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7 Acute Neuromuscular and Hormonal Responses to Different

8 Exercise Loadings Followed by Sauna

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11

## 12 **ABSTRACT**

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

35

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

## 37 INTRODUCTION

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

48

49 The study of Mero et al. (24) investigated recovering effects of low temperature far-infrared  
50 sauna (30 min, 35°C–50°C) compared to the traditional one but at the same low temperature  
51 (30 min, 35°C–50°C) and sitting in the room temperature (30 min, 21°C) after typical  
52 hypertrophic strength and maximal endurance training sessions in recreationally physically  
53 active men. They found that far-infrared heat might have favourable recovery effects after the  
54 maximal endurance performance in these low temperatures. A traditional sauna bath usually  
55 has higher air temperature (70–100 °C) (4, 8, 14, 20) and it is more often used after exercise  
56 than far-infrared sauna. Nevertheless, higher temperature might also induce neuromuscular  
57 fatigue and act as a stress stimulus.

58

59 Acute effects of a typical hypertrophic strength loading and those of high-intensity interval  
60 endurance exercise as well as combined endurance and strength training sessions are rather  
61 well known. They all lead to decreases in maximal isometric force (ILPF<sub>max</sub>) and rapid force

62 produced during the first 500 ms (F0–500) in leg extensor muscles in the seated leg press (9,  
63 29, 31, 33). A decrease is usually observed also in explosive dynamic performance such as  
64 countermovement jump (CMJ) after high-intensive strength and endurance loadings (25),  
65 although endurance-trained subjects can sometimes even show potentiation in their explosive  
66 performance after endurance exercise (2). Great acute elevations of serum cortisol (COR),  
67 testosterone (TES) and 22 kD growth hormone (GH<sub>22kD</sub>) have been observed immediately post  
68 high-intensity endurance exercise (17, 35). Serum TES and COR concentrations have also been  
69 reported to elevate after resistance loading and the highest values may be reached about 15-30  
70 minutes after exercise, if moderate to high intensities, short rest periods and large muscle mass  
71 are used (28). Large elevations in blood lactate concentrations have been observed after each  
72 exercise type but especially after hypertrophic loadings (10, 15, 23, 28, 29, 33). It is also  
73 important that the time of day in various experimental loading protocols are carefully planned  
74 since neuromuscular performance and especially serum TES and COR concentrations change  
75 during the day in circadian rhythm (11, 16).

76

77 After high volume hypertrophic strength loading TES returns to the baseline level in about one  
78 hour but cortisol concentration may remain elevated for more than two hours (10, 28). On the  
79 other hand, during the following 48 hours after the exercise resting morning concentration of  
80 TES may even decrease under the Pre-level, when very high volume heavy resistance loading  
81 protocols have been used (10). Serum immunoreactive GH<sub>22kD</sub> concentrations have also  
82 significantly elevated after high volume resistance loading but returns rather rapidly to its basal  
83 levels (10). Combined endurance and strength loading also elevates TES after the loading (29).  
84 Interestingly, serum TES morning concentrations have then decreased for two recovery days  
85 after the loading indicating the stressfulness of this loading protocol (29). Previous studies of

86 combined endurance and strength loadings have typically only used constant loads in  
87 endurance loadings.

88

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

105

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

## 111 **METHODS**

### 112 **Experimental approach to the problem**

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

131 \*\*\*\*\* Figure 1 about here \*\*\*\*\*

### 132 **Subjects**

133 Twenty-seven physically active and healthy men (age  $32.7 \pm 6.9$  years, height  $181.0 \pm 5.8$  cm,  
134 body mass  $80.5 \pm 6.4$  kg, body fat percentage  $15.8 \pm 4.5$  %, body mass index  $24.6 \pm 1.9$ ,  $VO_{2max}$   
135  $46 \pm 6$  mL $\cdot$ min $^{-1}$  $\cdot$ kg $^{-1}$ ) from the Jyväskylä region in Central Finland were included in the

136 study. All the subjects were over 18 years old, experienced with taking a sauna bath regularly,  
137 and had some training background for recreational purposes, in both endurance and strength  
138 training. No specific endurance or strength training programs were followed by the subjects  
139 before the intervention. The subjects were free of any medication that would affect their  
140 endocrine function. All subjects went through the resting ECG-scan and the medical  
141 questionnaire before inclusion. Thirty subjects initially volunteered in the study but three of  
142 them dropped out because of injuries (N=2) and personal reasons (N=1). They had reported to  
143 exercise, at least two times, and sauna bath, at least once a week. The subjects were informed  
144 about the risks and benefits of the study before any data collection, and thereafter, an  
145 institutionally approved written informed consent document to participate to this study was  
146 signed by all the subjects.

