Author(s): Rissanen, Joonas A.; Häkkinen, Arja; Laukkanen, Jari; Kraemer, William J.; Häkkinen, Keijo

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Acute Neuromuscular and Hormonal Responses to Different Exercise Loadings Followed by Sauna

Rissanen, J.A., Häkkinen, A., Laukkanen, J. Kraemer, W.J., Häkkinen, K.

ABSTRACT

The purpose of this study was to investigate acute responses of endurance (E+SA), strength (S+SA) and combined endurance and strength exercise (C+SA) followed by traditional sauna bath (70 °C, 18% relative humidity) on neuromuscular performance and serum hormone concentrations. Twenty-seven recreationally physically active men who were experienced with taking a sauna participated in the study. All the subjects performed sauna bath only (SA) first as a control measurement followed by S+SA and E+SA (paired matched randomization) and C+SA. Subjects were measured PRE (before exercise), MID (immediately after exercise and before sauna), POST (after sauna), POST30min (30 minutes after sauna) and POST24h (24 hours after PRE). Maximal isometric leg press ($ILPF_{max}$) and bench press ($IBPF_{max}$) forces, maximal rate of force development (RFD) and counter movement vertical jump (CMVJ), serum testosterone (TES), cortisol (COR) and 22 kD growth hormone (GH_{22kD}) concentrations were measured. All exercise loadings followed by sauna decreased $ILPF_{max}$ (-9 to -15%) and RFD (-20 to -26%) in POST. $ILPF_{max}$, RFD and CMVJ remained at significantly (P ≤0.05) lowered levels after S+SA in POST24h. $IBPF_{max}$ decreased in POST in S+SA and C+SA and remained lowered in POST24h. SA decreased $ILPF_{max}$ and $IBPF_{max}$ in POST and POST30min and remained lowered in $ILPF_{max}$ (-4.1%) at POST24h. GH_{22kD}, TES and COR elevated significantly in all loadings measured in the afternoon in MID. SA only led to an elevation (15%) in TES in POST. The strength exercise followed by sauna was the most fatiguing protocol for the neuromuscular performance. Traditional sauna bathing itself seems to be strenuous loading and it may not be recommended 24 hours before the next training session. Sauna bath after the loadings did not further change the hormonal responses recorded after the exercise loadings.

Keywords: Sauna Bath, Exercise, Loading, Performance, Acute Response, Recovery

INTRODUCTION

The combination of exercise followed by sauna bath is rather widely used as part of the overall training process and by some people's view sauna is as a recovery and relaxation method among physically active people. Saunas are most commonly located in many fitness clubs and gyms around the world. Despite the popularity of this combination, there is only a limited amount of experimental data about the acute effects of different exercise types followed by sauna. In addition, it is not quite clear, whether sauna bathing can be considered as a recovery method or actually a stressful loading itself. To our knowledge, there are no studies that have investigated the stressfulness of the combination of different exercise modalities followed by a high temperature sauna bath with regard to the neuromuscular performance and hormone responses.

The study of Mero et al. (24) investigated recovering effects of low temperature far-infrared sauna (30 min, 35°C–50°C) compared to the traditional one but at the same low temperature (30 min, 35°C–50°C) and sitting in the room temperature (30 min, 21°C) after typical hypertrophic strength and maximal endurance training sessions in recreationally physically active men. They found that far-infrared heat might have favourable recovery effects after the maximal endurance performance in these low temperatures. A traditional sauna bath usually has higher air temperature (70–100 °C) (4, 8, 14, 20) and it is more often used after exercise than far-infrared sauna. Nevertheless, higher temperature might also induce neuromuscular fatigue and act as a stress stimulus.

Acute effects of a typical hypertrophic strength loading and those of high-intensity interval endurance exercise as well as combined endurance and strength training sessions are rather well known. They all lead to decreases in maximal isometric force (ILPFmax) and rapid force produced during the first 500 ms (F0–500) in leg extensor muscles in the seated leg press (9, 29, 31, 33). A decrease is usually observed also in explosive dynamic performance such as countermovement jump (CMJ) after high-intensive strength and endurance loadings (25), although endurance-trained subjects can sometimes even show potentiation in their explosive performance after endurance exercise (2). Great acute elevations of serum cortisol (COR), testosterone (TES) and 22 kD growth hormone (GH_{22KD}) have been observed immediately post high-intensity endurance exercise (17, 35). Serum TES and COR concentrations have also been reported to elevate after resistance loading and the highest values may be reached about 15-30 minutes after exercise, if moderate to high intensities, short rest periods and large muscle mass are used (28). Large elevations in blood lactate concentrations have been observed after each exercise type but especially after hypertrophic loadings (10, 15, 23, 28, 29, 33). It is also important that the time of day in various experimental loading protocols are carefully planned since neuromuscular performance and especially serum TES and COR concentrations change during the day in circadian rhythm (11, 16).

After high volume hypertrophic strength loading TES returns to the baseline level in about one hour but cortisol concentration may remain elevated for more than two hours (10, 28). On the other hand, during the following 48 hours after the exercise resting morning concentration of TES may even decrease under the Pre-level, when very high volume heavy resistance loading protocols have been used (10). Serum immunoreactive GH_{22kD} concentrations have also significantly elevated after high volume resistance loading but returns rather rapidly to its basal levels (10). Combined endurance and strength loading also elevates TES after the loading (29). Interestingly, serum TES morning concentrations have then decreased for two recovery days after the loading indicating the stressfulness of this loading protocol (29). Previous studies of combined endurance and strength loadings have typically only used constant loads in endurance loadings.

To the best of our knowledge, only the study by Hedley et al. (7) has investigated the effects of sauna bathing alone on neuromuscular performance in euhydrated subjects. They reported in the experimental group of ten subjects the decrease in dynamic leg press 1RM performance but no change in dynamic bench press 1RM, while muscular power in vertical jump did not decrease. Sauna bathing has been reported to elevate serum levels of GH to 2- to 5-fold right after the sauna bath (4, 18, 21, 22, 32). Acute effects of sauna bathing (80–100 °C) on serum cortisol levels are somewhat contradictory. Some studies have reported elevated (27), some decreased and unchanged (18) cortisol values, while some studies did not show any change immediately after sauna (12, 19). After the post sauna cooling period serum cortisol concentration seems to elevate if there has been a slight elevation or no change during the sauna but to decrease, if there has been a decrease already during the sauna (12, 18, 19, 27). Various cortisol responses to sauna bathing may depend on the different durations and temperatures used in these studies and the trend is that the higher sauna humidity and temperature will lead to higher elevations in cortisol immediately after the sauna bath or after the post sauna cooling period (18, 27). Nevertheless, no changes in serum testosterone concentration have been observed after sauna bathing (18, 21).

The primary purpose of this study was to compare acute neuromuscular and hormonal responses and recovery patterns after the strength, endurance and combined endurance and strength exercise sessions followed by traditional sauna. Secondly, the purpose was to investigate, whether sauna bathing can be considered as a relaxation and recovery method or as a stressfulness loading itself.

METHODS

Experimental approach to the problem

Each participant had the baseline measurements and 4 different loading measurement sessions all separated by a minimum of 7 days between two sessions to wash out the acute effects of each session. All the measurements took place during the summer time. At first, all the subjects went through the baseline measurements for blood variables, body composition, body mass, height, several neuromuscular performance measurements. In addition, maximal oxygen consumption (VO_{2max}) and maximal heart rate (HR_{max}) were determined during the graded exercise test on the cycle ergometer. These measurements were used for the baseline information of the subjects and to determine the relative loads for each subject in the exercise loading protocols. Thereafter, subjects performed 4 different loading protocols: first sauna only loading (SA) as the control loading, followed by strength exercise + sauna loading (S+SA) and endurance exercise + sauna loading (E+SA) (paired matched randomization) and finally combined endurance and strength exercise + sauna loading (C+SA). The subjects were measured during the loading protocols five times: PRE (before loading), MID (after loading), POST (after sauna), POST30min (30 minutes of recovery after sauna) and POST24h (24 h after the starting of the PRE measurements), but in the SA loading protocol no MID measurements were included (Figure 1). Each subject performed his measurements always at the same time of the day either in the morning or in the afternoon in order to standardize the neuromuscular and hormonal conditions.

