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Revision 2

Recovery from sauna bathing favorably modulates cardiac autonomic nervous system

Running title: Sauna and heart rate variability

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Highlights

Sauna bathing, an activity that has been a tradition in Finland for thousands of years and mainly used for the purposes of pleasure and relaxation, is becoming increasingly popular in many other populations. Emerging evidence suggests that beyond its use for pleasure, sauna bathing may be linked to several health benefits, which include reduction in the risk of vascular diseases such as high blood pressure, cardiovascular disease, and neurocognitive diseases. It has been postulated that regular sauna bathing may improve cardiovascular function via improved endothelium-dependent dilatation, reduced arterial stiffness, modulation of the autonomic nervous system. This study investigated the effects of sauna bathing on HR and HRV parameters. The study showed that a single sauna exposure leads to significant changes in cardiac autonomic nervous balance as indicated by modulation in the parameters of HRV such as RMSSD, STDRR, LF, HF, and total power.

Abstract

Objective: Sauna bathing is becoming a common activity in many countries and it has been linked to favorable health outcomes. However, there is limited data on the heart rate (HR) and heart rate variability (HRV) responses to an acute sauna exposure.

Design: We conducted a single-group, time series longitudinal study utilizing a pre-post design to examine acute effects of sauna bathing on the autonomic nervous system as reflected by HRV. A total of 93 participants (mean [SD] age: 52.0 [8.8] years, 53.8% males) with cardiovascular risk factors were exposed to a single sauna session (duration: 30 minutes; temperature: 73°C; humidity: 10-20%) and data on HRV variables were collected before, during and after sauna.

Results: Time and frequency-domain HRV variables were significantly modified ($p<0.001$) by the single sauna session, with most of HRV variables tending to return near to baseline values after 30 minutes recovery. Resting heart rate was lower at the end of recovery (68/min) compared to pre-sauna (77/min). A sauna session transiently diminished the vagal component, whereas the cooling down period after sauna decreased low frequency power ($p<0.001$) and increased high frequency power in HRV ($p<0.001$), favorably modulating the autonomic nervous system balance.

Conclusions: This study demonstrates that a session of sauna bathing induces an increase in heart rate. During the cooling down period from sauna bathing, HRV increased which indicates the dominant role of parasympathetic activity and decreased sympathetic activity of cardiac autonomic nervous system. Future randomized controlled studies are needed to show if HR and HRV changes underpins the long-term cardiovascular effects induced by regular sauna bathing.

Keywords: sauna bathing, heat therapy, heart rate variability, cardiovascular response

1. Introduction

Emerging evidence suggests that sauna bathing, a passive form of heat therapy, has several health benefits.[1] Regular sauna bathing has beneficial effects on the cardiovascular system and which include improved endothelial and microvascular function and reduced arterial stiffness and blood pressure.[2-5] Consistent with these observations, it has been shown that frequent sauna bathing is associated with a reduced risk of dementia,[6] fatal cardiovascular outcomes and all-cause mortality.[7] Sauna may favorably modulate the autonomic nervous system, which is a contributing risk factor for cardiovascular disease (CVD).[8-10] There is a broad body of evidence on the association between cardiac autonomic nervous dysfunction and the risk of fatal arrhythmias.[11-12] Regular sauna bathing has been postulated to exert a potential therapeutic effect on blood pressure[13] which may be partly explained via favorable effects on cardiac autonomic nervous system balance.

Heart rate variability (HRV) is a marker of autonomic nervous system balance, which is a measure of heart rate (HR) fluctuations around the mean HR and has been used to indicate the balance between parasympathetic and sympathetic function of the autonomic nervous system. Higher HRV is indicative of a greater capacity of the cardiovascular system to respond to changes in stressful conditions.[14] A reduced HRV is associated with an increased risk for hypertension, CVD, sudden cardiac death (SCD), and cardiac arrhythmias;[8,15-17] indeed, autonomic nervous system imbalance with an increased sympathetic or reduced vagal tone has been implicated in the pathophysiology of SCD.[11,18] HRV analysis provides additional insight into cardiovascular responses to heat exposure. It has been suggested that endurance exercise training and many other physical activities may increase vagal activity and decrease sympathetic activity at rest and recovery.[19-21] There is evidence to suggest that relaxation techniques may increase HRV.[22] Sauna bathing, a common life-style habit used mainly for relaxation and pleasure purposes to release body stress,[23,24] may have effects on parasympathetic activity of the autonomic nervous system.

