Medicina Sportiva
Med Sport 12 (3): 103-108, 2008
DOI: 10.2478/v10036-008-0020-z

THE INFLUENCE OF HYPERTHERMIA EXPOSURE IN SAUNA ON THERMAL ADAPTATION AND SELECT ENDOCRINE RESPONSES IN WOMEN

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Abstract

Introduction: The physiological responses to single and repeated hyperthermia exposure in men are well described in the literature, but less information is available on the effects of repeated thermal exposure in women.

Aim of the study: The purpose of this study was to investigate the influence of single and repeated sauna exposure on selected endocrine responses in women.

Methods: Ten healthy, eumenhorreic, female volunteers (19-21 yr old) were exposed to sauna bath seven times every second day. In all women the experiment started in the early follicular phase.

Results: Body mass decreased by 0.68 kg and by 0.67 kg after the first and the last sauna respectively. Rectal temperature increased by 1.1°C and 0.8°C after the first and the last heat exposure. Plasma volume decreased by 4.6% after the first sauna, and by 6.1% after the last one. Statistically significant decrease in plasma T_3 concentration was observed after the last sauna exposure, whereas more than a threefold increase in hGH was observed after the first and more than twofold increase was noted after the last sauna. There were significant increases in ACTH and cortisol after each sauna bath, however the rise in these hormones was less pronounced after the last sauna.

Conclusion: Less pronounced changes in core temperature as well as in the level of stress hormones may be the evident of adaptation to the thermal stress in women similar to that seen in men.

Key words: *women, heat exposure, sauna, core temperature, stress hormones, thyroid hormones, acclimatization*

Introduction

The Finnish sauna has become a very popular heat therapy treatment, being used as a therapeutic, preventative and hygienic aid in healthcare. Recently it has been described that repeated sauna therapy decrease weight in obese patients after 2 weeks of treatment (1). Sauna baths may relieve pain in musculoskeletal disorders and improve joint mobility in patients with rheumatic disease (2,3). Sauna treatment has not appeared to be of risk for patients with hypertension, coronary heart disease and congestive heart failure, when they are in stable medical condition because of medication (3). Moreover, there are studies that suggest that long-term sauna bathing may help lower blood pressure and can be an effective therapeutic modality for patients with cardiovascular disease, especially for patients with congestive heart failure, improving vascular endothelial function and the left ventricular ejection fraction (2,4,5).

The core temperature of human body increases quickly with sauna exposure. The most effective physiologic method of cooling the human body in a hot environment is with sweating and evaporation of the sweat from the surface of the skin once formed. The thermoregulatory system, however, is not an independently operating system. Responses to heat exposure depend on cardiovascular system proper reactions such as shift of blood volume from the central circulation to the skin and peripheral vasodilatation of skin vessels with simultaneous increase in heart rate and ejection fraction (6-8). Additionally, the endocrine system strongly affects and interacts with the thermoregulatory system and as such there are a multitude of hormonal changes under thermal stress. These hormonal responses are particularly robust in people not used to heat exposure such as sauna. For example, a common hormonal response to thermal stress is activation of the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system. This leads to increased circulating levels of adrenocorticotropic hormone (ACTH), cortisol, epinephrine and norepinephrine (9-12).

Another hormone, whose secretion is increased by thermal stress, is growth hormone (hGH). Previous papers report a large increase of circulating hGH was observed after sauna exposure (13-16). These studies, however primarily used men as subjects.

Hormones of the hypothalamic-pituitary-thyroid axis also play an important role in dealing with thermal stress. Thyroid stimulating hormone (TSH), a key hormone of the axis, selectively triggers the action of the thyroid gland. Both thyroid hormones – thyroxine (T_4) and triiodothyronine (T_3) intensify bodily catabolic processes and affect the metabolism of fats and carbohydrates as fuels (11). All of these thyroidal hormones are influenced by heat exposure to some degree (11).