******************************** Figure 1 about here ***************************

Subjects

Twenty-seven physically active and healthy men (age 32.7 ± 6.9 years, height 181.0 ± 5.8 cm, body mass 80.5 ± 6.4 kg, body fat percentage 15.8 ± 4.5 %, body mass index 24.6 ± 1.9, VO_{2max} 46 ± 6 $mL \bullet min^{-1} \bullet kg^{-1}$) from the Jyväskylä region in Central Finland were included in the study. All the subjects were over 18 years old, experienced with taking a sauna bath regularly, and had some training background for recreational purposes, in both endurance and strength training. No specific endurance or strength training programs were followed by the subjects before the intervention. The subjects were free of any medication that would affect their endocrine function. All subjects went through the resting ECG-scan and the medical questionnaire before inclusion. Thirty subjects initially volunteered in the study but three of them dropped out because of injuries (N=2) and personal reasons (N=1). They had reported to exercise, at least two times, and sauna bath, at least once a week. The subjects were informed about the risks and benefits of the study before any data collection, and thereafter, an institutionally approved written informed consent document to participate to this study was signed by all the subjects.

The study was approved by the Ethics Committee of the Central Finland Health Care District (K-SSHP Dro 5U/2016), Finland, and conducted in accordance with the Declaration of Helsinki. The subjects were advised to avoid any strenuous exercise for two days and totally refrain from alcohol consumption for three days before each session. During the 24-hour recovery period any exercising or alcohol consumption was also strictly forbidden. Otherwise, subjects were advised to maintain their daily activity levels, training and sauna bathing routines.

Procedures

Height, Body Mass and Body Fat Measurements

Height was measured with a measuring tape while standing against the wall. Body fat percentage was measured in a fasted state in the morning using the bioelectrical impedance method (Inbody 720, Biospace Co., Seoul, South Korea). The hydration status was controlled in the body fat measurement. Height and body fat percentage were determined only in the baseline measurements.

In the loading protocols body mass was measured to determine the weight loss. Drinking water was provided ad libitum to the subjects in order to keep them fully hydrated during the loadings. The Seca 708 lab scale (Seca GmbH, Hamburg, Germany) was used for body mass measurements during the loading conditions. All the subjects were weighed in PRE, MID, POST, POST30min and POST24h in the loading protocols.

Venous Blood Samples

The measurement sessions started with fasting state venous blood samples at 7:30 ± 0:20 am. (>10 h of fasting overnight before the measurement) followed by a small low-fat breakfast including two slices of rye bread and one banana to standardize the nutritional status of the subjects. Thereafter, venous blood samples were taken in PRE, MID, POST, POST30min and POST24h in the loading protocols. With the morning subjects, the fasting state blood sample was determined as a PRE-sample, but the afternoon subjects gave a new PRE-sample in the afternoon just before their started their loading protocols. The afternoon subjects were told to eat their lunch >2 hours before their afternoon PRE-sample to standardise their nutrition status as well.

All venous blood samples were taken from the antecubital vein into serum tubes (Venosafe, Terumo Medical Co., Leuven, Hanau, Belgium). The samples were allowed to cool down >30 minutes in room temperature and then centrifuged in 3600 rpm for 10 minutes (Megafuge 1.0 R, Heraeus, Germany) to separate the serum and the blood cells. Thereafter, the serum samples were stored in the freezer (-20 °C) until analysed during the next two months. Serum hormone concentrations of TES, COR and GH_{22kD} were analysed using chemical luminescence techniques and hormone-specific immunoassay kits (Immulite 2100, Siemens, New York, NY, USA). Sensitivities for TES, COR and GH_{22kD} were 0.5 nmol●L^{-1}, 5.5 nmol●L^{-1} and 0.03 mlU●L^{-1}, respectively. Intra-assay coefficients of variation for TES, COR and GH_{22kD} were 9.8 ± 3.9 %, 7.1 ± 1.1 % and 6.0 ± 0.5 %, respectively. Inter-assay coefficients of variation for TES, COR and GH_{22kD} were 12.0 ± 6.3 %, 7.9 ± 1.2 % and 5.8 ± 0.3 %, respectively.

Blood Lactate Measurements

Blood lactate (BL) samples were taken in PRE, MID, POST and POST30min in the loading measurements. The samples were taken from fingertip to 20 µL capillary tubes using a safety lancet (Sarstedt AG & Co, Nümbrecht, Germany). The capillaries were collected into Safe Lock -tubes and lactate analyses were made using a Biosen C-Line device, (EKF Diagnostics GmbH, Barleben, Germany).

Body temperature Measurements

The ear thermometer (Braun ThermoScan PRO 6000, Braun GmbH, Kronberg, Germany) was used for body temperature (BT) measurement. No statistical difference between core temperature measured with the digital contact thermometer and temperature measured from the ear with the new generation infrared tympanic thermometer has been found (6). Average of two consecutive measurements was used in the analysis. The values were recorded with the accuracy of 0.1 °C and all the measurements were taken from the left ear of the subjects, while they were sitting silently on the bench. The Mid and Post measurements were taken 2.5 minutes after the exercise or sauna loadings.

Neuromuscular Performance Measurements

The warm-up protocol before the PRE measurements consisted of 10 minutes of cycling with a light load followed by 2 x 10 repetitions with the load of 55 % of 1RM in the dynamic bilateral bench press.

Counter Movement Vertical Jump (CMVJ) was measured using the force platform (Neuromuscular Research Center, Biology of Physical Activity, University of Jyväskylä, Finland) and the data were captured and analysed with Signal software version 4.14 (Cambridge Electronic Design Ltd., Cambridge, United Kingdom). The jump height was calculated from the force impulse. In the starting position of CMJ, subjects were standing in the upright position and the hands on their hips. Subjects started CMJ by making a fast movement towards the ground by bending their knees down to about 90 degrees, then simultaneously changed the direction and pushed off the ground. In every trial, subjects were encouraged to jump as high as possible. PRE and POST24h measurements consisted of three trials with a 30-second rest between the jumps and MID, POST and POST30min measurements of two attempts with 20 seconds rest in between. The best attempt was chosen for analysis.

Isometric Bilateral Bench Press ($IBPF_{max}$) was measured using the custom-built bench press dynamometer (University of Jyväskylä, Finland). Subjects started the test laying on their back on the bench, hands on the bar and elbows in the 90 degrees of angle. The bar was placed horizontally at the same level as subject´s inferior part of the pectoralis major. Subjects were instructed to fill up their lungs before starting the trial and then push as hard as they can towards the bar for 3–5 seconds. Strong verbal encouragement was used during the attempts. The requirements of the accepted trial were keeping their feet on ground, hips and shoulders on the bench. The maximum isometric force was taken in kilograms from the monitor of the bench press machine. The measurement consisted of three trials with 60 seconds of rest between the attempts and the best attempt of these three trials was chosen for further analysis. In the loading measurement sessions only two attempts with 20 seconds of rest in between were allowed in MID, POST and POST30min.

