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Effect of a Four-Week Extreme Heat (100 ± 2 °C) Sauna Baths Program in Combination with Resistance Training on Lower Limb Strength and Body Composition: A Blinded, Randomized Study

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Abstract

Introduction: Nowadays, there is evidence regarding a beneficial effect of heat on neuromuscular strength and muscle hypertrophy development. The aim of this study is to evaluate the effects of a 4-week passive sauna bathing program to extreme heat (100 ± 2 °C) as a support for a resistance strength training program on maximal strength and body composition. **Methods:** 30 young male subjects participated in the study. They were randomly assigned to a Hyperthermia group (HG, *n* = 14; age: 20.48 (19.12–22–30) years; weight: 76.30 (71.00–79.00) Kg; BMI: 23.92 (22.93–24.87) Kg/m^2), or to a Normothermia group (NG, *n* = 15; age: 19.95 (19.10–21–94) years; weight: 61.70 (59.45–72.90) Kg; BMI: 21.56 (20.42–23.26) Kg/m^2). All participants followed the same lower limb strength training program (2 exercises; 4 sets of 10 repetitions at 75% 1RM with progressive loading). Additionally, HG underwent two weekly sessions of exposure to extreme heat in a sauna (100 ± 2 °C and 24 ± 1% relative humidity, four sets of 10 min, 2 days per week). The intervention lasted for 4 weeks, followed by a 4-week deconditioning period. Maximum isometric knee flexion-extension strength, maximum counter-resistance strength, as well as body composition and anthropometric variables were assessed. **Results:** The HG group significantly increased body weight ($p < 0.05$) and muscle mass ($p < 0.05$), while their sum of six skinfolds (Σ6 skinfolds) significantly decreased ($p < 0.05$). Both groups improved their 1RM squat performance following the intervention program ($p < 0.05$; HG: r = 0.86; NG: r = 0.89). However, only the HG group continued to improve their squat 1RM after the deconditioning period ($p < 0.001$; r = 0.93), as well as their leg press 1RM ($p < 0.01$; r = 0.94). Maximal isometric strength increased only in the NG group at the end of the training program, with a significant increase in knee flexion torque ($p < 0.05$; r = 0.76). In contrast, the HG group showed significant increases in isometric strength after the deconditioning period in both knee extension ($p < 0.05$; r = 0.76) and knee flexion ($p < 0.05$; r = 0.75). **Conclusions:** A four-week period of passive sauna bathing at extreme heat appears to alter the chronology of strength responses. It also seems to induce favorable responses in terms of strength development and body composition.

Keywords: sauna bath; hyperthermia; resistance training; strength; performance; body composition; sauna; isometric torque

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1. Introduction

In recent years, heat stress has gained particular interest in the field of hypertrophy and strength development [1], especially for clinical purposes [2] and health-related issues associated with aging [3]. The positive effect of heat therapies on muscle hypertrophy and performance has recently been reviewed [4].

Nowadays, the molecular and cellular mechanisms underlying these hypertrophic and performance-enhancing responses have been studied [1] playing the mammalian target of rapamycin (mTOR) [3] and heat shock proteins (HSP) [5,6] two key roles in these heat-induced responses [7]. In this context, a positive hormonal response has been observed when resistance training is combined with heat therapy [2], particularly in relation to muscle hypertrophy development [8,9]. Additionally, in recent years, the relationship between heat exposure, resistance training, and muscle anabolism has emerged as a significant topic of research interest [4,8,10]. In this context, the role of heat therapy in muscle recovery [11], its pre- and post-exercise effects on muscle damage [12,13], and its specific influence on cellular anabolic pathways has already been investigated [9,14,15].

Another emerging research topic is the potential relationship between heat exposure as a physiological stimulus and improvements in body composition. It has been demonstrated that heat can exert beneficial effects on body composition, particularly through reductions in fat mass [16]. However, despite these promising findings and the observed anabolic response to heat therapy [4], the current evidence remains limited and inconclusive in human studies. With respect to body composition and muscle hypertrophy, heat exposure has been linked to notable muscular adaptations, which are generally associated with improvements in muscular strength [3,16]. These effects have been documented in both young adults [17] and older populations [3].

In human studies, the temperatures used for these purposes have primarily involved moderate heat (30–40 °C) [4] or high heat exposure (60–70 °C) [8], while the use of extreme temperatures (>80 °C) remains uncommon in the scientific literature. So, there is currently little research on the topic regarding the link between extreme heat (80 °C and more) and strength performance. Interestingly, positive effects have been observed in the development of maximum counter-resistance strength at both acute [18] and after a period of combined maximal isometric strength training with exposure to extreme heat (100 °C) in a sauna [17]. In relation to these observations, it has also been confirmed that certain hyperthermic stimuli can induce a clear facilitating effect on tasks involving high neuromuscular demand [19,20].

Simultaneously, the use of dry heat through Finnish saunas has been tested as an effective and safe method to induce beneficial responses in physiological systems related to hypertrophy and strength development, such as the endocrine [21] or cardiovascular system [22]. In this regard, it has also been observed that heat acclimatization using thermal chambers has beneficial effects on the nervous system [23,24].

Therefore, the objective of this study is to evaluate the effect of a 4-week passive sauna bathing program to extreme heat (100 ± 2 °C) as a support for a resistance strength training program on the development of maximum strength and body composition in young physically active subjects. Considering the aforementioned evidence, it can be hypothesized that the use of extreme heat sauna baths may serve as a beneficial strategy, in combination with resistance training, to improve body composition and strength.

2. Materials and Methods

2.1. Ethical and Biosafety Criteria

Prior to its implementation, the study design was approved by the bioethics and biosafety committee of the University of Extremadura (registration number: 32//20), in

compliance with all ethical guidelines of the Helsinki Declaration for research involving human subjects, as updated in the World Medical Assembly of Fortaleza (2013).

All participants willingly took part in the study and were informed in advance about its characteristics. Each participant provided voluntary signed consent, and anonymity was ensured at all times by assigning a unique alphanumeric code to each of them.

Finally, all research activities were conducted under the supervision of a medical professional, and all participants underwent a general medical assessment before the study commencement to rule out potential contraindications.

2.2. Participants

A total of 30 male subjects (Age: 20.15 (19.01–22.57) years; Weight: 70.61 (62.15–78.20) kg; Height: 176.80 (164.89–185.44) cm; BMI: 22.51 (21.35–23.15)) participated in the study. All of them met the inclusion criteria, which included being male, aged between 18 and 25 years, having no diseases or contraindications for resistance training, not undergoing any pharmacological and/or nutritional treatment in the 12 months prior to the start of the research, and not having engaged in any strength or resistance training program in the 12 months prior to the study. Additionally, the consumption of coffee, tea, or caffeine was prohibited during assessments and training, as well as the intake of sports nutritional supplements or dietary changes.

Furthermore, experimental dropout would be considered if any of the following exclusion criteria were met: suffering from musculoskeletal injury at the beginning or during the research phase, consuming any doping substance or anabolic supplements, initiating any pharmacological or nutritional treatment, changing the type of diet or dietary regimen, or not attending any of the training or acclimatization sessions. Throughout the study, only one participant experienced experimental dropout due to illness.

