tions substantially above or below the horizontal (30° to 45°, for example).

These acoustic observations suggest that a change in the location of the sound source over a vertical angle span from horizontal to 45° above or below the horizontal is associated with a change from 45 to 60 μsec in the delay of the external ear's secondary reflection after the primary impulse. Experiments on the ability of *Eptesicus fuscus* to perceive changes in the time of occurrence of echoes of sonar signals much like those emitted in this vertical angle experiment indicate an echo delay acuity of about 1 μsec (*12*). Since vertical angles spanning 45° are accompanied by external ear echo delay changes of 15 μsec, the bat ought to be able to perceive a vertical angle change of 3° if its 1-μsec, echo delay acuity applies to external ear echoes also. Thus, there is good correspondence between the vertical angle acuity demonstrated in Fig. 1 and the acuity expected if the external ear secondary reflection is, in fact, perceived as a delayed reflection of the sonar echo arriving directly at the ear canal.

Such a correspondence suggests that the tragus functions as a reflecting surface in generating acoustic cues for vertical localization of sonar targets by *Eptesicus fuscus*. The tragus produces a second, slightly longer path for sound to travel along to the ear canal, in effect simulating a second opening leading to the tympanic membrane. The neural mechanisms of vertical localization in this bat must involve cells specialized for responding to secondary reflections with delays of 45 to 60 μsec, and they may make up one of the many nuclei of the lower auditory system. It is not entirely clear what roles time- and frequency-domain representations of echoes play in vertical localization: does the auditory system "observe" the timing of nerve spikes to evaluate these reflections, or does it observe peaks and nulls in the composite spectrum of primary and secondary signals? The echo delay discrimination experiments (*12*) indicate that the former is likely.

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Type A Behavior and Elevated Physiological and Neuroendocrine Responses to Cognitive Tasks

Abstract. *Qualitatively distinct patterns of cardiovascular and neuroendocrine responses were observed in male college students during mental work and during sensory intake task performance. During mental work, Type A (coronary-prone) subjects showed greater muscle vasodilatation and more enhanced secretion of norepinephrine, epinephrine, and cortisol than Type B subjects. During sensory intake, Type A hyperresponsivity was found for testosterone and, among those subjects with a positive family history of hypertension, for cortisol. As a demonstration of combined cardiovascular, sympathetic nervous system, and neuroendocrine hyperresponsivity to specific cognitive tasks in Type A subjects, this study breaks ground in the search for mechanisms mediating the increased coronary disease risk among Type A persons.*

It is now generally accepted that the Type A behavior pattern is an independent risk factor for acute coronary events, and there is also extensive evidence that Type A persons show more severe and extensive coronary atherosclerosis on coronary arteriography (*1*). Studies of Type A persons documenting both cardiovascular and catecholamine hyperresponsivity to a variety of behavioral challenges have led to the hypothesis that such hyperresponsivity represents a mechanism for the expression of excess coronary events and atherosclerosis among Type A persons (*2*). Rarely are both cardiovascular and catecholamine responses assessed in the same study, and the secretion of other neuroendocrine substances in response to behavioral challenge among Type A and B subjects has not been assessed at all. Although available studies lack consistency regarding which response measures are enhanced among Type A persons, they, and not the Type B's, have been the ones to show hyperresponsivity. For example, during work on an impossible jigsaw puzzle in the presence of loud noise, Type A subjects showed excessive norepinephrine but not epinephrine secretion (*3*); during a competitive television "pong" game with harassment, however, they showed hyperresponsivity only in epinephrine secretion (*4*). Some studies of cardiovascular responses to behavioral challenge have found hyperresponsivity in systolic blood pressure, heart rate, or both among Type A subjects (*5*). These studies have used a wide variety of behavioral challenges with varying types of incentive and harassment.