147

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

155

## 156 **Procedures**

### 157 **Height, Body Mass and Body Fat Measurements**

158 Height was measured with a measuring tape while standing against the wall. Body fat  
159 percentage was measured in a fasted state in the morning using the bioelectrical impedance  
160 method (Inbody 720, Biospace Co., Seoul, South Korea). The hydration status was controlled



161 in the body fat measurement. Height and body fat percentage were determined only in the  
162 baseline measurements.

163

164 In the loading protocols body mass was measured to determine the weight loss. Drinking water  
165 was provided ad libitum to the subjects in order to keep them fully hydrated during the loadings.

166 The Seca 708 lab scale (Seca GmbH, Hamburg, Germany) was used for body mass  
167 measurements during the loading conditions. All the subjects were weighed in PRE, MID,  
168 POST, POST30min and POST24h in the loading protocols.

169

### 170 **Venous Blood Samples**

171 The measurement sessions started with fasting state venous blood samples at  $7:30 \pm 0:20$  am.  
172 ( $>10$  h of fasting overnight before the measurement) followed by a small low-fat breakfast  
173 including two slices of rye bread and one banana to standardize the nutritional status of the  
174 subjects. Thereafter, venous blood samples were taken in PRE, MID, POST, POST30min and  
175 POST24h in the loading protocols. With the morning subjects, the fasting state blood sample  
176 was determined as a PRE-sample, but the afternoon subjects gave a new PRE-sample in the  
177 afternoon just before their started their loading protocols. The afternoon subjects were told to  
178 eat their lunch  $>2$  hours before their afternoon PRE-sample to standardise their nutrition status  
179 as well.

180

181 All venous blood samples were taken from the antecubital vein into serum tubes (Venosafe,  
182 Terumo Medical Co., Leuven, Hanau, Belgium). The samples were allowed to cool down  $>30$   
183 minutes in room temperature and then centrifuged in 3600 rpm for 10 minutes (Megafuge 1.0  
184 R, Heraeus, Germany) to separate the serum and the blood cells. Thereafter, the serum samples  
185 were stored in the freezer ( $-20$  °C) until analysed during the next two months. Serum hormone

186 concentrations of TES, COR and GH<sub>22kD</sub> were analysed using chemical luminescence  
187 techniques and hormone-specific immunoassay kits (Immulite 2100, Siemens, New York, NY,  
188 USA). Sensitivities for TES, COR and GH<sub>22kD</sub> were 0.5 nmol•L<sup>-1</sup>, 5.5 nmol•L<sup>-1</sup> and 0.03  
189 mIU•L<sup>-1</sup>, respectively. Intra-assay coefficients of variation for TES, COR and GH<sub>22kD</sub> were 9.8  
190 ± 3.9 %, 7.1 ± 1.1 % and 6.0 ± 0.5 %, respectively. Inter-assay coefficients of variation for  
191 TES, COR and GH<sub>22kD</sub> were 12.0 ± 6.3 %, 7.9 ± 1.2 % and 5.8 ± 0.3 %, respectively.

192

### 193 **Blood Lactate Measurements**

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

199

### 200 **Body temperature Measurements**

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

### 209 **Neuromuscular Performance Measurements**

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

213

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

225

226 Isometric Bilateral Bench Press ( $IBPF_{max}$ ) was measured using the custom-built bench press  
227 dynamometer (University of Jyväskylä, Finland). Subjects started the test laying on their back  
228 on the bench, hands on the bar and elbows in the 90 degrees of angle. The bar was placed  
229 horizontally at the same level as subject's inferior part of the pectoralis major. Subjects were  
230 instructed to fill up their lungs before starting the trial and then push as hard as they can towards  
231 the bar for 3–5 seconds. Strong verbal encouragement was used during the attempts. The  
232 requirements of the accepted trial were keeping their feet on ground, hips and shoulders on the  
233 bench. The maximum isometric force was taken in kilograms from the monitor of the bench  
234 press machine. The measurement consisted of three trials with 60 seconds of rest between the

235 attempts and the best attempt of these three trials was chosen for further analysis. In the loading  
236 measurement sessions only two attempts with 20 seconds of rest in between were allowed in  
237 MID, POST and POST30min.

