 who had shown casual SBP levels of 135 mm Hg or greater during routine examinations at the student health center or when checked at the campus screening booth, as well as 8 others who showed at least one SBP reading of 135 or greater during laboratory
relaxation sessions. The remaining 31 subjects consistently showed SBP levels less than 135 mm Hg on these occasions. The sample was also divided into those high and low in HR reactivity to the onset of the shock avoidance task. HR rather than BP increases were chosen to index cardiovascular reactivity to this task because previous studies have shown that HR increases during this event are mediated almost entirely by beta-adrenergic mechanisms; SBP increases involve a substantial beta-adrenergic contribution but are affected by other factors as well. To reflect the maximum change shown by each subject, increases from the lowest levels seen during relaxation in the laboratory to the levels reached during the first 2 minutes of shock avoidance, when peak HRs are typically seen, were used to define HR reactivity. Using a median split based on the responses of all 60 subjects, the 30 subjects showing HR increases from 2-33 bpm were classed as low HR reactors, while the 30 with increases from 34-69 bpm were designated high HR reactors.

To compare the cardiovascular responses of the high vs low HR reactors and the subjects with vs without casual SBPs ≥ 135 mm Hg under these various conditions, a series of repeated measures analyses of variance were performed using the BMDP 2V computer program. Where significant main effects or interactions were obtained, pairwise comparisons among means were made using the Tukey HSD test; post hoc nonpairwise comparisons were made using the Scheffé method.

Results

The tendency toward marginally elevated casual SBP levels under low stress conditions and high HR reactivity to stress were found to be independent characteristics. Among subjects with casual SBPs ≥ 135, there were 15 low and 14 high HR reactors; among those with casual SBPs < 135, there were 15 low and 16 high HR reactors. Mean HR, SBP and DBP levels of these four subgroups under all conditions are presented in figures 1, 2 and 3, respectively. As shown in figures 1 and 2, subjects with high HR reactivity to stress reached higher SBP as well as higher HR levels than those with lower HR reactivity not only during the avoidance test but during every event of the laboratory stress session, including the prestress rest period (p's < 0.001). For both high and low HR reactors, SBP and HR levels were higher during minutes 1-2 and 3-4 than later in the avoidance task (p's < 0.05). In contrast to these stress session measures, high and low HR reactors could not be distinguished on the basis of HR or SBP levels obtained during relaxation, or those measures reported by the family doctor, or from self-determinations of BP.

![Figure 1](http://hyper.ahajournals.org/Downloadedfrom)

**Figure 1.** Heart rates (HR) of high and low HR reactors in the stable and labile systolic blood pressure (SBP) groups. Mean HR ± SE of each group is presented for events from laboratory stress and relaxation sessions (L indicates lowest relaxation levels), and family physician determinations. A significant difference between high and low HR reactors was obtained for prestress rest, cold pressor (CP), erotic film, and the entire shock avoidance task (p's < 0.001). A significant difference between casual SBP groups was obtained only during min 1-2 and 3-4 of shock avoidance (p's < 0.05).
DIFFERENCES IN HR AND BP DURING REST AND STRESS/Light and Obrist

Figure 2. Systolic blood pressure (SBP) levels of high and low heart rate (HR) reactors in the stable and labile SBP groups. Mean pressure ± se of each group is presented for events from laboratory stress and relaxation sessions (L indicates lowest relaxation levels), family doctor determinations, and the mean of two days of self-determinations in the home environment. (For home values, n's are smaller than those listed in the figure, equalling 9, 6, 11 and 12 for the various groups, respectively.) A significant difference between high and low HR reactors was obtained for prestress rest, cold pressor (CP), erotic film and shock avoidance (p's < 0.01). A significant difference between casual SBP groups was obtained under every condition (p's < 0.05).

Figure 3. Diastolic blood pressure levels of high and low heart rate (HR) reactors in the stable and labile systolic blood pressure (SBP) groups. Mean pressure ± se of each group is presented for events from laboratory stress and relaxation sessions (L indicates lowest relaxation levels), family doctor determinations, and the mean of the two days of self-determinations in the home environment. (For home values, n's are smaller than those listed in the figure, equalling 9, 6, 11, and 12 for the various groups, respectively.) No significant differences between high and low HR reactors were obtained. A significant difference between casual SBP groups was obtained during pre-stress rest, cold pressor (CP), erotic film, shock avoidance, relaxation onset, relaxation end and lowest relaxation (L) conditions (p's < 0.05).
made at home. As figure 3 shows, high and low reactors did not differ in DBP under any condition.

