Acute effects of sauna bathing on cardiovascular function

Short title: sauna and cardiovascular health

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Abstract

Emerging evidence suggests beneficial effects of sauna bathing on the cardiovascular system. However, the effects of sauna bathing on parameters of cardiovascular function and blood-based biomarkers are uncertain. We aimed to investigate whether sauna bathing induces changes in arterial stiffness, blood pressure (BP) and several blood-based biomarkers. We conducted an experimental study including 102 participants (mean age (SD): 51.9 (9.2) years, 56 % male) who had at least one cardiovascular risk factor. Participants were exposed to a single sauna session (duration: 30 minutes; temperature: 73°C; humidity: 10-20%) and data on cardiovascular as well as blood-based parameters were collected before, immediately after and after 30-minutes recovery. Mean carotid-femoral pulse wave velocity was 9.8 (2.4) m/s before sauna and decreased to 8.6 (1.6) m/s immediately after sauna ($p<0.0001$). Mean systolic BP decreased after sauna exposure from 137 (16) to 130 (14) mmHg ($p<0.0001$) and diastolic BP from 82 (10) to 75 (9) mmHg ($p<0.0001$). Systolic BP after 30 minutes' recovery remained lower compared to pre-sauna levels. There were significant changes in hematological variables during sauna bathing. Plasma creatinine levels increased slightly from sauna until recovery period, whereas sodium and potassium levels remained constant. This study demonstrates that sauna bathing for 30 minutes has beneficial effects on arterial stiffness, BP, and some blood-based biomarkers. These findings may provide new insights underlying the emerging associations between sauna bathing and reduced risk of cardiovascular outcomes.

Keywords: sauna bathing, experimental study, arterial stiffness, cardiovascular adaptation

What is known about topic:

- Frequent sauna bathing is associated with a reduced risk of fatal cardiovascular and all-cause mortality events
- Increased sweating during sauna bathing is accompanied by increase in circulation and body temperature
- Passive heat therapy may improve vascular function

What this study adds:

- This is the largest experimental study showing acute effects of sauna exposure on body physiology, hemodynamics and cardiovascular function.
- Sauna bathing improved arterial compliance and lowered systemic blood pressure
- Sauna bathing is a safe and recommendable health activity in a population with cardiovascular risk factors

Introduction

Sauna bathing, a form of passive heat therapy, is commonly used for relaxation and pleasure purposes[1,2]. Repeated sauna therapy has been shown to increase left ventricular ejection fraction and reduce plasma levels of norepinephrine and brain natriuretic peptide and increase the 6-minute walk distance[3]. After one week of repeated sauna exposure (twice a day) in 10 healthy male volunteers, diastolic blood pressure (BP) was shown to decrease substantially[4]. Warm water immersion, which is also a form of passive heat therapy, is also associated with health benefits which include improved endothelial and microvascular function as well as reduced arterial stiffness (AS) and blood pressure[5,6]. Passive heat therapy (hot tub) improves cutaneous microvascular function by enhancing nitric oxide-dependent dilation in sedentary humans[5]. It has also been demonstrated that sauna exposure results in elevations in core temperature and changes in cardiovascular haemodynamics, such as cardiac output and vascular shear stress, which are similar to the effects of exercise, and thus may provide an alternative means of improving health[6]. In a two week trial of once-a-day infrared-sauna exposure for patients with cardiovascular risk factors, flow-mediated endothelium-dependent dilation was significantly improved[7].

However, there is still lack of evidence showing the positive effects of typical Finnish sauna bathing on cardiovascular function, which might potentially reduce cardiovascular disease (CVD) risk. Sauna exposure may improve vascular compliance, which has previously been demonstrated in subjects with cardiovascular risk factors, indicating a protective role of heat therapy on arterial stiffening[7]. However, although sauna bathing is well tolerated, there is evidence that sauna use might induce myocardial ischemia in patients with coronary artery disease.[8] Consistent with the positive effects of passive heat therapy, there is some evidence showing that blood pressure may be decreased as a result of increased ambient temperature[9-11]. Using a long-term general population-based prospective study, our group has recently shown that frequent Finnish sauna exposure has multiple beneficial effects, which include reduced risk of hypertension, dementia, fatal cardiovascular outcomes, and all-cause mortality[12-14].

Sauna bathing leads to certain changes in the cardiovascular system such as vasodilation of circulatory system, blood re-distribution and increase in sweating in an attempt to maintain body homeostasis due to heat stress. The acute physiological responses to the hot temperatures during sauna-bathing induce fluid loss with an increase in heart rate[15,16]. Some previous studies have shown an association between passive heat therapy and augmented cardiovascular function, with positive adaptations in arterial compliance and peripheral microvascular function[5,17-20].

The aim of this study was to investigate acute hemodynamic and physiological vascular responses and their respective recovery profiles 30 minutes after sauna bathing. This study setting will further clarify if sauna bathing leads to beneficial effects on cardiovascular function, including changes in blood pressure and AS as well as blood biomarkers among participants with cardiovascular risk factors. The main focus of this study is to evaluate the most immediate physiological and cardiovascular effects of a single Finnish sauna exposure in a large sample of both men and women in an experimental setting to confirm its protective effects on cardiovascular health and safety.

Methods

Participants

Participants (n=102) were recruited from the city of Jyväskylä, Central Finland region, through the local out-of-hospital health care center. The final study group consisted of asymptomatic participants (no cardiovascular symptoms) with at least one conventional risk factor, such as a history of smoking, hypertension, dyslipidaemia, obesity or family history of CHD/CVD. Hypertension was defined as SBP > 140mmHg, diastolic blood pressure (DBP) > 90mmHg, or use of antihypertensive therapy. Dyslipidaemia was defined as the use of cholesterol drugs or serum LDL cholesterol over 3.5 mmol/L and obesity as body mass index (BMI) over 30kg/m^2.

Participants with diagnosed CVD were not included in the study. Prior to the participation of the study, all participants were informed about the research purposes and measurement procedures, and were screened by a cardiac specialist. The research protocol and study design were reviewed and approved by the institutional review board of the Central Finland Hospital District ethical committee, Jyväskylä, Finland (Dnro 5U/2016). All study participants provided written informed consent.

Clinical examination

A clinical evaluation with baseline data collection was conducted on a separate screening day prior to the experiment. During the screening visit, medical history, physical examination, and resting electrocardiogram (ECG) were assessed. All baseline and sauna exposure measurements were performed from May to June 2016. Resting blood pressure was measured on the screening day as well as on the day of sauna exposure, using the same standard operating protocol; it was recorded as the mean of two measurements obtained while the participant was in supine with a standardized measurement protocol. Body mass index was calculated by dividing measured weight in kilograms by the square of height in meters. Assessment of baseline characteristics and diseases were based on a self-reported questionnaire[21] which was checked by a cardiologist during the screening visit. The regular use of medication was assessed by a detailed questionnaire. All questionnaires have been previously validated in a Finnish population-based cohort study.[22,23]

Assessment of self-reported physical activity and sauna bathing habits

Physical activity was assessed using the baseline questionnaire and classified as endurance training, resistance training or any leisure-time physical activity. Assessment of duration and frequency of physical activity was based on a self-reported questionnaire[23]. Previous regular sauna bathing habits were assessed by the questionnaires and the information collected was based on frequency (weekly sauna sessions), duration of sauna exposure and temperature in the sauna room. The questionnaires were checked at the time of baseline data collection.

Sauna exposure

Sauna exposure was based on a traditional Finnish sauna, which is characterized by air with a relative humidity of 10-20% and high temperature[12]. Sauna exposure was a typical Finnish sauna bathing session; the total duration was 30 minutes, and it was interspersed at 15 minutes with a short, two-minute warm shower. There were separate sauna rooms for women and men; the sauna rooms were similar in the terms of space, humidity, temperature and air conditioning. The sauna temperature was controlled and monitored by internal temperature sensors designed by Harvia Oy, Finland. The temperature was measured continuously by using a 2-channel thermometer in the sauna room and the respective data was collected during experiment. Data obtained via the temperature tracking device showed that the mean temperature was 73 (standard deviation, SD 2) °C with a relative humidity of 10-20 %.