The vast majority of the research on the thermal responses to sauna has originated from Scandinavian countries (i.e., principally Finland). This papers cannot, perhaps, be compared with literature from other countries on this subject. This is primarily because the research subjects were very likely accustomed to sauna exposure since the early childhood (i.e., cultural and societal influence). Additionally, much of this research has also been done with all male volunteers or in a few case mixed gender groups. It appears little or no attention was paid to the difference in the thermoregulatory responses between the genders in such studies. Only a comparative paper by Ježova et al. (9) appears to touch upon the issue of gender differences in hormonal reaction caused by sauna exposure. It also appears in the studies using women as subjects, the influence of menstrual status has not always been systematically controlled (17,18).

Therefore, the main goal of the study was to analyze select responses of the endocrine system in women (to whom the sauna was novel), subjected to a single as well as repeated thermal stress in the Finnish sauna.

Material and methods

Ten healthy, non-smoking female volunteers, aged 19-21 yr participated in the study. No subject had any existing endocrinological problems on entering the study and all were eumenorrheic. Furthermore, none of the subjects had ever used the sauna prior to the experiment. Methods and procedures were approved by the Ethics Committee, in the University School of Medicine in Krakow. Volunteers were fully informed regarding methods of experiment and gave their full consent in participating. These were performed before the subjects began the study.

All volunteers were similar in anthropometrical parameters – measurements (Table 1).

Table 1. *Selected characteristics of the subjects*

	min	max	mean	SD
Age [yr]	19	20	19.8	0.4
Height [cm]	154	175	165.8	6.5
Body mass [kg]	50.88	69.10	60.03	6.67
BMI [$kg \cdot m^{-2}$]	19.39	26.01	21.82	1.93
Body surface [m^2]	1.50	1.80	1.67	0.12

The experimental procedures of the study were begun with the women in their follicular phase (i.e., on the 4^{th} – 5^{th} day) of the ovarian cycle, and none of them were using birth control pills.

The women underwent a series of seven exposures (baths) in Finnish sauna. Baths were taken every second day, always in the morning at 08:00-10:00. Each sauna exposure lasted 45 minutes (two 20 min periods divided by one five minutes break for cooling under a shower with water [~20–22°C]). During the sauna bath the subjects rested in a half-recumbent position. The average temperature in sauna was 80.1°C (measured at chest level), and the air relative humidity ranged from 5 to 26.6%.

All physiological data and blood for biochemical assessments was collected during the first day and fourteenth day of study before sauna after lying in recumbent position for 20 min and immediately after the sauna exposure (i.e., before and after the first and the final sauna bath). On the first and the fourteenth day the subjects were fasting ten hours before the experiment and all blood collections occurred in the morning (i.e., subjects had not eaten or drank after 10 pm of the previous day). Blood serum was separated and stored at -20°C for later measurements of hormones concentration.

The following physiological indexes were measured in the experiment: rectal temperature (Tre) [°C], tympanic temperature (Tty) [°C], body mass (BW) [kg], heart rate (HR) [beats/min]

Rectal and tympanic temperatures were monitored using an Ellab (Dania Inc.) electrometer with accuracy of ± 0.1 °C. Body mass was measured before entering the sauna and after the thermal exposition, using a Sartorius electronic scale with accuracy of ± 1g. Blood samples (10 cm^3) were taken for biochemical testing, from the antecubital vein after subjects' rest in supine position for 10 minute before entering sauna room, and in the same position three minutes after sauna bath. From the whole blood the following were measured: hematocrit (Hct) by the microhematocrit method [%], hemoglobin (Hb) concentration by the cyanmethemoglobin method [g/dL], Changes of these indexes were subsequently used for calculations of variations of the plasma volume according to the Dill-Costill formula as modified by Harrison [19], where $[Hb]_1$ ($g \cdot dl^{-1}$) and Ht_1 (%) are mean initial values, $[Hb]_2$

and Ht_2 are post-exercise values. The Ht was multiplied by 0.96 and 0.91 to correct for trapped plasma and peripheral sampling respectively.

$$\Delta PV = 100 \{(Hb_1/Hb_2) \times [100 - (Hct_2 \times 0.874)] / [100 - (Hct_1 \times 0.874)] - 1\}$$

where: Hb_1, Hct_1 – pre-exposure; Hb_2, Hct_2 – post-exposure

The after sauna exposure hormone concentrations were corrected for the changes of plasma volume (ΔPV).

