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Thermoregulation in hypertensive men exercising in the heat with water ingestion

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Abstract

Hydration is recommended in order to decrease the overload on the cardiovascular system when healthy individuals exercise, mainly in the heat. To date, no criteria have been established for hydration for hypertensive (HY) individuals during exercise in a hot environment. Eight male HY volunteers without another medical problem and 8 normal (NO) subjects (46 ± 3 and 48 ± 1 years; 78.8 ± 2.5 and 79.5 ± 2.8 kg; 171 ± 2 and 167 ± 1 cm; body mass index = 26.8 ± 0.7 and 28.5 ± 0.6 kg/m^2; resting systolic (SBP) = 142.5 and 112.5 mmHg and diastolic blood pressure (DBP) = 97.5 and 78.1 mmHg, respectively) exercised for 60 min on a cycle ergometer (40% of VO_{2peak}) with (500 ml 2 h before and 115 ml every 15 min throughout exercise) or without water ingestion, in a hot humid environment (30ºC and 85% humidity). Rectal (T_{re}) and skin (T_{sk}) temperatures, heart rate (HR), SBP, DBP, double product (DP), urinary volume (V_u), urine specific gravity (G_u), plasma osmolality (P_{osm}), sweat rate (S_R), and hydration level were measured. Data were analyzed using ANOVA in a split plot design, followed by the Newman-Keuls test. There were no differences in V_u, P_{osm}, G_u and S_R responses between HY and NO during heat exercise with or without water ingestion but there was a gradual increase in HR (59 and 51%), SBP (18 and 28%), DP (80 and 95%), T_{re} (1.4 and 1.3%), and T_{sk} (6 and 3%) in HY and NO, respectively. HY had higher HR (10%), SBP (21%), DBP (20%), DP (34%), and T_{sk} (1%) than NO during both experimental situations. The exercise-related differences in SBP, DP and T_{sk} between HY and NO were increased by water ingestion ($P < 0.05$). The results showed that cardiac work and T_{sk} during exercise were higher in HY than in NO and the difference between the two groups increased even further with water ingestion. It was concluded that hydration protocol recommended for NO during exercise could induce an abnormal cardiac and thermoregulatory responses for HY individuals without drug therapy.

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- Thermoregulation

Introduction

During exercise, the increased metabolism and heat production require an increased cardiac output which is achieved through higher stroke volume and heart rate and through adjustments in systemic blood flow. The redistribution of blood flow to the skin and the elevated sweat rate, allowing increased evaporative cooling, represent the major autonomic physiological mechanisms of thermoregulation during physical activity in the heat. Heat stress during exercise represents an overload for the cardiovascular system because muscle and skin circulation must compete for blood flow. Moreover, the rise in cardiac output directed at the skin lowers both central venous pressure and stroke volume because of the shift in blood volume inside the cutaneous veins, leading to a compensatory tachycardia (1,2).

Systemic arterial hypertension is a very common disease and regular physical activity has been recommended in addition to drug treatment for this condition (3,4). Since hypertensive subjects show higher blood pressure levels during exercise for a specific muscular strain (5), arterial hypertension is expected to impose an extra overload on the cardiovascular system during acute exercise (6).

The relationship between arterial hypertension and abnormal cardiovascular adjustments in hot environments at rest is also controversial (7). Moreover, there are only a few studies with hypertensive individuals exercising in a hot environment (5,8) and the question remains if arterial hypertension would cause any impairment of cardiovascular and thermoregulatory responses to exercise in a hot environment. Indeed, fluid ingestion before and during exercise is recommended to maintain a normal hydration status in healthy people and to attenuate the rise in core temperature (9), as well as to decrease the risk of hyperthermia, to maintain the performance level and to delay fatigue (2,10-16). It is known that arterial hypertension is accompanied by disturbances in fluid balance, a fact raising the question whether fluid ingestion and replacement schedules should be applied to hypertensive and normotensive individuals (17).

The purpose of the present study was to assess the thermoregulatory and cardiovascular responses of hypertensive subjects during exercise in a hot and humid environment compared to normal subjects and to determine whether conventional fluid ingestion and replacement with pure water would influence these responses.