Participants were supervised by a physician and were allowed to leave the sauna at any time they felt uncomfortable. All participants underwent the recommended sauna protocol successfully. To make up for fluid loss due to increased sweating, participants were given 500ml of room temperature still water for drinking during the entire sauna session, including the recovery period after sauna. Immediately after sauna exposure, participants were instructed to rest in a designated relaxing waiting lounge (mean temperature 21 °C) for 30 minutes´ recovery. Body temperature was measured for each participant by the tympanic method.

Exercise testing

A maximal exercise test was conducted on a cycle ergometer utilizing a graded exercise test protocol with ECG to assess the level of aerobic exercise capacity. The exercise test with continuous ECG (CardioSoft software V.1.84, GE Healthcare, Freiburg, Germany) recordings was performed at baseline between using an electrically braked cycle ergometer (Monark Exercise AB, Sweden). The symptom-limited exercise test was started with 3 minutes' warm-up without workload for each participant and continued with 20 Watts (W) increments applied every 1 min until volitional exhaustion. Exercise capacity was expressed in metabolic equivalents (METs) and maximal exercise workload (W). All exercise tests were supervised by an experienced physician with the assistance of a trained nurse and were not performed on the same day of sauna session.

Arterial stiffness

The measurement of AS followed established guidelines[24,25] with written and verbal instructions given to all participants informing them to avoid meals, caffeine and smoking within 3 hours of the measurement. All measurements were taken on the right side of the body in the supine position in a quiet room with a stable temperature (21 °C). All AS related measurements before, after and at 30 minutes' recovery from sauna were taken by a single trained tonometer operator and the same transit distances measured during baseline clinical evaluation were used throughout the experiment for consistency and reliability. Supine brachial systolic and diastolic blood pressures were obtained using Microlife BP A200 (Microlife Corp., Taipei, Taiwan) [26]. Two sequential readings were measured and the mean values were used. Pulse pressure was calculated as the difference between SBP and DBP. Participants rested in the supine position for 10 minutes before AS was measured at baseline and due to the nature of the study on acute effects of sauna, AS was measured immediately after and after 30 minutes of recovery from sauna following blood pressure measurements. Heart rate was recorded with the assessment of AS.

Pulse wave velocity (PWV) data was collected by the software at a sample rate of 1000 Hz (PulsePen, DiaTecne s.r.l., Milan, Italy). PWV was defined as the distance between the measuring sites divided by the time delay between the distal pulse wave from the proximal pulse wave, using the ECG trace as reference [27]. The software is able to define augmentation index in relation to the level and early rise time of the reflected wave with other indexes of arterial stiffness. Augmentation index is a parameter which provides an indication of the contribution of reflected waves to the total pulse pressure and was defined as the difference between the second and first systolic peak on arterial pulse waveform and was expressed as a percentage of central pulse pressure. Arterial tonometry with simultaneous ECG was obtained from carotid and femoral arteries with the use of a commercially available tonometer that has been well validated previously [25,27,28]. Transit distances were assessed by body surface measurements using a tape measure from the suprasternal notch to each pulse recording site (carotid and femoral). Direct carotid to femoral measurement was adjusted to 80% (common carotid artery – common femoral artery x 0.8) for the calculation of PWV as recommended by current guidelines[25]. Left ventricular ejection time (LVET), diastolic time (DT), and augmentation index were obtained from the carotid pressure waveform analysis. This measurement relies on the R-R interval on an ECG. The point corresponding to the end of LVET and the beginning of DT is identified by the dicrotic notch in the carotid pulse waveform. This point is automatically estimated by the PulsePen software.[29]

Laboratory analyses

Venous blood samples for the determination of plasma total cholesterol, high density lipoprotein (HDL), low density lipoprotein (LDL), Apolipoprotein A1 (ApoA1), Apolipoprotein B (Apo B), triglycerides (TG) and plasma glucose concentrations were collected by a qualified laboratory technician from the antecubital vein, into serum and plasma tubes (BD Vacutainer, Plymouth. UK). Participants were instructed to abstain from strenuous physical activity 24h before the blood samples were taken. Whole blood samples were stored for 10 min before being centrifuged at 3500 rpm (Megafuge, Heraeus, Germany) and serum and plasma samples stored at -80°C until analysis using a spectrophotometry analyzer (Konelab 20XTi, Thermo Fisher Scientific, Vantaa, Finland). Basic hematological parameters (hemoglobin concentration, leucocytes and thrombocytes count) were analyzed on site by Sysmex KX 21 (Sysmex Co., Kobe, Japan) analyzer. Venous blood samples for the determination of plasma biomarkers were analyzed using chemiluminecent immunoassay by Siemens Immulite 2000 XPi analyzer (Siemens Healthcare Diagnostics Products Ltd., Llanberies, UK). Serum sodium and potassium were measured using Gem Premier 3000 (IL laboratories, Barcelona, Spain) and were assessed before and after sauna.

Statistical analyses

Data are presented as means ± (SDs) or median [interquartile range, IQR] for continuous variables based on their distribution and as proportions for categorical variables. Normality was checked using the Shapiro-Wilk test as well as through observing the Q-Q-plots. Absolute values (means) of physiological, AS and laboratory variables before and after sauna were firstly analyzed for any within-group (time) changes with an analysis of variance (ANOVA) test. Normally distributed and log-transformed non-normally distributed data were further analyzed for within-group changes with a paired t-test to compare immediately after sauna values and post 30 min sauna values to pre-sauna values. Supplementary analyses were performed to analyze respective relative changes in physiological, cardiovascular and laboratory variables. The level for significance was set at $p<0.05$. All statistical analyses were carried out with Stata version 14.1 (Stata Corp, College Station, Texas, U.S.).

Results

Characteristics of population

Overall, there were 56 male and 46 female participants; their characteristics are shown in **Table 1**. The mean age was 51.9 (SD 9.2) years and BMI of overall participants was 27.2 [IQR: 24.5-30.7 kg/m^2]. The proportion of current smokers was 14.4 % and the mean resting SBP and DBP were 136 (16) and 84 (10) mmHg, respectively. Biochemical parameters were slightly different between males and females and are reported in **Table 1.**

Underlying clinical conditions or cardiovascular risk factors of participants included hypertension (14.3%), dyslipidaemia (63.0%), type 1 diabetes (2.0%), type 2 diabetes (1.0%), respiratory diseases (5.1%), thyroid disease (3.1%), skin disease (4.0%) and rheumatoid arthritis (1.0%). Family history of CHD was a common risk factor (34.0%) in this study population (**Table 1**).

Cardiorespiratory fitness level as assessed by median exercise capacity was 8.8 METs [7.8-10.4], being 9.7 [8.5-10.9] and 8.3 [6.7-9.3] in males and female participants, respectively.

Most of participants achieved age-adjusted target maximal heart rate level during exercise test. The highest mean SBP during exercise test was 213 (24) mmHg for men and 196 (24) mmHg for women, while exercise-induced ST-segment changes of over 1 mm, indicating minor ischemic changes, were not common (6.5%). Detailed exercise testing results are shown in **Table 1.**

Participants bathed in their own sauna from 1 to 4 times per week based on the baseline questionnaires (**Table 1**). Most participants preferred to use sauna 3 times per week (43.9%), whereas 16.3% of participants used sauna 1 or 2 times per week respectively. A sauna session lasted between 20-40 minutes for most participants (56.7%) and the average self-reported temperature was 72°C.

