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ORIGINAL ARTICLE

Cardiovascular and renal responses to mental challenge in highly and moderately active males with a family history of hypertension

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The objective of this study was to compare FBF and renal responses to mental challenge in highly and moderately active males with a family history of hypertension. Normotensive, healthy males with a family history of hypertension ($n = 18$) were recruited into moderately active and highly active groups. Cardiovascular, FBF, and renal responses to a 10-min Stroop mental challenge were measured. Urine was analysed for levels of sodium and potassium pre and post stressor as an indicant of renal blood flow. The results were that the moderately active males demonstrated a significantly higher level of FBF reactivity to mental challenge compared with that of the highly active. Heart rate change and FBF change during the stressor were positively correlated ($r = 0.75$, $P < 0.01$). Both groups, however, demonstrated a similar pattern of sodium excretion to mental challenge. These findings suggest that physical activity level is associated with FBF reactivity but not renal reactivity to mental challenge in offspring hypertensives. That sodium excretion was no different post-stressor in the moderately active group suggests that the exaggerated forearm vasodilatation response was not due to renal vasoconstriction.
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Keywords: sodium retention; vascular reactivity; physical activity; familial hypertension; mental stress

Introduction

A critical factor in the development of hypertension is the failure of the kidneys to maintain blood pressure within normal limits by excreting sufficient salt and water.[1] Exercise training is known to be an effective non-pharmacological method to reduce high blood pressure[2] and a number of studies[3,4] have linked exercise antihypertensive effects to renal depressor mechanisms. For example, Kohno *et al*[3] have shown that the renin angiotensin system and sympathetic nervous system were suppressed (significant reductions in plasma renin and noradrenaline activity) after 4 weeks exercise training in hypertensive subjects. A number of studies have also found altered renal haemodynamics both at rest and during mental stress in individuals with a family history of hypertension.[5,6] Furthermore, during stress sodium retention is known to manifest itself particularly in genetically predisposed individuals.[7] Thus, continued exposure to mental stress may be an important contributor to the early development of hypertension in individuals with a genetic predisposition to retain sodium. Although Holmes and Cappo[8] have shown that highly fit offspring hypertensives demonstrate reduced heart rate and blood pressure reactivity to mental challenge compared with less fit offspring hypertensives, the effect of fitness/physical activity level on the renal responses to stress in genetically predisposed individuals appear to be undetermined.

An exaggerated skeletal muscle vasodilatation response to mental stress is also thought to play a key role in the development of hypertension by initiating a vascular re-modelling process.[9] Anderson *et al*[10] suggested that a possible explanation for the enhanced forearm blood flow (FBF) response to stress in offspring hypertensives may have been due to differences in regional blood flow. This hypothesis is supported by a number of researchers[5,6] who have shown that during mental challenge offspring hypertensives have significantly reduced blood flow to the kidney. Activation of the renal α-adrenergic receptors is thought to induce sodium retention through activation of the renin-angiotensin-aldos-

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terone system causing renal constriction (altering glomerular filtration rate) and/or altering the tubular re-absorption of sodium.[11] Thus, if exaggerated FBF reactivity to mental challenge is in part due to a renal vasoconstrictor response then FBF reactors should also display sodium retention. However, no research as yet has examined this relationship.

Thus, given the possible renal depressor effects of regular aerobic exercise, it was hypothesised that highly active offspring hypertensives would demonstrate little or no change in urinary sodium excretion during mental challenge and would also demonstrate reduced FBF reactivity. In contrast it was predicted that moderately active offspring hypertensives would demonstrate sodium retention and exaggerated FBF reactivity to mental challenge.

Methods

Subjects

Eighteen healthy normotensive males with a family history of hypertension were recruited from a student population and from local athletic clubs. The study was approved by a university human ethics committee and all subjects were provided written informed consent before participation.

Subjects were provided with dietary guidelines 24-h prior to testing in order to control for salt intake, which has previously been linked with enhanced cardiovascular reactivity to stress.[12,13] Subjects were also required to abstain from alcohol, caffeine, and rigorous physical activity. Subjects completed a full medical history questionnaire, physical activity readiness questionnaire, the State-Trait Anxiety questionnaire,[14] and were questioned concerning their physical activity levels using the 7-day Physical Activity Recall (PAR).[15] The PAR is a semi-structured interview designed to examine subjects' physical activity during the previous 7 days. Total daily energy expenditure is estimated from the amount of time spent: sleeping (1 MET/h); light activity such as working at a desk (1.5 MET/h); moderate activity such as brisk walking (4 MET/h); hard activity such as playing tennis (6 MET/h); and very hard activity such as running (10 MET/h). Nine males involved with recreational physical activities up to three times per week (eg, football) were recruited for the moderately active group (MOD) whereas nine males who were all aerobic athletes involved with daily aerobic training were recruited for the highly active group (HIGH). Subjects were also asked to provide details of their family history of hypertension which was defined as treated essential hypertension in parents or grandparents. Although subject recall of family history of hypertension has been found to be a reliable method to identify offspring hypertensives in America[16] reliability of the method has not been assessed with UK populations. Thus future research should be directed toward establishing the accuracy of reports of family health history in the UK.