Sauna bathing leads to an increase in HR,[25] thereby imitating moderate physical activity and its possible effects on autonomic nervous system without active skeletal muscle work. Additionally, it is known that the acute physiological responses to high temperatures during sauna bathing induces fluid loss with an increase in HR.[25,26] Evidence also suggests that exposure to high ambient temperature is associated with an increase in HRV.[27] A number of studies have shown that other passive heat therapies (eg. infrared-ray sauna, Waon therapy, etc) improve cardiac function and autonomic nervous activity in patients with pre-existing conditions such as heart failure and chronic respiratory disease.[29-30] There is however very limited data on the effects of typical Finnish sauna bathing on autonomic nervous system indices such as HRV in participants with cardiovascular risk factors. Given the overall evidence, we hypothesized that immediately after a single sauna exposure, it is possible to identify favorable cardiac autonomic responses. In this context, we conducted an experimental study to investigate cardiac autonomic nervous system responses, by using HRV measurements, during and immediately after sauna bathing among participant with at least one cardiovascular risk factor.

2. Methods

2.1. Participants

This study was part of the sauna and cardiovascular health study, which has been described in previous reports.[4,5] Participants (n=93) were recruited from the city of Jyväskylä, Central Finland region, through the local out-of-hospital health care center. The study group consisted of participants without symptomatic CVD who had at least one cardiovascular risk factor, such as a history of smoking, dyslipidemia, hypertension, obesity, diabetes, or family history of coronary heart disease (CHD). 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, measurement procedures, and were interviewed and examined by a cardiologist.

The investigation was concordant with the principles outlined in the Declaration of Helsinki and its future amendments. 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 participants provided written informed consent.

2.2. Clinical examination

A clinical evaluation with baseline data collection was conducted on a separate day prior to the actual sauna experiment. During the screening visit, medical history, physical examination, and resting electrocardiogram (ECG) were assessed. All baseline and sauna measurements were performed from May to June 2016, as a part of the sauna and cardiovascular health study.[4] Resting blood pressure was measured as the mean of two measurements, obtained while the participant was supine with a standardized measurement protocol. Body mass index (BMI) 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 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.[31]

2.3. Assessment of sauna bathing habits

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 of the sauna during the exposure. The questionnaires were cross-checked at the time of baseline data collection.

2.4. Sauna exposure

Sauna exposure was based on dry air and relatively high temperature.[7] Sauna exposure was a typical Finnish sauna bathing session; the total duration was 30 minutes, and it was divided into two 15 minutes sessions with a short, two-minute warm (temperature of 38°C) shower in-between the sessions. The given sauna protocol is applicable for our study population with regard to safety issues and it also corresponds very well with typical sauna use in Finland. The sauna rooms were gender specific. The temperature and humidity were measured continuously by using a 2-channel thermometer in the sauna room (Harvia Co., Finland) and the respective data was collected during the entire experiment. The temperature of sauna was measured at 10 seconds intervals during the sauna sessions. 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%.[4]

Experiments were supervised by a physician and participants were given the opportunity to leave the sauna at any time they felt uncomfortable. All participants underwent the recommended sauna protocol successfully. Participants remained in a seated upright position. Immediately after sauna exposure, participants were instructed to rest in a designated relaxing waiting lounge (mean temperature 21°C) for 30 minutes´ recovery. To make up for fluid loss due to increased sweating, participants were given 500 mL still water at room temperature for drinking during the entire sauna session, including the recovery period after sauna.[4,25,26] Body temperature was measured for each participant by the tympanic method (Apteq RA600, Rossmax International Ltd Rossmax Swiss GmbH).

2.5. Assessment of heart rate and heart rate variability

HR and HRV data were collected by a Polar V800 monitor (Polar, Finland), using a chest strap transmitter. Previous findings have shown the validity of the Polar V800 and its ability to produce RR interval recordings consistent with an ECG, and HRV variables derived from these recordings are also highly comparable.[32] Raw HR data was analysed by Kubios HRV system (version 3.0.2),[33] which is an advanced software for HRV analysis. The software computes all the commonly used time-domain and frequency-domain HRV and several nonlinear variables based on beat-to-beat RR interval data.[33]