Subjects and Methods

The study was approved by the Ethics Committee of the Federal University of Minas Gerais. Prior to participation and after a verbal and written description of the procedures, the volunteers signed an informed voluntary consent form. All were free to withdraw from the study at any time. Forty-five men were invited to participate and all of them were submitted to a previous evaluation including medical examination, with exercise electrocardiogram and indirect measurement of individual peak oxygen consumption (VO_{2peak}) using a cycle ergometer protocol (initial load of 25 watts, with a 50-watt increase at 2-min intervals until exhaustion) in a thermoneutral environment (20-22ºC and 55-60% relative humidity). Sixteen men were accepted as volunteers and inclusion criteria were the absence of any disease or use of medication, except moderate arterial hypertension for the hypertensive group, and normal electrocardiogram. The subjects were classified as normotensive (N = 8) or hypertensive individuals (N = 8). The inclusion criteria for hypertensive were resting systolic blood pressure (SBP) higher than 140 mmHg and/or diastolic blood pressure (DBP) higher than 90 mmHg (4). SBP and DBP were obtained with a sphygmomanometer and brachial auscultation and were re-

corded at the first and last Korotkoff's sounds, respectively. The exclusion criterion was any abnormal response during stress testing.

The two groups were matched statistically ($P > 0.05$) for age (46 ± 3 and 48 ± 1 years), weight (78.8 ± 2.5 and 79.5 ± 2.8 kg), height (171 ± 2 and 167 ± 1 cm) and body mass index (26.8 ± 0.7 and 28.5 ± 0.6 kg/m^2) for hypertensive and normotensive, respectively. The hypertensive and normal volunteers had similar ($P > 0.05$) QRS voltage ($S_2 + V_5$ = 26.5 ± 0.3 and 23.5 ± 2.5 mV) and QRS axis (+59.3 ± 5.6 and +58.1 ± 7.1 grades) in the electrocardiogram. Also, they had similar acclimation status and habitual physical activity. The only previous differences between groups were the higher hypertensive resting arterial blood pressure (SBP = 142.5 and 112.5 mmHg; DBP = 97.5 and 78.1 mmHg for hypertensive and normotensive subjects, respectively) and SBP, DBP and heart rate during stress testing ($P < 0.05$; Figure 1).

During the experimental conditioning, the individuals exercised randomly on two occasions separated by a one-week interval: with and without pure water drinking (control). They exercised in a hot and humid environment (27.8ºC wet bulb temperature, 30ºC dry bulb temperature and 85% relative humidity), corresponding to 28.5ºC in the Wet Bulb-Globe Temperature (WBGT) index. They were dressed only in shorts and sport shoes and exercised in an environmental chamber (Russells®, Holland, MI, USA) for 60 min at 60-watt power output (~40% VO_{2peak}) on a Monark® (Varberg, Sweden) cycle ergometer.

Two hours before the water drinking situation, the individuals ingested 500 ml of pure water at an environmental temperature of 18ºC (11). During the water-exercise situation, the individuals ingested pure water corresponding to the expected sweat rate estimated from exercise caloric expenditure (~260 kcal/h) and environmental stress (28.5ºC WBGT), based on a regression equation previously obtained in our laboratory for healthy people (H_2O (ml/2 h) = 51.95 x WBGT (ºC) + 2.44 x kcal/h - 1177.9). The estimated total amount of water (460 ml) during exercise was divided into 4 equal doses ingested at 15-min intervals. Before and during the control-exercise situation the individuals did not receive any water.

During the experimental period, rectal temperature was measured with disposable rectal probes (Yellow Springs Incorporated, YSI 4400 series - 4491-E, Yellow Springs, OH, USA). Mean skin temperature was calculated using the Ramanathan equation (15) from 4 skin temperatures obtained with 4 probes (YSI® 400-A) placed on chest, arm, thigh and leg and connected to a YSI® thermometer. Measurements were made at 5-min intervals.