Reported frequency of total leisure-time physical activity was distributed as follows: the proportion of those with 1 physical activity session per week was 25.8%, 1-3 sessions was 32.3%, 3-5 sessions was 30.6%, and >5 sessions was 9.7%. The distributions of duration of total physical activity in groups of <20 min, 20-39 min, 40-60 min and >60 min per a single session are reported in **Table 1**.

Sauna and body temperature, heart rate and blood pressure

There were statistically significant effects of sauna heat exposure on body temperature, heart rate and blood pressure values. The directions of change in parameters evaluated were similar in both genders (**Table 2 and Figure 1)**. Body temperature, heart rate and blood pressure changed immediately after sauna and at 30 minutes' recovery from sauna bathing. Mean body temperature was 36.4°C before sauna, 38.4°C immediately after sauna and 36.6°C at the end of recovery period (**Table 2 and Figure 1**). SBP was 137 (16) mmHg before sauna, 130 (14) mmHg immediately after sauna, and 130 (14) mmHg after 30 minutes' recovery. The corresponding values for DBP were 82 (10), 75 (9), and 81 (9) mmHg (**Table 2**). The respective heart rate values at the time of blood pressure and AS measurements were 64 [59-70], 79 [70-90], and 65 [59-71] beats per minute.

The mean relative changes in SBP and DBP were -4.3% (p<0.0001) and -8.7% (p<0.0001), respectively, comparing post-sauna to pre-sauna blood pressure. Blood pressure remained lower until the end of recovery period compared to pre-sauna blood pressure. The respective relative changes from pre-sauna to post sauna values are presented in **Supplementary Table 1**. **Supplementary Figure 1** shows relative changes in temperature, heart rate and blood pressure.

Sauna and arterial stiffness

Table 3 and **Figure 1** show changes in AS parameters after sauna. Mean carotid-femoral PWV before sauna was 9.8 (2.4) m/s and decreased to 8.6 (1.6) m/s immediately after sauna, being 9.0 (1.7) m/s after 30 minutes' recovery period. Values for augmentation index were 9.6 (15.8) pre sauna, 4.1 (15.7) immediately after sauna, and 7.5 (15.6) 30 minutes after sauna. Left ventricular ejection time and diastolic time were lower immediately after sauna (**Table 3**). From pre-sauna to immediate post-sauna assessment time points, left ventricular ejection time decreased from 306.7 (26.2) to 275.1 (31.8) ms and diastolic time from 633.2 (116.0) to 493.3 (113.8) ms. The relative changes in PWV, left ventricular ejection time and diastolic time post-sauna were significant as shown in **Supplementary Table 2**. All indices of AS including PWV, augmentation index, left ventricular ejection time and diastolic time changed in the same direction for both genders after sauna exposure, and relative changes of AS parameters were statistically significant in the study group immediately after sauna (**Supplementary Table 2 and Supplementary Figure 1**).

Sauna and laboratory parameters

There were significant changes in hemoglobin level, leucocyte and thrombocyte count during sauna exposure as presented in **Table 4 and Figure 1**. Hemoglobin levels increased from pre-sauna level of 141 (11) to 144 (13) g/l immediately after sauna. Blood leucocytes count increased from 6.2 (1.6) to 6.8 (1.6) x10^9/l and the leucocyte count was at the highest level immediately after sauna and thrombocyte levels were significantly higher immediately after sauna compared with pre-sauna values (**Table 4**, **Supplementary Table 3**). Although changes in hemoglobin, leucocyte, and thrombocyte over-time were statistically significant, hemoglobin and thrombocytes returned to the pre-sauna level after 30 minutes recovery. Changes in plasma creatinine, sodium and potassium are presented in **Table 4 and Figure 1.** Mean plasma creatinine levels increased from 76 to 79 μmol/l ($p<0.0001$). Minimal changes were observed for sodium and potassium levels from pre-sauna levels until 30 minutes' recovery, and the respective percentage changes are presented in **Supplementary Table 3**. Hematological and biochemical parameters are also shown as relative changes in **Supplementary Figure 1)**.

Discussion

This study was conducted to demonstrate effects of a single sauna bathing session on cardiovascular function in participants with at least one conventional cardiovascular risk factor. The main objective of the study was to evaluate the acute effects of sauna bathing on systemic blood pressure and AS as well as common laboratory parameters, immediately before and after heat exposure and at 30-minute recovery phase. Blood pressure levels and AS were modulated positively due to sauna exposure, while the sauna bathing-induced reduction in blood pressure remained constant when comparing baseline values to recovery phase data. Hemoglobin levels, leucocyte and thrombocyte counts increased significantly due to sauna exposure; with the exception of leucocyte, they all returned to pre-sauna levels after recovery time. The increase in creatinine levels were sustained at the time of recovery, whereas the changes in levels of sodium and potassium as a result of sauna exposure were very minimal. On basis of measured basic laboratory values, it seems that 30 minutes sauna exposure is safe in terms of electrolyte (sodium/potassium) balance. Rise of hemoglobin levels could be attributed to sauna-induced fluid-loss, although 500 ml water was available to balance increased sweating.

This study showed that sauna bathing leads to significant decrease in blood pressure, which is a clinically important finding among participants with cardiovascular risk factors. As sauna bathing produces acute vasodilation which causes a significant drop in blood pressure, it can be postulated that regular sauna bathing could potentially result in longer-term reduction of blood pressure[16]. Systolic blood pressure remained lower compared to pre-sauna levels during the whole 30 minutes' recovery period. It is suggested that a short sauna session may reduce blood pressure in patients with hypertension[3,9,30]. In patients with slightly elevated blood pressure, sauna therapy produced positive effects on systemic blood pressure, including 24-hour blood pressure levels[3,9]. Increased sweating during sauna bathing is accompanied by reduction in blood pressure and a higher heart rate, whiles cardiac stroke volume is largely maintained; although a part of blood volume is diverted from the internal organs to body peripheral parts with decreasing venous return which is not facilitated by active skeletal muscle work. Indeed, comparable with exercise-induced adaptations, repetitive heat stress could improve endothelial function and arterial stiffness and may lower resting blood pressure in sedentary humans [6,31]. Due to the increased skin blood flow under heat stress conditions, cutaneous microvascular function is improved by passive repeated heat therapy[5].

This study showed that hot sauna bathing leads to changes in cardiovascular function which include beneficial effects on AS with decrease in blood pressure. We found for the first time that PWV was decreased significantly after sauna bathing. Consistently, left ventricular ejection time and diastolic time decreased due to sauna exposure. Enhanced AS is a possible protective link between heat exposure and changes in vascular function. Our study showed that all indicators of cardiovascular compliance were improved after a single session of sauna bathing. We have also shown that heat exposure of sauna has positive effects on arterial compliance, providing a possible protective pathway against arterial stiffening which is a progressive pathology of the arterial wall[5,6,17]. Although resting blood pressure levels are correlated with AS, studies have shown that AS is an additional indicator of both compliance of arteries and an independent marker of predicting CVD outcomes[32]. These beneficial effects of sauna bathing on indices of cardiovascular function may underpin the long-term protective effects of sauna bathing on cardiovascular and mortality risk, as recently demonstrated[12]. The proposed positive effects on vascular function in the current study were based on traditional hot and dry Finnish sauna bathing, which is not comparable to saunas operating at lower temperatures and heated water immersion[5,6,30].

We also assessed changes in hematological indices and their profile; hemoglobin levels were observed to be increased after sauna, which may be an indicator of increased hemoconcentration. This is consistent with findings showing that hemoglobin levels were significantly increased after sauna [4,33]. Our study also showed that leucocytes and thrombocytes increased slightly after sauna bathing and electrolyte levels remained stable. The levels of plasma creatinine tended to increase slightly due to sauna bathing, although the changes were within normal range and unlikely to lead to long-lasting changes in kidney function. There are no previous comparable studies showing changes in basic laboratory parameters after sauna bathing.