Measures

Impedance cardiology was used (Minnesota Impedance Cardiograph, Model 304B: Instrumentation for Medicine, Greenwich, CN, USA) to estimate stroke volume (SV) using the formula proposed by Kubicek *et al*,[17] and an electrocardiogram (Amlab Physiograph) was used to measure heart rate (HR). Blood pressure (BP) was monitored continuously on a beat-to-beat basis by a Finapres (Model Ohmeda 2300: Ohmeda, Madison, WI, USA). FBF was measured using strain gauge plethysmography.[18] Urine samples were analysed for sodium and potassium content using flame photometry (Gallenkamp FGA-350-L, England). Sodium and potassium measures were corrected for urinary creatinine concentration, and expressed as mmol/mgCr. Urinary creatinine concentration was measured using a spectrophotometer (Model UV–150–02: Shimadzu, Japan) to detect the difference in colour intensity measured at or near 500 nm before and after acidification, which is proportional to creatinine concentration.[19]

Experimental protocol

All testing started at 9 am, after an overnight fast, and was performed in a quiet, air-conditioned laboratory held at a constant room temperature of 24°C.

Baseline: Subjects were instructed to provide a baseline urine sample immediately on awakening on the morning of testing. After 20-min of quiet rest subjects were required to void their bladder. Then an 8-min baseline period of data collection was initiated. During minutes 6–8 baseline FBF was measured.

Mental challenge: This consisted of the Stroop word/colour task.[20] Briefly, subjects were presented with one slide every second on a computer screen for a period of 10 min. Each slide had the name of a colour printed in a contrasting coloured ink for which subjects were requested to identify the colour of the ink, not the name of the colour. Subjects' perceived difficulty of the task, using the Borg 6–20 scale,[21] together with mistakes were recorded. Subjects were encouraged to make as few mistakes as possible. FBF was measured during minutes 0–2 and 8–10 of the mental challenge, but all other cardiovascular variables were measured continuously.

Recovery: Two minutes of recovery in the supine position followed the mental challenge during which all variables were continuously measured. After a further 15-min period of seated upright recovery subjects were instructed to provide another urine sample. Both urine samples were immediately frozen for subsequent analysis.

Maximal oxygen uptake ($\dot{V}O_{2max}$): Finally, subjects were required to undergo an incremental exercise

test to volitional exhaustion in order to measure cardio-respiratory fitness. $\dot{V}O_{2max}$ was assessed using the Douglas bag collection method and gases were analysed using a zirconia oxide O_2 analyser, and an infra-red CO_2 analyser. Subjects exercised in the upright position on a stationary electronic ergometer (Excalibur Sport. The Netherlands) at a cadence of 70 rpm until volitional exhaustion. The initial load was 30 W for the first 2 min and was increased by 1 W every 2 s thereafter. The end point was achieved when the subject was unable to continue, and/or heart rate at age-estimated maximum, plateau of oxygen consumption, and a respiratory exchange ratio greater than 1.10.

Data reduction

Impedance cardiograph signals were processed using ensemble averaging to eradicate artefact from the impedance cardiograph every 25 s, and cardiac cycle timing was verified from heart sounds recorded by a phonograph microphone. Each impedance wave was edited through the edit mode of the COP software (COP, Microtronics, Chapel Hill, NC, USA). Cardiac output (CO) was derived from the product of SV and HR and total peripheral resistance (TPR) was calculated from MAP/CO.80, expressed as dyne-seconds per cm^{-5}.

An arterial occlusion wrist cuff was continuously inflated to suprasystolic pressures (180 mm Hg) during FBF measurements, while a venous occlusion upper arm cuff was inflated to 50 mm Hg for 5 of every 15 s providing one blood flow measurement every 15 s. The gradient of the blood flow wave was representative of change in forearm volume, which was calibrated for equivalent changes in voltage from the strain gauge. The first second was disregarded to avoid errors from movement artefact. A minimum of six blood flow measurements was used to calculate average FBF for each 2-min block of measures. Forearm vascular resistance (FVR) was subsequently derived by dividing mean arterial pressure (MAP) by FBF.

Statistical analysis

Repeated measures analysis of variance (ANOVA) was employed to identify changes in cardiovascular variables over time and group differences. The within subject factor comprised of baseline, minutes 0–2, 4–6, and 8–10 of Stroop, and recovery (2 min). The between subject factor was the two groups (highly and moderately active). A similar analysis was used for FBF and FVR, except no data was collected for minutes 4–6 of Stroop for these variables.