238

239 Isometric Bilateral Leg Press ( $ILPF_{max}$ ) was measured using the custom-built  
240 electromechanical dynamometer (University of Jyväskylä, Finland). The knee angle of  $107^\circ$   
241 ( $180^\circ$  represents the full extension position of the legs) was used in this measurement. Subjects  
242 were instructed to fill up their lungs and hold a breath before pushing as hard and as fast as  
243 they can towards the plate under their feet for 3–5 seconds. Strong verbal encouragement was  
244 given during the attempts. 60-second rest periods were used between the trials and the best  
245 attempt of three trials was chosen for further analysis. In the loading measurement sessions two  
246 attempts with 20 seconds of rest in between were allowed in MID, POST and POST30min.  
247 The high reproducibility of the present isometric leg press measurement protocol has been  
248 observed in several previous studies (10, 11, 26, 34). Maximal isometric leg press force  
249 ( $ILPF_{max}$ ) in Newtons (N), average force during 0-500 ms from the start of the force production  
250 ( $F_{0-500}$ ) in Newtons (N) and maximal rate of force development (RFD) in Newtons per second  
251 ( $N \bullet s^{-1}$ ) were analysed from the leg press data. The data analyses were made using Signal  
252 software version 4.14 (Cambridge Electronic Design Ltd., Cambridge, United Kingdom).

253

## 254 **Loadings**

### 255 **Sauna Loading (SA)**

256 SA lasted for a total of 32 minutes and performed in three 10-minute intervals with 1-minute  
257 cooling periods in between as typically done in Finland. A traditional Finnish sauna with the  
258 electrical stove was used and 2 dL of water was thrown to the rocks in the beginning and after  
259 5 minutes of each 10-minute sauna interval. Mean air temperature and humidity (measured at

260 the bather's face level) during the sauna loadings were  $70.2 \pm 1.0$  °C and  $18.2 \pm 6.6$  %,  
261 respectively. The measurements were taken before the first sauna interval and in the end of  
262 each sauna interval with the sauna hygrometer and bimetal thermometer specially designed to  
263 be used in sauna. The similar sauna loading started 15 minutes after the exercise loadings.

264

#### 265 **Endurance Exercise + Sauna Loading (E+SA)**

266 E+SA was performed using the high intensity interval protocol on a cycle ergometer. The  
267 endurance exercise loading consisted of 15 minutes of progressively graded loads followed by  
268 typical 4 x 4 minutes intervals with 4 minutes of recovery in between. The total duration was  
269 43 minutes. The intensities were determined from the graded exercise protocol performed in  
270 the baseline measurements and the pedalling frequency of 70 was used. The first 10 minutes  
271 of the exercise was pedalled with 65 % of  $HR_{max}$ , following 2.5 minutes with 70 % of  $HR_{max}$ ,  
272 and the next 2.5 minutes with 75 % of  $HR_{max}$ . The interval intensities were 90, 92.5, 95 and 95  
273 % of  $HR_{max}$  and during the recovery periods heart rate was recovered down to 70 % of  $HR_{max}$ .  
274 HR of each load was measured using an average of the last 15 seconds of the load.

275

#### 276 **Strength Exercise + Sauna Loading (S+SA)**

277 The hypertrophic strength loading protocol in dynamic bilateral bench press and leg press was  
278 used. The bench press exercise was followed by the leg press. Both exercises consisted of 2 x  
279 12 warm up sets with 2 minutes recovery. The actual exercise sets were 4 x 10 with 3 minutes  
280 recovery after each set. In the bench press exercise the loadings were 50 and 60 % of 1RM in  
281 the warm-up sets and 75, 80, 80 and 80 % of 1 RM in the actual exercise sets. The leg press  
282 exercise loads were 50 and 70 % of 1RM in the warm-up sets and 85, 90, 95 and 95 % of 1RM  
283 in the actual exercise sets. In both exercises, the last repetitions of the last two sets were slightly  
284 assisted by the research assistant, if the subject reached the voluntary failure before 10

285 repetitions were performed. The IBP  $F_{\max}$  was measured in the middle of the exercise, 30  
286 seconds after the last bench press set before starting the leg press loading. All the other MID  
287 measurements were taken after the whole loading.