In addition to detailed HR data collection in sauna, the following HRV variables - mean RR interval, root mean square of the successive differences between RR intervals (RMSSD), standard deviation of normal RR intervals (STDRR), low frequency (LF) power, high frequency (HF) power, total power, LF power normalized (nu) and HF power nu - were collected from six different assessment times with the participants placed at stable sitting position before, during and after the sauna exposure (time 1 = before sauna; 2 = 5-10 minutes in sauna; 3 = 15-20 minutes in sauna; 4 = 25-30 minutes in sauna; 5 = 2-7 minutes after sauna; 6 = at the end of 30 min recovery after sauna). These assessment points represent HR and HRV changes from pre-sauna to in-sauna phase until the end of recovery period post sauna allowing us to investigate HR and HRV profile during and in the 30-minute period after a single sauna bathing session. Participants were seated at least10 minutes in the chair in the quiet lounge room before and after sauna when HR and HRV data was collected. FFT was used for the spectrum estimation. Bandwidths was LF 0.04-0.15 and HF 0.15-0.4. LF and HF powers were expressed both in absolute values (ms^2) and in normalized values (nu). The normalisation of LF and HF was performed by subtracting the very low frequency component (VLF) from the total power. LF and HF were normalized by calculating LF/(TP-VLF)*100 and HF /(TP-VLF)*100, respectively, to receive values independent of total power. This procedure reduces the effects of noise due to artifacts and minimizes the effects of the changes in total power on the LF and HF components. RR interval, RMSSD, STDRR were measured in milliseconds (ms) whereas total power, LF and HF were measured in ms^2.

2.6. Exercise testing

To assess and confirm potential safety issues in our participants with cardiovascular risk factors before sauna exposure, a graded maximal standard clinical (ECG monitoring) exercise test was conducted on a cycle ergometer and the level of cardiorespiratory (aerobic) fitness was assessed.[4] The exercise test with continuous ECG (CardioSoft software V.1.84, GE Healthcare, Freiburg, Germany) recordings was performed at baseline visit using an electrically braked cycle ergometer (Monark Exercise AB, Sweden). The test was started with 3 minutes' warm-up with no resistance added and continued with 20-watt increments applied each 1 min until volitional exhaustion. Cardiorespiratory fitness was expressed in metabolic equivalents (METs) and maximal exercise workload in watts. 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.[4]

2.7. Laboratory analyses

Venous blood samples for the determination of plasma total, high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, 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). These analyses were taken to define cardiometabolic risk factor profile on the day participants were screened. All other blood samples for other analyses were taken on the day of the sauna experiment.[4] Participants were instructed to abstain from strenuous physical activity and sauna use 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). Venous blood samples for the determination of plasma biomarkers including hs-C-reactive protein and plasma creatinine were analyzed using chemiluminecent immunoassay by Siemens Immulite 2000 XPi analyzer (Siemens Healthcare Diagnostics Products Ltd., Llanberies, UK).

2.8. Statistical analyses

Data are presented as means (SDs) or median (interquartile range) for continuous variables according to their distribution and as number (proportions) for categorical variables. Normality was checked using the Shapiro-Wilk test as well as through observing the Q-Q-plots. Differences of normally distributed and log-transformed non-normally distributed HRV variables before (time 1), during (times 2, 3, 4) and after (times 5,6) sauna were estimated using repeated measures mixed models with an independent covariance. Before sauna exposure and during the recovery data were analysed for within-group changes with a paired t-test. To investigate possible effects of sauna bathing on autonomic nervous balance during recovery (e.g. changes in parasympathetic activity), we compared HR and HRV before sauna (time 1) to the two assessment points at the recovery phase (time 5 and 6), both of which were defined as after the sauna. Both absolute and relative changes in HR and HRV analyses were performed. The associations between HR responses during sauna with cardiorespiratory fitness, age and BMI were analyzed. 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.) and results are reported with 95% confidence intervals.