Participants' body temperature increased from the mean level of 36.4°C until 38.4°C immediately after sauna; however, all participants underwent sauna session successfully. Body temperature tended to decrease during the recovery period at an average room temperature back to individual pre-sauna levels. In general, a temperature for a typical Finnish sauna is usually adjusted around 80°C. In this study, the temperature of sauna was stabilized and controlled for every participant, and measured at 10 seconds intervals during the sauna sessions. Body weight increased significantly during sauna session, which might be due to water consumption. In this study, participants were each allowed to drink 500 ml still water during the sauna session and recovery period (total amount 500ml). All consumed water was accurately controlled. The wet swimming suits after the sauna sessions could also explain the increased body weight.

The current study evaluates the acute effects of 30 minutes' sauna exposure on body physiology and cardiovascular function in a large sample. Our study employed a large number of participants, which provided adequate pre-defined power to assess meaningful clinical changes in indices evaluated. In this study, the assessment of cardiovascular parameters such as blood pressure and AS was performed using standard measurement protocols. Currently, PWV is considered the most reliable non-invasive measurement of AS.

Conditions in the sauna including the duration of use simulated a typical dry and hot Finnish sauna session, and there were no any adverse events during the sauna. Study participants were allowed to drink water during sauna and recovery period, according to guidance of the local ethical committee. Limitations included the before and after exposure design with the short-term nature of the intervention without serial repeated post-sauna measurements during the recovery period and lack of a control group. However, the study setting is novel in this research context focusing on most immediate effects of sauna bathing on cardiovascular function and biological variables. Our previous epidemiological study suggests that to reduce CVD risk, frequent sauna sessions at 19 minutes per single sauna session may be required to have beneficial effects on the cardiovascular system[12]. Consistently with our previous findings, we have recently shown that sauna bathing is associated with a lowered risk of future hypertension.[13] In the current study, we demonstrated acute cardiovascular adaptations of 30 minutes' sauna session. However, the most beneficial duration of sauna for cardiovascular health has to be defined and as to whether combining a sauna bathing session with physical activity may be more beneficial needs exploration. In addition, a similar intervention using a long-term randomized controlled trial is needed in order to gain a better perspective of the benefits of sauna (heat stress) and to investigate long-term health effects in different populations since short-term findings have been currently documented.

In conclusion, this study showed the effects of a typical Finnish sauna on short-term cardiovascular outcomes. Our study indicated that 30 minutes' heat exposure of sauna leads to short-term decrease in blood pressure and positive alterations in AS parameters. Sauna bathing with its beneficial effects on cardiovascular function is a recommendable activity in a population with risk factors. Further studies are warranted to establish the potential mid- and longer-term effects of sauna bathing on cardiovascular adaptation.

Conflicts of Interest Statement

None

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Financial Disclosures

Authors have nothing to declare

Table 1: Baseline characteristics

Clinical characteristics	N	Total	M	F	p-value**
Age (years)	53/45	51.9 ± 9.2	51.8 ± 10.1	52.0 ± 8.3	0.9377
Body weight (kg)	54/46	82.7 ± 16.0	88.9 ± 13.4	75.5 ± 15.9	<0.0001
Body mass index (kg/m^2)	52/45	27.2 [24.5-30.7]	27.7 [25.1-30.6]	26.7 [23.8-31.0]	0.5612
Smokers	51/46	14 (14.4%)	9 (17.7%)	5 (10.9%)	0.3429
Systolic blood pressure (mmHg)	52/42	136.5 ± 16.2	137.2 ± 14.4	135.8 ± 18.3	0.7951
Diastolic blood pressure (mmHg)	52/42	82.1 ± 9.6	84.2 ± 9.6	79.6 ± 9.2	0.0252
Resting HR (bpm)	52/42	64 [59-70]	64 [56.5-70]	65 [61-70]	0.6222
Total cholesterol ($Chol_{tot}$; mmol/L)	52/44	5.4 ± 1.0	5.4 ± 1.1	5.4 ± 0.9	0.6017
Low density lipoprotein (LDL; mmol/L)	52/44	3.0 ± 0.8	3.1 ± 0.8	3.0 ± 0.8	0.4179
High density lipoprotein (HDL; mmol/L)	52/44	1.4 ± 0.4	1.3 ± 0.4	1.5 ± 0.4	0.0025
Triglycerides (mmol/L)	52/44	1.6 [1.0-2.3]	1.8 [1.2-2.6]	1.3 [0.9-2.0]	0.0094
Glucose (mmol/L)	52/44	5.2 ± 0.9	5.3 ± 1.0	5 ± 0.9	0.1302
Apo A1 (g/L)	52/44	1.5 [1.3-1.7]	1.5 [1.3-1.7]	1.6 [1.4-1.8]	0.0412
Apo B (g/L)	52/44	1.0 [0.8-1.2]	1.0 [0.8-1.2]	0.9 [0.7-1.1]	0.0395
Self-reported conditions and family history					
Hypertension	52/46	14 (14.3%)	11 (21.2%)	3 (6.5%)	0.0388
Hypercholesterolaemia*	52/44	63 (63.0%)	37 (66.1%)	26 (59.1%)	0.6168
Type 1 diabetes	52/46	2 (2.0%)	1 (1.9%)	1 (2.2%)	0.9302
Type 2 diabetes	52/46	1 (1.0%)	1 (1.9%)	0 (0.0%)	0.3445
Respiratory diseases (incl. Asthma)	52/46	5 (5.1%)	2 (3.8%)	3 (6.5%)	0.5480
Thyroid disease (hypo)	52/46	3 (3.1%)	1 (1.9%)	2 (4.3%)	0.4868
Skin disease (atopic)	52/46	4 (4.1%)	3 (5.8%)	1 (2.2%)	0.3693
Rheumatoid arthritis	52/46	1 (1.0%)	0 (0.0%)	1 (2.2%)	0.2852
Family history of coronary heart disease	51/46	33 (34.0%)	15 (29.4%)	18 (39.1%)	0.3131
Exercise testing					
Exercise capacity, METs	48/44	8.8 [7.8-10.4]	9.7 [8.5-10.9]	8.3 [6.7-9.3]	0.0210
Exercise capacity, watts	48/44	228.2 ± 52.9	260.7 ± 44.7	192.6 ± 35.4	<0.0001
Maximal heart rate, beats per minute	48/44	173.7 ± 13.5	175.6 ± 15.1	171.7 ± 11.2	0.1589
Percentage of maximal predicted heart rate	48/44	103.4 ± 7.8	104.7 ± 8.5	102.0 ± 6.8	0.0970
Maximal systolic blood pressure, mmHg	48/44	205.2 ± 25.4	213.5 ± 24.1	196.1 ± 23.7	0.0008
Maximal diastolic blood pressure, mmHg	48/44	87.0 ± 11.4	87.9 ± 11.6	86.0 ± 11.1	0.4379
Reason to terminate exercise test	48/44				
…Fatigue		47 (51.1%)	26 (54.2%)	21 (47.7%)	0.6766
…Leg discomfort		45 (48.9%)	22 (50.0%)	23 (52.3%)	
Exercise induced ST-segment changes	48/44	6 (6.5%)	4 (8.3%)	2 (4.6%)	0.4623
Self-reported sauna habits and physical					
Frequency of sauna bathing, times/week	52/46				
…1		16 (16.3%)	6 (11.5%)	10 (21.7%)	0.2009
…2		16 (16.3%)	7 (13.5%)	9 (19.6%)	
…3		43 (43.9%)	23 (44.2%)	20 (43.5%)	
…4		23 (23.5%)	16 (30.8%)	7 (15.2%)	
Duration of sauna, minutes/session	52/45				
…<20		17 (17.5%)	8 (15.4%)	9 (20.0%)	0.5902
…20-40		55 (56.7%)	28 (53.8%)	27 (60.0%)	
…>40-60		21 (21.6%)	14 (26.9%)	7 (15.6%)	
…>60		4 (4.1%)	2 (3.8%)	2 (4.4%)	
Average temperature of sauna, °C	52/44	72.0 ± 8.5	73.0 ± 9.0	70.9 ± 7.8	0.2162
Frequency of physical activity, times/week	30/32				
…0		1 (1.6%)	1 (3.3%)	0 (0.0%)	0.7161
…1		16 (25.8%)	7 (23.3%)	9 (28.1%)	
…>1-3		20 (32.3%)	11 (36.7%)	9 (28.1%)	
…>3-5		19 (30.6%)	9 (30.0%)	10 (31.3%)	
…>5		6 (9.7%)	2 (6.7%)	4 (12.5%)	
Duration of physical activity, minutes/session	35/35				
…<20		7 (10.0%)	2 (5.7%)	5 (14.3%)	0.1616
…20-40		18 (25.7%)	12 (34.3%)	6 (17.1%)	
…>40-60		19 (27.1%)	11 (31.4%)	8 (22.9%)	
…>60		26 (37.1%)	10 (28.6%)	16 (45.7%)	