A dependent *t*-test was employed to identify changes in urinary variables pre and post stressor within each group and an independent *t*-test was used to identify differences in change scores between groups.

Pearson correlations were performed to investigate the relationship between change in urinary variables and HR change during Stroop, change in urinary variables and FBF change, and HR change and FBF change during Stroop. Also, all subjects were classified into three groups according to the extent of their family history of hypertension. Subjects were put into the highest risk group if they had one parent and one grandparent of hypertensive status, the moderate risk group consisted of offspring with one hypertensive parent, and the low risk group consisted of offspring with a hypertensive grandparent. Correlations were then performed to examine the relationship between risk status with resting blood pressure and reactivity variables.

Results

Physical characteristics and baseline

Subjects' physical characteristics and 24-h dietary intake summary are displayed in Table 1. Three subjects were classified as high risk (a hypertensive parent and grandparent), 11 subjects as moderate risk (a hypertensive parent), and four subjects as low risk (a hypertensive grandparent). The HIGH group displayed significantly higher levels of physical activity and higher $\dot{V}O_{2max}$. Although the HIGH group had higher caloric intake, salt intake was comparatively similar for both groups. Baseline cardiovascular values are shown in Table 2. The HIGH displayed significantly lower resting HR and greater resting SV.

Response to mental challenge

During the Stroop mental challenge there was no significant differences in perceived task difficulty (mean ± SE: 14.6 ± 0.6 *vs* 14.3 ± 0.4) or mistakes (70 ± 12 *vs* 56 ± 14) for the MOD and HIGH groups respectively.

Central cardiovascular responses: For HR there was a significant main effect over time (*F* (4,

Table 1 Descriptive characteristics and 24-h dietary intake details of moderately active (MOD; $n = 9$) and highly active (HIGH; $n = 9$) subjects with family history of hypertension (mean ± s.e.)

Variable	*MOD*	*HIGH*
Age (yrs)	20.1 ± 0.5	25.3 ± 1.5*
Body mass (kg)	73.1 ± 2.5	75.1 ± 2.5
Height (cm)	179.6 ± 2.5	182.9 ± 3.0
Body fat (%)	14.4 ± 1.0	12.6 ± 1.0
Physical activity (kcal/kg/d)	35.0 ± 0.2	45.0 ± 1.8*
$\dot{V}O_{2max}$ (ml/kg/min)	48.3 ± 1.9	55.3 ± 2.4*
State anxiety	30.7 ± 2.4	30.8 ± 1.5
Calorie consumption (kcal)	1571 ± 121	2002 ± 186
Salt intake (g/100 kcal)	0.28 ± 0.03	0.40 ± 0.05
Total salt intake (g)	4.4 ± 0.5	7.7 ± 0.9*
Total sodium intake (mg)	1724 ± 205	3025 ± 354*

*Significant difference between groups ($P < 0.05$).

Table 2 Response to Stroop mental challenge in moderately active (MOD; $n = 9$) and highly active (HIGH; $n = 9$) males with family history of hypertension (mean ± s.e.)

Variable	*Condition*									
	Baseline		*Stroop (0–2 min)*		*Stroop (4–6 min)*		*Stroop (8–10 min)*		*Recovery*	
	MOD	*HIGH*	*MOD*	*HIGH*	*MOD*	*HIGH*	*MOD*	*HIGH*	*MOD*	*HIGH*
HR (b/min)	65.4 ± 3	49.8 ± 3†	78.4 ± 6	64.6 ± 4	69.3 ± 8	60.5 ± 4	70.4 ± 6	59.2 ± 4	58.6 ± 7	51.5 ± 3
CO (1/min)	6.1 ± 0.5	5.9 ± 0.05	6.1 ± 0.8	6.2 ± 0.5	5.9 ± 0.9	6.3 ± 0.6	6.2 ± 0.7	6.4 ± 0.6	5.5 ± 0.8	6.1 ± 0.6
SV (ml)	92.4 ± 6	119.8 ± 10†	73.2 ± 7	98.0 ± 7	78.6 ± 9	105.5 ± 8	82.5 ± 7	108.9 ± 8	87.5 ± 9	120.0 ± 10
SBP (mm Hg)	122 ± 3	128 ± 4	142 ± 5	142 ± 5	152 ± 6	153 ± 6	151 ± 5	149 ± 6	143 ± 5	141 ± 6
DBP (mm Hg)	62 ± 3	60 ± 3	77 ± 4	73 ± 3	82 ± 4	77 ± 3	80 ± 3	75 ± 3	73 ± 3	69 ± 4
MAP (mm Hg)	81 ± 3	82 ± 5	98 ± 4	95 ± 3	105 ± 4	102 ± 4	103 ± 4	99 ± 4	96 ± 4	92 ± 4
TPR (dyne-s/cm^5)	1132 ± 101	1197 ± 128	1242 ± 99	1296 ± 117	1326 ± 116	1376 ± 122	1273 ± 96	1338 ± 135	1294 ± 124	1325 ± 155
FBF (ml/100 ml/min)	4.5 ± 1	3.6 ± 0.4	9.0 ± 0.8	5.8 ± 0.9*	–	–	7.5 ± 1	5.6 ± 0.7	4.0 ± 0.9	3.8 ± 0.5
FVR (mm Hg/ ml/100 ml/min)	23.2 ± 4	26.5 ± 3	11.4 ± 0.9	19.9 ± 3*	–	–	16.3 ± 2	20.4 ± 3	31.4 ± 5	28.5 ± 5
U-Na (mmol/mgCr)	0.8 ± 0.1	1.4 ± 0.4	–	–	–	–	–	–	1.7 ± 0.3	2.2 ± 0.7
U-K (mmol/mgCr)	0.04 ± 0.004	0.09 ± 0.03	–	–	–	–	–	–	0.12 ± 0.02	0.18 ± 0.02