Isometric Bilateral Leg Press ($ILPF_{max}$) was measured using the custom-built electromechanical dynamometer (University of Jyväskylä, Finland). The knee angle of 107° (180° represents the full extension position of the legs) was used in this measurement. Subjects were instructed to fill up their lungs and hold a breath before pushing as hard and as fast as they can towards the plate under their feet for 3–5 seconds. Strong verbal encouragement was given during the attempts. 60-second rest periods were used between the trials and the best attempt of three trials was chosen for further analysis. In the loading measurement sessions two attempts with 20 seconds of rest in between were allowed in MID, POST and POST30min. The high reproducibility of the present isometric leg press measurement protocol has been observed in several previous studies (10, 11, 26, 34). Maximal isometric leg press force ($ILPF_{max}$) in Newtons (N), average force during 0-500 ms from the start of the force production ($F_{0\text{-}500}$) in Newtons (N) and maximal rate of force development (RFD) in Newtons per second ($N \bullet s^{-1}$) were analysed from the leg press data. The data analyses were made using Signal software version 4.14 (Cambridge Electronic Design Ltd., Cambridge, United Kingdom).

Loadings

Sauna Loading (SA)

SA lasted for a total of 32 minutes and performed in three 10-minute intervals with 1-minute cooling periods in between as typically done in Finland. A traditional Finnish sauna with the electrical stove was used and 2 dL of water was thrown to the rocks in the beginning and after 5 minutes of each 10-minute sauna interval. Mean air temperature and humidity (measured at the bather´s face level) during the sauna loadings were 70.2 ± 1.0 °C and 18.2 ± 6.6 %, respectively. The measurements were taken before the first sauna interval and in the end of each sauna interval with the sauna hygrometer and bimetal thermometer specially designed to be used in sauna. The similar sauna loading started 15 minutes after the exercise loadings.

Endurance Exercise + Sauna Loading (E+SA)

E+SA was performed using the high intensity interval protocol on a cycle ergometer. The endurance exercise loading consisted of 15 minutes of progressively graded loads followed by typical 4 x 4 minutes intervals with 4 minutes of recovery in between. The total duration was 43 minutes. The intensities were determined from the graded exercise protocol performed in the baseline measurements and the pedalling frequency of 70 was used. The first 10 minutes of the exercise was pedalled with 65 % of HR_{max}, following 2.5 minutes with 70 % of HR_{max}, and the next 2.5 minutes with 75 % of HR_{max}. The interval intensities were 90, 92.5, 95 and 95 % of HR_{max} and during the recovery periods heart rate was recovered down to 70 % of HR_{max}. HR of each load was measured using an average of the last 15 seconds of the load.

Strength Exercise + Sauna Loading (S+SA)

The hypertrophic strength loading protocol in dynamic bilateral bench press and leg press was used. The bench press exercise was followed by the leg press. Both exercises consisted of 2 x 12 warm up sets with 2 minutes recovery. The actual exercise sets were 4 x 10 with 3 minutes recovery after each set. In the bench press exercise the loadings were 50 and 60 % of 1RM in the warm-up sets and 75, 80, 80 and 80 % of 1 RM in the actual exercise sets. The leg press exercise loads were 50 and 70 % of 1RM in the warm-up sets and 85, 90, 95 and 95 % of 1RM in the actual exercise sets. In both exercises, the last repetitions of the last two sets were slightly assisted by the research assistant, if the subject reached the voluntary failure before 10 repetitions were performed. The IBP F_{max} was measured in the middle of the exercise, 30 seconds after the last bench press set before starting the leg press loading. All the other MID measurements were taken after the whole loading.

Combined Endurance and Strength Exercise + Sauna Loading (C+SA)

The volume of C+SA was matched with that of the S+SA and E+SA using the half of the volume of both loading protocols but otherwise the same protocols were used. In the Endurance loading part, the first 5 minutes of the exercise was pedalled with 65 % of HR_{max}, following 1.25 minutes with 70 % of HR_{max}, and the next 1.25 minutes with 75 % of HR_{max}. The interval intensities were 90, and 95 % of HR_{max} and during the recovery periods heart rate was recovered down to 70 % of HR_{max}. The strength training exercises consisted of one warm up set of 12 reps and 2 actual exercise sets of 10 reps with 2 minutes of recovery after the warm-up set and 3 minutes of recovery after the first exercise set. In the bench press the loads were 60, 80 and 80 % of 1RM and in the leg press the loads were 70, 90 and 95 % of 1RM, respectively. The IBP F_{max} in MID in C+SA was also measured in the middle of the exercise similarly as in S+SA. The order of exercises was the same in all subjects so that the endurance exercise was performed first followed by the bench press and leg press exercises. The Sauna loading started 15 minutes after the end of the combined endurance and strength exercise loading session (Fig 1). Each MID, POST and POST30min measurement was taken at the same time point after the loading except for IBP F_{max} in S+SA and C+SA in MID (Table 1).

*************************** Table 1 about here ******************************

Statistical analyses

Mean PRE-values in all the loadings are reported in the absolute scale with standard deviation (SD) and all the other measurements as the relative change with 95 % confidence interval (95% CI) The only exception was GH_{22kD} which is reported in the absolute change scale in all measurement points. Serum testosterone and cortisol results are analysed separately for the morning and afternoon groups due to the circadian rhythm. The statistical significances between groups in PRE were tested by using one way Anova. Between group differences and within group changes were tested by Generalized Estimating Equations -model (GEE-model). Pairwise post-hoc analyses were made by using Sidak correction. All statistical analyses were performed using IBM SPSS Statistics -software version 24 (SPSS, Inc., Chicago, IL, USA).

RESULTS

Maximal Isometric Leg Press Force (ILP F_{max})

All three exercise loadings led to the significant decreases in ILP F_{max} in MID (Table 2). Significant changes took also place between PRE and POST, and PRE and POST30min, in all four loadings, including SA (Table 2). After 24 hours of recovery there were statistically significant decreases between PRE and POST24h only in the SA and S+SA (Table 2). Significant differences were observed between loadings in MID (p=0.011), POST (p<0.001), POST30min (p<0.001) and POST24h (p<0.001).

**************************** Table 2 about here ****************************

Isometric Leg Press Maximal Rate of Force Development (RFD)

RFD decreased significantly in all exercise loadings followed by sauna in MID (-30.6 to -20.4 %), POST (-26.2 to -19.9 %) and POST30min (-22.1 to -21.2 %) compared to PRE (Table 2). SA showed the significant decrease (-16.9 %) only in POST30min. In POST, RFD in C+SA recovered more than in S+SA and no recovery was observed in E+SA. In POST30min all three loadings of C+SA, S+SA and E+SA were at the same level. There were significant differences between the loadings in the POST (p=0.001) and POST30min (p=0.039) measurement points.

Isometric Leg Press Average Force during 0-500 ms ($F_{0\text{-}500ms}$)

Statistically significant decreases in $F_{0\text{-}500ms}$ were observed in MID, POST and POST30min in all exercise loadings followed by sauna as well as in SA in POST and POST30min (Table 2). In POST24h, the subjects were recovered to the PRE-level except in S+SA in which fatigue was still observed on the next day after the loading -13.1 % (-25.7 to -0.5 %). Significant differences occurred between the loadings in POST (p=0.001) and POST30min (p=0.003) and POST24h (p=0.010).

Counter Movement Vertical Jump (CMVJ)

CMJ decreased significantly from PRE to MID, POST and POST30min significantly in S+SA and C+SA (Table 2). In SA and E+SA significant decreases occurred in POST30min (Table 2). After 24 h of recovery only S+SA -4.3 (-7.1 to -1.5) % did not recover to the baseline level. Between groups difference was significant in MID (p=0.001), POST (p=0.001), POST30min (p=0.004) and POST24h (p<0.001).