Numbers are reported as Mean ± SD or median [interquartile range] for continuous variables and n (%) for categorical variables; *Based on total cholesterol level of > 5.17mmol/L (=200mg/dL); **, p-value for difference between men and women (log-transformed values for variables reported as median [interquartile range])

Table 2. Physiological parameters and blood pressure before and after sauna				
Body temperature, ˚C	**N (M/F)**	**Total**	**M**	**F**
…pre	56/46	36.4 ± 0.5	36.3 ± 0.5	36.5 ± 0.4
…post	56/46	38.4 ± 0.7	38.6 ± 0.8	38.2 ± 0.6
…post 30 min	45/43	36.6 ± 0.4	36.5 ± 0.4	36.7 ± 0.4
***p*-value**		**<0.0001**	**<0.0001**	**<0.0001**
Body weight, kg				
…pre	54/46	82.7 ± 16.0	88.9 ± 13.4	75.5 ± 15.9
…post	54/45	83.1 ± 15.9	88.9 ± 13.4	76.1 ± 16.0
…post 30 min	54/44	83.0 ± 15.7	88.7 ± 13.3	75.9 ± 15.7
***p*-value**		**<0.0001**	**0.0013**	**0.0001**
Heart rate, beats/min				
…pre	52/42	64 [59-70]	64 [57-70]	65 [61-70]
…post	52/43	79 [70-90]	84 [75-98]	75 [68-82]
…post 30 min	52/44	65 [59-71]	68 [59-74]	63 [60-68]
***p*-value**		**<0.0001**	**<0.0001**	**<0.0001**
Systolic blood pressure, mmHg				
…pre	52/42	136.5 ± 16.2	137.2 ± 14.4	135.8 ± 18.3
…post	52/43	130.3 ± 14.4	131.5 ± 14.3	128.9 ± 14.6
…post 30 min	52/44	129.8 ± 13.8	129.4 ± 13.4	130.3 ± 14.9
***p*-value**		**<0.0001**	**<0.0001**	**<0.0001**
Diastolic blood pressure, mmHg				
…pre	52/42	82.1 ± 9.6	84.2 ± 9.6	79.6 ± 9.2
…post	52/43	75.1 ± 9.3	77.2 ± 9.2	72.5 ± 8.8
…post 30 min	52/44	80.6 ± 9.2	82.5 ± 9.9	78.4 ± 7.7
***p*-value**		**<0.0001**	**<0.0001**	**0.0015**

Heart rate and blood pressure were measured during the assessment of the arterial stiffness; numbers are reported as Mean ± SD or median [interquartile range]; M = male; F = female; Total = total population

Table 3. Arterial stiffness parameters before and after sauna bathing				
Pulse wave velocity, m/s	**N (M/F)**	**Total**	**M**	**F**
…pre	52/42	9.8 ± 2.4	10.1 ± 2.5	9.5 ± 2.3
…post	52/43	8.6 ± 1.6	8.8 ± 1.5	8.2 ± 1.6
…post 30 min	52/44	9.0 ± 1.7	9.3 ± 1.7	8.6 ± 1.7
***p*-value**		**<0.0001**	**<0.0001**	**0.0007**
Augmentation index				
…pre	52/42	9.6 ± 15.8	4.9 ± 14.7	15.5 ± 15.3
…post	52/43	4.1 ± 15.7	-1.9 ± 16.2	11.2 ± 11.7
…post 30 min	52/43	7.5 ± 15.6	-0.1 ± 13.1	16.7 ± 13.5
***p*-value**		**0.0021**	**0.0113**	**0.0147**
Left ventricular ejection time, ms				
…pre	52/42	306.7 ± 26.2	297.4 ± 26.8	318.2 ± 20.6
…post	52/43	275.1 ± 31.8	260.5 ± 30.4	292.9 ± 23.7
…post 30 min	52/44	297.0 ± 26.9	286.0 ± 28.0	310.0 ± 18.7
***p*-value**		**<0.0001**	**<0.0001**	**<0.0001**
Diastolic time, ms				
…pre	52/42	633.2 ± 116.0	638.2 ± 124.6	627.1 ± 105.4
…post	52/43	493.3 ± 113.8	469.5 ± 123.6	522.1 ± 94.3
…post 30 min	52/44	634.1 ± 121.9	625.4 ± 133.8	644.4 ± 106.7
***p*-value**		**<0.0001**	**<0.0001**	**<0.0001**
Augmentation ratio				
…pre	52/42	1.3 ± 0.1	1.3 ± 0.1	1.3 ± 0.1
…post	52/43	1.3 ± 0.1	1.2 ± 0.1	1.3 ± 0.1
…post 30 min	52/43	1.3 ± 0.1	1.3 ± 0.1	1.3 ± 0.1
***p*-value**		**0.0851**	**0.0001**	**0.0383**

All presented data was collected at the time of assessment of arterial stiffness; M = male; F = female; Total = total population

Table 4. Laboratory parameters before and after sauna bathing				
Hemoglobin, g/l	**N (M/F)**	**Total**	**M**	**F**
…pre	53/46	141.0 ± 11.1	147.6 ± 8.9	133.3 ± 8.1
…post	53/46	144.3 ± 13.1	152.8 ± 9.5	134.4 ± 9.2
…post 30 min	50/37	141.6 ± 10.9	147.6 ± 8.9	133.5 ± 7.8
***p*-value**		**<0.0001**	**<0.0001**	**0.0076**
Leucocyte count, x10^9/l				
…pre	53/46	6.2 ± 1.6	5.9 ± 1.5	6.4 ± 1.7
…post	53/46	6.8 ± 1.6	6.7 ± 1.6	6.8 ± 1.7
…post 30 min	53/46	6.4 ± 1.6	6.1 ± 1.5	6.8 ± 1.6
***p*-value**		**<0.0001**	**<0.0001**	**<0.0001**
Thrombocyte count, x10^9/l				
…pre	53/46	246.2 ± 51.5	232.6 ± 51.5	261.9 ± 46.2
…post	53/46	261.1 ± 55.2	256.3 ± 57.1	270.0 ± 52.2
…post 30 min	53/46	242.4 ± 50.0	234.2 ± 52.9	253.5 ± 44.3
***p*-value**		**<0.0001**	**<0.0001**	**0.0001**
Creatinine, µmol/L				
…pre	54/46	76 [67-84]	82 [77-87]	67 [61-73]
…post	54/46	78 [65-85]	83 [78-90]	65 [61-73]
…post 30 min	51/38	79 [69-90]	87 [80-93]	69 [60-72]
***p*-value**		**<0.0001**	**<0.0001**	**0.0074**
Sodium, mEq/L				
…pre	54/46	141.3 ± 3.2	141.6 ± 2.8	140.8 ± 3.6
…post	53/46	141.5 ± 3.6	142.6 ± 3.2	140.3 ± 3.7
…post 30 min	50/38	140.6 ± 3.2	141.5 ± 3.0	139.5 ± 3.2
***p*-value**		**0.0085**	**0.0119**	**0.0022**
Potassium, mEq/L				
…pre	54/46	3.9 ± 0.3	4.0 ± 0.3	3.9 ± 0.3
…post	53/46	4.0 ± 0.3	4.0 ± 0.3	3.9 ± 0.3
…post 30 min	50/38	4.0 ± 0.4	4.0 ± 0.3	3.9 ± 0.4
***p*-value**		**0.0726**	**0.1027**	**0.4414**