HR: heart rate; SV: stroke volume; CO: cardiac output; SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure; TPR: total peripheral resistance; FBF: forearm blood flow; FVR: forearm vascular resistance; U-Na: urinary sodium excretion; U-K: urinary potassium excretion.
*Significant difference in change between groups in comparison with baseline ($P < 0.05$).
†Significant difference in baseline between groups ($P < 0.05$).

64) = 10.79, $P < 0.05$), but no interaction or between subject effects. HR was significantly increased only during the first 2-min of Stroop in comparison with baseline. There was no significant main effect over time within subjects or between subject effects for CO (F (4, 64) = 0.82, $P > 0.05$). There was a significant main effect over time within subjects for SV (F (4, 64) = 13.77, $P < 0.05$), and between subject effects (F (1, 16) = 6.43, $P < 0.05$), but no group interaction over time. SV was significantly reduced during all stages of the Stroop with respect to baseline (see Table 2).

Blood pressure: There was a significant main within subjects effect over time for SBP (F (4, 64) = 41.97, $P < 0.05$), diastolic BP (DBP) (F (4, 64) = 71.01, $P < 0.05$], and MAP (F (4, 64) = 60.95, $P < 0.05$), but no interaction or between subject effects. Systolic BP (SBP), DBP, and MAP were elevated during all stages of Stroop and recovery in comparison to baseline (see Table 2).

Peripheral vascular responses: There was a significant main effect within subjects for TPR (F (4, 64) = 10.53, $P < 0.05$), but no interaction or between subject effects. TPR was significantly elevated during all stages of Stroop and recovery in comparison to baseline. There was a significant main effect (F (3, 48) = 50.75, $P < 0.05$), and interaction (F (3, 48) = 7.3, $P < 0.05$) over time within subjects for FBF. FBF was significantly increased during both the first and last 2 min of Stroop in comparison with baseline. Subsequent analysis revealed that during the first 2 min of Stroop the MOD group displayed a significantly greater increase in FBF compared with that of the HIGH (F (1, 16) = 7.9, $P < 0.05$) (see Figure 1). There was a significant main effect for FVR (F (3, 48) = 20.39, $P < 0.05$), and a trend for an interaction over time. FVR was significantly reduced during both the first and last 2 min of Stroop in comparison with baseline. Also, during the first 2 min of Stroop the MOD group displayed a significantly

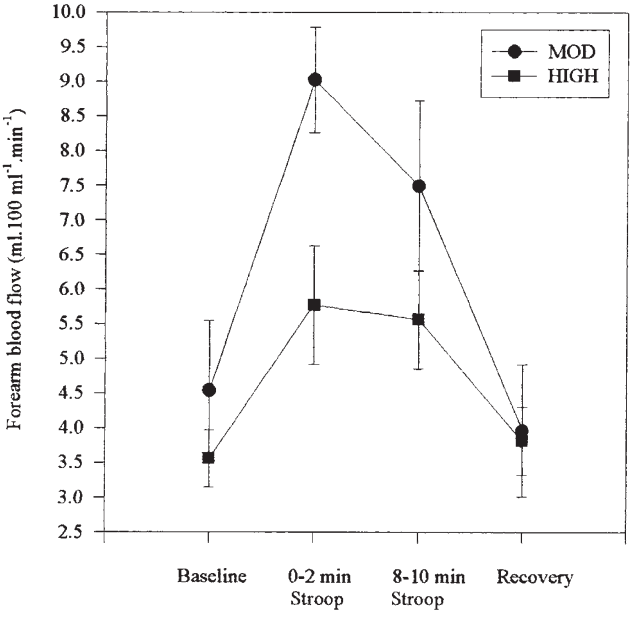

Figure 1 Forearm blood flow response to Stroop mental challenge in highly and moderately active offspring hypertensives.