Mason has proposed that a given neuroendocrine substance does not respond to a behavioral challenge in isolation but as one component of a broad array of multiple, concurrent responses; in addition, different types of challenge may elicit different patterns of neuroendocrine response (*6*). On the basis of Mason's suggestions (*6*), on theorizing by Lacey and Lacey (*7*), and on our findings of muscle vasodilatation during mental work behavior and muscle vasoconstriction during sensory intake (*8*), we have proposed that these two behaviors are associated with qualitatively distinct patterns of both cardiovascular and neuroendocrine response, and that enhanced expression of these patterns could explain the increased risk of coronary heart disease among Type A persons (*9*). Accordingly, we evaluated a broad range of cardiovascular and neuroendocrine responses among Type A and B subjects during mental arithmetic (mental work) and reaction time (sensory intake) tasks. The Type A subjects were hyperresponsive on both cardiovascular and neuroendocrine measures. The pat-

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Table 1. Cardiovascular and neuroendocrine responses (change from baseline) during performance of mental arithmetic and reaction time tasks among Type A and B subjects. Each value represents the mean ± standard error of the mean. N.S., not significant.

Response	Mental arithmetic			Reaction time		
	A (N = 11)	B (N = 10)	P*	A (N = 11)	B (N = 10)	P*
Cardiovascular						
Heart rate (beat/min)	+18 ± 2	+13 ± 2	N.S.	+4 ± 2	+2 ± 1	N.S.
Systolic blood pressure (mmHg)	+20 ± 4	+19 ± 4	N.S.	+7 ± 2	+6 ± 2	N.S.
Diastolic blood pressure (mmHg)	+14 ± 2	+11 ± 2	N.S.	+6 ± 2	+7 ± 2	N.S.
FBF (ml per 100 ml per minute)	+1.5 ± 0.3	+0.7 ± 0.1	.02	+0.3 ± 0.2	−0.1 ± 0.1	N.S.
FVR (100 ml/min)	−14.0 ± 2.2	−4.8 ± 2.3	.01	−1.9 ± 3.1	+6.1 ± 3.2	N.S.
Neuroendocrine						
Norepinephrine (pg/ml)	+188 ± 35	+103 ± 24	.05	+76 ± 22	+37 ± 20	N.S.
Epinephrine (pg/ml)	+47 ± 15	+12 ± 6	.05	+4 ± 3	+15 ± 19	N.S.
Cortisol (μg per 100 ml)	+8.3 ± 2.3	+0.2 ± 0.9	.006	−1.1 ± 2.0	−0.6 ± 1.0	N.S.
Prolactin (ng/ml)	+2.9 ± 0.9	+0.8 ± 0.9	N.S.	−0.7 ± 0.8	+1.2 ± 0.7	N.S.
Testosterone (ng/ml)	+0.5 ± 0.5	+0.3 ± 0.5	N.S.	+2.1 ± 0.5	−0.2 ± 0.9	.05

*Two-tailed t-test or analysis of covariance with baseline as covariate; criterion α = .05.

tern of such hyperresponsivity was not general, however, but specific for certain responses, as well as for the two types of behavioral challenge.