M = male; F = female; Total = total population

Supplementary Tables:

Supplementary Table 1: Percentage mean changes in physiological parameters				
Body temperature	**N (M/W)**	**Total**	**M**	**F**
…post	56/46	5.6 (5.2; 6.0)	6.3 (5.7; 6.9)	4.9 (4.5; 5.3)
…post 30 min	45/43	0.4 (0.2; 0.6)	0.5 (0.1; 0.9)	0.4 (0; 0.8)
p-value (post-pre)		**<0.001**	**<0.001**	**<0.001**
p-value (post30-pre)		**0.004**	**0.044**	**0.042**
Body weight				
…post	54/45	0.2 (0.2; 0.2)	0 (-0.2; 0.2)	0.6 (0.6; 0.6)
…post 30 min	54/44	0 (-0.2; 0.2)	-0.2 (-0.4; 0)	0.1 (-0.1; 0.3)
p-value (post-pre)		**<0.001**	**0.878**	**<0.001**
p-value (post30-pre)		**0.562**	**0.008**	**0.371**
Heart rate*				
…post (highest)	52/43	5 (4.2; 5.8)	6.1 (5.1; 7.1)	3.7 (2.9; 4.5)
…post 30 min	52/44	0.4 (0; 0.8)	0.7 (-0.1; 1.5)	0 (-0.6; 0.6)
p-value (post-pre)		**<0.001**	**<0.001**	**<0.001**
p-value (post30-pre)		**0.133**	**0.064**	**0.896**
Systolic blood pressure				
…post	52/43	-4.3 (-5.9; -2.7)	-4.1 (-6.5; -1.7)	-4.5 (-6.3; -2.7)
…post 30 min	52/44	-4.8 (-6; -3.6)	-5.5 (-6.9; -4.1)	-3.9 (-5.7; -2.1)
p-value (post-pre)		**<0.001**	**0.001**	**<0.001**
p-value (post30-pre)		**<0.001**	**<0.001**	**<0.001**
Diastolic blood pressure				
…post	52/43	-8.7 (-10.1; -7.3)	-8.3 (-10.1; -6.5)	-9.1 (-11.1; -7.1)
…post 30 min	52/44	-3 (-5.5; -0.5)	-2.1 (-3.7; -0.5)	-4.2 (-9.9; 1.5)
p-value (post-pre)		**<0.001**	**<0.001**	**<0.001**
p-value (post30-pre)		**0.024**	**0.01**	**0.148**

Heart rate and blood pressure were measured during the assessment of the pulse wave velocity; percentages are reported as Mean (95%CI); * Log-transformed values

Supplementary Table 2: Percentage mean changes in cardiovascular parameters				
Pulse wave velocity	**N**	**Total**	**M**	**F**
…post	52/43	-6.4 (-8.6; -4.2)	-7 (-10.1; -3.9)	-5.6 (-8.9; -2.3)
…post 30 min	52/44	-1.5 (-3.5; 0.5)	-1.9 (-4.6; 0.8)	-1.0 (-3.7; 1.7)
p-value (post-pre)		**<0.001**	**<0.001**	**0.002**
p-value (post30-pre)		**0.132**	**0.180**	**0.481**
Augmentation index				
…post	52/43	-58.6 (-93.5; -23.7)	-138.3 (-239; -37.6)	-27.2 (-55.6; 1.2)
…post 30 min	52/43	-19.2 (-50.6; 12.2)	-101.7 (-174.4; -29)	14.9 (-16.1; 45.9)
p-value (post-pre)		**0.001**	**0.010**	**0.067**
p-value (post30-pre)		**0.234**	**0.008**	**0.351**
Left ventricular ejection time				
…post	52/43	-10.5 (-11.9; -9.1)	-12.4 (-14.4; -10.4)	-8.3 (-9.7; -6.9)
…post 30 min	52/44	-3.4 (-4.4; -2.4)	-3.8 (-5.4; -2.2)	-2.8 (-3.8; -1.8)
p-value (post-pre)		**<0.001**	**<0.001**	**<0.001**
p-value (post30-pre)		**<0.001**	**<0.001**	**<0.001**
Diastolic time				
…post	52/43	-22.3 (-25.6; -19)	-26.4 (-31.1; -21.7)	-17.1 (-20.8; -13.4)
…post 30 min	52/44	-0.5 (-3.0; 2.0)	-2.0 (-5.5; 1.5)	1.5 (-2.0; 5.0)
p-value (post-pre)		**<0.001**	**<0.001**	**<0.001**
p-value (post30-pre)		**0.727**	**0.269**	**0.415**
Augmentation ratio				
…post	52/43	-2.2 (-4.4; 0)	-5.2 (-8.1; -2.3)	1.6 (-0.8; 4.0)
…post 30 min	52/43	-1.1 (-2.5; 0.3)	-0.7 (-2.7; 1.3)	-1.6 (-3.6; 0.4)
p-value (post-pre)		**0.043**	**0.001**	**0.215**
p-value (post30-pre)		**0.132**	**0.493**	**0.135**

Percentages are reported as Mean (95%CI).

Supplementary Table 3: Percentage mean changes in laboratory parameters				
Hemoglobin	**N (M/W)**	**Total**	**M**	**F**
…post	53/46	2.3 (1.7; 2.9)	3.5 (2.7; 4.3)	0.8 (0; 1.6)
…post 30 min	50/37	0.2 (-0.4; 0.8)	0.4 (-0.4; 1.2)	-0.2 (-0.8; 0.4)
p-value (post-pre)		**<0.001**	**<0.001**	**0.058**
p-value (post30-pre)		**0.519**	**0.270**	**0.465**
Leucocyte count				
…post	53/46	9.6 (7.8; 11.4)	12.3 (9.9; 14.7)	6.8 (4.4; 9.2)
…post 30 min	50/37	3.4 (1.6; 5.2)	2.8 (0.8; 4.8)	4.2 (1.5; 6.9)
p-value (post-pre)		**<0.001**	**<0.001**	**<0.001**
p-value (post30-pre)		**<0.001**	**0.010**	**0.006**
Thrombocyte count				
…post	53/46	6.1 (4.5; 7.7)	8.9 (6.7; 11.1)	3.1 (0.9; 5.3)
…post 30 min	50/37	0.9 (-0.7; 2.5)	2.2 (-0.2; 4.6)	-0.7 (-2.5; 1.1)
p-value (post-pre)		**<0.001**	**<0.001**	**0.008**
p-value (post30-pre)		**0.255**	**0.073**	**0.444**
Creatinine*				
…post	54/46	0.1 (-0.1; 0.3)	0.5 (0.1; 0.9)	-0.4 (-0.8; 0)
…post 30 min	51/38	0.8 (0.6; 1.0)	1.2 (0.8; 1.6)	0.2 (-0.2; 0.6)
p-value (post-pre)		**0.493**	**0.009**	**0.055**
p-value (post30-pre)		**<0.001**	**<0.001**	**0.362**
Sodium				
…post	53/46	0.2 (-0.2; 0.6)	0.7 (0.1; 1.3)	-0.4 (-0.8; 0)
…post 30 min	50/38	-0.4 (-0.8; 0)	-0.1 (-0.5; 0.3)	-0.9 (-1.5; -0.3)
p-value (post-pre)		**0.321**	**0.022**	**0.055**
p-value (post30-pre)		**0.027**	**0.754**	**0.006**
Potassium				
…post	53/46	0.5 (-0.7; 1.7)	0.2 (-1.4; 1.8)	0.7 (-1.1; 2.5)
…post 30 min	50/38	1.6 (0; 3.2)	1.5 (0.1; 2.9)	1.8 (-1.5; 5.1)
p-value (post-pre)		**0.444**	**0.769**	**0.429**
p-value (post30-pre)		**0.051**	**0.038**	**0.294**