3. Results

The mean (SD) age, BMI, and cardiorespiratory fitness of the participants included in this study were 52.0 (8.8) years, 27.5 (4.5) kg/m^2, and 9.0 (2.1) METs, respectively. Proportion of current smokers was 14.4% and the resting systolic blood pressure and diastolic blood pressure were 137 (17) and 82 (10) mmHg, respectively. The proportion of participants with hypertension was relatively low (15.4%); hyperlipidemia and a family history of CHD were common cardiovascular risk factors in the study population **(Table 1).** The majority of participants reported using sauna baths 3 times per week (47.3%); the proportion of those using sauna 1 or 2 times per week was 15.4%. Other characteristics of study's participants are shown in **Table 1.**

Mean temperature of sauna room was 72°C. None of the participants demanded to leave the sauna room before the 30-minute sauna exposure period and no adverse events occurred. Mean body temperature increased during sauna session and tended to return to pre-sauna values at the end of 30-minute period after sauna - 36.4 (0.5) °C before sauna, 38.4 (0.7) °C immediately after sauna and 36.6 (0.4) °C at recovery ($p<0.001$) -. Sauna exposure was associated with a statistically significant increase in HR. HR and RMSSD profiles along the six measurements performed in the study are shown in **Figure 1a** and **b**, respectively. Mean HR increased from pre-sauna 77 beats per minute (time 1) to 120 per minute values (time 4). Immediately after sauna, mean HR was 83 beats per minute (time 5), decreasing to 68 beats per minute (time 6) at the end of recovery phase as reported in **Table 2**. Relative changes in HR, compared to baseline, are presented in **Supplementary Figure 1.**

Sauna bathing had significant effects on HRV variables as shown in **Table 2** and **Figure 2**. In addition to HR changes, mean RR interval, RMSSD, STDRR, LF, HF and total power were also changed when comparing pre-sauna values to immediate post sauna and post-30 min after sauna (**Table 2).** Mean RR was significantly higher post 30-min minutes after sauna as compared to pre-sauna levels. When comparing pre-sauna HRV variables to immediately after sauna or after 30 minutes recovery, most of HRV variables changed significantly. The reduction in LF power was -38.3% from pre-sauna to the end of recovery with a parallel increase in HF power of 27.8% (**Table 2**). In addition to total power change, normalized LF (20%) and HF (67 %) power changed significant ($p<0.001$) from pre-sauna until the end of recovery.

Supplementary Figure 2 shows the relationship of the difference between maximum HR response during sauna vs individual-level characteristics including maximal HR, cardiorespiratory fitness, age and BMI. The greater the levels of maximum exercise test , the lower the maximum HR level during sauna (up to 50% smaller in participants with maximum exercise HR of around 190-200 bpm). There were no significant associations between the magnitude of HR response during sauna and levels of cardiorespiratory fitness, age or BMI (**Supplementary Figure 2**).

4. Discussion

This single-group time series study investigated the effects of sauna bathing on HR and HRV parameters in adults with risk factors but without diagnosed CVD. The results from this study showed that a single sauna exposure leads to significant changes in cardiac autonomic nervous balance as indicated by changes in the HRV variables, including RMSSD, STDRR, LF, HF, and total power. HRV was favorable modulated after 30 minutes sauna exposure, suggesting a potential beneficial cardiovascular effect and a stress-releasing effect of sauna bathing during the recovery period.

These new results on sauna and HRV are in line with recent population-based study findings which indicate sauna bathing to be associated with reduced risk of CVDs.[1,7,13] Evidence on the role of Finnish sauna bathing on HRV is very limited, and thus this study provides novel findings on the effects of sauna bathing on autonomic nervous system modulation. Previous evidence on the beneficial effects of sauna on the autonomic nervous system have been based on the long-term effects of other passive heat therapies such as infrared-ray sauna and Waon therapy employed in patients with pre-existing conditions such as chronic heart failure (CHF). In a randomised control trial (RCT) of 4 weeks of Waon therapy versus usual care in patients with CHF, Waon therapy was demonstrated to have beneficial effects on several indices of the autonomic nervous system.[28] In another RCT of infrared-ray dry sauna versus no sauna treatment in patients with CHF, HRV was increased after 5 weeks of sauna treatment.[29] Six weeks of Thai sauna treatment in patients with allergic rhinitis led to significant changes in HRV.[30]

In contrast to these studies, our findings were based on a 30 minute exposure to Finnish sauna in participants with at least one cardiovascular risk factor with no pre-existing history of CVD. It has been shown that LF/HF ratio was increased after the sauna exposure in normal control subjects and patients with coronary artery disease.[34] A single sauna session may induce a significant alteration of autonomic cardiovascular control in patients with untreated hypertension who generally experience increased sympathetic and decreased parasympathetic activity.[35] These changes in cardiac autonomic nervous system were largely recovered within a period of 15 to 120 minutes after sauna bathing.[35] Another study suggested that post-exercise sauna exposure caused mild to moderate changes in resting vagal related HRV.[10] HR response to heat stress is considered to be similar to the physiological cardiovascular response to physical exercise, which may further influence favorably on HRV and cardiac autonomic nervous system. Even mild heat stress has been shown to influence main components of HRV, leading to a reduced HF component and increased LF/HF ratio within minutes of heat exposure.[36] In the current study, HRV was lowered during heat exposure, whereas HRV-HF activity, as an indicator of modulation in vagal activity, was substantially increased during the recovery (cooling down) phase from sauna.