Continuous heart rate was recorded at 5-s intervals using a Polar® Vantage NVTM instrument (Polar Electro Oy, Kempele, Finland) and arterial blood pressure was measured at 0, 10, 20, 30, 40, 50 and 60 min during exercise.

Sweating rate (g m^{-2} h^{-1}) was calculated from the difference between pre- and post-exercise body weight corrected for urinary volume (V_u) and water ingestion during the period of exercise. The subjects were weighed naked immediately before the beginning of exercise and at the end of exercise. The subjects skin was wiped with a cotton towel. The accuracy of the scale was 100 g (Balanças Toledo® Ltda., São Paulo, SP, Brazil). Body surface area (BSA, m^2) was calculated using the equation: BSA = 0.00718 x weight$^{0.425}$ x height$^{0.725}$. Percent dehydration was calculated by dividing the body mass change, including the urinary volume and fluid intake, by the initial body mass for all experimental conditions.

Environmental thermal stress inside the environmental chamber was estimated by the measurement of wet (27.8ºC) and dry temperatures (30ºC) using the WBGT equation = 28.5ºC (18). The average metabolic

expenditure (kcal/h) was calculated from the power sustained for 60 min on the cycle ergometer, assuming an efficiency of 20%.

Two venous blood samples (7 ml) were collected (pre- and post-exercise) into a tube containing 0.1% heparin. Plasma osmolality (P_{osm}) was measured with a cryoscopic osmometer using the freezing point depression method. V_u was measured pre- and post-exercise using a 600-ml graduated cylinder. Urinary specific gravity (G_u) was measured using a refractometer (Uridens, Inlab, São Paulo, SP, Brazil) (17).

The experimental design consisted of the following four situations: normotensive individuals with or without water ingestion and hypertensive individuals with or without water ingestion. All values are reported as means ± SD. Data analysis was performed by the following analysis of variance: the treatments were defined by the 2 x 2 x 7 factorial (two water treatments, two groups of patients within plots and seven times of collections as subplots) in a split plot design, with eight repetitions. The *post hoc* differences were evaluated by the Newman-Keuls test. Statistical significance was accepted at $P < 0.05$.

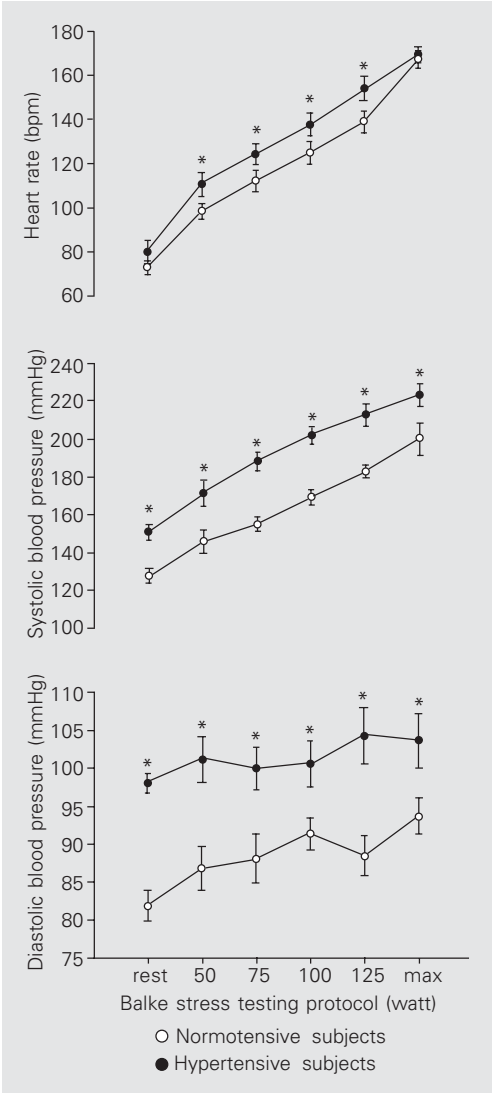

Figure 1. Heart rate and systolic and diastolic blood pressure of normotensive (NO) and hypertensive (HY) individuals, at rest and during cycle ergometer stress testing in a thermoneutral environment. Data are reported as the mean ± SD for N = 8 normotensive subjects (open circles) and N = 8 hypertensive subjects (filled circles). The conditions of the thermoneutral environment were temperature of 22ºC and 55% relative humidity. *P < 0.01 for HY > NO (ANOVA and *post hoc* Newman-Keuls test).