A priori sample size estimation was performed using G*Power software (Version 3.1.9.6; Universität Düsseldorf, Germany; www.gpower.hhu.de, accessed on 20 December 2024) for a repeated measures ANOVA with a within-between interaction design. Parameters were based on previous literature assessing the acute effects of heat on muscular strength [18], with an effect size (f) of 0.30, an alpha level (α) of 0.05, and a desired statistical power of 0.90. The study design included two groups and three repeated measurements, assuming a correlation of 0.5 among repeated measures and a nonsphericity correction of 1. The sample size calculation indicated that a total of 26 participants would be required, which was exceeded by the present study's sample size (n = 29), thereby ensuring sufficient statistical power to detect meaningful effects.

Figure 1 depicts the consort flow diagram, outlining the enrollment process, participant allocation, and the progression of participants through each phase of the study

2.3. Study Design

The study was conducted over a total of 13 weeks, as illustrated in Figure 2. The first week involved a familiarization phase, during which all participants visited the facilities where the research would take place. In the laboratory, they were introduced to the sauna and assessment instruments, while in the weight training room, they performed a warm-up similar to that of the experimental phase and familiarized themselves with the machines used for assessments and training. Subsequently, participants were randomly assigned to either the Hyperthermia Group (HG, n = 15; age: 20.48 (19.12–22–30) years; body weight: 76.30 (71.00–79.00) kg; BMI 23.82 (22.93–24.87) kg/m^2 or the Normothermia Group (NG, n = 14; age: 19.95 (19.10–21–94) years; weight: 65.40 (59.45–72.90) kg; BMI: 21.55 (20.42–23.26) kg/m^2).

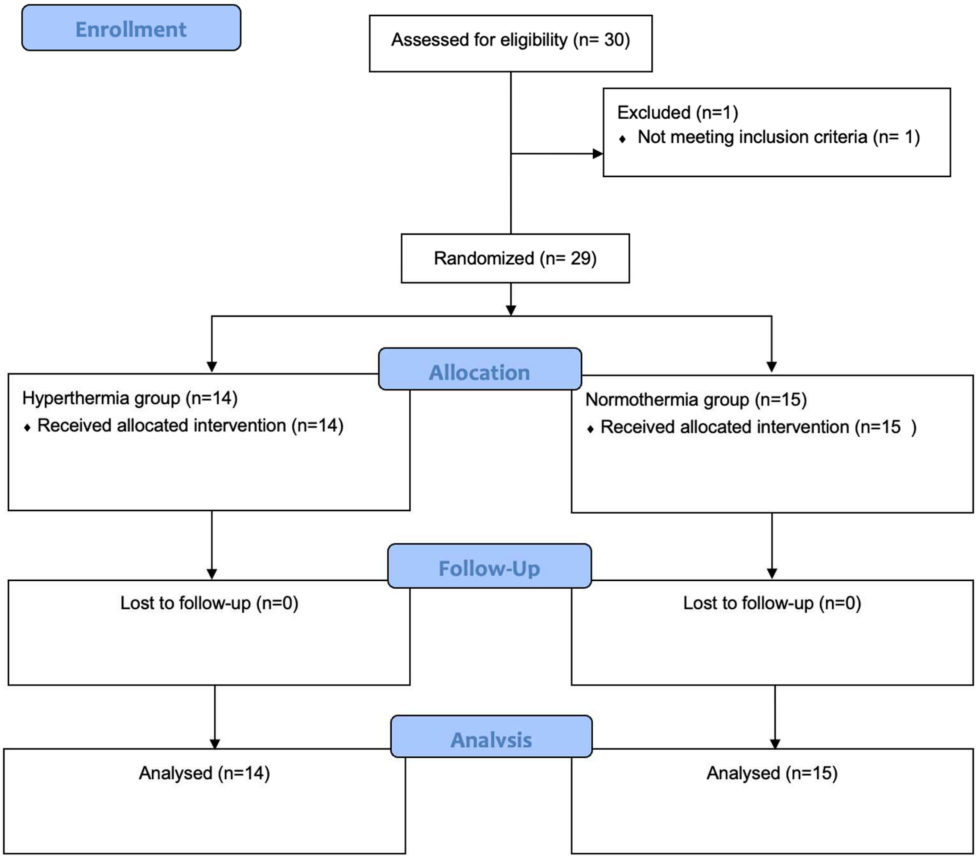


Figure 1. CONSORT flow diagram.

Group randomization was performed using a specialized online tool (Versión 4.0; Social Psychology Network, EE. UU.; www.randomizer.org). To maintain blinding conditions, participants received a specific informed consent form tailored to their assigned group and their participation status in the sauna program. During the study, participants from different groups were scheduled on separate days to prevent overlap at the facilities and minimize the risk of participants becoming aware of the activities performed by other groups.

Following a one-week break, the initial assessment was conducted, consisting of an evaluation of the level of physical activity, anthropometric parameters, body composition, and assessment of lower limb strength in both isometric and counter-resistance conditions.

In the third week of the study, after another week of rest, both the counter-resistance strength training and the sauna bathing program began. These programs spanned 4 weeks, with a frequency of 2 sessions per week, allowing 48 h of recovery between sessions. Both groups followed the same training program. Additionally, the HG engaged in a passive sauna bath immediately after each training session. The training and sauna programs will be described later.

One week after completing the training and sauna programs, the assessments carried out in the initial evaluation were repeated, adhering completely to the same protocol, test order, and assessment schedules, which remained consistent for each participant in both assessments. In order to avoid negative interaction effects derived from circadian chronobiology, the hours of evaluation did not vary along the survey.

Subsequently, a 4-week period of disadaptation was allowed. During these weeks, participants resumed their normal lifestyle, refraining from both counter-resistance training and sauna sessions.