This study showed that sauna bathing leads to significant modulation in cardiac autonomic nervous balance including increased parasympathetic activity after sauna bathing as indicated by changes in the balance of RMSSD, STDRR, LF and HF power, and HRV total power variables. High frequency power and HF-power nu increased while LF-power with LF-power nu decreased, which potentially affects favorably on the cardiac autonomic nervous system by increasing vagal tone activity in the 30-minute after sauna period. Increased sweating during sauna bathing is accompanied by reduction in blood pressure and a higher HR, whilst cardiac stroke volume is largely maintained; although a part of blood volume is diverted from the internal organs to peripheral body parts with decreasing venous return which is not facilitated by active skeletal muscle work. Indeed, comparable with exercise-induced adaptations, heat stress could increase HR up to 150 per minute.[26] Exposure to a Finnish sauna bath with an intensive thermal stimulus has been shown to increase HR with a corresponding decrease in HF-HRV component.[37] Our study showed that the mean HR increased from 77 beats per minute to 120 per beats minute level, while the highest observed HR of a participant was 150 per minute. Heart rate increased gradually from the beginning of sauna bath until the end, corresponding with an increase in body temperature.

It has been previously proven that hypertension, malignant arrhythmias, coronary artery disease and acute myocardial infarction are associated with a reduction of HRV.[11,38] Regular physical exercise, perhaps in combination with sauna bathing, is a potential preventive strategy to favorably increase HRV in population, most probably by inducing larger increases in cardiac vagal activity.[19,20] Regular sauna bathing has been shown to decrease risk of cardiovascular outcomes such as hypertension, fatal CVD events, SCD and neurodegenerative diseases.[6,7,13] Then, it is highly possible that the benefits of sauna bathing may be partly explained via effects of improved cardiac autonomic nervous system balance.[1] Also, our current study shows an inverse relationship between maximal HR during exercise and HR response to sauna: participants with lower HR levels during maximal exercise test achieved higher HR responses during sauna. It is interesting to note that sauna bathing may increase HR to the level which corresponds with moderate intensity of exercise.