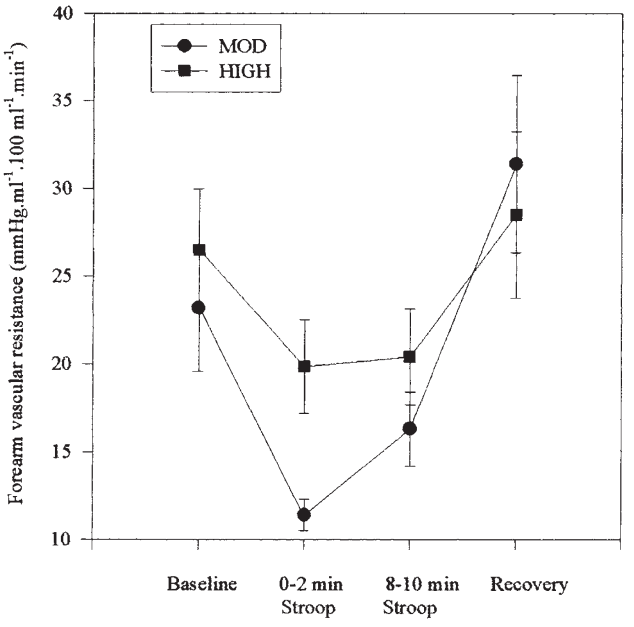

Figure 2 Forearm vascular resistance response to Stroop mental challenge in highly and moderately active offspring hypertensives.

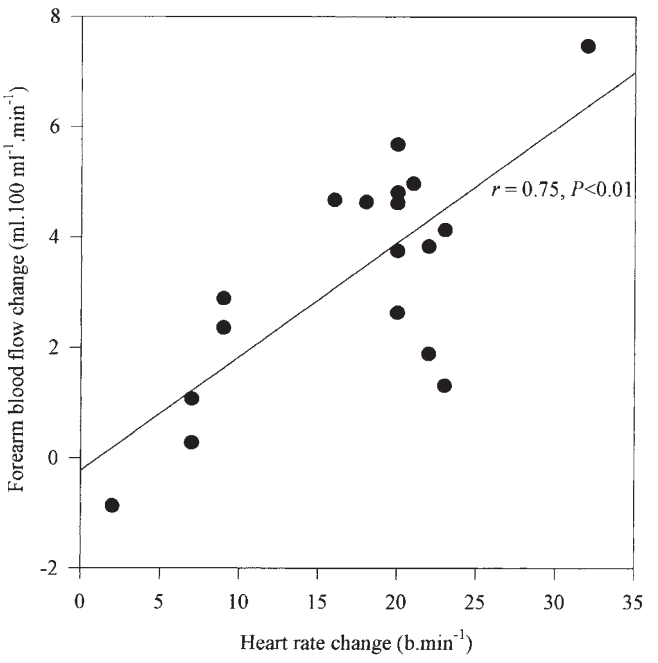

Figure 3 The relationship between change in heart rate and forearm blood flow during the first 2 min of Stroop mental challenge in male offspring hypertensives.

greater reduction in FVR compared with the HIGH (F (1, 16) = 9.09, $P < 0.05$) (see Figure 2 and Table 2).

Renal responses: There was a significant increase in urinary sodium (t (1, 17) = 3.65, $P < 0.05$) and potassium levels (t (1, 17) = 4.77, $P < 0.05$), post stress in comparison with baseline (see Table 2). The change in sodium and potassium levels from pre to post stressor were however not significantly different between groups.

Correlations

There was no relationship between urinary sodium change and HR change ($r = -0.33$, $P > 0.05$) or urinary potassium change and HR change ($r = -0.24$, $P > 0.05$). Nor was there a relationship between urinary sodium change and FBF change ($r = -0.09$, $P > 0.05$) or urinary potassium change and FBF change ($r = -0.11$, $P > 0.05$). There was however a significant correlation ($r = 0.75$, $P < 0.01$) between HR change and FBF change during the first 2 min of the Stroop mental challenge (see Figure 3).

There was a significant correlation between risk status and both SBP ($r = 0.88$, $P > 0.05$) and DBP change to the Stroop ($r = 0.75$, $P > 0.05$) only in the MOD group. That is, individuals with higher risk status demonstrated greater changes in BP during Stroop.

Discussion

The purpose of the study was to investigate the association between physical activity level and cardiovascular and renal responses to mental challenge in offspring hypertensives. If exaggerated FBF during mental challenge was due to a renal vasoconstrictor response then it was predicted that high forearm vascular responsiveness should be characterised by sodium retention. Because the moderately active offspring hypertensives displayed greater FBF reactivity to mental challenge it was expected that this group would also retain sodium. However, this was not the case, despite similar CO and BP responses to mental challenge between the high (MOD group) and low FBF reactors (HIGH group). These results suggest there may be regional blood flow differences in other vascular beds. It is possible that all of the major skeletal muscle vascular beds do not react in a similar way to mental challenge. However, Halliwell[22] has suggested there is a strong correlation between the skeletal muscle vascular reactivity of the forearm and calf. Research using spontaneously hypertensive rats (SHR) and normotensive controls (Wistar-Kyoto (WKY)) has shown that although both strains demonstrate similar BP changes to the defence response, regional blood flow changes are different.[23] Specifically, SHR demonstrated increases in mesenteric vascular resistance that appeared to be offset by more pronounced decreases in hindquarter vascular resistance (increased skeletal muscle vasodilatation).