Bench Press Maximal Isometric Force (IBP F_{max})

IBP F_{max} significantly decreased in S+SA (-30.0 (-34.8 to -25.2) %) and C+SA (-23.8 (-30.1 to -17.6) %) from PRE to MID. IBP F_{max} remained at the significantly lower level also in POST, POST30min and POST24h in both S+SA and C+SA loadings (Table 2). The SA loading also showed the significant decrease in POST and POST30min. Between groups differences were statistically significant (p<0.001) in MID, POST, POST30min and POST24h.

Serum Testosterone Concentrations (TES)

Significant elevations in TES took place in the afternoon subject group in MID in all the exercise loadings (Figure 2 and Table 3). The SA loading showed the significant TES elevation in POST and S+SA in POST24h. No significant between group differences were found in the afternoon subjects.

In the morning subject group TES showed no significant changes in MID compared to PRE, (Figure 2 and Table 3). In POST and POST30min significant decreases occurred in the SA and S+SA and there were significant differences between the loadings in MID (p=0.020) and POST (p=0.034) in the morning subjects.

****************************** Figure 2 about here *************************

Serum Cortisol Concentrations (COR)

In the afternoon subjects COR elevated after all the exercise loadings from 64.4 to 75.7 % between PRE and MID (Figure 3 and Table 3). In SA, the significant decrease in COR was found in POST30min -19.1 (-35.2 to -3.1%) but neither in POST or POST24h.

In the morning subjects COR decreased significantly in all loadings, including SA, in POST and POST30min (Figure 3 and Table 3). In POST and POST30min there was a significant difference between the loadings (p<0.001).

****************************** Figure 3 about here *************************

Serum Growth Hormone Concentrations (GH_{22kD})

Significant elevations were observed in GH_{22kD} concentration from PRE to MID in all exercise loadings (Table 3). The elevated absolute values were in E+SA 9.24 (4.78 to 13.70) μg●L^{-1}, in C+SA 5.63 (2.74 to 8.52) μg●L^{-1} and in S+SA 4.91 (2.33 to 7.50) μg●L^{-1}. In the POST measurements, the elevations were still observed in all the loadings, but in POST 30 only in S+SA (Table 3). Significant elevations compared to the PRE measurement were also observed in SA in the POST (4.10 (1.61 to 6.59) μg•L^{-1}) and POST30min (1.96 (0.49 to 3.43) μg•L^{-1}). Significant between loadings difference was observed in MID ($p=0.011$).

***************************** Table 3 about here ****************************

Blood Lactate and Body Temperature

Mean (SD) BL significantly elevated after exercise in all loadings in MID ($p<0.001$). In S+SA (10.62 (3.17) mmol•L^{-1}) and C+SA (9.85 (2.81) mmol•L^{-1}) BL levels elevated more than in E+SA (8.20 (2.58) mmol•L^{-1}) in MID and the significant difference between loadings ($p<0.001$) was found. After sauna in the POST measurements BL levels recovered to the PRE-level. BT increased in MID compared to PRE by 0.6 °C, 0.3 °C and 0.3 °C in E+SA, C+SA and S+SA, respectively. In POST the increases compared to PRE were 1.3 °C, 1.2 °C, 1.1 °C and 1.0 °C, in C+SA, E+SA, S+SA and SA, respectively.

DISCUSSION

As expected, large acute decreases took place in the neuromuscular performance after the present exercise loadings followed by sauna indicating the strenuousness of this type of combination. The present strength loading followed by sauna was more fatiguing for the neuromuscular performance than that of the endurance or the combined exercise followed by sauna most likely due to less activated muscles in endurance and combined loading (29, 31). The neuromuscular performance returned to the PRE-level in E+SA and C+SA in POST24h but in the case of both upper and lower body it remained at the lower level in S+SA due to higher neuromuscular stimulus caused by the present strength loading protocol. The hormonal responses were typical for the present exercise loadings, because acute significant elevations in growth hormone concentration were observed in all loading conditions in MID and POST. Several previous studies have shown that both physical exercise and sauna elevate serum GH levels (4, 17, 35). Serum testosterone concentration elevated only in the afternoon group immediately after the strength, endurance, combined loadings and after sauna only.

The S+SA loading was the only exercise + sauna loading after which maximal leg press force was still significantly lowered at 24h and indicating a need for a longer recovery time. Maximal isometric bench press force was also significantly decreased after all loadings in POST except in E+SA and the similar trend in the lower recovery rate in S+SA compared to the other loadings was observed after the following 24 hours. The significant decreases in the explosive performance of the lower body, measured both in the isometric (RFD and $F_{0\text{-}500}$) and dynamic (CMJ) conditions, were larger both in S+SA and C+SA which included strength exercises. The finding that no significant decrease in IBP F_{max} was found in E+SA in POST is plausible, because the upper body was not loaded during the endurance exercise loading. Nevertheless, the significant decrease was observed in the E+SA loading in POST30min both in IBP F_{max} and CMJ but these decreases were, percentwise, smaller than in the two groups that did perform strength exercises. In addition, IBP F_{max} and CMJ in S+SA and C+SA decreased from POST to POST30min which might be in part due to the cooling of the body temperature after the sauna bath, when subjects stayed in the room temperature. The findings that sauna bathing itself decreased acutely neuromuscular performance and the performance was still at the lower level after 24 hours suggest that sauna bathing, when using the present high temperature and duration, might not be recommended for physically active people too close before an intensive strength training session. This might be a valid recommendation in the case of the becoming competition in athletes to make sure that it has no negative effects on the neuromuscular performance. The mean weight loss during the present measurements stayed < 0.9 % in all of the loadings and the measurement time points due to water drinking. The previous study by

Judelson et al. (13) did not find any significant difference between the 0, 2.5 and 5 % dehydration groups in maximal isometric force or vertical jump performance.

When comparing the upper and lower body, the present bench press loading led to a much higher acute decrease in IBP F_{max} in comparison to the decrease caused by the leg press loading in ILP F_{max} in MID. Nevertheless, after the sauna bath the decrease in maximal strength in POST was smaller in the upper body than in the lower body. This might be due to the longer recovery time after the isometric bench press measurement than that of after the isometric leg press measurement, because the bench press loading was performed first. However, the present strength loading for the lower body followed by the sauna bath appeared to be more demanding for the neuromuscular system than the strength loading for the upper body followed by the sauna bath. In POST24h the order was again vice versa and the upper body was more fatigued and the significant decrease was found in both S+SA and C+SA in IBP F_{max} but only in S+SA in ILP F_{max}. The present results suggest that 24 hours seems to be the time that is enough for the lower body to recover after the present E+SA and C+SA loadings but not after the S+SA because the neuromuscular load for the lower body is much more fatiguing in S+SA than in E+SA or C+SA. This comparison indicates that the acute effects of sauna bath appear to be different for the lower and upper body but further experimental research is needed regarding the mechanisms behind this phenomenon. The larger muscle mass of the lower body might have an influence on this phenomenon but also the fact that hot air in the sauna rises upwards which makes it hotter for upper body than lower body. In addition, the separate measurement sessions for the upper and lower body should be considered in the future.