When the responses of those subjects with casual SBPs ≥ 135 and < 135 mm Hg were compared, those subjects with occasional marginally elevated casual SBPs showed consistently higher SBP levels during all resting and stressful conditions and higher DBP levels under all conditions except the family doctor and mean home measures (p's < 0.05). During prestress rest and the three stresses, the effects of HR reactivity and casual SBP levels on BP were found to be roughly additive. That is, the highest SBP levels were achieved by those subjects with both high HR reactivity and casual SBP's ≥ 135, while intermediate levels were seen in subjects with either high reactivity or marginally elevated casual SBP but not both traits, and lowest levels were seen in subjects with neither characteristic.

Discussion

In 1971, when reviewing and synthesizing the available findings on those everyday life experiences and conditions which are associated with elevated blood pressure levels, Gutmann and Benson developed the following generalization: "Elevated systemic arterial pressures seems to be more consistently related to environmental situations which require continuous behavioral adjustments on the part of the individual." Recently, several psychophysio-logic studies of cardiovascular response to stressful cognitive and psychomotor tasks have led to a similar conclusion: that is, when a difficult task is combined with strong incentives for good performance, leading the subject to be continuously engaged in actively coping with the task requirements, then blood pressure increases are greater than when there is less incentive or need for such effortful coping. Furthermore, the temporary cardiodynamic state evoked in some normotensive individuals by such active coping tasks strongly parallels the alterations frequently associated with labile or borderline hypertension. Borderline hypertension is a condition which may in some cases be a precursor to later sustained hypertension; it has been reported to involve elevations of cardiac output, stroke index and heart rate which are markedly reduced following administration of propranolol, a beta-adrenergic antagonist. Similar cardiovascular changes, including increases in heart rate, systolic pressure and indirect indices of cardiac performance have been repeatedly observed in subjects actively coping with a difficult shock avoidance reaction time task, and as with borderline hypertension, these increases have been shown to be largely abolished following beta-adrenergic blockade with propranolol. Thus, investigators concerned with the role which behavioral stress may play in the development of essential hypertension have two reasons to focus on this type of stressful event: first, it is similar to real-life conditions which evoke BP increases, and second, it can evoke sympathetically-mediated cardiovascular changes which mimic borderline hypertension.

The present study extends previous observations regarding the cardiovascular changes induced by coping with the shock avoidance task in several ways. First, these findings indicate that subjects who show occasional marginal SBP elevations under low stress conditions are not always above-average in HR reactivity to this stressful task. In fact, in this sample of 60 healthy young males, equal numbers of high HR reactors were seen in the groups with and without casual SBPs of 135 or greater. This finding confirms that high cardiovascular reactivity to stress can be evoked in persons who do not yet have hypertension, including some individuals with average or below-average casual blood pressures. This observation adds support to the hypothesis that high reactivity may be an antecedent condition rather than a secondary effect in cases of essential hypertension.

Second, the present findings demonstrate that high HR reactors to shock avoidance show higher systolic pressures as well as higher HR levels during this task and during other unrelated stressful events as well. The consistency of these group differences across different stressful conditions reinforces the suggestion that above-average cardiovascular reactivity to stress is a stable characteristic of some individuals who do not yet have hypertension. It should be noted that high and low reactors received an equal number of shocks during this task (X = 1.9 for both groups), and that both groups reached peak HR and SBP levels before any shocks had actually been delivered. However, high reactors were observed to show faster reaction times than low reactors, which suggests that they were somewhat more engaged in actively coping with the task than the less reactive individuals.