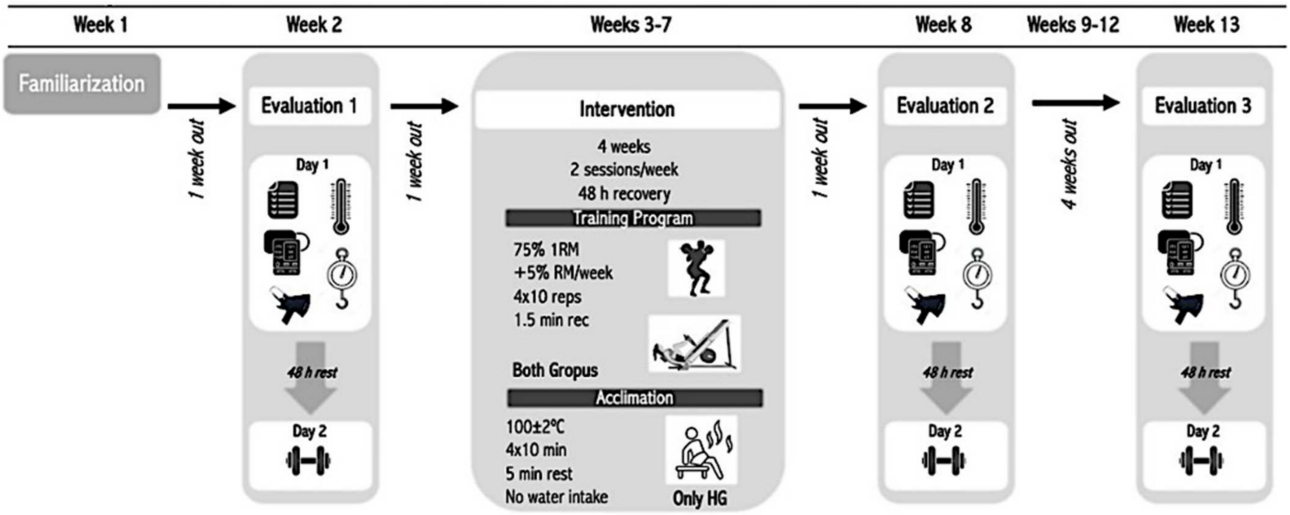


Figure 2. Graphical summary of the general study design (Legend: HG: Hyperthermia Group; NG: Normothermia Group). 30 participants were initially recruited to take part in the study. They were randomly assigned to either the HG or the NG. Once assigned, the study took place over 13 weeks. Week 1 involved familiarization with the facilities and equipment. After a week of rest, the initial assessment was conducted. A week later, the intervention program began, consisting of a 4-week training with 2 sessions per week separated by 48 h of recovery. Participants performed 4 sets of 10 repetitions at 75% of their 1RM, with 1.5 min of recovery. This percentage of 1RM increased by 5% each week. Exercises included half squats and leg presses. Additionally, the HG group, after each training session, underwent an interval sauna bath at 100 °C, consisting of 4 sets of 10 min. After a week of rest, the final assessment was conducted, followed by a 4-week period of detraining and a subsequent assessment of detraining. Each assessment followed the same protocol, evaluating lifestyle, body temperature, blood pressure, body composition, and maximum isometric strength on two different days. After 48 h of recovery, indirect assessments of 1RM were conducted for half squats and leg presses.

Finally, after these 4 weeks, assessments were repeated in an identical manner, adhering to the protocol, test order, and assessment schedules used in the initial evaluations. All assessments and protocols will be described in the following sections.

2.4. Assessments

2.4.1. Structure, Timing, and Order of Assessments

Each of the 3 assessments (Initial, Final, and Disadaptation) took place on 2 different days, with a 48 h separation between them. On the first day, participants completed the following laboratory assessments, following the indicated order: (1) Lifestyle and physical activity assessment; (2) Body temperature assessment; (3) Body composition and anthropometric assessment; and (4) Maximum isometric strength assessment. After a 48 h recovery period, participants underwent a (5) Counter-resistance strength assessment in the weight training room. Each of these assessments will be described in detail below.

To minimize potential influences related to evaluation scheduling and human chronobiology, both training and evaluation times were kept consistent for each participant throughout the study. Prior to the start of the study, participants were asked about their preferred time of day (morning or afternoon, including specific time slots), and these preferences were respected and maintained for the duration of the study. Consequently, all training sessions and evaluations were conducted within the same designated time slots.

2.4.2. Physical Activity and Fitness Evaluations

The assessment of lifestyle and the level of physical activity was conducted using the International Physical Activity Questionnaire (IPAQ) [25]. The questionnaire was

anonymously completed in the laboratory at the beginning of each evaluation, following the same protocol and schedule for each participant.

2.4.3. Body Temperature Assessment

After completing the questionnaire, both internal (IT) and external (ET) body temperatures were assessed under resting conditions. Additionally, both temperatures were monitored throughout the acclimatization program, daily over the 4 weeks. During each acclimatization session, both temperatures were measured immediately before entering each sauna set and immediately after exiting.

The assessment was performed following the protocol, techniques of Siquier-Coll et al. [26]. A high-precision infrared thermometer calibrated for research with human subjects (TAT 5000, Exergen, Watertown, MA, USA) was used for thermal evaluations. Before each assessment, the thermometer was disinfected with hydroalcoholic gel and dried with vegetable paper. IT was always assessed first, with the measurement taken in the mucosa on the right side inside the mouth, with the mouth fully closed. Subsequently, ET was measured on the middle part of the participants' foreheads after drying sweat and cleaning the skin with vegetable paper.

2.4.4. Resting Cardiovascular Response

Following the assessment of body temperatures, systolic blood pressure (SBP), diastolic blood pressure (DBP), and resting heart rate (RHR) were evaluated. These parameters were measured using a calibrated digital blood pressure monitor (Visomat comfort 20/40, Hoffmann-La Roche, Basel, Switzerland), under recommended resting conditions [27].

2.4.5. Body Composition and Anthropometry

After the blood pressure assessments, body composition was evaluated using bioelectrical impedance. This assessment was conducted using a Tanita body composition analyzer (BF-350, Tanita Corp., Tokyo, Japan), with participants barefoot and in underwear. To maximize measurement reliability, clinical usage recommendations were followed [28], and assessments were performed in a fasting state without fluid intake.

Additionally, various anthropometric parameters were assessed. Skinfold thickness was measured using a skinfold caliper (Holtain, Crymych, UK). The assessed skinfolds included pectoral, abdominal, suprailiac, subscapular, tricipital, and leg. Bistyloid bicondylar and bihumeral bone diameters were measured using a calibrated caliper (Holtain, Crymych, UK). Finally, chest, arm, waist, hip, thigh, and leg circumferences were measured. All measurements were conducted by an experienced evaluator, performed in a fasting state immediately after bioelectrical impedance, and followed the guidelines of the International Society for the Advancement of Kinanthropometry (ISAK) [29].

2.4.6. Maximum Isometric Strength

After the previous assessments, participants had a two-hour period for hydration and breakfast. After this period, they were summoned back to the laboratory for a isometric strength evaluation.

The maximum peak torque generated under isometric conditions in knee flexion and extension was evaluated using an isokinetic dynamometer (Biodex 3 PRO, Biodex Medical Systems, New York, NY, USA). Knee extension and flexion force were assessed in the dominant limb. The dynamometer position was configured according to the manufacturer's guidelines, aligning the rotation axis with the middle part of the knee. The dynamometer configuration was recorded for each participant, and the same measures were repeated in all assessments.

Before the assessment, each participant underwent a warm-up consisting of 5 min on a stationary bicycle at 150 watts and 70–80 rpm. Following this, knee mobility exercises were performed for 1 min, as well as a gentle stretch of the quadriceps and hamstrings, lasting 12 s, without causing any discomfort to the participant. Subsequently, 10 half squats without load were performed, followed by a 5 s isometric unloaded half squat. Finally, participants mounted the dynamometer, and their hip, thigh, and leg were secured with straps. The assessment was conducted at a 45° knee flexion angle, and 3 rounds of maximum isometric contractions of knee extension and flexion were performed. Each contraction lasted 6 s. The best absolute peak force value in flexion and the best absolute peak value in extension were recorded from the three rounds.