Levels of the following hormones were determined in the blood using commercial assay kits, specifically: Thyroid Stimulating Hormone (TSH) using immunoradiometric procedures via a Spectria TSH IRMA [^{125}I] kit (Orion Diagnostica, Finland); Triiodothyronine (T_3) using radioimmunological procedures via a OPiDI RIA-T3 kit (Department of Radiology OPiDI, Świerk, Poland); Thyroxine (T_4) using radioimmunological procedures via a OPiDI RIA-T4 kit (Department of Radiology OPiDI, Świerk, Poland); Growth Hormone (hGH) using radioimmunological procedures via a OPiDI RIA-hGH kit (Department of Radiology OPiDI, Świerk, Poland); Adrenocorticotropic Hormone (ACTH) using radioimmunological procedures via a ACTH-K-PR kit (CIS Bio-International, France); Cortisol using radioimmunological procedures via a [^{125}I] Radioimmunoassy Kit (Orion Diagnostica, Finland).

All measurements are presented as arithmetic means ± SD. Statistical analysis for differences of the data was determined by non-parametric analysis (Wilcoxon's test) as recommended for this type data [20]. Mean differences were considered statistically significant at the $p<0.05$ level and involved Bonferroni adjustments for alpha inflation.

Results

Table 2 presents physiological responses of the subjects before and after exposure to the sauna. The body mass after the first sauna decreased on average by 0.68 kg (1.13 % of the initial body mass) and after the final sauna by 0.67 kg (1.12 % of the initial body mass. Both of these mass decreases were significant (before vs. after comparison), but the level of reduction at the first and final sauna exposure did not differ significantly.

The subjects had normal rectal and tympanic temperatures before exposing themselves to the first and seventh sauna. In response to the sauna, rectal and tympanic temperatures increased significantly before and after each exposure ($p<0.01$), but the increase after the last sauna was significantly smaller than after the first sauna ($p<0.005$).

Heart rate (HR) increased by 51 beats/min after the first sauna exposure ($p<0.005$) and by 35 beats/min after the 7th sauna ($p<0.005$). The increase of HR was significantly smaller after the last sauna than after the first one ($p<0.005$).

Also, after each sauna exposure there was a hemoconcentration of the blood as determined by observing the significant increases of hematocrit and hemoglobin concentration ($p<0.01$). The calculated changes in the plasma volume (ΔPV) suggested a greater degree of dehydration tended to occur after the last exposure to heat than after the first one; although this difference did not reach statistical significance.

The changes in the different levels of the thyroid hormones in response to the thermal stress of the

Table 2. *Changes of the selected physiological reactions under the influence of the 1st and the 7th sauna bath exposure*

Physiological and Hematological Indicators		1st sauna bath			7th sauna bath		
		before	after	Δ	before	after	Δ
Body mass [kg]	mean ±SD	60.03 6.67	59.35 6.62	-0.68***	59.88 6.32	59.21 6.26	-0.67***
Rectal temperature [°C]	mean ±SD	37.1 0.3	38.1 0.5	1.1***	37 0.4	37.8 0.3	0.8**†
Tympanic temperature [°C]	mean ±SD	36.7 0.4	38.7 0.7	2.0***	37 0.4	38.2 0.5	1.2**†*
Hear Rate [beats·min^{-1}]	mean ± SD	67 ± 10.5	118 ± 18	51***	61 ± 10.5	96 ± 10	35***†
Htc [%]	mean ±SD	41.25 1.34	42.5 1.7	1.25***	40.80 1.18	41.80 1.65	1.0*
Hb [g·dl^{-1}]	mean ±SD	14.35 0.86	14.79 0.84	0.44*	14.24 0.84	14.99 0.88	0.75*
Delta PV [%]	mean ±SD			-4.6*** 2.6			-6.14* 5.3

