

Heat Acclimatization Bridging the Gap Between High Performance and General Health

Alberto Hermo-Argibay ^{1, 2, *}, Jose Luis Sánchez-Jiménez ², Susana Rovira-Llopis ¹, Jose I. Priego-Quesada ² and Víctor M. Víctor ¹

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¹ Department of Endocrinology and Nutrition, University Hospital Doctor Peset, Foundation for the Promotion of Health and Biomedical Research in the Valencian Region (FISABIO), 46017, Valencia, Spain

² GIBD, Departamento de Educación Física y Deportiva, Universitat de València, Valencia, España

Correspondence

Alberto Hermo-Argibay

Department of Endocrinology and Nutrition, University Hospital Doctor Peset, Foundation for the Promotion of Health and Biomedical Research in the Valencian Region (FISABIO), 46017, Valencia, Spain

hermoargibay@gmail.com

Abstract

The increase in temperature due to climate change poses significant health risks for both the general population and athletes, particularly those with low thermoregulatory capacity, who may experience increased stress responses that could lead to vascular complications like atherosclerosis. To mitigate these effects, athletes have adopted heat acclimatization protocols, which could also benefit the general population. In our study, ten physically active subjects (6 males, 4 females) underwent a heat training protocol twice a week for eight weeks, involving 30 minutes of constant-power exercise at 36°C. Subjects were tested incrementally and had blood samples taken to evaluate physical fitness and atherosclerosis risk. Results showed improvements in body composition, cardiovascular function, thermoregulatory capacity and metabolic response to heat as well as an improvement in the risk of developing cardiovascular diseases.

Keywords

heat training; acclimatization; cardiovascular fitness; atherosclerosis; thermoregulation

1 Introduction

The increase in temperature due to climate change is a significant health issue for both the general population and athletes (Ebi et al., 2021). This problem not only has acute effects but also poses medium- to short-term risks for

individuals with low thermoregulatory capacity. These individuals may experience increased stress responses (cortisol, reactive oxygen species, or blood viscosity, among others), which could promote the genesis and development of atherosclerosis and other



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vascular complications (Cheng & Su, 2010). To mitigate acute adverse effects, athletes have implemented strategies to improve heat tolerance through acclimatization protocols (Périard et al., 2015). Similar strategies could be beneficial for enhancing physical capacity and health in the general population.

2 Material and Methods

2.1 Participants

Ten physically active subjects (6 females/4 males) underwent a heat training protocol twice a week for eight weeks (16 sessions). To classify them as physically active, we used the IPAQ questionnaire, and they had to achieve a "HIGH" score according to the questionnaire guidelines:

- Vigorous-intensity activity on at least 3 days, accumulating at least 1500 MET-min/week.
- 7 or more days of any combination of walking, moderate-intensity, or vigorous-intensity activities, accumulating at least 3000 MET-mins/week.

Subjects ceased their weekly training and only performed the heat training sessions during the intervention to avoid interference with the results. The criteria established for subject recruitment were as follows:

- Inclusion: Age between 40 and 60 years, high physical activity score according to the IPAQ questionnaire, and normal hematological profile.
- Exclusion: Autoimmune disease, BMI >40, and history of malignant neoplasia.

2.2 Methodology

The training protocol consisted of 50 min of heat exposure distributed as follows. First, the subjects underwent a 10-min passive acclimatization, followed by a 5-min warm-up on the cycle ergometer. This was followed by the main part of 30 min, and finally, the subjects performed a 5-min cool-down, all at a

temperature of $36 \pm 1^\circ\text{C}$. The intensities for the warm-up and cool-down corresponded to 90% of LT1, and the main part to 110% of LT1.

To observe the changes induced by this protocol, subjects underwent three incremental step tests (beginning, middle, and end). The incremental tests consisted of 5-min step tests, where subjects performed increments of 20 or 15 watts for men and women, respectively, until they could no longer sustain the required intensity or dropped below a cadence of 60. Capillary blood samples were taken from the earlobe to analyze lactate concentration within the last 20 seconds of each step. The determination of thresholds was conducted based on data obtained from incremental step tests. To obtain the thresholds, baseline +0.5 and +1.5 criteria were used for LT1 and LT2, respectively.

Subjects were scheduled for appointments before and after the intervention at the Endocrinology Department of Hospital Peset in Valencia. During these appointments, blood pressure measurements and blood samples were taken from the antecubital vein. A fraction of the blood sample was used for analysis (complete blood count, biochemistry, and leukocyte count); another fraction was processed to extract polymorphonuclear leukocytes and perform the leukocyte adhesion technique (As can be seen in the methodology section of Luna-Marco et al., 2023).