Percentages are reported as Mean (95%CI); * Log-transformed values

References

1. Perasalo J. Traditional use of the sauna for hygiene and health in Finland. *Ann Clin Res.* 1988;20(4):220-223.

2. Valtakari P. The sauna and bathing in different countries. *Ann Clin Res.* 1988;20(4):230-235.

3. Ohori T, Nozawa T, Ihori H, et al. Effect of repeated sauna treatment on exercise tolerance and endothelial function in patients with chronic heart failure. *Am J Cardiol.* 2012;109(1):100-104.

4. Leppäluoto J, Tuominen M, Väänänen A, Karpakka J, Vuori J. Some cardiovascular and metabolic effects of repeated sauna bathing. *Acta Physiol Scand.* 1986;128(1):77-81.

5. Brunt VE, Eymann TM, Francisco MA, Howard MJ, Minson CT. Passive heat therapy improves cutaneous microvascular function in sedentary humans via improved nitric oxide-dependent dilation. *J Appl Physiol (1985).* 2016;121(3):716-723.

6. Brunt VE, Howard MJ, Francisco MA, Ely BR, Minson CT. Passive heat therapy improves endothelial function, arterial stiffness and blood pressure in sedentary humans. *J Physiol.* 2016;594(18):5329-5342.

7. Imamura M, Biro S, Kihara T, et al. Repeated thermal therapy improves impaired vascular endothelial function in patients with coronary risk factors. *J Am Coll Cardiol.* 2001;38(4):1083-1088.

8. Giannetti N, Juneau M, Arsenault A, et al. Sauna-induced myocardial ischemia in patients with coronary artery disease. *Am J Med.* 1999;107(3):228-233.

9. Gayda M, Paillard F, Sosner P, et al. Effects of sauna alone and postexercise sauna baths on blood pressure and hemodynamic variables in patients with untreated hypertension. *J Clin Hypertens (Greenwich).* 2012;14(8):553-560.

10. Kunutsor S. Ambient temperature or seasonal variations in blood pressure: how important is this in sub-Saharan Africa? *Ethn Dis.* 2010;20(1):1.

11. Kunutsor SK, Powles JW. The effect of ambient temperature on blood pressure in a rural West African adult population: a cross-sectional study. *Cardiovasc J Afr.* 2010;21(1):17-20.

12. Laukkanen T, Khan H, Zaccardi F, Laukkanen JA. Association between sauna bathing and fatal cardiovascular and all-cause mortality events. *JAMA internal medicine.* 2015;175(4):542-548.

13. Zaccardi F, Laukkanen T, Willeit P, Kunutsor SK, Kauhanen J, Laukkanen JA. Sauna Bathing and Incident Hypertension: A Prospective Cohort Study. *Am J Hypertens.* 2017.

14. Laukkanen T, Kunutsor S, Kauhanen J, Laukkanen JA. Sauna bathing is inversely associated with dementia and Alzheimer's disease in middle-aged Finnish men. *Age Ageing.* 2016;46(2):245-249.

15. Kukkonen-Harjula K, Kauppinen K. Health effects and risks of sauna bathing. *Int J Circumpolar Health.* 2006;65(3):195-205.

16. Hannuksela ML, Ellahham S. Benefits and risks of sauna bathing. *Am J Med.* 2001;110(2):118-126.

17. Crandall CG, González-Alonso J. Cardiovascular function in the heat-stressed human. *Acta Physiol (Oxf).* 2010;199(4):407-423.

18. Hillebrand S, Gast KB, de Mutsert R, et al. Heart rate variability and first cardiovascular event in populations without known cardiovascular disease: meta-analysis and dose-response meta-regression. *Europace.* 2013;15(5):742-749.

19. Lietava J, Vohnout B, Valent D, Celko J. Comparison of hemodynamics during hyperthermal immersion and exercise testing in apparently healthy females aged 50-60 years. *Ital Heart J.* 2004;5(7):511-516.

20. Stanley J, Halliday A, D'Auria S, Buchheit M, Leicht AS. Effect of sauna-based heat acclimation on plasma volume and heart rate variability. *Eur J Appl Physiol.* 2015;115(4):785-794.

21. Salonen JT. Is there a continuing need for longitudinal epidemiologic research? The Kuopio Ischaemic Heart Disease Risk Factor Study. *Ann Clin Res.* 1988;20(1-2):46-50.

22. Laukkanen JA, Laaksonen D, Lakka TA, et al. Determinants of cardiorespiratory fitness in men aged 42 to 60 years with and without cardiovascular disease. *Am J Cardiol.* 2009;103(11):1598-1604.

23. Lakka TA, Venäläinen JM, Rauramaa R, Salonen R, Tuomilehto J, Salonen JT. Relation of leisure-time physical activity and cardiorespiratory fitness to the risk of acute myocardial infarction. *N Engl J Med.* 1994;330(22):1549-1554.

24. Tomlinson LA. Methods for assessing arterial stiffness: technical considerations. *Curr Opin Nephrol Hypertens.* 2012;21(6):655-660.

25. Van Bortel LM, Laurent S, Boutouyrie P, et al. Expert consensus document on the measurement of aortic stiffness in daily practice using carotid-femoral pulse wave velocity. *J Hypertens.* 2012;30(3):445-448.

26. Wiesel J, Arbesfeld B, Schechter D. Comparison of the Microlife blood pressure monitor with the Omron blood pressure monitor for detecting atrial fibrillation. *Am J Cardiol.* 2014;114(7):1046-1048.

27. Salvi P, Lio G, Labat C, Ricci E, Pannier B, Benetos A. Validation of a new non-invasive portable tonometer for determining arterial pressure wave and pulse wave velocity: the PulsePen device. *J Hypertens.* 2004;22(12):2285-2293.

28. Joly L, Perret-Guillaume C, Kearney-Schwartz A, et al. Pulse wave velocity assessment by external noninvasive devices and phase-contrast magnetic resonance imaging in the obese. *Hypertension.* 2009;54(2):421-426.

29. Salvi P, Palombo C, Salvi GM, Labat C, Parati G, Benetos A. Left ventricular ejection time, not heart rate, is an independent correlate of aortic pulse wave velocity. *J Appl Physiol (1985).* 2013;115(11):1610-1617.