Serum TES and COR concentrations were analysed separately in the morning and afternoon groups due to the circadian rhythm of these hormones demonstrated in several earlier studies (e.g. 11, 16). Earlier studies have observed that TES response to a typical heavy hypertrophic strength training protocol is very short and the rise of total testosterone seems to end immediately post (16) or at the latest after 15 minutes of recovery (28). In addition, the studies by Ratamess et al. (28) and Häkkinen & Pakarinen (10) have showed that serum TES concentration seems to return to the Pre-level in about one hour after the strength exercise session. In the present study, the time between the MID and POST measurements was about one hour which indicates that the sauna bath after the exercise may not lead to the continued elevation in serum testosterone concentration. Häkkinen & Pakarinen (10) have showed that the very high volume and intensive heavy resistance loading protocol leads to the large acute elevation in serum TES but, thereafter, the significant decrease in serum basal morning TES levels took place after a recovery period of 24-48 hours. That finding indicated how a long time it may take to recovery from the strenuousness of this type of loading. However, the overall volume of the present loading was much smaller and serum TES concentration was significantly recovered after 24 h in the afternoon subjects. Nevertheless, the possibility that sauna bathing after the strength exercise has some effects on TES levels of the next day cannot be totally excluded. In the morning subjects most of the TES changes were most likely masked by the circadian rhythm (11, 16). Earlier studies have also shown that the present type of strength exercise stimulus in the morning has caused the acute elevation in serum testosterone concentration but the post exercise level has still been somewhat lower than the morning baseline value (11, 16). The same phenomenon was observed in the present study, when the significant decreases in the morning group were observed in SA in POST and POST30min, in C+SA in POST and in S+SA in POST30min. Thus, it is very likely that the present exercise stimulus was not high enough to lead to the elevated TES values to overcome the effect of the circadian rhythm on hormonal regulation. Despite the significant differences observed in the acute responses in serum TES between the morning and afternoon subjects in all of the loadings, no systematic differences were observed in the loading induced acute responses of these two groups in the neuromuscular performance (data not shown).

It is known that sauna bath (27), endurance (3), strength (1), and combined endurance and strength exercise (30) sessions can all induce some fluctuation in blood plasma volume immediately after the exercise that can have minor effects on blood hormone concentrations. Usually, from small to moderate decreases in blood plasma volume immediately after the exercise (1, 3, 30) or sauna bathing (27) but an elevation of plasma volume back to the baseline level or even slightly over can be observed after 30–60 minutes of recovery (1, 3). However, the duration of the loadings in the present study were quite short (~35-45 minutes) and plasma volume changes were probably rather similar between the exercises and sauna bath. Thus, the influences of the plasma volume changes on hormone concentrations have probably been rather low, and, most likely, they may have not influenced markedly on the comparability of serum hormone concentrations because of possible similarity of plasma volume decreases between the present loadings.

Extensive acute elevations in serum cortisol concentrations were found after all exercise loadings in the afternoon subjects in MID. After sauna in POST the elevations were still rather high but not significant anymore. Previous studies have showed that COR returns slower to the basal level after the exercise than TES (10, 28). A similar trend might be observed in the present study and the sauna bath might somewhat still delay the COR decrease after the exercise, although large inter individual variation was observed in COR concentrations. Nevertheless, SA alone significantly decreased COR in POST30min in the afternoon subjects which might indicate the opposite reaction after the present sauna loading for some individuals. The morning subjects showed the decrease of -50.1 % in COR in SA in POST. This finding indicates that the morning sauna bath with the combined effect of the normal COR circadian rhythm leads to the decrease in serum COR in the morning masking possible effects of the sauna bath as in the case of serum TES. Earlier studies have showed somewhat contradictory results regarding the COR concentrations during sauna bathing (12, 18, 19, 27). Jezová et al. (12) even discussed about the possibility of biphasic response of COR to the sauna exposure so that COR concentration may first decrease during the initial phase of sauna bath and then elevate during the remaining part of sauna bath. Nevertheless, more frequent blood sampling would be needed for further conclusions. In the present study significant differences in COR between the morning and afternoon subjects were observed in MID, POST and POST30min in all the loadings (data not shown) as in the case in serum TES.

The GH_{22kD} is secreted mostly in pulses during the day and night from the anterior pituitary gland (5) and the circadian pattern that it follows is different from TES and COR. Therefore, all the subjects were analysed as one group in the GH_{22kD} analysis. Serum GH_{22kD} elevated significantly after three exercise loadings in MID and in all loadings including the sauna bath alone in POST, which supports the previous findings so that both the exercise (10, 35) and sauna bath (18, 21, 22, 32) can stimulate the anterior pituitary gland to secrete the GH_{22kD} pulse. Possible long-term effects of frequent sauna bathing on body composition, GH_{22kD} basal levels and acute GH_{22kD} responses after the sauna may be interesting aspects to study in the future. After the sauna bath in POST serum GH_{22kD} in the SA loading was at the higher level than in the other loadings at the same time point, but due to large inter individual variation no significant difference between the loadings was found.

The duration of the present sauna bath was 30 minutes as e.g. in the study by Mero et al. (24) which investigated recovery effects of far-infrared sauna after exercise. However, in the real life, a sauna bath session may normally last from 5 to 20 minutes (8, 20). A shorter duration of sauna bath would probably be less taxing for the neuromuscular system but it would very likely have some effects on hormonal responses, too. The higher sauna temperature (70 °C) lasting for 30 minutes seems to be very fatiguing for the neuromuscular performance as the control loading (SA) in the present study showed. Therefore, it is very unlikely that the present sauna protocol would have recovery effects if the study design of Mero et al. (24) is replicated.

In the future, it might be beneficial to conduct studies using shorter durations with various temperatures in the sauna bath after the exercise session. The strength of the present study was the comprehensive study design where the neuromuscular performance of both upper and lower body was measured showing their different responses to the present loadings. The number of subjects (n=27) in the present study was also reasonably high compared to other studies in this field. The limitation of the present study was that the effects of exercise loading followed by sauna were investigated only in men. Since previous studies have showed that both neuromuscular and hormonal responses to various strength exercise sessions in men differ from those observed in women (9), it would be also interesting to investigate these responses after the exercise followed by sauna in women. In addition, more frequent blood sampling would be beneficial during the loading protocols in the future studies to investigate more accurately the hormonal responses to the different stimuli.

PRACTICAL APPLICATIONS

The intensive strength exercise session followed by sauna is more fatiguing for the neuromuscular performance than intensive endurance exercise or the combined endurance and strength exercise followed by sauna. Therefore, a longer recovery time before the next training session is recommended after the strength training session followed by sauna. Although elevations of serum cortisol, testosterone and growth hormone concentrations are observed after high-intensive exercises, no further changes in hormone concentrations are observed after a post exercise sauna bathing session. High temperature sauna bath lasting 30 minutes as such is a fatiguing stress stimulus for the neuromuscular performance. Thus, it is recommended to avoid a strenuous sauna bath, at least, 24 hours before the next training session to ensure non-fatigued conditions. It also seems that in the future it would be beneficial to conduct studies by using sauna bathing with both shorter durations and lower temperatures in attempts to optimise loadings conditions and possible recovery effects of sauna.

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Figure legends

Figure 1. Timeline of the loading protocols (except for SA that included neither exercise loading nor MID measurements)

Figure 2. Relative changes from PRE-level (=100 %) in serum testosterone concentrations in all loadings by dividing subjects into the Afternoon (Aft) and Morning (Mor) groups. Within groups levels of significance compared to PRE $*p<0.05$ and $**p<0.01$ and $***p<0.001$

Figure 3. Relative changes from PRE-level (=100 %) in serum cortisol concentrations in all loadings by dividing subjects into the Afternoon (Aft) and Morning (Mor) groups. Within groups levels of significance compared to PRE $*p<0.05$ and $**p<0.01$ and $***p<0.001$.