Haemodynamic effects

During the mental challenge a number a haemodynamic changes occurred for both groups that were characteristic of the defence response. These changes included significant increases in HR, BP,

TPR, and skeletal muscle vasodilatation. BP and FBF were significantly elevated throughout the mental challenge whilst HR was only significantly elevated at the beginning. This suggests that peripheral compared with central haemodynamic response may play a more important role in the defence reaction brought about by continued exposure to mental challenge.

Vascular stress-reactivity mechanism

The finding that HR change and FBF change during mental challenge were significantly correlated supports the notion that one common mechanism underlies cardiac and vascular reactivity. It is plausible that this mechanism may involve sympathetic activation of β1- and β2-adrenergic receptors that produce increased HR and skeletal muscle vasodilatation. This notion is supported by the findings of Miller and Ditto[24] that strongly implicate the sympathetic nervous system in the exaggerated cardiovascular response to stress in offspring hypertensives. Their study employed the use of selective pharmacological blockade (a β1-adrenergic blocker and an α1-adrenergic blocker). HR and FBF response between offspring hypertensives and controls during a 1-h active coping psychological stressor under a placebo and two drug conditions was compared. Under the placebo condition the offspring hypertensives demonstrated exaggerated HR and FBF responses to the stressor. Under the β1-adrenergic blocking condition only differences in HR response were abolished. These results suggest that the initial forearm vasodilatation response to stress and the reductions in forearm vascular resistance are reinforced by β2-adrenergic or cholinergic activity. Furthermore, Halliwell *et al*[25] examined skeletal muscle vasodilatation to mental stress in order to determine the extent to which this response was due to sympathetic withdrawal, active neurogenic vasodilatation, or β-adrenergically mediated vasodilatation. Firstly, they found that muscle sympathetic nerve activity to the forearm was inhibited during mental stress (a 2.5-min Stroop task), suggesting that sympathetic vasoconstrictor withdrawal may contribute to the vasodilatation response. However, the vasodilatation during mental stress continued to occur after both selective blockade of α-adrenergic neurotransmission and local anaesthetic blockade of the stellate ganglion. Also, after administration of propanolol (a β-2 blocker) the vasodilatation response to stress was reduced but not completely abolished. Thus, the authors concluded that sympathetic withdrawal, through a reduction in discharge of noradrenaline from the autonomic nervous system, may mediate the initial vasodilatation. Then the response could be further augmented by both adrenaline, secreted from the adrenal gland, acting via β-adrenergic receptors and activation of local mechanisms that release nitric oxide. Such local mechanisms may include the release of acetylcholine from selected endothelial cells stimulated mechanically by increases in blood flow and rises in arterial BP. The locally released acetylcholine is then thought to act on muscarinic receptors and cause nitric oxide release producing vasodilatation.[26]

Exercise-induced reactivity lowering mechanism

Differences in sympathetic withdrawal, β-adrenergic receptor activation, and/or local vasodilatation mechanisms may explain the difference in FBF reactivity to mental challenge between the moderately and highly active offspring hypertensives. However, it is interesting to note that the forearm vasodilatation response was only significantly different between the groups during the initial first 2 min of the mental challenge. This therefore suggests that differences in the response are more likely to be due to sympathetic withdrawal and β-adrenergic mechanisms because local mechanisms are thought to sustain rather than initiate the response. Results from animal studies have shown that after an acute bout of exercise vascular responsiveness was reduced.[27] Using vasoactive agonists infused into the hindlimb of the conscious rabbit, blood flow responses in the isolated hindlimb were markedly reduced following a bout of treadmill exercise to exhaustion. The authors suggested that this may be due to an exercise-induced down regulation of α and/or β-adrenergic receptors. Furthermore, longitudinal studies[4,28,29] have consistently shown that endurance training reduces resting plasma catecholamine concentration. However, because plasma catecholamine levels represent a measure of average sympathetic neural activity, it is difficult to determine whether central, peripheral, or local mechanisms are primarily or secondarily responsible for the changes. Studies employing methods to measure post-ganglionic sympathetic nerve traffic have suggested that the reduction in sympathetic nervous activity from training originates from a central effect of training.[30]

Therefore, the mechanism responsible for a possible exercise-induced vascular stress reactivity lowering effect may be a downregulation of α-receptors reducing the sympathetic withdrawal response. Also a down regulation of β-adrenergic receptors and/or reductions in sympatho-adrenal activation, reducing adrenaline discharge, and thus reducing the β-adrenergic vasodilatation response could occur. Evidence from the SHR model[23] suggests that the enhanced β-2 adrenergic vasodilatation in the SHR during the defence response is due to an increased release of adrenaline as opposed to greater receptor sensitivity. Research studying plasma catecholamine concentration during mental stress in human offspring hypertensives also supports findings from the SHR study. Falkner *et al*[31] have shown that post-stress plasma catecholamines were higher in offspring hypertensives compared with controls.