Additionally, relative maximum force was calculated for the subject's body mass and muscle mass by dividing each of the absolute peak values by total mass. Similarly, the flexor-extensor force ratio was calculated by dividing the absolute torque peak in extension by the absolute torque peak in flexion.

2.4.7. Resistance Strength

After a 48 h recovery period following the isometric strength assessment, participants were called to the weight room, maintaining the same appointment time throughout all evaluations.

Upon arriving at the weight room, and before starting warm-up and assessments, the leg press machine (Telju Shock, Telju Fitness, Toledo, Spain) and the multipower station (Telju Fitness, Toledo, Spain) were individually configured for each participant. This configuration aimed for participants' comfort as well as for ensuring safe knee flexion-extension angles [30], which were determined using goniometers (GIMA, Gessate, Italy). Once this position was determined, and after confirming it in the warm-up of the first assessment, it remained constant for each participant throughout the entire study, both in evaluations and training sessions.

The assessment of maximum resistance strength was indirectly performed in the guided half squat exercise on the multipower station as well as in the leg press exercise. This assessment was carried out following the calculations and protocols for the indirect determination of maximum repetition (1RM) by Bryzcki et al. [31]. Prior to the 1RM assessment, all participants performed a warm-up, consisting of 5 min on a cycle ergometer at 150 watts and 70–80 rpm. Subsequently, they did joint mobility exercises for the trunk and lower body, as well as gentle stretches lasting 12 s for the quadriceps, calves, and hamstrings.

Once this part was completed, they began the specific warm-up in the half squat on the multipower station. For safety reasons, the descent was limited without exceeding 90° of knee flexion in the eccentric phase. The specific warm-up began with a set of 15–20 repetitions without weight. Then, the weight was gradually increased, performing 2–3 repetitions and recovering for 30–40 s. Every 3–4 attempts had a 2 min rest break.

To determine the 1RM, the criterion was set that muscular failure should be reached before completing 6 repetitions. To achieve this, if the execution speed did not decrease significantly in the 3rd or 4th repetition of each attempt, the set was stopped, a 2 min recovery was taken, and the protocol was continued. Once failure was achieved, a confirming repetition was performed after a 2 min passive recovery. After confirming failure, both the lifted weight and the completed repetitions were recorded. The 1RM was indirectly calculated using these variables [31]

After a 5 min passive rest and gentle lower-body stretching, the same assessment protocol was carried out on the leg press.

2.5. Training Program

All participants followed the same training program, which was individualized based on the initial 1RM assessment. Each participant completed 2 weekly resistance training sessions, with a 48 h rest between sessions. Each training session began with a warm-up, similar to that performed in the assessments. Subsequently, 4 sets of 8–10 repetitions were performed in the guided half squat exercise on the multipower station, followed by 4 sets of 8–10 repetitions on the leg press. Recoveries were passive, with a duration of 1.5 min between sets and 3 min between exercises. The load was initially set at 75% of the initial 1RM and increased by 5% weekly, finishing the last week with 90% of the initial 1RM.

To reduce contamination from technique, each participant maintained the same position and configuration for both the machine positions and joint angles used in the initial assessment, remaining constant throughout the entire study. The training sessions were conducted at a room temperature of 23 ± 1 °C and 24 ± 1% relative humidity (RH).

2.6. Sauna Bathing Program

In addition to the training sessions, participants in the HG completed a sauna session immediately after each workout, totaling 2 sessions per week. Sauna sessions were passive, with participants sitting inside the sauna.

The sauna was set to 100 ± 2 °C with normal ambient relative humidity, and participants completed 4 sets of 10 min each, with passive breaks of 5 min at room temperature (23 ± 1 °C). The RH of both laboratory and sauna was 24 ± 1%. The sauna was preheated in advance to ensure that participants completed the entire exposure time at the desired temperature.

2.7. Hydration Control

Hydration was restricted only during both strength training and sauna sessions. During training, fluid intake immediately before and during the workout was limited to a maximum of 250 mL for all participants.

Additionally, participants in the HG could ingest a moderate amount of water (300 mL) immediately after finishing the workout, but during the sauna sessions, they were prohibited from ingesting liquids until completing the last set.

2.8. Statistical Analysis

The statistical analysis was conducted using IBM SPSS® Statistics® version 24 for Macintosh OS. The analysis included an initial normality study using the Shapiro–Wilk test. Subsequently, the Friedman Anova and post hoc test were used to assess intragroup differences, and the Mann–Whitney U test was employed to examine differences between study groups. Finally, effect sizes for the found significances were calculated using Cohen's r for non-parametric data, following the guidelines of Fritz et. Al. [32]. According to this author, 0.5 values can be considered as a large effect, 0.3 values can be considered as a medium effect, and 0.1 values can be considered as a small effect [32,33]. All data are presented as median and interquartile range (25th–75th quartiles), and a significance level of $p < 0.05$ was set for statistical significance.

3. Results

3.1. Anthropometric and Body Composition

Table 1 reflects the results related to the level of physical activity, anthropometric parameters, and body composition throughout the study.

Table 1. Level of physical activity, anthropometric parameters, and body composition throughout the entire study.