Results

Figure 1 shows that all volunteers had similar resting heart rate, whereas SBP and DBP were higher in the hypertensive group. During stress testing, heart rate and arterial pressure were higher in hypertensive subjects than in normal subjects, except for maximal heart rate. The electrocardiogram of hypertensive and normotensive subjects was within normal limits. The VO_{2peak} of hypertensive and normotensive (28.5 ± 1.5 and 29.9 ± 2.2 ml min^{-1} kg^{-1}) was similar and corresponded to the expected physical fitness for age (18).

Figures 2 and 3 show the cardiovascular responses during exercise in the hot environment. Heart rate increased throughout exercise for both hypertensive and normotensive and was higher for hypertensive subjects. Water ingestion did not affect the heart rate of either group.

The SBP of hypertensive was higher than that of normotensive during rest and the increase in SBP during exercise was similar for both groups but water ingestion increased the SBP of hypertensive subjects after 20, 30 and 40 min.

DBP was higher for hypertensive during rest and exercise reduced DBP for both groups. Water ingestion did not affect the pattern of DBP response to exercise for hypertensive or normotensive.

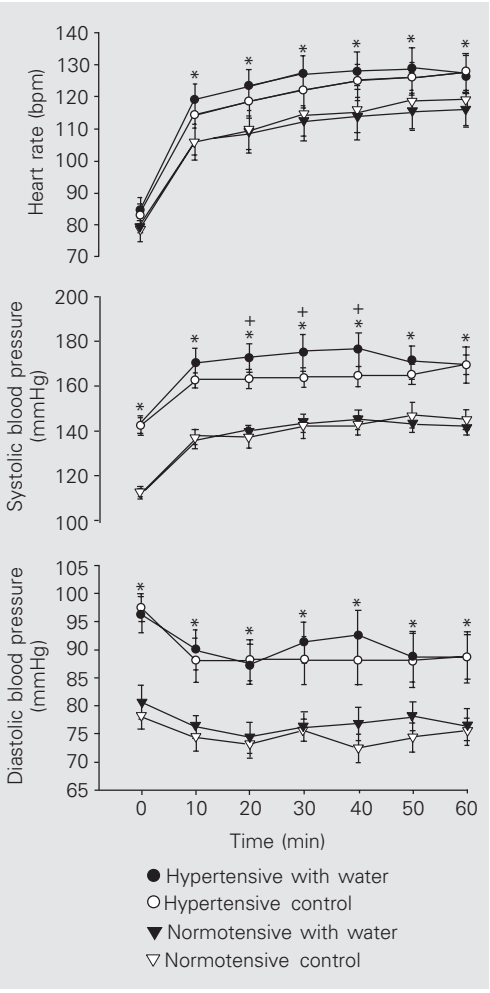

Figure 2. Cardiovascular responses of normotensive (NO) and hypertensive (HY) individuals during cycle exercise (60 min at 40 VO_{2peak}) with or without (control, C) water ingestion in a hot and humid environment (30ºC and 85% relative humidity). Portions of water (120 ml each) were ingested at 15, 30, 45 and 60 min. Data are reported as the mean ± SD. The number of subjects in each group was: 8. *P < 0.05 = HY > NO, $^{+}$P < 0.05 for HY-W > HY–C (ANOVA with 2 x 2 x 7 factorial: two water treatments, two groups of patients within plots and seven times of collections as subplots, in a split plot design, with eight repetitions with the *post hoc* Newman-Keuls test).