Third, although clear differences in SBP and DBP levels of subjects with as opposed to without casual SBP levels of 135 or greater were evident under less as well as more stressful conditions, the high and low HR reactors to stress in each casual SBP group could not be discriminated on the basis of BP or HR levels during relaxation, at the family doctor's office, or at home. These findings indicate that high reactivity to this active coping task provides information about the subject which is quite distinct from high resting levels of BP or HR. The latter measures are more easily obtained and have well-documented predictive value in determining risk of future hypertension, but this finding suggests that measures of reactivity to stress could add further information which may improve the predictive power of such established indices.

In addition to the differences seen during the actual exposure to the various laboratory stresses, high HR reactors also showed higher HR and SBP levels than low HR reactors during the prestress rest period. For the low reactors, responses during prestress rest were no different from those seen during the onset of relaxation, while for the high reactors, prestress resting levels were significantly higher than relaxation levels. This finding may reflect a difference in the way these
two groups responded to the unfamiliar laboratory setting, or the anticipation of the stressful events, or both. Based on these observations, it is recommended that investigations focusing on individual differences in cardiovascular responses to behavioral events should include monitoring under familiar, relaxing conditions to serve as a baseline. No differences between high and low HR reactors were seen for self-determined BP levels in the home environment. However, since these mean home levels were no higher than relaxation levels obtained in the laboratory, this lack of differentiation is not surprising. In order to adequately reflect cardiovascular responses to the stresses of daily life, automated systems which are not dependent on the subject selecting his own time of measurement and do not require interruption of ongoing activities may be necessary.

Only information from long-term prospective studies can verify whether cardiovascular reactivity to active coping stresses like shock avoidance can be helpful in the identification of individuals who have a greater risk of developing later hypertension. Nonetheless, demonstrations of an association between high reactivity to stress and family history of hypertension, an established risk factor, suggest that this may be true. Children of hypertensive parents have been repeatedly shown to have an increased risk of developing hypertension themselves. Falkner and colleagues studied hemodynamic responses to the stress of mental arithmetic in adolescents with and without at least one hypertensive parent. Their findings revealed that those young normotensive subjects with parental history of hypertension showed greater HR and BP increases during stress; this effect was even more pronounced in those subjects with occasional DBP elevations as well as at least one hypertensive parent. Their findings revealed that those young normotensive subjects with parental history of hypertension showed greater HR and BP increases during stress; this effect was even more pronounced in those subjects with occasional DBP elevations as well as at least one hypertensive parent. Their findings revealed that those young normotensive subjects with parental history of hypertension showed greater HR and BP increases during stress; this effect was even more pronounced in those subjects with occasional DBP elevations as well as at least one hypertensive parent.

In our own laboratory, we have recently completed a study in which we obtained health history information from the parents of 130 subjects who had been monitored during exposure to the shock avoidance task during the past several years. As part of this larger investigation, the parents of 52 of the 60 subjects from the present study were contacted by mail and asked to provide information on their health. This information was provided by parents of 37 subjects, a relatively small sample, but the trends shown by these 74 parents in terms of incidence of hypertension were quite dramatic. As Table 1 depicts, the percentage of parents with hypertension was roughly five times as great among subjects with high as compared to low HR reactivity to the avoidance task. The incidence of parental hypertension was highest among subjects who demonstrated both high HR reactivity to the avoidance task and occasional SBP levels of 135 mm Hg or greater. Because of the small sample size, these data must be regarded as only suggestive, but the strong relationship between parental hypertension and the HR and SBP levels observed during shock avoidance has been statistically confirmed in our larger sample as well. These data support the position that cardiovascular reactivity to such active coping stresses is a meaningful index, and one which, when considered together with resting blood pressure and cardiodynamic information, may be prognostically useful.

In conclusion, this study has demonstrated that normotensive individuals with similar blood pressure and heart rate levels under low stress conditions can show dramatic and stable differences in cardiovascular responses to behavioral events during various stressful events. This study distinguishes between high heart rate reactivity to behavioral stress and a tendency toward occasional casual SBP elevations, and shows how both factors contribute to blood pressure levels reached during stress. Finally, this study demonstrates an association between high heart rate reactivity to stress and greater incidence of hypertension among the subjects' parents.

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<th>TABLE 1. Incidence of Hypertension Among Parents Based on Parental Reports</th>
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<td>Subjects with casual SBP &lt; 135 mm Hg</td>
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<td>No. parents responding</td>
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