In this study, HRV was measured to detect the modifications in sympatho-vagal activity during (at 73°C degrees) and after sauna (at 21°C degrees) using a common Finnish sauna protocol. The temperature of sauna was stabilized and controlled for every participant and measured at 10 seconds intervals during the sauna sessions. Participants' body temperature increased from the mean level of 36.4°C to 38.4°C immediately after sauna, although body temperature tended to decrease during the 30 minutes recovery period at a normal room temperature back to individual pre-sauna temperature levels. The positive effects on the autonomic nervous system were based on traditional hot and dry Finnish sauna bathing, which is unlike other types of saunas operating at lower temperatures or heated water immersion.[2,3] As this is the first study showing acute effects of 30 minutes' sauna exposure imitating a typical sauna session with a short 1-2 minutes 38°C shower combined with 30 minutes recovery period among participants with risk factors, we focused only on immediate effects of sauna bathing on body heat physiology, HR and HRV. However, it is unclear if sauna bathing induced changes in plasma volume might have effect on HRV responses.[39,40] Among athletes, acute exposure to extreme heat stress via sauna produced alterations in heart rate and cardiac autonomic modulations, with increased RMSSD during a sauna session.[41] Our current study is based on a relatively large number of participants, which provided adequate power to assess changes in HRV variables. In this study, the assessment of HR and HRV were performed using standard measurement protocols using HRV analysis system.[33] The limitations of this study deserve consideration. First, our study was based on a single group intervention pre-post design (without a control group or crossover design), which obviously has limitations compared to RCTs. The lack of a comprehensive control period limits the interpretation of the data on HR and HRV before and after sauna. However, given the pilot experimental nature of the novel study and limited funding available, we considered this design appropriate. Second, we were unable to adjust HRV for HR values, given that it is well established that measures of HRV are nonlinearly dependent on HR.[42,43] Indeed, it has been suggested that HRV should not be used alone to assess autonomic nervous system activity.[35,40] However, our study evaluated both HRV and HR, which are two distinct indices of cardiac autonomic function. On the other hand, there are studies indicating that we should not underestimate the possibility that the change in HRV reflect the change in HR. Due to the inverse curvilinear relationship between HR and R-R interval, HR per se can profoundly influence HRV parameters.[44] Some authors have suggested that HRV is dependent on HR and cannot be used in a simple way to assess autonomic function.[45] Third, our HRV measurements were not collected with paced breathing and we could not collect any measurements on breathing. We had no respiratory rate data available before, during or after the sauna bathing, which may partly limit our interpretation with regards to vagal tone changes. Fourth, it would have been appropriate to adjust fluid intake by assessing fluid loss using body weight before and after sauna exposure, however, we aimed to test traditional Finnish sauna habits. Fifth, the intervention was relatively short-term without serial repeated HRV measurements during a longer recovery period. The study design is, however, novel in this context focusing on immediate acute effects of sauna bathing on cardiac autonomic nervous system function. Findings from a previous epidemiological study suggest that to reduce CVD risk, frequent and regular sauna sessions of at least 20 minutes in duration for a single session may be required to exhibit beneficial effects on cardiovascular function.[1,7] We focused on population with cardiovascular risk factors as they might benefit from lifestyle interventions. The most beneficial duration of sauna has to be defined and as to whether combining a sauna bathing session with physical activity may be more effective with respect to changes in autonomic nervous system balance needs exploration. Indeed, we have previously shown that a combination of good cardiorespiratory fitness levels produced by aerobic exercise and frequent sauna bathing confer more protection on the risk of cardiovascular and all-cause mortality.[46-48] Finally, given that sauna bathing is a traditional habit in Finland, all our study participants were regular sauna users (minimum of one sauna session per week) as it was virtually impossible to recruit sauna naïve participants. Findings may therefore be confounded and not be generalizable to other populations that are not familiar with sauna bathing.[1,32,33]

This study showed the acute effects of a typical Finnish sauna on HR and HRV in a population with cardiovascular risk factors among regular sauna bathers. The results indicate that sauna bathing improves cardiac autonomic nervous system balance, leading to increase in vagal tone and decrease in sympathetic tone, with favorable modulations in HRV variables during the recovery from sauna. We found that a single sauna exposure leads to significant changes in cardiac autonomic nervous balance as indicated by modulation in the parameters of HRV such as RMSSD, STDRR, LF, HF, and total power. Sauna bathing is a recommendable habit for relaxation, although additional studies are warranted to establish the potential mid- and longer-term effects of sauna bathing on positive autonomic nervous system adaptations. On the basis of this study, HRV was modulated after 30 minutes sauna exposure, suggesting a stress-releasing effect of sauna bathing during the recovery period.

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Conflict of Interest

The authors declare that there are no competing interests.

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Figure Legends

Figure 1. Changes in heart rate during and after sauna bathing (a) and changes in root mean square of the successive differences (RMSSD) between RR intervals during and after sauna bathing (b)

Figure 2. Heart rate variability parameters change during and after sauna bathing