	Evaluation 1 Initial		Evaluation 2 Final		Evaluation 3 Detraining	
	HG (N = 14)	**NG (N = 15)**	**HG (N = 14)**	**NG (N = 15)**	**HG (N = 14)**	**NG (N = 15)**
Fitness (hours/week)	5.21 (4.35–5.77)	5.55 (4.66–6.10)	5.01 (4.22–5.50)	5.16 (4.44–5.79)	5.45 (4.37–6.15)	5.17 (3.92–5.98)
Body weight (Kg)	76.30 (71.00–79.00)	65.40 (59.45–72.90) ■	77.40 (70.90–79.90)	65.75 (58.40–73.05) ■	77.40 (72.7–79.7) ♦	65.40 (59.05–72.65)
BMI (Kg/m^2)	23.82 (22.93–24.87)	21.55 (20.42–23.26) ■	24.13 (22.53–24.93)	21.89 (20.39–23.39)	24.81 (23.04–24.95)	21.43 (20.42–23.26) ■
Sf. Abdominal (mm)	19.50 (14.50–23.2)	13.50 (11.75–20.60)	19.00 (13.00–21.80)	13.00 (10.50–18.50)	18.45 (13.10–23.00) ♦	13.25 (9.55–16.40)
Sf. Suprailiac (mm)	15.00 (8.70–18.00)	9.50 (7.65–13.10) ■	14.00 (8.80–18.00)	8.60 (6.00–12.45) ■	11.00 (9.00–15.10) ♦	10.10 (4.90–18.45)
Sf. Subscapular (mm)	11.50 (10.50–13–10)	10.00 (9.25–10.10) ■	10.50 (10.00–11.00)	9.40 (8.50–10.00)	9.90 (9.30–10.50) ♦	9.50 (7.70–10.35)
Sf. Tricipital (mm)	11.20 (10.00–13.00)	10.10 (8.75–12.10)	11.00 (10.00–12.00)	9.79 (7.50–12.90)	10.00 (8.80–13.00)	9.50 (6.50–14.45)
Sf. Thigh (mm)	17.50 (12.50–23.00)	17.40 (11.40–21.75)	16.50 (12.80–24.20) *	18.10 (13.45–21.00)	21.00 (15.50–26.00) ♦	16.00 (12.00–21.00)
Sf. Leg (mm)	11.54 (8.10–13.90)	13.00 (8.80–13.60)	9.77 (7.20–11.00)	12.80 (8.60–16.75) *	8.47 (6.90–10.00) ♦	12.10 (7.35–12.85)
Σ 6 Skinfolds (mm)	83.12 (69.90–92.40)	75.27 (69.10–83.80) ■	80.33 (66.18–94.90)	74.90 (66.00–88.40)	79.75 (62.32–85.78) ♦♦	75.15 (67.32–89.77)
Perim. Arm (cm)	32.50 (31.00–33.30)	28.60 (26.75–31.50)	32.90 (31.50–35.00)	28.20 (27.25–31.50) ■	32.70 (31.70–35.00)	27.40 (27.00–31.45) ■
Perim. Thigh (cm)	53.50 (46.50–54.00)	48.50 (40.05–49.25)	56.50 (50.50–57.20) *	48.32 (43.75–50.40) ■	54.20 (50.20–59.00) ♦	49.20 (48.85–52.90)
Perim. Leg (cm)	37.50 (34.50–39.20)	37.00 (35.10–42.55)	38.20 (37.50–39.00) *	36.00 (35.10–38.15)	38.10 (35.30–38.50) ♦	35.00 (34.15–35.85) ■ ♦
Fat mass (kg)	11.10 (10.00–14.70)	8.50 (5.85–11.05)	11.80 (10.60–16.40)	8.63 (5.75–11.10) ■	11.40 (10.10–15.70)	8.89 (6.00–10.30)
Fat mass (%)	14.80 (14.10–18.60)	12.60 (9.85–15.55)	15.20 (14.70–20.50)	12.75 (9.60–15.35)	15.00 (14.30–19.60)	12.30 (10.05–14.75)
Muscle mass (kg)	36.23 (32.40–39.50)	32.80 (28.40–38.60)	37.35 (33.16–40.10) *	32.40 (27.55–38.15) ■	37.60 (33.89–39.98) ♦	32.50 (26.99–39.12) ■
Muscle mass (%)	48.58 (44.35–52.19)	49.30 (43.80–51.78)	49.24 (44.89–53.15)	49.90 (42.57–52.00)	49.73 (45.12–53.89) ♦	49.47 (42.60–52.20)
Body water (kg)	47.10 (44.70–47.90)	40.30 (38.80–45.45) ■	46.50 (44.10–48.10)	40.60 (38.30–45.35)	47.60 (44.40.48.20)	40.40 (38.15–45.65) ■
Body water (%)	62.50 (59.60–63.00)	64.90 (61.80–65.90)	62.00 (58.20–62.50)	64.80 (62.05–65.70)	62.20 (58.90–62.70)	64.30 (62.40–65.85)

Legend: HG: Hyperthermia Group; NG: Normothermia Group; Sf: Skinfold; Perim: Perimeter; Σ6: 6 skinfolds summation. Differences between groups in each evaluation: ■ $p < 0.05$; Differences between consecutive evaluations: * $p < 0.05$; Differences between Initial and Detraining evaluations: ♦ $p < 0.05$; ♦♦ $p < 0.01$.

The table shows that the HG group exhibited significantly higher weight values in the final evaluation ($p < 0.05$) and BMI during the detraining evaluation ($p < 0.05$). Regarding weight changes, only the HG group experienced a slight increase ($p < 0.05$) in the detraining evaluation.

Regarding skinfold thickness, the NG group initially presented lower values in the suprailiac skinfold as well as in the total sum of six skinfolds. The HG group showed a significant decrease ($p < 0.05$) in thigh skinfold thickness at the final evaluation. Following the detraining period, the HG group exhibited significant reductions in abdominal ($p < 0.05$), suprailiac ($p < 0.05$), subscapular ($p < 0.05$), thigh ($p < 0.05$), leg ($p < 0.05$), and total sum of six skinfolds (Σ6 skinfolds; $p < 0.01$). In contrast, the NG group demonstrated increases in leg skinfold ($p < 0.05$) and Σ6 skinfolds ($p < 0.05$) at the final evaluation. No significant changes were observed in the NG group after the detraining period.

Regarding body circumferences, the HG group showed significant increases in thigh ($p < 0.05$) and leg ($p < 0.05$) perimeters at the final evaluation. Although no significant changes were observed during the detraining period, the thigh ($p < 0.05$) and leg ($p < 0.05$) circumferences remained higher than their initial values. Additionally, the HG group exhibited greater arm ($p < 0.05$) and thigh ($p < 0.05$) circumferences compared to the NG group at the final evaluation. During the detraining period, the HG group again demonstrated larger arm ($p < 0.05$) and leg ($p < 0.05$) perimeters. Conversely, the NG group experienced a significant decrease in leg circumference ($p < 0.05$) during the detraining period compared to its baseline values.

Body composition did not differ significantly between groups at baseline. In the final evaluation, the HG group showed a significant increase ($p < 0.05$) in muscle mass and exhibited greater total muscle mass ($p < 0.05$) and fat mass ($p < 0.05$) compared to the NG group. No significant changes were observed during the detraining evaluation; however, the HG group maintained higher muscle mass ($p < 0.05$) and muscle percentage ($p < 0.05$) compared to their baseline values. Additionally, at detraining, the HG group

demonstrated greater muscle mass ($p < 0.05$) and total body water content ($p < 0.05$) relative to the NG group.

3.2. Metabolic Rate, Body Temperatures, and Cardiovascular Parameters

No group experienced significant changes in body temperature, cardiovascular, or metabolic parameters. The only difference observed, as shown in Table 2, was a higher basal metabolic rate ($p < 0.05$) in the HG group compared to the NG group during the detraining evaluation.

Table 2. Body temperature, cardiovascular, and metabolic parameters throughout the study.