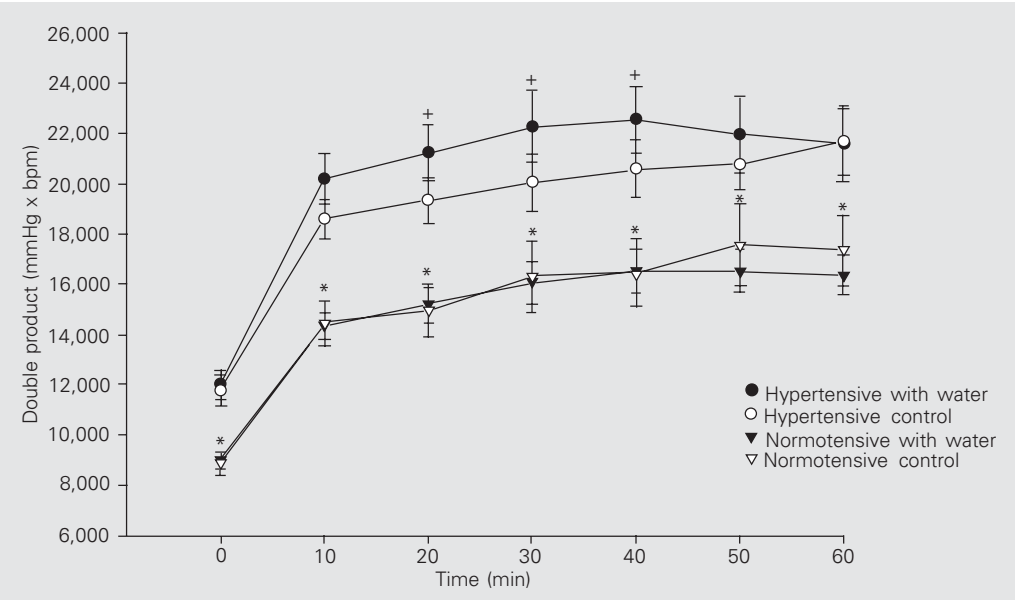

Figure 3. Double product (heart rate x systolic blood pressure, in mmHg x bpm) of normotensive (NO, N = 8) and hypertensive (HY, N = 8) individuals during cycle exercise with (W) or without (control, C) water ingestion in a hot and humid environment (30ºC and 85% relative humidity). Portions of water (120 ml each) were ingested at 15, 30, 45 and 60 min. *P < 0.05 = HY > NO, $^{+}$P < 0.05 = HY-W > HY–C (ANOVA with 2 x 2 x 7 factorial: two water treatments, two groups of patients within plots and seven times of collections as subplots, in a split plot design, with eight repetitions with the *post hoc* Newman-Keuls test).