Subjects were 31 male undergraduates. Both the structured interview and the Jenkins Activity Survey (JAS) (*10*) were used to categorize subjects as Type A or B. To ensure the greatest possible confidence in assessment of this measure, only those categorized as A (N = 11) or B (N = 10) by both techniques were included in the final sample. None were taking any medication and all abstained from coffee and smoking for at least 4 hours before being tested. A 19-gauge butterfly needle was placed in a superficial arm vein, after which subjects rested in a comfortable chair for 1 hour. At this point transducers, electrodes, and blood pressure cuffs were attached to permit recording of blood pressure (BP) (by a Roche Arteriosonde), heart rate, and forearm blood flow (FBF) (by venous-occlusion plethysmography and a mercury-in-Silastic strain gauge). These variables were recorded simultaneously at 1- to 1½-minute intervals throughout subsequent 20-minute baseline and task periods. Forearm vascular resistance (FVR) was also calculated (*11*). Continuous, integrated blood samples were obtained throughout baseline and task periods with a continuous exfusion pump (Cormed), ensuring that no episodic secretory bursts of any hormone were missed because of blood-sampling technique. Measures were averaged over 7-minute intervals. The blood samples, representing three 7-minute epochs for both baseline and task periods, were spun down, and the plasma was frozen at −40°C until subsequent assay. Catecholamines were assayed by a radioenzymatic technique (*12*). Cortisol, prolactin, and testosterone were assayed by radioimmunoassay with commercial kits. We compared cardiovascular and neuroendocrine responses of Type A and B subjects using the mean of the three baseline epochs versus the mean level obtained across the three task epochs. Responses were compared with t-tests, except for systolic and diastolic BP and FVR, for which analysis of covariance (baseline as covariate) was used because of baseline differences and the presence of significant correlations between baseline and response magnitude. The mental work task was serial subtractions of 13 from 7683, with a small prize at the end of the study (6 months later) to the subject with the highest subtraction rate. A choice reaction time task with warning-respond signal pairs presented every 1 to 1½ minute was used to induce sensory intake. Subjects were tested at the same time of day on two separate occasions, 1 week apart, with half the subjects performing the mental work task first.

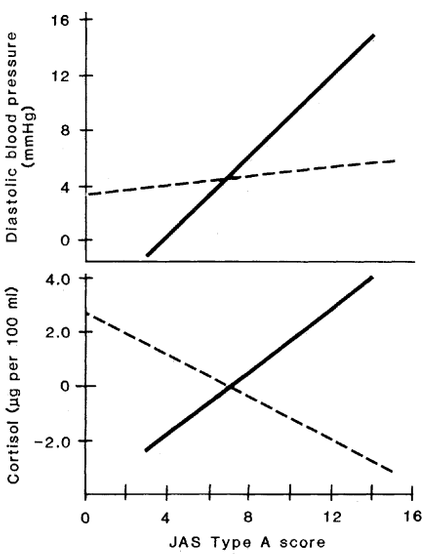

Fig. 1. Diastolic blood pressure and cortisol responses to the reaction time task as a function of Type A score on the Jenkins Activity Survey (*JAS*) in subjects with (———) and without a positive family history (– – –) of cardiovascular disease. Higher scores reflect increased Type A behavior.

Type A subjects exhibited hyperresponsivity, but only on certain measures and only during certain tasks (Table 1). During mental arithmetic, FVR decreased nearly three times as much for Type A as for Type B subjects, indicating a greater active muscle vasodilatation. In contrast, heart rate and blood pressure did not differ between groups. During mental arithmetic, Type A subjects showed greater increases than Type B subjects in norepinephrine, epinephrine, and cortisol but not in prolactin and testosterone.

During the reaction time task, the only significant difference between groups was an increase in testosterone among Type A subjects. Katkin *et al.* (*13*), however, found that among subjects with a positive family history (+FH) of cardiovascular disease, Type A (JAS-defined) subjects showed vasomotor hyperresponsivity during a reaction time task relative to Type B subjects; in the absence of a +FH, Type A subjects were, if anything, hyporesponsive. Therefore, we evaluated the Type A/+FH (defined as myocardial infarction, angina, or hypertension in a parent or sibling) interaction with respect to cardiovascular and neuroendocrine responses to our reaction time task. A strongly significant [F(1, 27) = 8.31, P = .008] interaction effect was found for the cortisol response; a similar tendency for diastolic BP was not significant (P = .11). Only in the presence of a +FH (N = 7; relatives of six of these had hypertension) did Type A subjects exhibit hyperresponsivity relative to

Type B subjects (Fig. 1). Despite their cardiovascular and neuroendocrine hyperresponsivity, Type A subjects performed no better on either task than Type B subjects.