	Evaluation 1 Initial		Evaluation 2 Final		Evaluation 3 Detraining	
	HG (N = 14)	NG (N = 15)	HG (N = 14)	NG (N = 15)	HG (N = 14)	NG (N = 15)
Metabolic Rate (Kcal/d)	1908.00 (1840.00–1910.00)	1716.00 (1254.75–1320.00)	1917.67 (1896.00–1922.00)	1719.00 (1263.65–1315.50)	1903.00 (1825.00–1919.00)	1717.00 (1257.75–1318.50) ■
Int. Temp. (°C)	36.40 (35.60–36.20)	36.62 (35.23–35.7)	36.60 (35.15–35.50)	36.41 (35.00–36.10)	36.60 (35.44–36.10)	36.40 (35.30–35.87)
Ext. Temp (°C)	36.20 (35.50–36.38)	36.71 (35.15–35.90)	36.65 (35.40–36.24)	36.42 (35.15–36.00)	36.72 (35.30–36.25)	36.65 (35.22–36.25)
SBP (mmHg)	124.21 (117.50–134.25)	126.70 (123.00–155.00)	126.15 (118.15–132.66)	128.80 (136.67–126.00–148.00)	126.12 (115.90–135.63)	126.76 (137.33–116.00–157.00)
DBP (mmHg)	76.10 (55.50–84.25)	81.37 (64.00–95.00)	74.52 (54.00–85.50)	77.43 (66.00–82.00)	75.00 (52.50–81.75)	78.80 (67.00–93.00)
RHr (bpm)	68.50 (49.00–55.00)	71.43 (60.00–103.00)	67.00 (52.25–79.50)	69.33 (57.00–72.00)	67.00 (46.50–80.25)	66.89 (56.00–78.00)
Squat reps (N°)	4.86 (4.12–5.10)	5.20 (4.22–5.30)	4.71 (4.00–5.50)	4.40 (4.10–5.20)	4.57 (4.44–5.30)	4.60 (4.02–5.55)
Leg Press Reps (N°)	4.86 (4.25–6.00)	4.80 (4.00–5.57)	4.00 (3.76–5.00)	4.40 (3.51–4.97)	5.43 (4.60–6.00)	4.40 (3.90–6.02)

Legend: HG: Hyperthermia Group; NG: Normothermia Group; Int. Temp: internal temperature; Ext. Temp: external temperature; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; RHr: Resting heart rate; Differences between groups in each evaluation: ■ $p < 0.05$.

3.3. Resistance Strength

Figure 3 compiles the data related to strength assessments under counter-resistance conditions. The figure shows the weight lifted in both RM tests, and the respective RMs in absolute and relative terms for total body mass.

The figure shows that, in the final evaluation, both groups significantly increased their absolute squat 1RM values ($p < 0.05$; HG r = 0.86; NG r = 0.89). After the detraining period, the HG group further increased its squat 1RM, with values significantly higher than baseline ($p < 0.001$; r = 0.93). In relative terms, the NG group showed no significant changes, whereas the HG group demonstrated significantly greater relative squat 1RM values at both the final evaluation ($p < 0.05$; r = 0.86) and after the detraining period ($p < 0.001$; r = 0.92) compared to their initial strength levels.

In the leg press exercise, the NG group showed significantly greater relative values in the final evaluation ($p < 0.05$, r = 0.86). The HG group demonstrated significant increases in leg press performance at the final evaluation in both absolute ($p < 0.05$, r = 0.86) and relative terms ($p < 0.05$, r = 0.87), exhibiting greater relative strength ($p < 0.05$) than the NG group. After the detraining period, the HG group presented higher values compared to baseline in both absolute ($p < 0.01$, r = 0.94) and relative ($p < 0.05$, r = 0.92) measures. At this time point, the HG group also showed greater absolute ($p < 0.05$) and relative ($p < 0.05$) leg press strength compared to the NG group.

3.4. Isometric Strength

Additionally, Figure 4 compiles all the information related to the evaluation of knee flexor-extensor strength under isometric conditions. The values are expressed in both absolute terms (Nm) and relative to body weight (Nm/Kg). Additionally, flexor-extensor force ratios have been calculated and are also expressed in both absolute and relative terms.

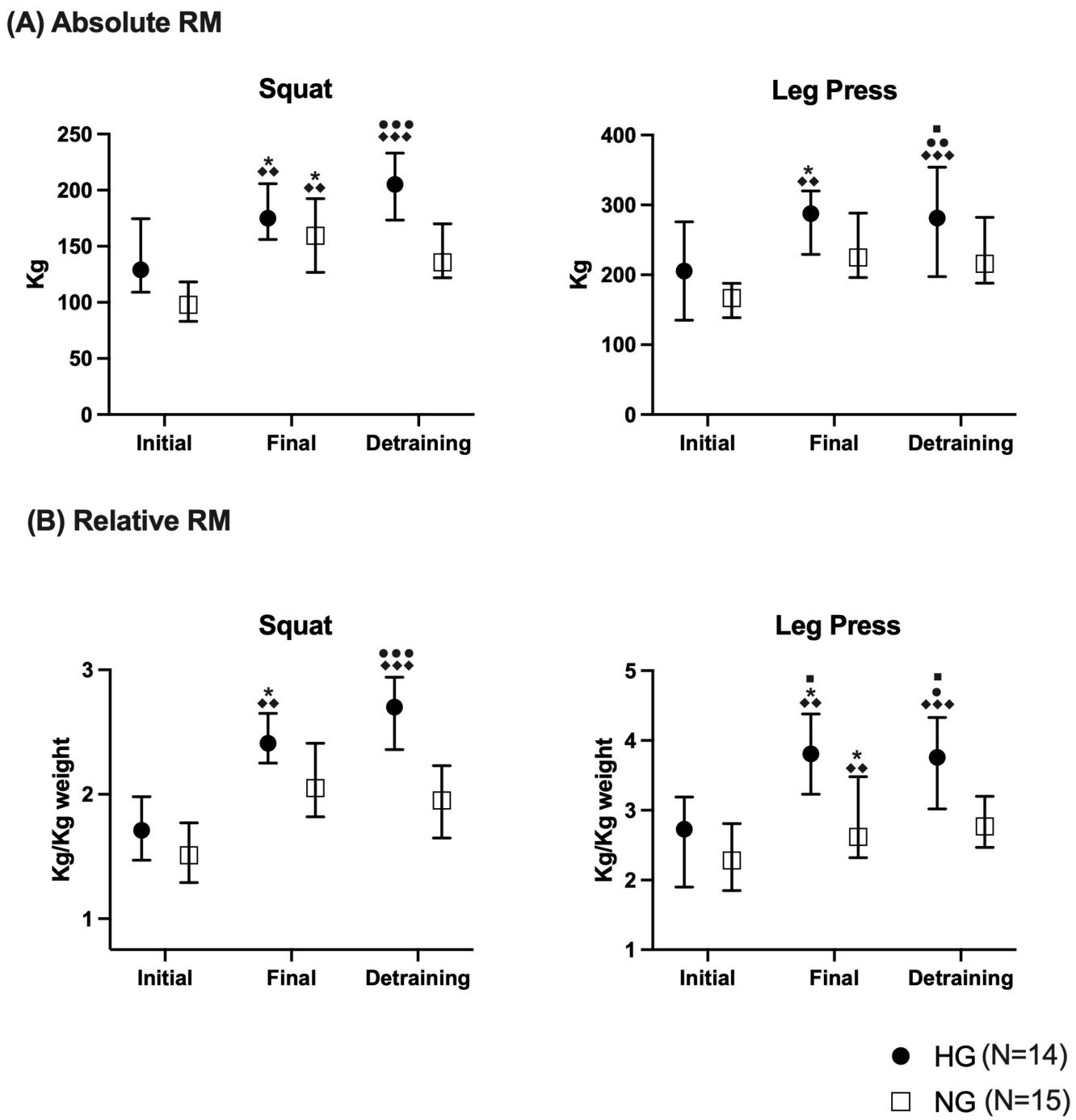


Figure 3. Main findings on the absolute and relative resistance strength along the study. (Legend: HG: Hyperthermia Group; NG: Normothermia Group; RM: Maximum repetition; (**A**) Absolute RM values in squat and leg press exercises; (**B**) Relative RM values in squat and leg press exercises; Differences between groups in each evaluation: ■ $p < 0.05$; Differences between consecutive evaluations: * $p < 0.05$; Differences between Initial and Detraining: • $p < 0.05$; •• $p < 0.01$; ••• $p < 0.001$; Effect size; ♦♦ r = 0.86−0.89; ♦♦♦ r > 0.90. Differences between groups in each evaluation: ■ $p < 0.05$).