Figure 1

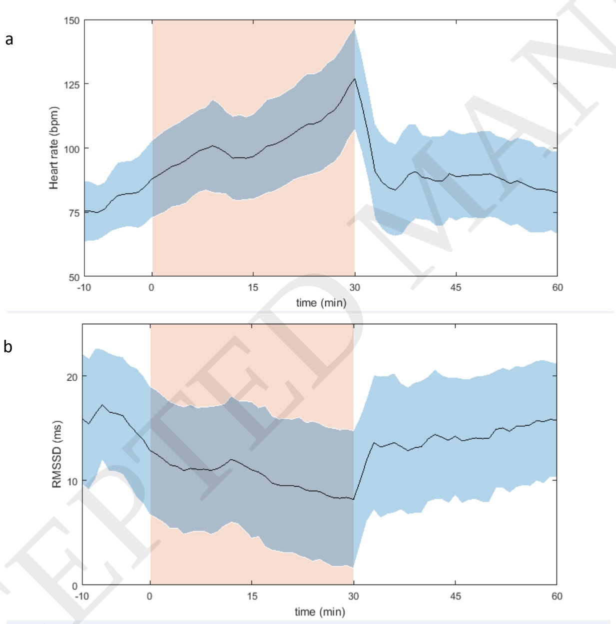
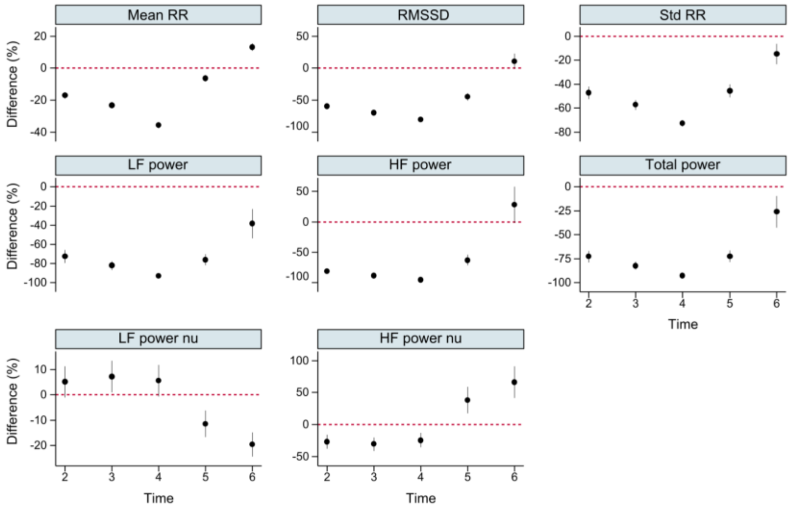


Figure 2



Percentage differences are reported for each time point vs baseline (time 1, pre-sauna). Estimates whose confidence intervals (spikes) do not cross the zero lines (red dotted lines) are statistically significant different ($p<0.05$) compared to time 1.

Mean RR = mean RR interval, RMSSD = root mean square of the successive differences between RR intervals; Std RR = standard deviation of normal RR interval; LF power =low frequency power; HF power = high frequency power; LF power nu = low frequency power normalized; HF power nu = high frequency power normalized

Time 1 = before sauna; 2 = 5-10 minutes in sauna; 3 = 15-20 minutes in sauna; 4 = 25-30 minutes in sauna; 5 = 2-7 minutes after sauna; 6 = in the end of 30 min recovery after sauna

Table 1: Characteristics of participants

Variable	N	Value*
Demographic and general parameters		
Age (years)	90	52.0 ± 8.8
Sex (M %)	93	50 (53.8)
Body weight (kg)	88	82.0 ± 15.7
Body mass index (kg/m^2)	88	27.5 ± 4.5
Systolic blood pressure (mmHg)	86	136.9 ± 16.5
Diastolic blood pressure (mmHg)	86	82.2 ± 9.7
Resting HR (bpm)	86	64.8 ± 10.4
Smoking (Yes, %)	90	13 (14.4)
~Hypertension (Yes, %)	91	14 (15.4)
^Hypercholesterolaemia (Yes, %)	91	51 (56.0)
Diabetes (Yes, %)	91	2 (2.2)
Family history of coronary heart disease (Yes, %)	90	28 (31.1)
Cardiorespiratory parameters$		
Achieved/Predicted Heart Rate (%)	86	103.6 ± 7.9
Maximum load (watt)	86	228.7 ± 53.5
Cardiorespiratory fitness (METs)	86	9.0 ± 2.1
Blood-based parameters		
Glucose (mmol/l)	91	5.2 ± 0.9
Total cholesterol (Tot Chol; mmol/L)	91	5.4 ± 1.0
Low density lipoprotein (LDL; mmol/L)	91	3.0 ± 0.8
High density lipoprotein (HDL; mmol/L)	91	1.4 ± 0.5
Triglycerides (mmol/L)	91	1.6 (0.9-2.3)
Creatinine (µmol/L)	93	76.3 ± 14.5
Hs-CRP (mg/l)	93	1.2 (0.5-2.5)
Regular typical Sauna use		
Frequency sauna (n/week)	91	
1 session		14 (15.4)
2 sessions		14 (15.4)
3 sessions		43 (47.3)
≥4 sessions		20 (21.9)
Duration sauna (min per session)	90	
≤30		54 (60.0)
30-60		22 (24.4)
≥60		14 (15.6)

*Continuous data are reported as mean ± SD or median (interquartile range) for normally and non-normally distributed variables, respectively; categorical data are shown as number (%).