*p<0.05; **p<0.01; ***p<0.005 after vs. before sauna bath; †p<0.005 1st vs. 7th sauna session

Table 3. *Changes of the selected biochemical indices under the influence of the 1st and the 7th sauna bath exposure*

Hormones		1st sauna bath			7th sauna bath		
		before	after	Δ	before	after	Δ
TSH	mean	1.379	1.13	-0.25	1.122	0.96	-0.164
[uIU·ml^{-1}]	±SD	0.86	0.85	n.s.	0.6	0.44	n.s.
T_3	mean	1.48	1.34	-0.14	1.43	1.33	-0.10*
[ng·ml^{-1}]	±SD	0.20	0.14	n.s.	0.19	0.17	
T_4	mean	8.00	8.10	0.10	7.72	7.20	-0.52
[ug·dl^{-1}]	±SD	1.3	1.21	n.s.	1.59	1.19	n.s.
HGH	mean	4.71	20.99	16.28**	7.09	19.61	12.52**
[ng·ml^{-1}]	±SD	4.3	13.8		4.37	12.12	
ACTH	mean	17.69	31.95	14.26*	20.77	29.4	8.63**
[pg·ml^{-1}]	±SD	9.42	11.93		4.96	7.32	
Cortisol	mean	117.16	212.73	94.84**	135.23	202.62	67.39**
[ng·ml^{-1}]	±SD	33.37	71.26		48.88	80.33	

n.s.=non-significant; *p<0.05; **p<0.01; ***p<0.005 after vs. before sauna bath

sauna are presented in the Table 3. The concentration of TSH and T_4 did not change significantly after the first and the last sauna exposure. On the other hand, a small but significant decrease (p<0.05) in the concentration of T_3 was observed after the 7-th sauna exposure. None of the changes noted in the thyroid hormones were statistically different between the first and last sauna exposure.

A substantial increase in the concentration of the hGH was observed after both the first and last sauna exposures (p<0.01). The hGH increase appeared to be greater after the first exposure, although this difference did not reach statistical significant. Large significant increases in both ACTH and cortisol were also observed after both sauna exposures (p<0.05). ACTH increased by 80% after the first sauna, and approximately 40% after the last (7th) sauna exposure (these differing increases between the 1st and 7th sauna were nearly significantly different [p<0.07]). The concentration of cortisol increased after the first exposure 82%, while the increase after the last sauna exposure was substantially smaller, ~50% (again these increases were nearly significantly different from one another [p=0.09]).

Discussion

The principle purpose of this study was to analyze the select endocrine system responses of women, subjected to the thermal stress of the Finnish sauna in which the exposure was novel. It is apparent from physiological changes we observed that our subjects did exhibit thermal stress responses across the 13 days of the experiment.

Physiologically, the only affective way the human organism can dissipate its heat in the hot environment of sauna is through the loss of heat via sweat evaporating from the skin surface. During a routine sauna bath, it has been calculated that humans lose an average of 400-600 g of water through this mechanism (21,22). Similar loses of water were observed in our study; based upon the body mass changes observed.

If the exposure to high temperature is prolonged enough, it leads to accumulation of heat by the organism core temperature increases, even if the thermoregulatory is working effectively. During a twenty minutes sauna bath, temperature of the body may increase by 0.5 to 2.0°C (9,21,22); both the rectal and tympanic temperatures of our subjects followed this trend and achieved corresponding results. However, a less pronounced increase in both temperatures as well as in heart rate was observed during the last sauna session. This suggests that our subjects were perhaps adapting during the two-week exposure to repeated heat in the sauna.