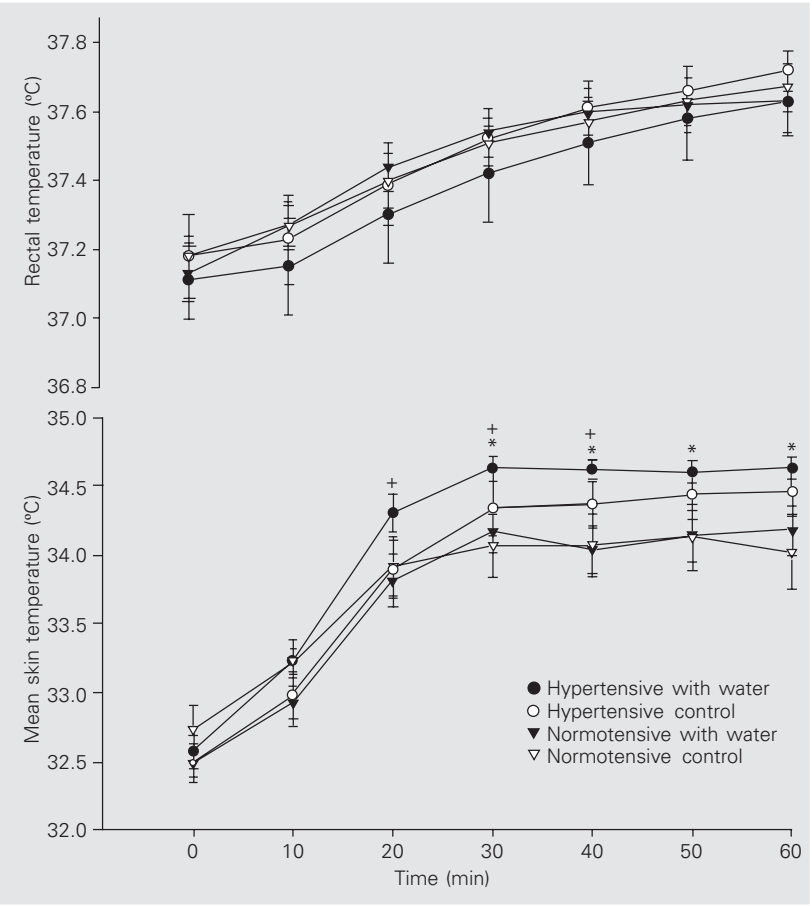

Figure 4. Thermoregulatory responses of normotensive (NO, N = 8) and hypertensive (HY, N = 8) individuals during cycle exercise, with (W) or without (control, C) water ingestion, in a hot and humid environment (30ºC and 85% relative humidity). Portions of water (120 ml each) were ingested at 15, 30, 45 and 60 min. Data are reported as means ± SD. *P < 0.05 = HY > NO; $^{+}$P < 0.05 = HY-W > HY–C (ANOVA with 2 x 2 x 7 factorial: two water treatments, two groups of patients within plots and seven times of collections as subplots, in a split plot design, with eight repetitions with the *post hoc* Newman-Keuls test).

Table 1. Plasma osmolality, urinary volume, urinary specific gravity, sweat rate, and hydration status during cycle exercise with or without water ingestion for normotensive (N = 8) and hypertensive individuals (N = 8), in a hot and humid environment.

	Normotensive individuals		Hypertensive individuals	
	Control	Water ingestion	Control	Water ingestion
Plasma osmolarity (mOsm/l)	-2.2 ± 4.5	-7.6 ± 6.4	-5.6 ± 4.6	-5.5 ± 2.2
Urinary volume (ml)	113 ± 56	192 ± 121	69 ± 34	112 ± 93
Urinary specific gravity	0.8 ± 4.2	3.3 ± 5.0	1.5 ± 4.8	2.0 ± 9.9
Sweat rate (g m^{-2} h^{-1})	264.9 ± 52.4	227.7 ± 60.4	232.8 ± 47.9	316.6 ± 42.1
Hydration status	-0.78%	-0.21%*	-0.66%	-0.31%*

Data are reported as the mean ± SD of the difference between values after 60-min exercise at 60% VO_{2peak} and initial values. The temperature and humidity of the hot humid environment were 30ºC and 85%, respectively.
*P < 0.05 compared to control (two-way ANOVA and *post hoc* Newman-Keuls test).

The double product (DP) of hypertensive was higher than that of normotensive during rest and exercise. Figure 3 shows that water ingestion did not affect the DP of normotensive, whereas in the hypertensive group DP was higher throughout 20, 30 and 40 min of the exercise period with than without water ingestion.

The results of heart rate, SBP and DP measurements indicate a greater cardiovascular response in the hypertensive than in the normotensive and an even higher transient cardiac work (SBP and DP) for the hypertensive subjects when they ingested water.

Figure 4 shows the thermoregulatory responses during exercise in the hot environment. Rectal temperature increased from rest to the end of exercise for both hypertensive and normotensive and was not affected by water ingestion in either group.

Skin temperature increased from rest to the end of exercise for both groups and skin temperature was higher in hypertensive and water ingestion increased the skin temperature of hypertensive during the 20-, 30- and 40-min periods.

Table 1 shows the variables related to the body fluid responses.

The experimental situations did not affect $P_{osm,}$ V_u or G_u in either the hypertensive or normotensive group. The dehydration level was similar for normotensive and hypertensive without water ingestion but was lower with than without water ingestion in both groups.

Discussion

As expected, during stress testing in a thermoneutral environment the hypertensive subjects showed a higher heart rate, SBP and DBP (5,8) (Figure 1). This may be due to a higher sympathetic activity in the hypertensive group needed to maintain the same muscular power during exercise. Essential hypertension has been accompanied by altered baroreceptor sensitivity (19,20) and a lower

reflex could explain the higher heart rate observed in the hypertensive subjects during stress testing.