Also, Horikoshi *et al*[32] found that offspring hypertensives who were high BP responders to mental stress also displayed significantly higher levels of adrenaline throughout mental stress.

Renal responses to stress

That sodium retention was not displayed in the offspring hypertensives in the present study is in contrast with the findings of Light *et al*[7] who found that out of a sample of 13 offspring hypertensives, those who displayed high HR reactivity to mental challenge ($n = 7$) had reductions in sodium and water excretion of 27% and 35% respectively. This was in comparison with the low HR reactors with family history of hypertension ($n = 6$) who demonstrated increases in sodium and fluid excretion of 4%, and individuals with no family history demonstrating 8% increases. Given the high correlation between HR reactivity and sodium retention ($r = 0.64$, $P < 0.05$) in the Light *et al*[7] study, a common mediation by the sympathetic nervous system for the cardiac and renal reactivity responses was suggested. This relationship has also been shown in the SHR where renal denervation reduces sodium retention and delays the pathogenic process.[33] There are a number of reasons to explain why subjects in the present study reacted in a similar manner to the low risk group in the Light study (ie, displayed sodium excretion responses to stress), despite the presence of significant cardiac reactivity in the present subjects. Firstly, although Light *et al*[7] employed a similar type of mental stress (cognitive processing task), their task lasted for a period of 1 h compared with 10 min in the present study. Miller and Ditto[24] demonstrated that during an extended 1-h active-coping stressor a pattern of increasing vascular resistance was observed that is thought to be due to increased α-adrenergic involvement. Thus, extended periods of stress may be required to produce renal vasoconstriction responses and sodium retention. Secondly, because all subjects in the present study were physically active, a moderate level of physical activity may be adequate to reduce a familial tendency to retain sodium. It should be noted that subjects in the moderately active group were in fact all physically fit with an average $\dot{V}O_{2max}$ of 47.88 ml/kg/min. Lastly, in another study that investigated the effect of prolonged isometric exercise on renal excretion of sodium and potassium, there were no differences in this response between offspring hypertensives and controls.[34] Therefore, because sodium retention following isometric exercise is seen in hypertensive patients, it is possible that the sodium retention response to stressors is a consequence of, rather than a predisposing factor to, hypertension.

Summary

Both the highly and moderately active offspring hypertensives displayed a sodium excretion response to stress. Although neither group demonstrated disturbed renal responses during mental challenge, which has previously been identified as a significant risk marker for hypertension development, the moderately active offspring hypertensives demonstrated an enhanced FBF reactivity response to mental challenge. Repeated episodes of a hyperreactive vascular response to stress has in itself been linked to the development of hypertension through a vascular re-modelling process.[9] Furthermore, that risk index was associated with the SBP response to stress in the moderately active but not highly active group provides further evidence that habitual physical activity is associated with reduction in genetic risk factors of hypertension.

In conclusion, habitual physical activity is associated with reduced vascular reactivity to a laboratory stressor in offspring hypertensives. That differences in renal response to mental challenge between highly and moderately active groups have not been observed suggests that either a moderate level of physical activity may alleviate familial abnormalities in renal functioning, or that physical activity level is not associated with renal responses to stress in offspring hypertensives.

References

1 Guyton AC *et al*. Role of the kidney in hypertension. *Circulation* 1974; **34**: 159.
2 Hagberg JM, Brown MD. Does exercise training play a role in the treatment of essential hypertension? *J Cardiovasc Risk* 1995; **2**: 296–302.
3 Kohno K *et al*. Renal depressor mechanisms of physical training in patients with essential hypertension. *Am J Hypertens* 1997; **10**: 859–868.
4 Meredith IT *et al*. Exercise training lowers resting renal but not cardiac sympathetic activity in humans. *Hypertension* 1991; **18**: 575–582.
5 Hollenburg NK, Williams GH, Adams DF. Essential hypertension: abnormal renal vascular and endocrine responses to a mild psychological stimulus. *Hypertension* 1981; **3**: 11–17.
6 Van Hooft IMS *et al*. Renal hemodynamics and the renin-angiotensin-aldosterone system in normotensive subjects with hypertensive and normotensive parents. *N Engl J Med* 1991; **324**: 1305–1311.
7 Light KC, Koepke JP, Obrist PA, Willis PW. Psychological stress induces sodium and fluid retention in men at risk for hypertension. *Science* 1983; **220**: 429–431.
8 Holmes DS, Cappo BM. Prophylactic effect of aerobic fitness on cardiovascular arousal among individuals with a family history of hypertension. *J Psychosom Res* 1987; **31**: 601–605.
9 Folkow B. Structural factor in primary and secondary hypertension. *Hypertension* 1990; **16**: 89–101.
10 Anderson EA, Mahoney LT, Lauer RM, Clarke WR. Enhanced FBF during mental stress in children of hypertensive parents. *Hypertension* 1987; **10**: 544–549.
11 DiBona GF. The functions of the renal nerves. *Rev Physiol Biochem Pharmacol* 1982; **94**: 76–181.
12 Miller SB, Friese M, Sita A. Parental history of hyper-