288

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

290 The volume of C+SA was matched with that of the S+SA and E+SA using the half of the  
291 volume of both loading protocols but otherwise the same protocols were used. In the Endurance  
292 loading part, the first 5 minutes of the exercise was pedalled with 65 % of  $HR_{\max}$ , following  
293 1.25 minutes with 70 % of  $HR_{\max}$ , and the next 1.25 minutes with 75 % of  $HR_{\max}$ . The interval  
294 intensities were 90, and 95 % of  $HR_{\max}$  and during the recovery periods heart rate was recovered  
295 down to 70 % of  $HR_{\max}$ . The strength training exercises consisted of one warm up set of 12  
296 reps and 2 actual exercise sets of 10 reps with 2 minutes of recovery after the warm-up set and  
297 3 minutes of recovery after the first exercise set. In the bench press the loads were 60, 80 and  
298 80 % of 1RM and in the leg press the loads were 70, 90 and 95 % of 1RM, respectively. The  
299 IBP  $F_{\max}$  in MID in C+SA was also measured in the middle of the exercise similarly as in  
300 S+SA. The order of exercises was the same in all subjects so that the endurance exercise was  
301 performed first followed by the bench press and leg press exercises. The Sauna loading started  
302 15 minutes after the end of the combined endurance and strength exercise loading session (Fig  
303 1). Each MID, POST and POST30min measurement was taken at the same time point after the  
304 loading except for IBP  $F_{\max}$  in S+SA and C+SA in MID (Table 1).

305 \*\*\*\*\* Table 1 about here \*\*\*\*\*

### 306 **Statistical analyses**

307 Mean PRE-values in all the loadings are reported in the absolute scale with standard deviation  
308 (SD) and all the other measurements as the relative change with 95 % confidence interval (95%  
309 CI) The only exception was  $GH_{22kD}$  which is reported in the absolute change scale in all

310 measurement points. Serum testosterone and cortisol results are analysed separately for the  
311 morning and afternoon groups due to the circadian rhythm. The statistical significances  
312 between groups in PRE were tested by using one way Anova. Between group differences and  
313 within group changes were tested by Generalized Estimating Equations -model (GEE-model).  
314 Pairwise post-hoc analyses were made by using Sidak correction. All statistical analyses were  
315 performed using IBM SPSS Statistics -software version 24 (SPSS, Inc., Chicago, IL, USA).

316

## 317 **RESULTS**

### 318 **Maximal Isometric Leg Press Force (ILP $F_{max}$ )**

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

325 \*\*\*\*\* Table 2 about here \*\*\*\*\*

326

### 327 **Isometric Leg Press Maximal Rate of Force Development (RFD)**

328 RFD decreased significantly in all exercise loadings followed by sauna in MID (-30.6 to -20.4  
329 %), POST (-26.2 to -19.9 %) and POST30min (-22.1 to -21.2 %) compared to PRE (Table 2).  
330 SA showed the significant decrease (-16.9 %) only in POST30min. In POST, RFD in C+SA  
331 recovered more than in S+SA and no recovery was observed in E+SA. In POST30min all three  
332 loadings of C+SA, S+SA and E+SA were at the same level. There were significant differences  
333 between the loadings in the POST ( $p=0.001$ ) and POST30min ( $p=0.039$ ) measurement points.

334

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

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

342

**343 Counter Movement Vertical Jump (CMVJ)**

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

349

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

351 IBP  $F_{max}$  significantly decreased in S+SA (-30.0 (-34.8 to -25.2) %) and C+SA (-23.8 (-30.1 to  
352 -17.6) %) from PRE to MID. IBP  $F_{max}$  remained at the significantly lower level also in POST,  
353 POST30min and POST24h in both S+SA and C+SA loadings (Table 2). The SA loading also  
354 showed the significant decrease in POST and POST30min. Between groups differences were  
355 statistically significant ( $p<0.001$ ) in MID, POST, POST30min and POST24h.

356

**357 Serum Testosterone Concentrations (TES)**

358 Significant elevations in TES took place in the afternoon subject group in MID in all the  
359 exercise loadings (Figure 2 and Table 3). The SA loading showed the significant TES elevation



360 in POST and S+SA in POST24h. No significant between group differences were found in the  
361 afternoon subjects.

362

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

367 \*\*\*\*\* Figure 2 about here \*\*\*\*\*

368

### 369 **Serum Cortisol Concentrations (COR)**

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

373

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

377 \*\*\*\*\* Figure 3 about here \*\*\*\*\*

378

### 379 **Serum Growth Hormone Concentrations (GH<sub>22kD</sub>)**

380 Significant elevations were observed in GH<sub>22kD</sub> concentration from PRE to MID in all exercise  
381 loadings (Table 3). The elevated absolute values were in E+SA 9.24 (4.78 to 13.70)  $\mu\text{g}\cdot\text{L}^{-1}$ , in  
382 C+SA 5.63 (2.74 to 8.52)  $\mu\text{g}\cdot\text{L}^{-1}$  and in S+SA 4.91 (2.33 to 7.50)  $\mu\text{g}\cdot\text{L}^{-1}$ . In the POST  
383 measurements, the elevations were still observed in all the loadings, but in POST 30 only in  
384 S+SA (Table 3). Significant elevations compared to the PRE measurement were also observed

385 in SA in the POST (4.10 (1.61 to 6.59)  $\mu\text{g}\bullet\text{L}^{-1}$ ) and POST30min (1.96 (0.49 to 3.43)  $\mu\text{g}\bullet\text{L}^{-1}$ ).  
386 Significant between loadings difference was observed in MID ( $p=0.011$ ).