It is important to note that as the subjects completed the 7th sauna they were approaching their luteal menstrual cycle phase when the body temperature should increase by 0.3-0.4°C (17,18). No difference in initiated before temperatures existed in the women, suggesting the subjects had not experienced the menstrual temperature elevation and thus not confounded our results (10,23,24). This is important as shifting to a different menstrual cycle phase may also effect of secretion hormones especially if under thermal stress exposure (23).

Generally speaking, thermal stress stimulates the endocrine system, which increases hormonal secretion and circulatory levels. In general, this was observed within our data. Specifically, ACTH increased by 80% after the first sauna bath, and by 40% after the last one. However, several Scandinavian authors observed a smaller increase of ACTH after heat exposure in sauna (10,23,24). On the other hand, non-Scandinavian authors observed that ACTH increased as much as 90-350% after sauna bath exposure, more in agreement with our data (9,13,25). The differences between our findings and the Scandinavian data may be connected with the fact that the Scandinavian participants were adapted to sauna thermal stress exposure. A very point also conveyed by others (9,13).

In accordance with a smaller ACTH response, a smaller increase of cortisol secretion was observed after the last sauna session, which suggests that our subjects were adapting and becoming familiarizes to the hot environment (i.e., more heat tolerant). This remark is based upon the work of Follenius et al. (26) whom report increased cortisol response should be considered a sensitive indicator of stress reaction and intolerance of heat.

In stress conditions, the same factors stimulating secretion of ACTH are associated with release of hGH (11,12). A statistically significant increase of hGH was observed after the first and the last sauna session. Similar changes were observed and reported by others, however, a greater increase in hGH was reported by some investigators studying men, than was seen in the women of our present experiment (14-16,25,27). Several factors cause increased secretion of hGH in a hot environment, such as: stimulation of adrenenergic system, dehydration, and increased secretion of vasopressin (13,14,28). Additionally, a correlation between the stimulation of hGH secretion and increase of the internal temperature was observed by Christensen et al. (29). However, the experiments by Doré and co-authors (30) did not confirm these latter findings. Why our hGH is not in agreement with of previous reported for men is unclear.

The regulation of the thyroid activity to a thermal stress is complicated and is not fully understood in humans. Researchers suggests the activity of the pituitary (via TSH) and thyroid gland have significance in the modifying the activity of the temperature regulatory center in the hypothalamus (31). The present data does not support this contention. All of the thyroidal hormone responses showed no significant changes, other than a small reduction in T_3 after the last sauna exposure. Perhaps this decrease of T_3 after the 7^{th} and final sauna exposure represents the beginning of an adaptation of thyroidal regulatory axis to the thermal stress exposure. This point is supported by the fact that T_4 responses after the 7^{th} sauna were also lower, but this hormonal change did not reach statistical significance. It would have been interesting to continue our experiment for several more days to see thyroid changes. Nevertheless, as it stands collectively our thyroid data are not extremely compelling and fail to elucidate clearly whether the axis is adapting to the thermal stress exposure over the 14 days of the experiment.

Conclusion

In conclusion, the present findings indicate that thermal stress in women due to a single sauna exposure stimulates the hypothalamic-pituitary-andrenal (H-P-A) axis and a pituitary hGH response. After 2 weeks of repeated sauna exposure, the H-P-A axis and hGH response still exist, but is diminished. Interestingly, thyroid hormones responses (T_3) tended to be reduced with repeated sauna exposure but only to a small degree. These responses suggests the human female organism (in the follicular phase) adapts to the thermal stress of sauna exposure over a 13 day period. The hormonal responses and adaptation that occurs is similar in many ways to that of men; although, the magnitude of the some hormonal responses may not be identical in the genders.

Acknowsledgements

Dr. A.C. Hackney was a Fulbright Scholar associated with the Department of Human Nutrition, Institute of Public Health, Faculty of Medicine at Jagiellonian University in Krakow.

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Received: August 08, 2008
Accepted: September 09, 2008
Published: September 11, 2008

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E – Manuscript Preparation
F – Literature Search
G – Funds Collection