During the exercise-heat stress, the demands on the cardiovascular system to maintain SBP, muscle blood flow, and body temperature are competing and the combined demands of muscle and skin for blood flow could exceed the subject's maximal cardiac output. The autonomic nervous system produces a greater vasoconstriction and diversion of blood flow volume from visceral organs and regions in an attempt to maintain the cardiac output and the required blood flow to the muscle and skin simultaneously (1). Thus, cardiac work is greater during exercise coupled with a heat stress. In the present study, during exercise in a hot and humid environment without water ingestion, both normal and hypertensive subjects increased their cardiovascular and thermoregulatory responses along time, but in different ways.

Without water ingestion, the hypertensive showed higher heart rate, SBP, DBP and DP than the normal subjects (Figures 2 and 3). This result does not seem to be related only to the hot environment because these responses had already been observed during stress testing in a thermoneutral environment. Thus, it was hypothesized that the same supposedly higher sympathetic activity in the hypertensive might have been responsible for the difference between hypertensive and normal subjects.

It was also observed that without water ingestion the hypertensive subjects had a higher skin temperature than normal subjects (Figure 4). This suggests an increased skin vasodilation (8) in the hypertensive group during exercise in a hot environment, in contrast to the data reported in previous studies. Kenney and co-workers (5,8) found that skin temperature was similar between hypertensive and normotensive individuals and that the increases in forearm blood flow were reduced in hypertensive individuals during periods of rising internal temperature induced by dynamic exercise. Carberry and co-workers (21) observed that hypertension reduces the maximal cutaneous vasodilation induced by local warming of the forearm skin. Nevertheless, the cited studies did not separate forearm muscle blood flow from cutaneous blood flow and Kellogg Jr. and co-workers (7) found that cutaneous vascular conductance was probably greater in hypertensive than in normotensive subjects during passive heat stress. In the present study, skin conductance was not measured but it is possible that the heat stress caused an increased skin vascular blood flow in the hypertensive group, which resulted in higher skin temperature.

The similar P_{osm}, V_u, G_u, sweat rate, and dehydration level results for hypertensive and normotensive indicate a physiological response of both groups and a partial replacement of fluid losses with water ingestion, as expected (22,23).

During exercise in a hot and humid environment with water ingestion, the hypertensive showed an even higher SBP and DP than normal subjects. Similar findings have not been previously reported in studies with hypertensive individuals. We hypothesize that the present observation could be the result of higher sympathetic activity secondary to the water ingestion reflex, as described by Jordan and colleagues (24). These investigators concluded that water drinking (480 ml) rapidly raises sympathetic activity (plasma norepinephrine) and blood pressure both in autonomic failure patients and in older normal subjects (57 ± 2.2 years) but not in younger control subjects.

The sympathetic reflex in response to water drinking could explain not only the higher DP and heart rate responses but also, indirectly, the higher skin temperature (Figure 4) observed in the hypertensive group. These thermoregulatory results suggest skin vasodilation related to water ingestion. It is known that during exercise the sweating rate

is increased through a sympathetic cholinergic pathway and that the nervous stimulation of sweat glands produces some vasoactive substances, which, in turn, cause skin vasodilation (7,25). In the present study, the sweating rate of hypertensive was similar to the sweating rate of normal subjects, which is not consistent with the supposed higher sympathetic cholinergic sweat gland stimulation-related vasodilation in hypertensive subjects.

On the other hand, it has been observed that during water ingestion there is an oropharyngeal reflex that decreases vasopressin secretion in humans (26). We might speculate whether both groups would exhibit such an oropharyngeal reflex.

In conclusion, these results suggest that hypertensive subjects respond in a different manner, i.e., with higher cardiac work and skin temperature, compared to normotensive subjects to a low-intensity exercise performed in a hot and humid environment and that water ingestion contributes to increasing the differences between the two groups of individuals. Further studies are needed to determine if water ingestion, as recommended to healthy people, could exert an overload effect on hypertensive individuals (with and without drug therapy) during exercise, also in a thermoneutral environment.

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