387 \*\*\*\*\* Table 3 about here \*\*\*\*\*

388

### 389 **Blood Lactate and Body Temperature**

390 Mean (SD) BL significantly elevated after exercise in all loadings in MID ( $p<0.001$ ). In S+SA  
391 (10.62 (3.17)  $\text{mmol}\bullet\text{L}^{-1}$ ) and C+SA (9.85 (2.81)  $\text{mmol}\bullet\text{L}^{-1}$ ) BL levels elevated more than in  
392 E+SA (8.20 (2.58)  $\text{mmol}\bullet\text{L}^{-1}$ ) in MID and the significant difference between loadings  
393 ( $p<0.001$ ) was found. After sauna in the POST measurements BL levels recovered to the PRE-  
394 level. BT increased in MID compared to PRE by 0.6 °C, 0.3 °C and 0.3 °C in E+SA, C+SA  
395 and S+SA, respectively. In POST the increases compared to PRE were 1.3 °C, 1.2 °C, 1.1 °C  
396 and 1.0 °C, in C+SA, E+SA, S+SA and SA, respectively.

397

### 398 **DISCUSSION**

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

410 levels (4, 17, 35). Serum testosterone concentration elevated only in the afternoon group  
411 immediately after the strength, endurance, combined loadings and after sauna only.

412

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

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

436

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

456

457 Serum TES and COR concentrations were analysed separately in the morning and afternoon  
458 groups due to the circadian rhythm of these hormones demonstrated in several earlier studies

459 (e.g. 11, 16). Earlier studies have observed that TES response to a typical heavy hypertrophic  
460 strength training protocol is very short and the rise of total testosterone seems to end  
461 immediately post (16) or at the latest after 15 minutes of recovery (28). In addition, the studies  
462 by Ratamess et al. (28) and Häkkinen & Pakarinen (10) have showed that serum TES  
463 concentration seems to return to the Pre-level in about one hour after the strength exercise  
464 session. In the present study, the time between the MID and POST measurements was about  
465 one hour which indicates that the sauna bath after the exercise may not lead to the continued  
466 elevation in serum testosterone concentration. Häkkinen & Pakarinen (10) have showed that  
467 the very high volume and intensive heavy resistance loading protocol leads to the large acute  
468 elevation in serum TES but, thereafter, the significant decrease in serum basal morning TES  
469 levels took place after a recovery period of 24-48 hours. That finding indicated how a long time  
470 it may take to recovery from the strenuousness of this type of loading. However, the overall  
471 volume of the present loading was much smaller and serum TES concentration was  
472 significantly recovered after 24 h in the afternoon subjects. Nevertheless, the possibility that  
473 sauna bathing after the strength exercise has some effects on TES levels of the next day cannot  
474 be totally excluded. In the morning subjects most of the TES changes were most likely masked  
475 by the circadian rhythm (11, 16). Earlier studies have also shown that the present type of  
476 strength exercise stimulus in the morning has caused the acute elevation in serum testosterone  
477 concentration but the post exercise level has still been somewhat lower than the morning  
478 baseline value (11, 16). The same phenomenon was observed in the present study, when the  
479 significant decreases in the morning group were observed in SA in POST and POST30min, in  
480 C+SA in POST and in S+SA in POST30min. Thus, it is very likely that the present exercise  
481 stimulus was not high enough to lead to the elevated TES values to overcome the effect of the  
482 circadian rhythm on hormonal regulation. Despite the significant differences observed in the  
483 acute responses in serum TES between the morning and afternoon subjects in all of the

484 loadings, no systematic differences were observed in the loading induced acute responses of  
485 these two groups in the neuromuscular performance (data not shown).