For the body composition analysis, the mBCA 515 (SECA, Germany) was used on the same day as the blood analysis. Therefore, subjects were required to fast and refrain from vigorous exercise and alcohol consumption for 24 hours prior to the test to minimize the limitations of the technique and ensure the most accurate results possible.

2.3 Statistical Analysis

For data analysis, SPSS® 20.0 software (IBM SPSS™ Statistics, Chicago, USA) was used. Normality of the population distribution was assessed using the Shapiro- Wilk test. Comparisons of variables were analyzed using Student's t-test for dependent parametric variables (pre vs. post). A 95% confidence interval was used, and differences were considered significant when $p\text{-value} < 0.05$.

3 Results

The data analyzed show improvements in body composition, with weight loss (-1.2 ± 0.9 kg; $p\text{-value} = 0.003$), and fat percentage ($-7.4 \pm 4.0\%$; $p\text{-value} < 0.001$), along with an increase in fluid percentage ($5.9 \pm 2.7\%$; $p\text{-value} = 0.016$). Resting heart rate (-6.8 ± 3.2 ppm; $p\text{-value} < 0.001$) and blood pressure data (systolic, diastolic, and mean arterial pressure, (-12.9 ± 11.0 mmHg; $p\text{-value} = 0.010$, -6.4 ± 3.0 mmHg; $p\text{-value} = 0.011$ and -6.9 ± 1.9 mmHg; $p\text{-value} = 0.006$ respectively) also improved. Muscle damage and renal function markers (urea, AST, CK) decreased (-6.9 ± 7.0 mg/dL; $p\text{-value} = 0.019$; -4.0 ± 5.3 mg/dL; $p\text{-value} = 0.041$ and -100.0 ± 84.3 UI/L; $p\text{-value} = 0.005$ respectively) and coagulation parameters indicated greater hemodilution due to increased plasma volume (prothrombin time (2.23 ± 0.62 s; $p\text{-value} < 0.001$) and in hematocrit values ($-2.2\% \pm 1.6\%$; $p\text{-value} = 0.003$)), despite an increase in red blood cell count ($+0.28 \times 10^{12} \pm 0.12 \times 10^{12}$ cells/L; $p\text{-value} = 0.028$). Regarding the subjects' metabolic response, there was a lower metabolic activation upon heat exposure, as indicated by a smaller difference in lactate values at rest between ambient and high temperatures (-0.3 ± 0.1 mmol/L; $p\text{-value} = 0.006$). In terms of physical performance, significant improvements were observed in LT1 and LT2 ($+0.4 \pm 0.3$ W/kg; $p\text{-value} = 0.027$ and $+0.36 \pm 0.15$ W/kg; $p\text{-value} < 0.001$ respectively), indicating greater physical

capacity. The leukocyte-endothelium interaction assay results showed fewer leukocyte interactions (-136 ± 160 cells/min; $p\text{-value} = 0.027$), with faster rolling (212.4 ± 180 $\mu\text{m/s}$; $p\text{-value} = 0.006$) and less adhesion (-6.8 ± 4.0 cells/mm²; $p\text{-value} = 0.006$), indicating a lower risk of atherosclerosis and inflammation.

4 Discussion

The data analyzed show significant improvements in body composition, including weight loss and reduction in fat percentage, which would imply a reduced risk of obesity-related diseases (Jayedi et al., 2022). Improvements were also observed in resting heart rate and blood pressure, thus preventing hypertension, metabolic syndrome and reducing mortality risk (Chen et al., 2024).

Markers of muscle damage and renal function decreased, indicating better muscle and renal health. Additionally, coagulation parameters suggest greater hemodilution due to increased plasma volume, despite an increase in red blood cell count, indicating better oxygen transport capacity and lower blood viscosity, thereby improving the subjects' hemodynamics (Lorenzo et al., 2010). Subjects present a smaller difference in resting lactate concentration between ambient temperature and heat due to the intervention, which shows a lower activation of the sympathetic system and catecholamines (Brenner et al., 1998). In terms of physical performance, significant improvements were observed in lactate thresholds, thus enhancing the subjects' physical capacity.

Finally, the results of the leukocyte-endothelium interaction assay indicated a lower risk of atherosclerosis, implying a reduced likelihood of developing cardiovascular diseases (Kilbey et al., 2025).

5 Conclusions

An eight-week heat training protocol had a significant impact on the subjects' cardiovascular health markers, reducing the risk of atherosclerosis development and progression. Additionally, subjects acclimated to heat, resulting in reduced metabolic stress responses and improved physical capacity in hot environments.

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Conflicts of Interest: The authors declare no conflict of interest.

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