tension, sodium loading, and cardiovascular response to stress. *Psychosom Med* 1995; **57**: 381–389.
13 Rollnik JD, Mills PJ, Dimsdale JE. Characteristics of individuals who excrete versus retain sodium under stress. *J Psychsom Res* 1995; **39**: 499–505.
14 Speilberger CD. *Manual for the Stait-Trait Anxiety Inventory*. Consulting Psychologists Press: Palo Alto, CA, USA, 1983.
15 Sallis JF, Haskell W, Wood P. Physical activity assessment methodology in the five city project. *Am J Epidemiol* 1985; **121**: 91–106.
16 Stoney CM, Matthews KA. Parental history of hypertension and myocardial infarction predicts cardiovascular responses to behavioural stressors in middle aged men and women. *Psychophysiol* 1988; **25**: 269–277.
17 Kubicek WG, Patterson RP, Witsoe DA. Impedance cardiography as a noninvasive method of monitoring cardiac function and other parameters of the cardiovascular system. *Ann NY Acad Sci* 1970; **170**: 724–732.
18 Barcroft H, Swan HJC. *Sympathetic Control of Human Blood Vessels*. Arnold: London, 1953.
19 Heinegard D, Tiderstrom G. Determination of serum creatinine by a direct colorimetric method. *Clin Chim Acta* 1973; **43**: 305.
20 Stroop JP. Studies in interference in serial verbal reactions. *J Exp Psychol* 1935; **18**: 643–662.
21 Borg GAV. *Physical Performance and Perceived Exertion*. Gleerup: Sweden, 1962.
22 Halliwell JR. Mechanisms and clinical implications of post-exercise hypotension in humans. *Exerc Sports Sci Rev* 2001; **29**: 65–70.
23 Kirby RF, Woodworth CH, Woodworth GG, Johnson AK. Beta-2 adrenoceptor mediated vasodilation: role in cardiovascular responses to acute stressors in spontaneously hypertensive rats. *Clin Exp Hyper – Theory Pract* 1991; **A13(5)**: 1059–1068.
24 Miller SB, Ditto B. Exaggerated sympathetic nervous system response to extended psychological stress in offspring of hypertensives. *Psychophysiol* 1991; **28**: 103–113.
25 Halliwell JR *et al*. Forearm sympathetic withdrawal and vasodilation during mental stress in humans. *J Physiol* 1997; **504**: 211–220.
26 Dietz NM *et al*. Nitric oxide contributes to the rise in FBF during mental stress in humans. *J Physiol* 1994; **480**: 361–368.
27 Howard MG, DiCarlo SE. Reduced vascular responsiveness after a single bout of dynamic exercise in the conscious rabbit. *J Appl Physiol* 1992; **73**: 2662–2667.
28 Duncan JJ *et al*. The effects of aerobic exercise on plasma catecholamines and blood pressure in patients with mild hypertension. *JAMA* 1985; **204**: 2609–2613.
29 Jennings G *et al*. The effect of changes in physical activity on major cardiovascular risk factors, hemodynamics, sympathetic function and glucose utilization in man. *Circulation* 1986; **73**: 30–40.
30 Grassi G, Seravalle G, Calhoun DA, Mancia G. Physical training and baroreceptor control of sympathetic nerve activity in humans. *Hypertension* 1994; **23**: 294–301.
31 Falkner B *et al*. Cardiovascular response to mental stress in normal adolescents with hypertensive parents. Hemodynamics and mental stress in adolescents. *Hypertension* 1979; **1**: 23–30.
32 Horikoshi Y *et al*. The adreno-sympathetic system, the genetic predisposition to hypertension, and stress. *Am J Med Sci* 1985; **289**: 186–191.
33 Winternitz SR, Katholi RE, Oparil S. Role of the renal sympathetic nerves in the development of hypertension in the spontaneously hypertensive rat. *J Clin Invest* 1980; **66**: 971.
34 Parfrey PS, Wright P, Ledingham JM. Prolonged isometric exercise. Part 2: Effect on circulation and on renal excretion of sodium and potassium in young males genetically predisposed to hypertension. *Hypertension* 1981; **3**: 188–191.