486

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

499

500 Extensive acute elevations in serum cortisol concentrations were found after all exercise  
501 loadings in the afternoon subjects in MID. After sauna in POST the elevations were still rather  
502 high but not significant anymore. Previous studies have showed that COR returns slower to the  
503 basal level after the exercise than TES (10, 28). A similar trend might be observed in the present  
504 study and the sauna bath might somewhat still delay the COR decrease after the exercise,  
505 although large inter individual variation was observed in COR concentrations. Nevertheless,  
506 SA alone significantly decreased COR in POST30min in the afternoon subjects which might  
507 indicate the opposite reaction after the present sauna loading for some individuals. The morning  
508 subjects showed the decrease of -50.1 % in COR in SA in POST. This finding indicates that

509 the morning sauna bath with the combined effect of the normal COR circadian rhythm leads to  
510 the decrease in serum COR in the morning masking possible effects of the sauna bath as in the  
511 case of serum TES. Earlier studies have showed somewhat contradictory results regarding the  
512 COR concentrations during sauna bathing (12, 18, 19, 27). Jezová et al. (12) even discussed  
513 about the possibility of biphasic response of COR to the sauna exposure so that COR  
514 concentration may first decrease during the initial phase of sauna bath and then elevate during  
515 the remaining part of sauna bath. Nevertheless, more frequent blood sampling would be needed  
516 for further conclusions. In the present study significant differences in COR between the  
517 morning and afternoon subjects were observed in MID, POST and POST30min in all the  
518 loadings (data not shown) as in the case in serum TES.

519

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

531

532 The duration of the present sauna bath was 30 minutes as e.g. in the study by Mero et al. (24)  
533 which investigated recovery effects of far-infrared sauna after exercise. However, in the real

534 life, a sauna bath session may normally last from 5 to 20 minutes (8, 20). A shorter duration of  
535 sauna bath would probably be less taxing for the neuromuscular system but it would very likely  
536 have some effects on hormonal responses, too. The higher sauna temperature (70 °C) lasting  
537 for 30 minutes seems to be very fatiguing for the neuromuscular performance as the control  
538 loading (SA) in the present study showed. Therefore, it is very unlikely that the present sauna  
539 protocol would have recovery effects if the study design of Mero et al. (24) is replicated.

540

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

553

## 554 **PRACTICAL APPLICATIONS**

555 The intensive strength exercise session followed by sauna is more fatiguing for the  
556 neuromuscular performance than intensive endurance exercise or the combined endurance and  
557 strength exercise followed by sauna. Therefore, a longer recovery time before the next training  
558 session is recommended after the strength training session followed by sauna. Although



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

567

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676 and the results of the present study do not constitute endorsement by the authors or the NSCA.