Figure 4 shows that, in absolute terms, the NG group increased knee flexion torque in the final evaluation ($p < 0.05$, r = 0.76), whereas the HG group demonstrated significant increases in both knee flexion ($p < 0.05$, r = 0.75) and extension ($p < 0.05$, r = 0.76) torque values after the detraining period. Both of these increases were significantly greater compared to the NG group ($p < 0.05$).

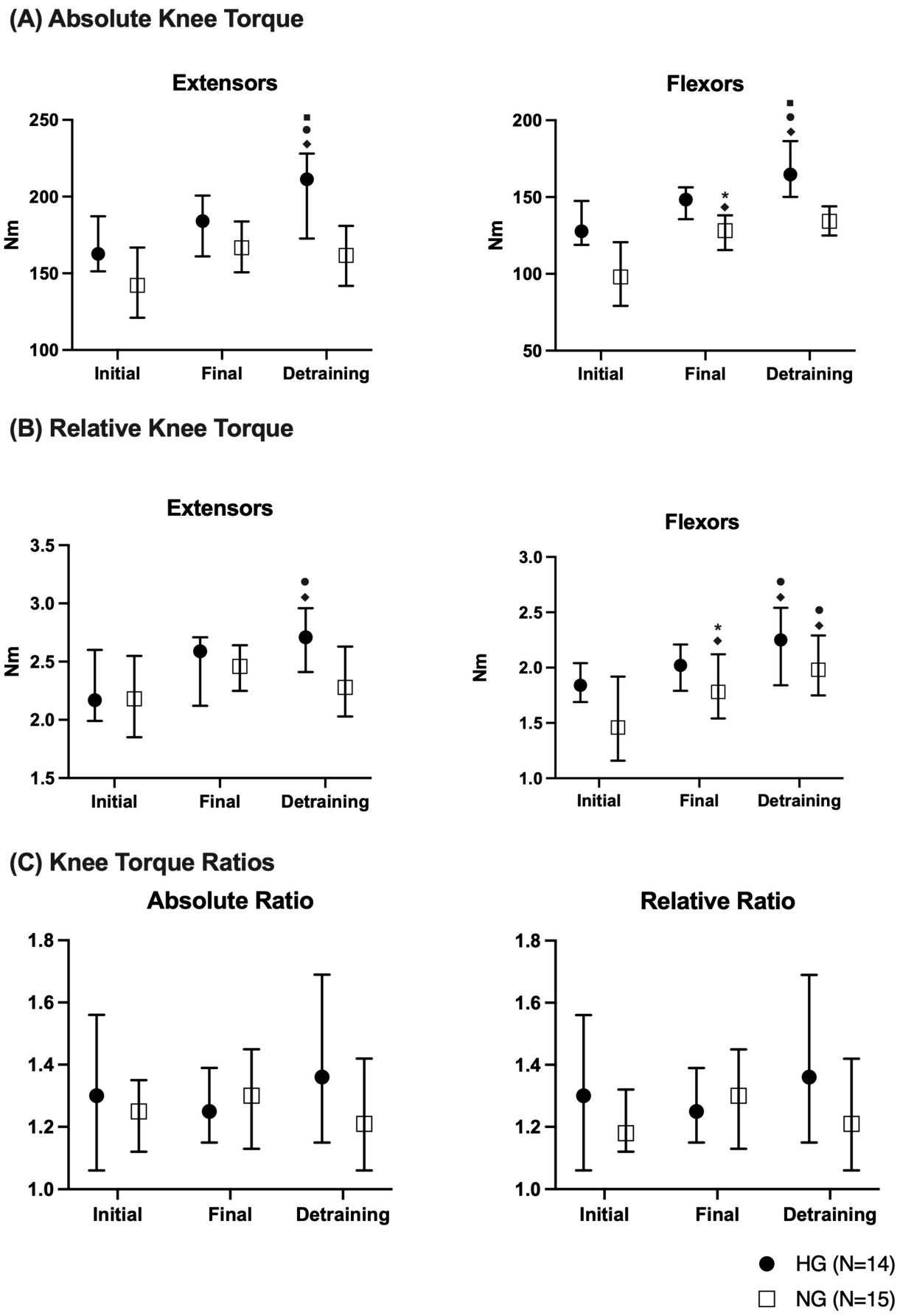


Figure 4. Main findings regarding the absolute and relative isometric knee strength throughout the study. (**Legend:** HG: Hyperthermia Group; NG: Normothermia Group; Extensors: Knee extensors

maximal strength; Flexors: Knee flexors maximal strength; Ratio: Strength resulting from dividing the maximal knee extension strength by the maximal knee flexion strength; (**A**) Absolute torque values in maximal isometric knee flexion and extension; (**B**) Relative torque values in maximal isometric knee flexion and extension; (**C**) Torque Ratio values expressed in absolute and relative terms; Differences between groups in each evaluation: Differences between groups in each evaluation: ■ $p < 0.05$; Differences between consecutive evaluations: * $p < 0.05$; Differences between Initial and detraining evaluations: • $p < 0.05$; Effect Size: ♦ r = 0.75–0.85).

Regarding relative torque strength, the NG group showed significant increases in knee flexion values at both the final ($p < 0.05$, r = 0.77) and detraining ($p < 0.05$, r = 0.75) evaluations compared to baseline. The HG group also demonstrated increased relative torque values, with higher knee extension torque observed after the detraining period ($p < 0.05$, r = 0.75) compared to baseline. Additionally, the HG group exhibited increased knee flexion torque after the detraining period ($p < 0.05$, r = 0.76) relative to their initial values. No significant differences between groups were observed in relative knee torque measures.

4. Discussion

The aim of this study was to assess the effect of implementing a passive sauna bathing program to extreme heat (100 ± 2 °C), in combination with counter-resistance strength training, on the maximum strength of the lower limbs, as well as on body composition and other physiological variables.

In this study, both study groups followed the same training program, which induced favorable and noticeable responses in both groups, as shown in Figure 3. Interestingly, due to the randomization process of the sample, the study groups were not initially homogeneous, and the HG presented higher initial values of body weight, BMI, body water content, and Σ6 Skinfolds. This factor should be taken into account when interpreting the results. Although no initial intragroup differences were observed in strength values, anthropometric variables may influence both absolute strength levels and physiological adaptations to resistance training [34,35]. To minimize the impact of anthropometric differences, strength levels were individualized and normalized based on each subject's anthropometric characteristics. Specifically, strength values were expressed relative to body mass, a widely accepted approach in sports and exercise science [36]. Nonetheless, given the differences in anthropometric variables between groups, the interpretation of the results should be approached with caution.

