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Are the blood pressure and endocrine responses of healthy subjects exposed to cold stress altered by an acutely increased sodium intake?

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Abstract In the study reported here, we examined blood pressure and endocrine responses in cold conditions during salt load in young healthy subjects who had previously shown increased resting blood pressure during acutely increased sodium intake. Subjects (n = 53) added 121 mmol sodium into their normal diet for 1 week. If their mean arterial pressure had increased by a minimum of 5 mmHg compared to the previous measure they were selected for subsequent experiments. The subjects (n = 8) were given 121 mmol supplemental sodium · day⁻¹ for 14 days. They were then put into a wind tunnel for 15 min (temperature −15 °C, wind speed 3.5 · m⁻¹). Their blood pressure increased (P < 0.05) during the cold exposure, independent of the sodium intake. Their mean (SEM) plasma noradrenaline increased from 3.58 (0.62) nmol · L⁻¹ to 5.61 (0.79) nmol · L⁻¹ (P < 0.05) when the subjects were given a normal diet, and from 2.45 (0.57) nmol · L⁻¹ to 5.06 (0.56) nmol · L⁻¹ (P < 0.05) when the subjects were given an elevated sodium diet. The starting concentrations and the endpoint concentrations were statistically similar. The plasma levels of the N-terminal fragment of pro-atrial natriuretic peptide decreased during the whole-body cold exposure: with the sodium load the change was from 256.6 (25.5) nmol · L⁻¹ to 208.0 (25.3) nmol · L⁻¹, and with the normal diet, from 205.8 (16.4) nmol · L⁻¹ to 175.1 (16.1) nmol · L⁻¹. The haematocrit and red blood cell count increased (P < 0.05) with normal and elevated sodium diet in cold conditions, but haemoglobin increased (P < 0.05) only with high salt in cold conditions. To conclude, acutely increased sodium intake does not change the blood pressure response or hormonal responses to exposure to acute cold stress in healthy subjects.

Key words Whole-body cold exposure · Sodium · Natriuretic peptides · Noradrenaline · Haemoconcentration

Introduction

A large number of studies have been published on the effects of dietary sodium intake on resting blood pressure in humans (for review, see Muntzel and Drüke 1992). Prolonged increased sodium intake has been postulated to be associated with increased blood pressure and an elevated risk of developing hypertension, although some subjects are sodium resistant (Weinberger 1996). Recently, a large population-based study showed no relationship between sodium intake and subsequent all-cause and cardiovascular-disease mortality in a general population (Alderman et al. 1998).

Low ambient temperature is a well-known environmental factor that increases blood pressure in man, but its effects have not been studied as extensively as those of dietary sodium intake. Studies in which the combined effects of sodium loading and cold exposure on blood pressure have been explored, are scarce. A previous report (Ditto et al. 1993) showed that in those using extra sodium (172 mmol sodium · day⁻¹, supplemental to a normal diet, for 2 weeks), the diastolic blood pressure in the cold pressor test was significantly higher than in the controls, while there was no difference in the systolic blood pressure increase. This finding was corroborated
by the study of Arjamaa et al. (1999), in which subjects of various age were exposed to cold (−15 °C, wind speed 3.5 m·s⁻¹, for 15 min) after having consumed about 290 mmol sodium·day⁻¹ in total for 2 weeks.

We tested a hypothesis that young healthy subjects, whose resting blood pressure increases during acutely elevated sodium intake, will also exhibit altered blood pressure and endocrine responses in cold conditions when sodium intake has been increased.

### Methods

#### Subjects

Fifty-three healthy, non-smoking students (17 males and 36 females) volunteered for the study. Resting blood pressure was measured according to Kaplan (1998). The subjects were seated in a quiet room at 22 °C for 15 min and then blood pressure was recorded once, automatically (ABPM Meditech, Meditech KFT, Hungary). Then the subjects added 121 mmol sodium·day⁻¹ (tablets of 1 g) to their normal diet for 1 week, after which their resting blood pressure was measured again. If mean arterial blood pressure had risen by at least 5 mmHg compared to the pressure recorded before sodium loading, the subject was selected for further experiments (Mates and Falkner 1999). These subjects (five males and three females) were nonobtensive, and ranged in age from 22 to 26 years, they had a mean (SEM) body mass of 63.1 (4.7) kg, height 174.3 (3.1) cm, and body mass index 21.3 (0.9) kg·m⁻². The experimental protocol was explained to them, and written consent was obtained from each subject before the study. The subjects were familiarised with the measurements and experimental conditions before the study started. The ethical committee of Oulu University Central Hospital approved the protocol.

#### Analyses

Dietary recordings were analysed by a Micro-Nutrica program (version 2.0, 1993). Blood samples were collected into both 10-ml serum vacuum tubes (first kept at room temperature for 30 min) and 3-ml ethylenediaminetetraacetic acid tubes, which were subsequently centrifuged (2000 g for 10 min) and stored at −80 °C until assayed, as were the urine samples. Haematocrit, haemoglobin and the red cell count were analysed immediately with the aid of an automatic cell counter (Coulter T-540-series, Coulter Electronics, UK). Changes in plasma volume were calculated according the formulae of Dill and Costill (1974). Sodium from blood and urine samples was measured by the direct ion selective method (Microlyte 3+2 Ion Selective Analyzer, Kone Instruments, Finland).

#### Radioimmunoassays

Atrial natriuretic peptide (ANP) was extracted from plasma using SepPak C₁₈ cartridges (Vuolteenaho et al. 1992). The N-terminal fragment of proANP (NT-proANP) was assayed directly from unextracted plasma. The radioimmunoassay protocols for ANP and NT-proANP have been described previously (Vuolteenaho et al. 1985, 1992). The sensitivities of the ANP and NT-proANP assays were 1.0 and 40 pmol·l⁻¹ plasma, respectively. The within- and between-assay coefficients of variation in each assay were <10% and <15%, respectively. Both assays were specific for the particulate peptide. The assays, however, cross-reacted fully with proANP. With these methods, the following plasma levels [mean (SD)] were detected in healthy adults aged 20-55 years: ANP 10.9 (4.0) pmol·l⁻¹ and NT-proANP 227 (84) pmol·l⁻¹.

Brain natriuretic peptide (BNP) was extracted from plasma with the same method as described for ANP (Vuolteenaho et al. 1992), and the assay was performed with the same protocol as described previously for ANP (Vuolteenaho et al. 1985, 1992). The sensitivity of the BNP assay was 1 pmol·l⁻¹ plasma. The within- and between-assay coefficient of variation in each assay were <10% and <15%, respectively. The BNP antisera cross-reacts less than 0.1% with ANP, NT-proANP and C-type natriuretic peptide.

Aldosterone (ICN Pharmaceuticals, Calif., USA) measurement was performed using a clinical radioimmunoassay kit in accordance with the instructions provided by the manufacturer.

#### Noradrenaline

A 500-μl sample of plasma was extracted into 30 mg Al₂O₃ in Tris-HCl buffer (pH 8.65). As an internal standard, 3,4 dihydroxybenzylamine hydrobromide (Sigma, St. Louis, Mo., USA) was used to correct absolute recovery variations in catecholamines. After washing four times with water, the noradrenaline was eluted into 100 μl 0.2 M HClO₄ solution. Noradrenaline levels in the eluates were measured by high-performance liquid chromatography with a multi-channel electrochemical detector (ESA,