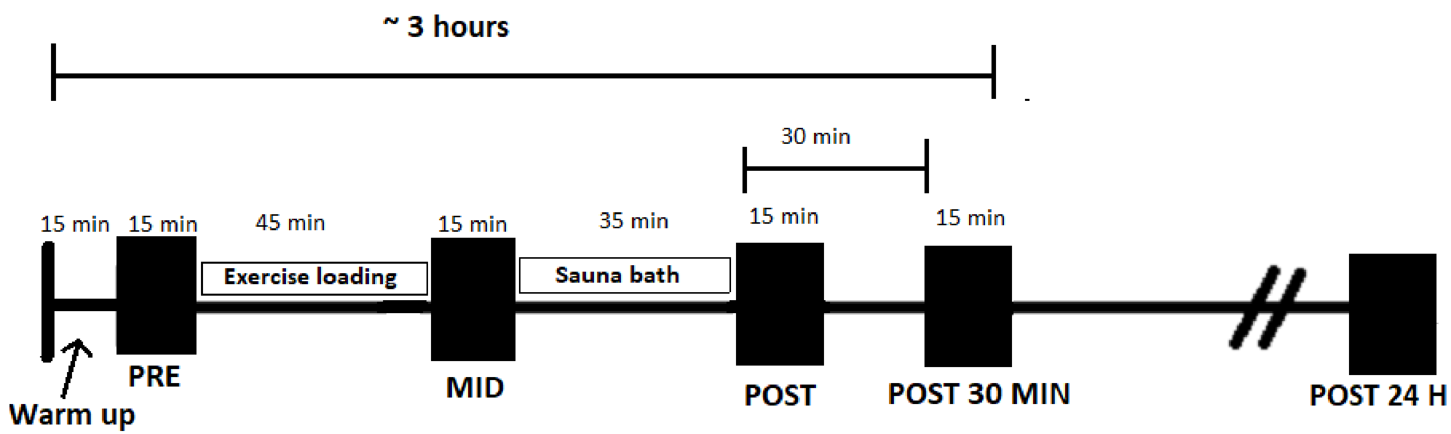
~ 3 hours
30 min
15 min
15 min
45 min
15 min
35 min
15 min
15 min
Exercise loading
Sauna bath
PRE
MID
POST
POST 30 MIN
POST 24 H
Warm up

Fig. 1.

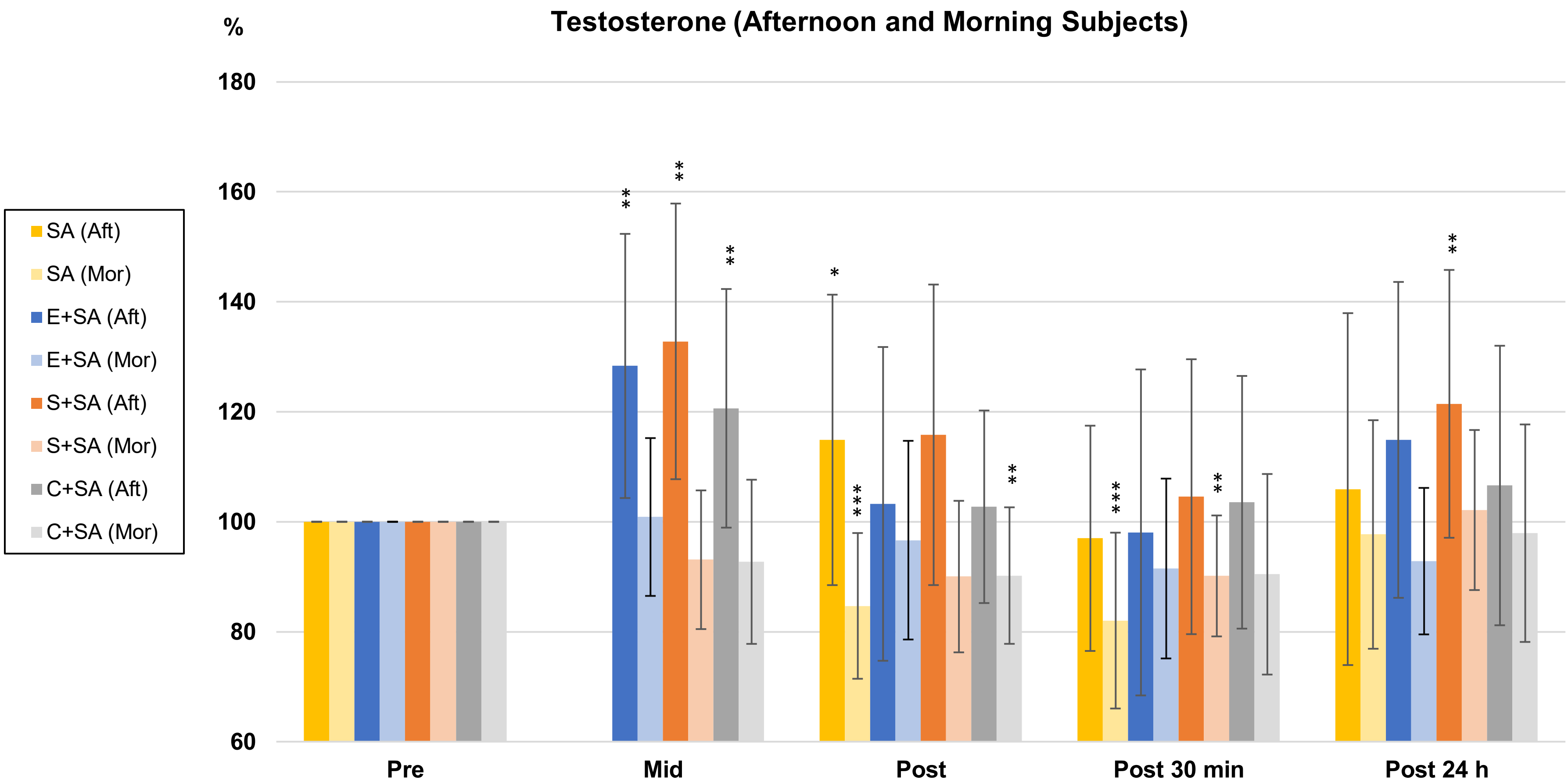
Testosterone (Afternoon and Morning Subjects)
%
180
160
140
120
100
80
60
SA (Aft)
SA (Mor)
E+SA (Aft)
E+SA (Mor)
S+SA (Aft)
S+SA (Mor)
C+SA (Aft)
C+SA (Mor)
Pre
Mid
Post
Post 30 min
Post 24 h

Fig. 2.