$ Estimated before (pulse wave velocity) and during cardiopulmonary exercise test
~ Blood pressure medications
^ LDL >5.17 mmol/L
*M = male

Table 2: Characteristics of heart rate variability parameters before, during and after sauna (N=93)

	Time						% mean difference vs. reference (95% CI)	
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**5 vs. 1**	**6 vs. 1**
Mean HR (1/min)	76.5 ± 10.3	92.9 ± 15.8	100.4 ± 17.0	119.8 ± 19.0	82.7 ± 15.5	67.9 ± 11.9	+8.1% (5.0, 11.1) ***	-11.3% (-14.0, -8.5) ***
Max HR (1/min)	90.6 ± 12.0	104.2 ± 17.0	112.0 ± 17.9	135.8 ± 19.6	93.2 ± 16.7	76.4 ± 13.0	+2.9% (0.1, 5.6) *	-15.6% (-18.2, -13.0) ***
Min HR (1/min)	66.2 ± 9.8	82.2 ± 14.9	89.8 ± 16.5	104.0 ± 19.0	74.5 ± 14.7	61.3 ± 11.0	+12.5% (8.8, 16.2) ***	-7.5% (-10.8, -4.2) ***
Mean RR (s)	0.8 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	-6.3% (-8.4, -4.2) ***	+13.3% (11.0, 15.7) ***
RMSSD (s)	0.02 (0.02-0.03)	0.01 (0.01-0.01)	0.01 (0.00-0.01)	0.00 (0.00-0.01)	0.01 (0.01-0.02)	0.03 (0.02-0.04)	-44.8% (-50.7, -38.9) ***	+10.8% (-1.0, 22.7)
STDRR (s)	0.03 (0.02-0.04)	0.02 (0.01-0.02)	0.01 (0.01-0.02)	0.01 (0.01-0.01)	0.02 (0.01-0.02)	0.03 (0.02-0.04)	-45.6% (-51.0, -40.3) ***	-14.9% (-23.2, -6.5) **
LF power (ms^2)	719 (345-1365)	240 (88-381)	128 (61-294)	56 (18-125)	173 (65-391)	406 (195-763)	-76.2% (-82.0, -70.3) ***	-38.3% (-53.4, -23.2) ***
HF power (ms^2)	156 (86-307)	27 (15-64)	17 (8-42)	7 (3-19)	76 (22-151)	229 (103-444)	-62.8% (-71.2, -54.4) ***	+27.8% (-1.2, 56.8)
Total power (ms^2)	1018 (600-1981)	311 (127-545)	195 (90-461)	78 (28-189)	289 (127-587)	793 (413-1449)	-72.6% (-78.7, -66.6) ***	-25.9% (-42.3, -9.6) **
LF power nu (n.u.)	80.5 (73.4-87.9)	86.4 (78.0-91.8)	88.2 (80.0-92.0)	87.8 (78.6-90.9)	74.1 (64.1-80.9)	64.3 (56.3-78.4)	-11.4% (-16.4, -6.4) ***	-19.6% (-24.1, -15.1) ***
HF power nu (n.u.)	19.5 (12.1-26.5)	13.6 (8.2-22.0)	11.8 (8.0-20.0)	12.2 (9.1-21.4)	25.9 (19.1-35.9)	35.7 (21.6-43.7)	+38.2% (18.0, 58.4) ***	+66.6% (42.2, 91.0) ***

Time 1 = before sauna; 2 = 5-10 minutes in sauna; 3 = 15-20 minutes in sauna; 4 = 25-30 minutes in sauna; 5 = 2-7 minutes after sauna; 6 = in the end of 30 min recovery after sauna

Mean HR = mean heart rate; max HR = maximal heart rate, min HR = minimum heart rate, at the six different measurement points (from 1 to 6); HR is expressed as beats/minute
.
Mean RR = mean RR interval, RMSSD = root mean square of the successive differences between RR intervals; STDRR= standard deviation of normal RR interval; LF power =low frequency power; HF power = high frequency power; LF power nu = low frequency power normalized; HF power nu = high frequency power normalized; s = seconds; ms = milliseconds

For each time point and variable, data are reported as mean ± SD or median (interquartile range) for normally and non-normally distributed variables, respectively.
Differences are shown as percentage mean differences (95% CI) comparing time 5 vs 1 and time 6 vs 1.

* p-value <0.05
** p-value <0.01
*** p-value <0.001