This control measure was also applied to the resistance training program, which was similar between both study groups. In combination with the strength training program, HG additionally implemented a passive sauna bathing program in its schedule.

Regarding body composition, as shown in Table 1, different responses were observed between the study groups. The NG group exhibited no significant changes following the resistance training intervention. In contrast, the HG group demonstrated a statistically significant reduction in the sum of skinfolds and an increase in skeletal muscle mass post-intervention, while fat mass and total body water remained unchanged. Notably, increases in muscle mass and certain anthropometric circumferences were observed immediately after the intervention and were maintained throughout the detraining period. Conversely, reductions in skinfold thickness reached statistical significance only after the detraining phase. As it was mentioned above, current evidence suggests that heat therapy may accelerate and positively affect the anabolic and hypertrophic responses linked to resistance training [6], that those anabolic responses can occur even after a single training session [37], and heat plays a crucial role in triggering immediate effects after thermal stimulus applica-

tion [38,39]. These anabolic responses have also been observed among older individuals training with low resistance loads [3].

Very recently, it has been published that heat, in combination with strength training, elicits strong anabolic responses [4], like the effect on heat shock proteins (HSP) [6] and anabolic hormones like GH [40], which is also highly responsive to resistance exercises [41]. There is also evidence of a strong and positive effect of sauna bathing, with increases in testosterone production and decreases in cortisol levels [21]. These findings may help explain the observed increases in muscle mass in the HG group. This is particularly noteworthy given that, despite following the same training program, the group that did not undergo sauna bathing did not experience any significant changes in muscle mass.

The reduction in the sum of skinfolds observed in the HG group, despite no changes in overall body fat levels, should be interpreted with caution. One possible explanation for this finding, potentially related to heat exposure, is a redistribution of body water [42]. In this context, previous studies have reported that heat acclimation programs can induce adaptations in body water content, typically manifested as an increase in plasma volume [43]. Unfortunately, plasma volume could not be assessed in the participants. Although hydration was monitored during the sauna sessions and training, overall daily hydration status may have influenced these results. It has been reported that hydration status can affect both performance and heat adaptations during heat acclimation [44]. Therefore, this represents a significant limitation that should be carefully controlled in future studies.

Regarding strength results, both groups experienced increases in their values. However, differences in the responses have been observed and are going to be discussed. In the case of counter-resistance strength, responses to the same training program differed between groups. Overall, the NG group exhibited a tendency toward increased strength levels at the final evaluation, which was followed by a decline during the detraining period. Interestingly, the HG also increased their strength levels after the intervention period and, furthermore, continued to increase their strength levels after the detraining period, experiencing a positive compensatory response. Under isometric conditions, the HG group did not show a statistically significant increase in torque values following the intervention program; however, they exhibited significant increases in torque after the 4-week detraining period. The real mechanism underlying this difference in strength responses is still unclear to the authors, but considering that the training program was identical for both groups (intensity, volume, density, and frequency), the difference between groups could be linked to heat therapy.

In this sense, it has been reported that extreme heat can tire out the central nervous system, decreasing human performance in tasks with high neuromuscular and cognitive demands, as the maximal torque evaluation [20]. Additionally, it is widely known that, in the initial weeks of training, improvements in force production are usually of a neural or metabolic nature, as they are adaptive responses with a faster temporality [45]. In terms of neural adaptations, these two facts could explain the difference observed between groups in strength responses. HG probably experienced a greater neural fatigue accumulation during the intervention period, deriving this greater fatigue from heat stress [19,20] as well as by training stress itself [46].

Finally, the fact that the HG continued to increase their strength levels after the detraining period, and NG did not, could be explained by several heat-induced mechanisms. First of all, it has been proven that the aforementioned HSPs generate anabolic and neuroprotective effects on various components of the nervous system [47], improving nerve transmission function [23]. Additionally, mTOR acts synergistically to enhance the action of brain-derived neurotrophic factor (BDNF), improving its neurotrophic actions [48,49]. It should be emphasized that it has been observed in healthy young subjects that a 5-week

resistance training significantly increased circulating levels of BDNF [50]. These findings may help explain the observed changes in both resistance and isometric strength in the HG group following the detraining period.

In this context, the potential effects of heat on nerve growth factor (NGF) should also be taken into consideration. NGF responds to strength training [51], has been enhanced by various families of HSPs, such as HSP25, 27, and 70 [52]. It has been observed that these factors are significantly activated by heat therapy [6,8].

The results observed in the HG group are supported by findings reported by Racinais et al. [23], who observed that heat acclimation at moderate temperatures (45–50 °C) led to improvements in force production.

The consideration of these findings is particularly relevant in relation to the isometric strength outcomes. In this work, both groups improved their levels of isometric knee flexion strength after the intervention period; however, participants in the HG experienced a greater increase after the readaptation period in absolute terms, which did not occur in participants who did not undergo the heat program. These mechanisms usually induce greater neural adaptations and could help in the explanation of the observed strength results.

Although several important limitations exist—such as the lack of strict hydration control, the heterogeneity of groups in terms of baseline strength levels and body composition, and the inclusion of female participants—the findings of the present study, together with existing evidence on the effects of extreme heat [17,18], suggest that exposure to high temperatures may synergistically enhance resistance training adaptations, promoting beneficial effects on strength development and body composition.

The results of the present study should be interpreted with caution; however, they may have practical implications in various contexts. In athletic training, the implementation of high-temperature sauna protocols has shown potential benefits for improving muscular strength and optimizing body composition in athletes. Additionally, in health and rehabilitation settings, these protocols may aid in enhancing muscle recovery, increasing muscle tone and mass, and accelerating rehabilitation or sports reconditioning processes.

Regarding women and older adults, the application of high-temperature sauna protocols should be approached cautiously. Due to physiological differences, particularly in older populations, further research is necessary before recommending these interventions for these groups. A gradual approach is advised, beginning with lower temperatures and progressively increasing heat exposure to ensure safety and tolerability.

5. Conclusions

In this study, it has been observed that the implementation of a 4-week program of passive acclimation to extreme dry heat, combined with a resistance training program, has induced favorable responses at the levels of strength development and anthropometrics.

The implementation of extreme-temperature sauna bathing combined with resistance training over a 4-week period resulted in an increase in muscle mass. Additionally, in the group that underwent sauna bathing, reductions in skinfold thickness, as well as increases in muscle mass and total body water, were observed after four weeks of detraining, compared to the group that did not receive sauna treatment. Both groups improved their strength levels in the squat exercise; however, only the sauna group continued to increase strength after the detraining period. In the leg press exercise, strength improvements were observed exclusively in the sauna group, both immediately post-training and following detraining. Finally, after the detraining period, the sauna group was the only one to exhibit increased isometric strength in both knee flexion and extension.

In conclusion, although further research is warranted, the implementation of extreme-temperature sauna bathing appears to be a safe and effective strategy for enhancing strength levels and body composition in healthy young adults.

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