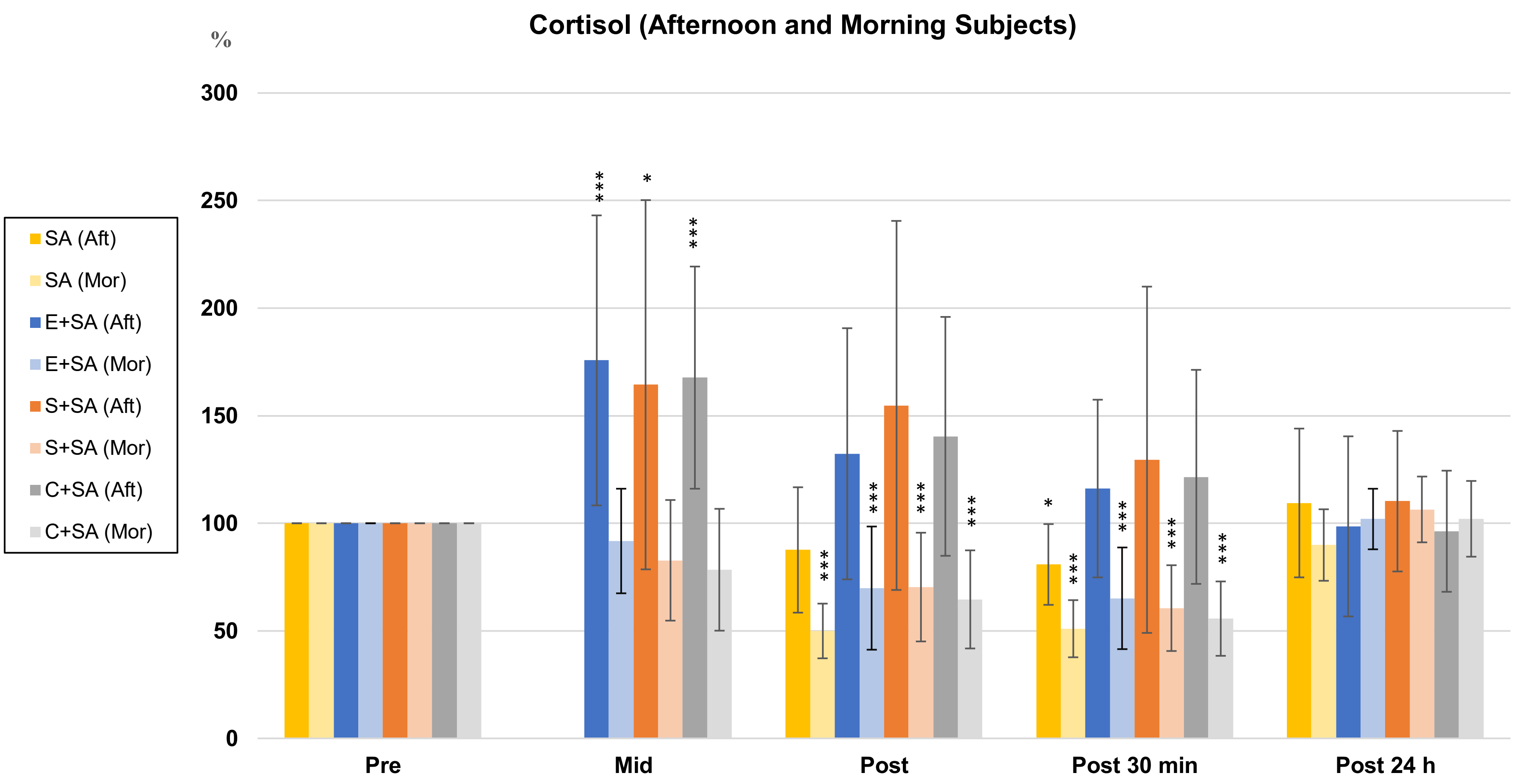
Cortisol (Afternoon and Morning Subjects)
%
300
250
200
150
100
50
0
SA (Aft)
SA (Mor)
E+SA (Aft)
E+SA (Mor)
S+SA (Aft)
S+SA (Mor)
C+SA (Aft)
C+SA (Mor)
Pre
Mid
Post
Post 30 min
Post 24 h

Fig. 3.

Table 1. Measurement times during the loading sessions

	MID* (Time after exercise)	POST (Time after sauna)	POST30min (Time after sauna)
Blood Lactate	2 min	2 min	32 min
Body Mass	7 min	7 min	37 min
Blood Sample	8 min	8 min	38 min
Isometric Bench Press	3.5 min**	10 min	40 min
Isometric Leg Press	0.5 min	11 min	41 min
Counter Movement Jump	2.5 min	12 min	42 min

*= MID measurements were not performed in SA
**= Different in S+SA and C+SA loadings

Table 2. Relative changes in neuromuscular variables compared to PRE during the loadings

	PRE Mean (SD)*	MID (after exercise) Mean Change (%) (95% CI)	POST (after sauna) Mean Change (%) (95% CI)	POST30min (after sauna) Mean Change (%) (95% CI)	POST24h (next day) Mean Change (%) (95% CI)	P-value $
Leg Press Fmax (N) (n=27)						
Sauna	**3327 (687)**	**-**	**-7.3 (-10.1 to -4.4)**	**-9.7 (-13.1 to -6.3)**	**-4.1 (-6.9 to -1.4)**	**<0.001**
Endurance + Sauna	**3133 (674)**	**-13.1 (-18.7 to -7.4)**	**-9.4 (-15.3 to -3.4)**	**-8.9 (-13.0 to -4.8)**	**-1.6 (-6.1 to 3.0)**	**<0.001**
Strength + Sauna	**3154 (638)**	**-17.9 (-22.8 to -13.1)**	**-14.7 (-19.1 to -10.2)**	**-15.1 (-19.8 to -10.3)**	**-6.7 (-11.3 to -2.1)**	**<0.001**
Combined + Sauna	**3089 (751)**	**-17.9 (-23.2 to -12.6)**	**-10.8 (-14.4 to -7.2)**	**-9.2 (-12.2 to -6.2)**	**-3.2 (-6.4 to 0.0)**	**<0.001**
P-value #	**0.605**	**0.011**	**<0.001**	**<0.001**	**<0.001**	
Leg Press Rate of Force Development ($N \cdot s^{-1}$) (n=27)						
Sauna	**18345 (9089)**	**-**	**-10.3 (-20.9 to 0.2)**	**-16.9 (-29.9 to -3.8)**	**-6.6 (-22.4 to 9.1)**	**0.002**
Endurance + Sauna	**15586 (7620)**	**-20.6 (-38.5 to -2.6)**	**-22.4 (-38.8 to -6.0)**	**-22.1 (-39.0 to -5.3)**	**-8.2 (-24.8 to 8.4)**	**<0.001**
Strength + Sauna	**16580 (7760)**	**-28.9 (-46.8 to -11.0)**	**-26.2 (-43.3 to -9.2)**	**-22.5 (-40.2 to -4.8)**	**-7.5 (-26.6 to 11.6)**	**<0.001**
Combined + Sauna	**15696 (6835)**	**-30.4 (-46.5 to -14.3)**	**-19.9 (-35.6 to -4.3)**	**-21.2 (-36.5 to -5.8)**	**-11.1 (-30.3 to 8.0)**	**<0.001**
P-value #	**0.548**	**0.218**	**0.001**	**0.039**	**0.169**	
Leg Press Rapid Force Production 0-500 ms Average Force (N) (n=27)						

Sauna	**2021 (603)**	**-**	**-9.9 (-15.5 to -4.4)**	**-12.8 (-19.3 to -6.4)**	**-6.2 (-14.4 to 2.0)**	**<0.001**
Endurance + Sauna	**1809 (554)**	**-18.7 (-27.6 to -9.8)**	**-18.5 (-26.7 to -10.4)**	**-16.5 (-27.1 to -5.9)**	**-1.8 (-10.2 to 6.6)**	**<0.001**
Strength + Sauna	**1865 (559)**	**-22.7 (-32.1 to -13.3)**	**-19.3 (-28.9 to -9.8)**	**-20.7 (-33.1 to -8.2)**	**-13.1 (-25.7 to -0.5)**	**<0.001**
Combined + Sauna	**1804 (593)**	**-21.2 (-33.7 to -8.7)**	**-13.8 (-22.0 to -5.6)**	**-11.6 (-19.9 to -3.4)**	**-5.1 (-17.1 to 7.0)**	**<0.001**
P-value #	**0.479**	**0.760**	**0.001**	**0.003**	**0.010**	
Counter Movement Jump (cm) (n=27)						
Sauna	**28.1 (6.0)**	**-**	**-2.6 (-6.3 to 1.2)**	**-6.4 (-9.3 to -3.4)**	**-0.1 (-2.6 to 2.5)**	**<0.001**
Endurance + Sauna	**27.5 (5.8)**	**-5.3 (-10.8 to 0.2)**	**-1.9 (-5.6 to 1.8)**	**-5.0 (-8.6 to -1.4)**	**0.0 (-3.1 to 3.0)**	**<0.001**
Strength + Sauna	**27.9 (6.2)**	**-12.7 (-18.9 to -6.5)**	**-8.8 (-12.5 to -5.1)**	**-10.6 (-14.0 to -7.2)**	**-4.3 (-7.1 to -1.5)**	**<0.001**
Combined + Sauna	**27.7 (6.0)**	**-11.9 (-19.6 to -4.2)**	**-6.1 (-10.0 to -2.2)**	**-7.0 (-10.6 to -3.4)**	**-0.5 (-3.3 to 2.2)**	**<0.001**
P-value #	**0.989**	**0.001**	**0.001**	**0.004**	**< 0.001**	
Isometric Bench Press Fmax (kg) (n=27)						
Sauna	**86.6 (20.4)**	**-**	**-2.6 (-5.1 to -0.1)**	**-3.1 (-5.1 to -1.0)**	**-1.3 (-3.7 to 1.1)**	**0.001**
Endurance + Sauna	**85.0 (20.2)**	**-1.7 (-5.0 to 1.5)**	**-2.7 (-5.6 to 0.3)**	**-4.3 (-6.9 to -1.7)**	**-1.7 (-3.7 to 0.2)**	**< 0.001**
Strength + Sauna	**86.0 (20.4)**	**-30.0 (-34.8 to -25.2)**	**-11.2 (-14.1 to -8.3)**	**-12.5 (-15.6 to -9.5)**	**-9.5 (-12.6 to -6.4)**	**< 0.001**
Combined + Sauna	**85.0 (20.9)**	**-23.8 (-30.1 to -17.6)**	**-5.9 (-9.3 to -2.6)**	**-8.6 (-13.0 to -4.3)**	**-4.9 (-8.9 to -0.9)**	**< 0.001**
P-value #	**0.996**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	