These findings suggest that young Type A men are not generally hyperresponsive to environmental challenge, but are specifically hyperresponsive only in certain physiological responses and only as a function of the type of challenge and genetic predisposition.

Our findings have potentially far-reaching implications for understanding mechanisms underlying the increased coronary disease risk observed among Type A persons. The combination of catecholamine and cortisol hyperresponsivity among Type A subjects could be particularly important in the pathogenesis of both coronary atherosclerosis and acute coronary events. Cortisol both stimulates catecholamine-synthesizing enzymes and inhibits a major catecholamine-degrading enzyme, catechol methyltransferase, as well as increases the sensitivity of adrenergic receptors to a given concentration of neurotransmitter (*14*). Hence, among Type A persons, the physiologic and metabolic effects of any given level of sympathetic activation could be potentiated by concomitant enhanced adrenocortical arousal. That such a mechanism may play such a role in accelerated atherogenesis is supported by the observation among Air Force personnel that elevated serial plasma coritsol concentrations during an oral glucose tolerance test are associated with increased severity of arteriographically documented coronary atherosclerosis (*15*). Since exogenous testosterone accelerates atherogenesis in rats (*16*), the testosterone hyperresponsivity of Type A subjects during sensory intake could also play a role in atherogenesis.

Prior studies (*5*) have found differences between Types A and B in heart rate and blood pressure responses to tasks superficially similar to those we have used. In nearly all cases, however, the tasks contained elements of both sensory intake and mental work, as well as some form of harassment. In addition, none of these studies have quantified peripheral hemodynamics so as to permit the drawing of sound inferences regarding specific mechanisms of pressor responses. We did not harass subjects, and we used a sensory intake or mental work task that was relatively free from contamination by the other behavioral mode. We found a greater muscle vasodilatation for Type A subjects during mental work but no difference in BP responses. The relatively "pure" sensory intake and mental work tasks without harassment seem to have resulted in more specific differentiation of cardiovascular responses of Types A and B. Thus, the greater muscle vasodilatation among Type A subjects attenuated any BP increase that might have resulted from their marginally greater heart rate increase. While our findings are in general agreement with the observation of greater catecholamine response among Type A subjects in other studies (*3, 4*), our data represent, to our knowledge, the first evidence of Type A hyperresponsivity with respect to other plasma neuroendocrine measures.

Neither Type A or B subjects showed the expected significant increase in FVR during the reaction time task, and the Type B subjects' small increase in FVR from resting levels was also not significant. Subsequent studies (*17*) have shown that with more frequent presentation of stimuli than every 1 to 1½ minute, a significant FVR increase is observed. Despite the lack of predicted FVR increase in this study, the greater testosterone response of Type A subjects to the reaction time but not to the mental arithmetic task supports the utility of our initial premise that these two behaviors would lead to different patterns of arousal. Further studies will be required, however, to document that it is the sensory intake-rejection dimension and not another (such as task difficulty or level of subject involvement) that is responsible for the differences in response pattern between the mental arithmetic and reaction time tasks.

We have no ready explanation for the Type A–FH interaction, although it is clearly related to hypertension; we have now replicated it with respect to FVR and systolic BP responses to a different sensory intake task (*17*). Considering the relatively small number of subjects with +FH in our studies, some variability in the measures in which it is expressed is not surprising. Selecting subjects for this characteristic would ensure greater power in studying the interaction. Its replication in three separate studies provides strong evidence that this finding merits further investigation.

To the extent that the specific cardiovascular and neuroendocrine hyperresponsivity we have found in the laboratory among Type A subjects during performance of mental work and sensory intake tasks also occurs among Type A persons when performing these ubiquitous behaviors in the real world, our findings could help to identify basic mechanisms mediating the increased risk of coronary heart disease among Type A persons. Such knowledge could be applied to the formulation of both pharmacological and behavioral interventions designed to reduce the risk of such disease.

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