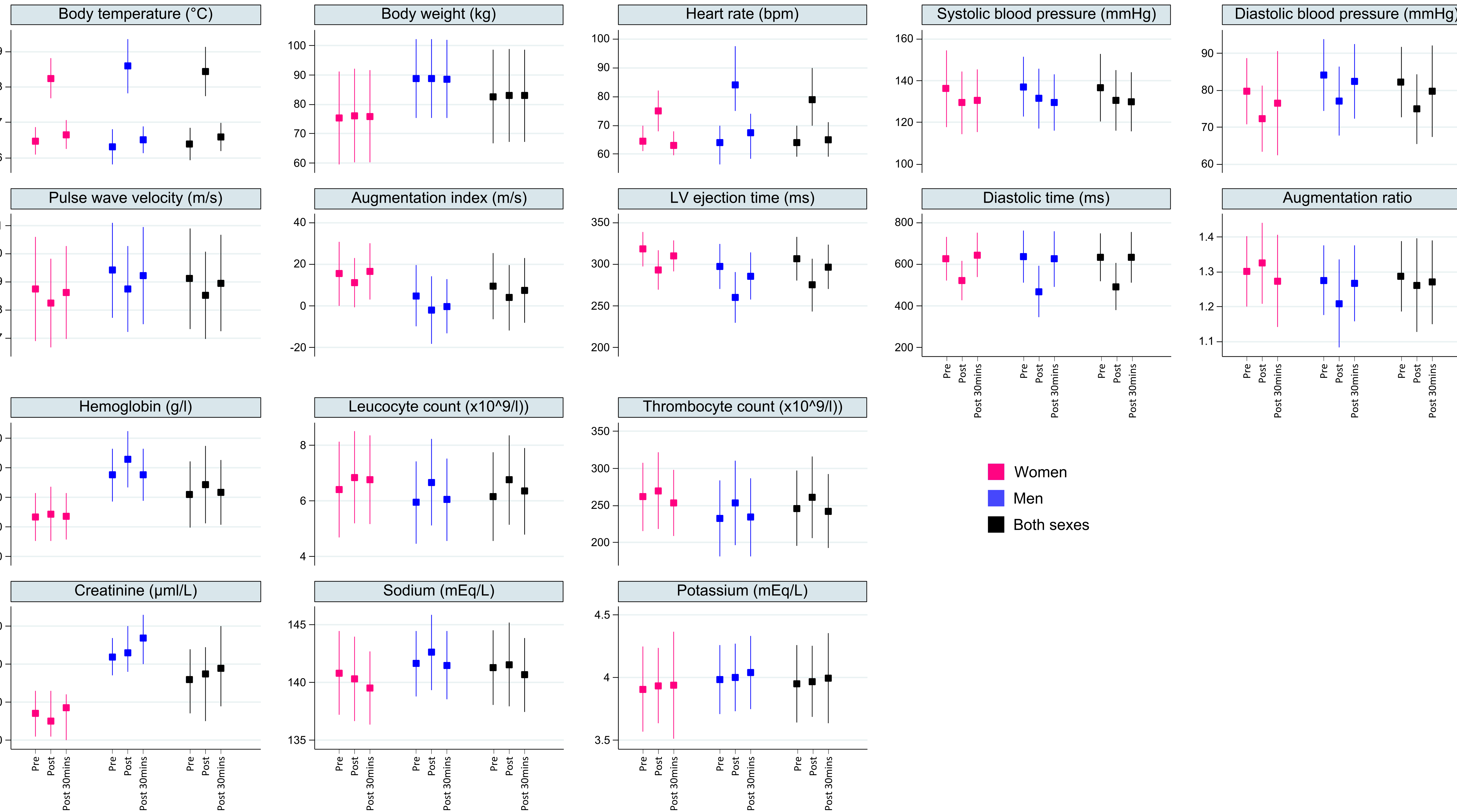
30. Redberg RF. Health benefits of sauna bathing. *JAMA internal medicine.* 2015;175(4):548.

31. Thomas KN, van Rij AM, Lucas SJ, Cotter JD. Lower-limb hot-water immersion acutely induces beneficial hemodynamic and cardiovascular responses in peripheral arterial disease and healthy, elderly controls. *Am J Physiol Regul Integr Comp Physiol.* 2017;312(3):R281-R291.

32. Franklin SS. Beyond blood pressure: Arterial stiffness as a new biomarker of cardiovascular disease. *J Am Soc Hypertens.* 2008;2(3):140-151.

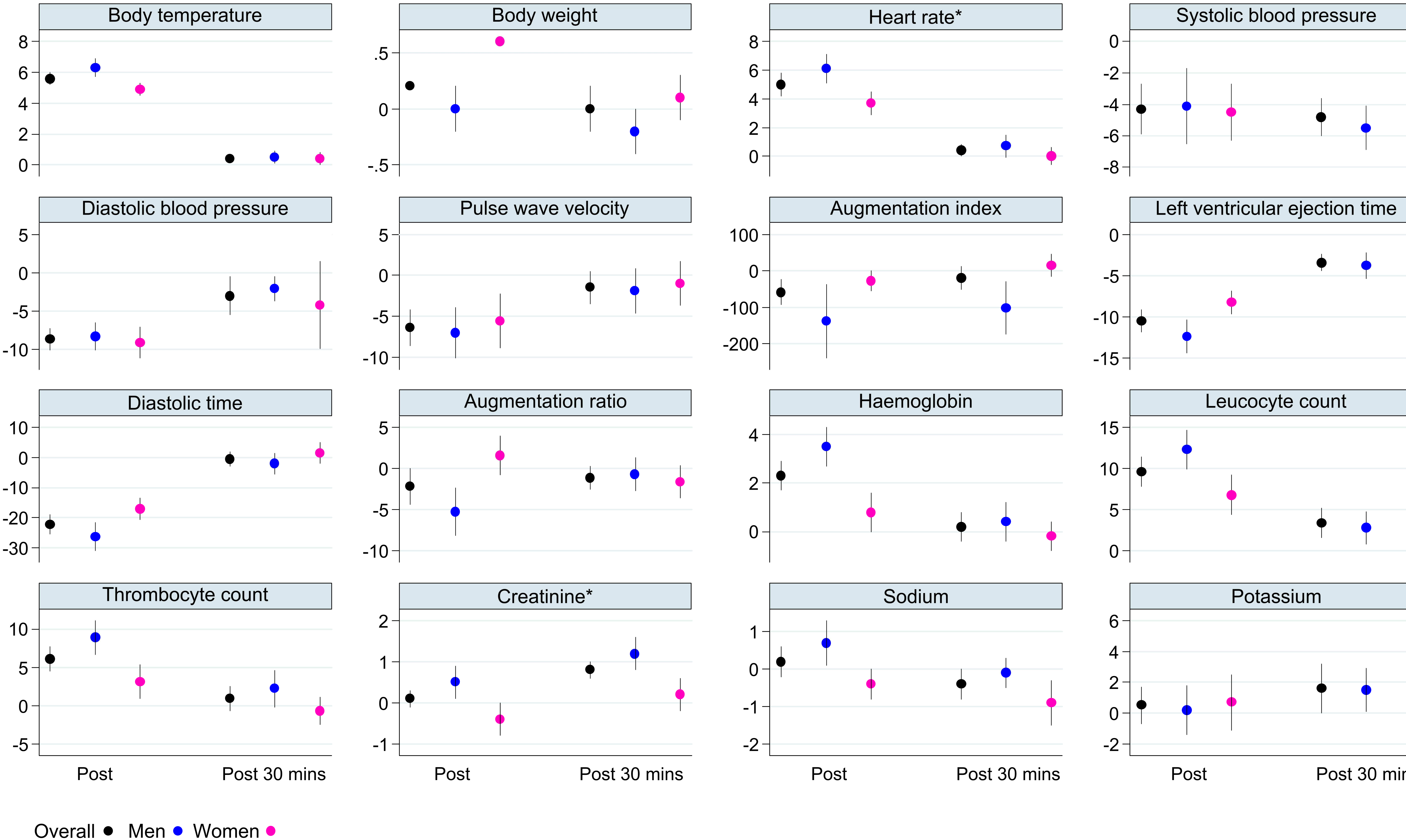
33. Schoffstall JE, Branch JD, Leutholtz BC, Swain DE. Effects of dehydration and rehydration on the one-repetition maximum bench press of weight-trained males. *J Strength Cond Res.* 2001;15(1):102-108.

Figure 1: Changes in parameters during sauna



Point estimates and spikes indicate means and standard deviations, except for heart rate and creatinine (medians and interquartile ranges)

Supplementary Figure 1: Percentage change vs baseline of parameters during sauna



* Log-transformed