= Between groups multiple testing using GEE-model, $ = Within groups multiple testing using GEE-model, * = Except in PRE, where between groups significances were tested using one-way ANOVA

Table 3. Changes in serum hormone concentrations compared to PRE during the loadings

	PRE* Mean (SD)	MID (after exercise) Mean Change (%) ** (95% CI)	POST (after sauna) Mean Change (%) ** (95% CI)	POST30min (after sauna) Mean Change (%) ** (95% CI)	POST24h (next day) Mean Change (%) ** (95% CI)	P-value $
Serum Testosterone Afternoon Subjects (nmol·L^{-1}) (n=12)						
Sauna	**10.2 (3.7)**	**-**	**14.9 (1.9 to 27.9)**	**-3.0 (-16.0 to 9.9)**	**5.9 (-9.9 to 21.8)**	**<0.001**
Endurance + Sauna	**10.3 (3.8)**	**28.3 (8.1 to 48.5)**	**3.3 (-15.3 to 21.8)**	**-1.9 (-18.5 to 14.6)**	**14.9 (-5.6 to 35.4)**	**<0.001**
Strength + Sauna	**9.4 (3.1)**	**32.8 (7.6 to 58.0)**	**15.8 (-8.0 to 39.7)**	**4.6 (-15.6 to 24.7)**	**21.4 (5.0 to 37.9)**	**<0.001**
Combined + Sauna	**10.7 (2.5)**	**20.6 (4.2 to 37.1)**	**2.7 (-10.9 to 16.3)**	**3.5 (-14.2 to 21.3)**	**6.6 (-8.6 to 21.8)**	**<0.001**
P-value #	**0.815**	**0.780**	**0.239**	**0.063**	**0.549**	
Serum Testosterone Morning Subjects (nmol·L^{-1}) (n=15)						
Sauna	**16.7 (3.8)**	**-**	**-15.3 (-23.7 to -7.0)**	**-18.0 (-27.7 to -8.3)**	**-2.3 (-15.0 to 10.4)**	**<0.001**
Endurance + Sauna	**16.9 (4.6)**	**0.9 (-11.0 to 12.7)**	**-3.3 (-16.0 to 9.3)**	**-8.5 (-20.8 to 3.8)**	**-7.2 (-16.3 to 1.9)**	**0.033**
Strength + Sauna	**15.9 (4.1)**	**-6.9 (-15.4 to 1.6)**	**-10.0 (-20.0 to 0.1)**	**-9.9 (-17.2 to -2.5)**	**2.1 (-7.9 to 12.1)**	**<0.001**
Combined + Sauna	**15.9 (5.3)**	**-7.3 (-17.5 to 2.9)**	**-9.8 (-18.0 to -1.6)**	**-9.6 (-22.7 to 3.6)**	**-2.1 (-15.9 to 11.7)**	**0.005**
P-value #	**0.892**	**0.020**	**0.034**	**0.099**	**0.550**	

Serum Cortisol Afternoon Subjects (nmol·L^{-1}) (n=12)						
Sauna	**251 (74)**	**-**	**-12.4 (-34.5 to 9.7)**	**-19.1 (-35.2 to -3.1)**	**9.4 (-14.7 to 33.6)**	**<0.001**
Endurance + Sauna	**246 (69)**	**75.7 (39.4 to 112.0)**	**32.3 (-4.2 to 68.8)**	**16.1 (-11.1 to 43.4)**	**-1.5 (-28.1 to 25.2)**	**<0.001**
Strength + Sauna	**247 (58)**	**64.4 (9.4 to 119.4)**	**54.8 (-7.8 to 117.3)**	**29.5 (-28.4 to 87.5)**	**10.3 (-17.0 to 37.5)**	**<0.001**
Combined + Sauna	**247 (69)**	**67.7 (26.4 to 109.0)**	**40.4 (-1.1 to 81.9)**	**21.6 (-17.8 to 60.9)**	**-3.7 (-24.6 to 17.1)**	**<0.001**
P-value #	**0.998**	**0.779**	**<0.001**	**<0.001**	**0.236**	
Serum Cortisol Morning Subjects (nmol·L^{-1}) (n=15)						
Sauna	**457 (88)**	**-**	**-50.1 (-61.5 to -38.6)**	**-49.0 (-60.2 to -37.8)**	**-10.1 (-23.5 to 3.3)**	**<0.001**
Endurance + Sauna	**422 (84)**	**-8.3 (-24.8 to 8.3)**	**-30.1 (-50.7 to -9.6)**	**-34.9 (-53.3 to -16.5)**	**2.0 (-8.2 to 12.2)**	**<0.001**
Strength + Sauna	**412 (83)**	**-17.2 (-34.6 to 0.2)**	**-29.7 (-48.2 to -11.1)**	**-39.4 (-55.5 to -23.4)**	**6.4 (-1.8 to 14.7)**	**<0.001**
Combined + Sauna	**425 (114)**	**-21.6 (-44.3 to 1.1)**	**-35.4 (-55.7 to -15.1)**	**-44.3 (-61.6 to -27.0)**	**2.1 (-9.3 to 13.5)**	**<0.001**
P-value #	**0.585**	**0.079**	**<0.001**	**<0.001**	**0.566**	
Serum Growth Hormone (µg·L^{-1}) (n=27)*						
Sauna	**0.17 (0.39)**	**-**	**4.10 (1.61 to 6.59)**	**1.96 (0.49 to 3.43)**	**0.29 (-0.34 to 0.93)**	**<0.001**
Endurance + Sauna	**0.46 (0.91)**	**9.24 (4.78 to 13.70)**	**2.15 (0.04 to 4.25)**	**0.58 (-0.49 to 1.65)**	**-0.17 (-0.54 to 0.20)**	**<0.001**
Strength + Sauna	**0.25 (0.59)**	**4.91 (2.33 to 7.50)**	**2.36 (0.73 to 3.99)**	**0.66 (0.03 to 1.28)**	**0.31 (-0.48 to 1.09)**	**<0.001**
Combined + Sauna	**0.20 (0.34)**	**5.63 (2.74 to 8.52)**	**2.12 (0.62 to 3.63)**	**0.64 (-0.03 to 1.30)**	**0.03 (-0.20 to 0.27)**	**<0.001**
P-value #	**0.270**	**0.011**	**0.089**	**0.101**	**0.352**	

= Between groups multiple testing using GEE-model, $ = Within groups multiple testing using GEE-model, * = Except in PRE, where between groups significances were tested using one-way ANOVA. ** = Growth hormone changes are shown in absolute scale ($\mu g \cdot L^{-1}$).