677

678 **Figure legends**

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

681

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

685

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

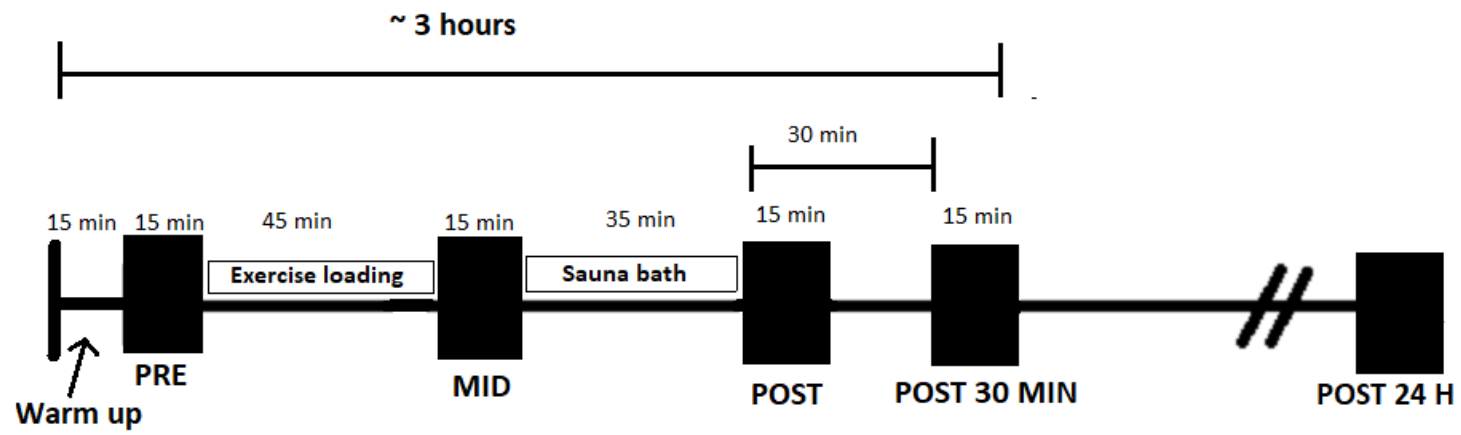
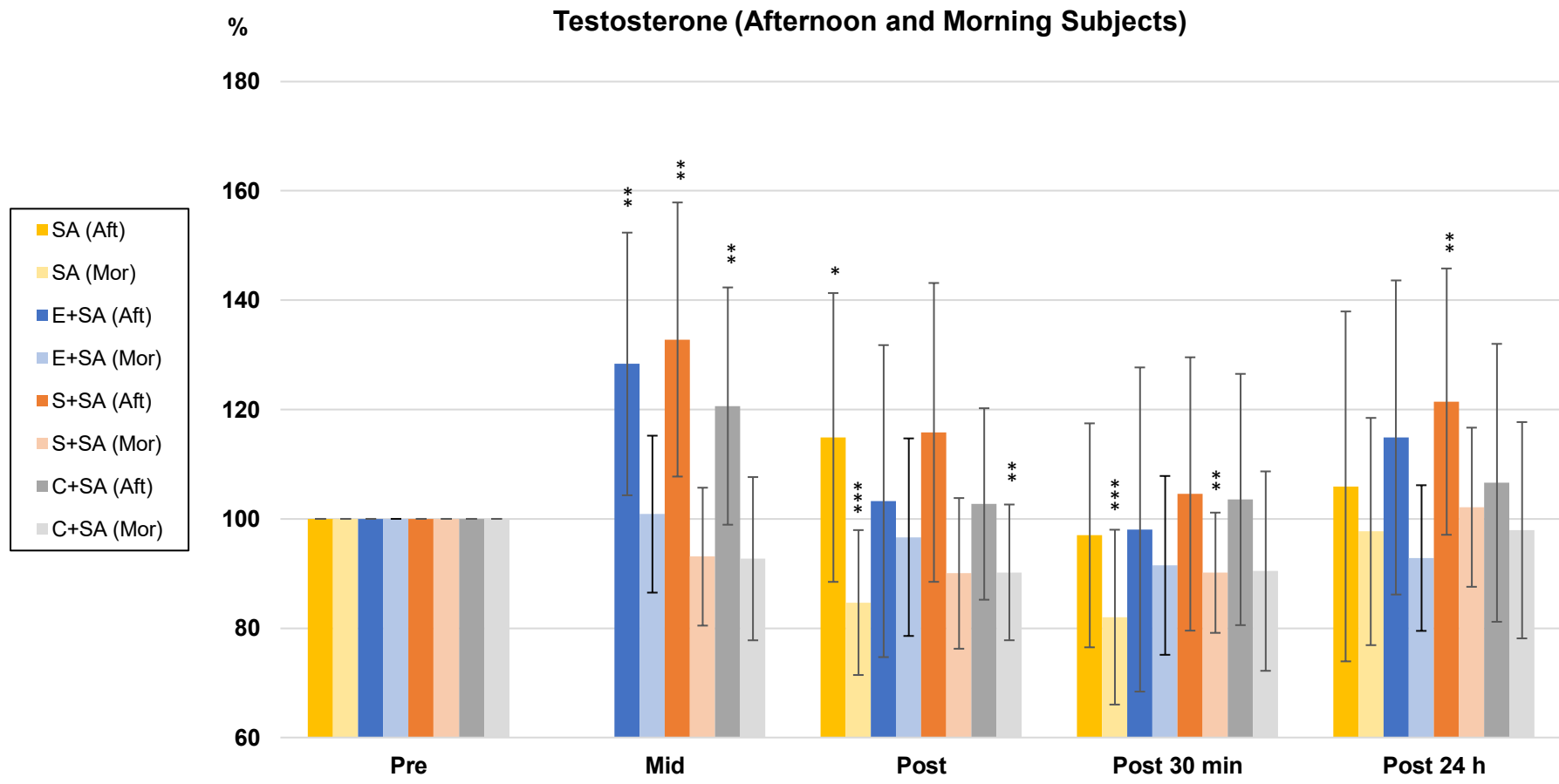
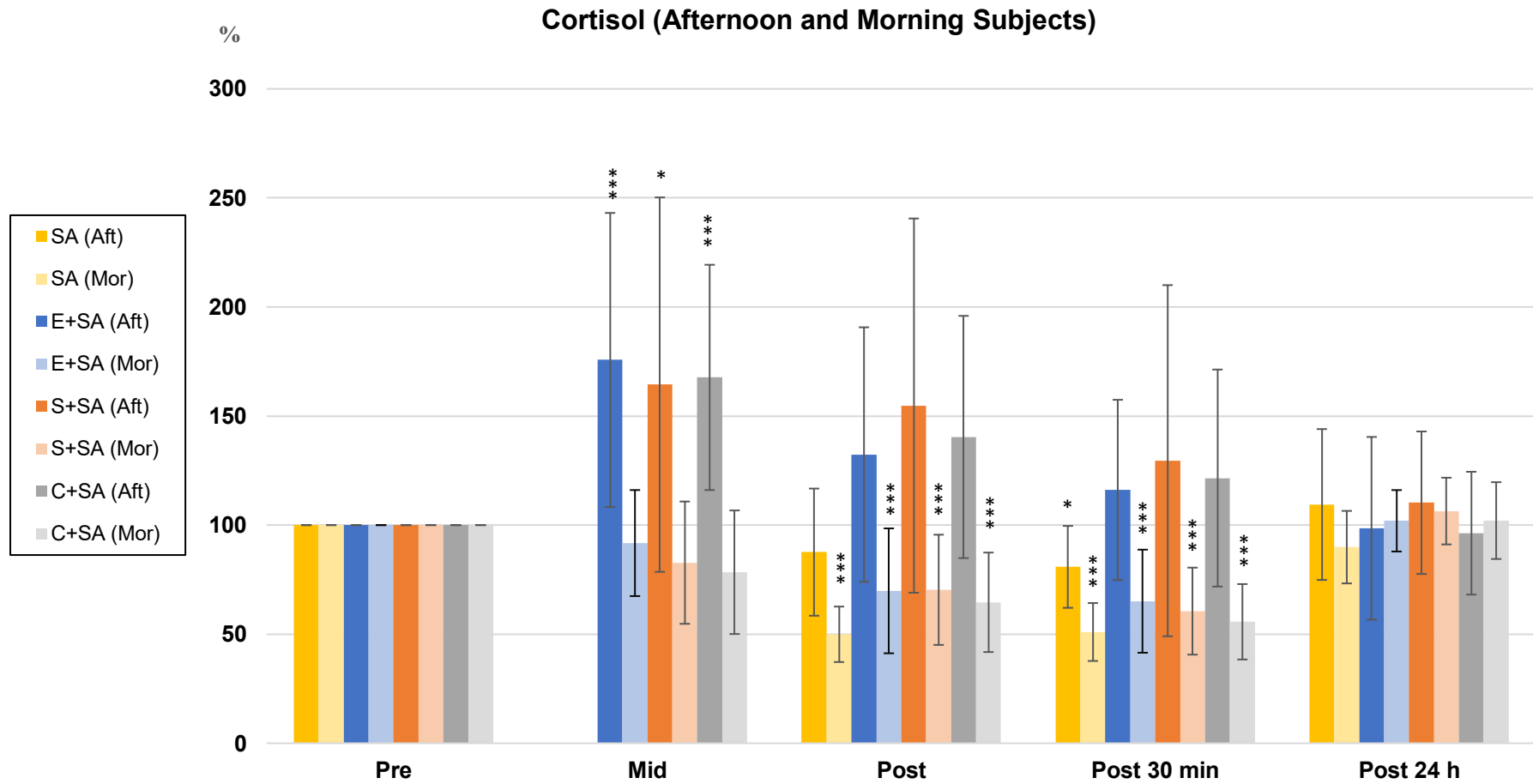


Fig. 1.



**Fig. 2.**





**Fig. 3.**

**Table 1.** Measurement times during the loading sessions

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

	<b>PRE</b>	<b>MID (after exercise)</b>	<b>POST (after sauna)</b>	<b>POST30min (after sauna)</b>	<b>POST24h (next day)</b>	<b>P-value \$</b>
	<b>Mean (SD)*</b>	<b>Mean Change (%)</b>	<b>Mean Change (%)</b>	<b>Mean Change (%)</b>	<b>Mean Change (%)</b>	
		<b>(95% CI)</b>	<b>(95% CI)</b>	<b>(95% CI)</b>	<b>(95% CI)</b>	
<b>Leg Press Fmax (N) (n=27)</b>						
<b>Sauna</b>	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
<b>Endurance + Sauna</b>	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
<b>Strength + Sauna</b>	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
<b>Combined + Sauna</b>	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
<b>P-value #</b>	<b>0.605</b>	<b>0.011</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	
<b>Leg Press Rate of Force Development (N·s<sup>-1</sup>) (n=27)</b>						
<b>Sauna</b>	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
<b>Endurance + Sauna</b>	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
<b>Strength + Sauna</b>	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
<b>Combined + Sauna</b>	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
<b>P-value #</b>	<b>0.548</b>	<b>0.218</b>	<b>0.001</b>	<b>0.039</b>	<b>0.169</b>	
<b>Leg Press Rapid Force Production 0-500 ms Average Force (N) (n=27)</b>						

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

# = 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

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

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

# = 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 ( $\mu\text{g}\cdot\text{L}^{-1}$ ).