Dahlquist DT, Dieter BP, Brotherhood J, & Koehle MS. The Effects of Post-Exercise Sauna Bathing on 5- and 10- km Performance in University Level Track Athletes.
J Sport Human Perf 2023; 11(1):13-22.

DOI: https://doi.org/10.12922/jshp.v11i1.189

JOURNAL OF SPORT AND HUMAN PERFORMANCE

ORIGINAL RESEARCH – PILOT STUDY OPEN ACCESS

THE EFFECTS OF POST-EXERCISE SAUNA BATHING ON 5- AND 10- KM PERFORMANCE IN UNIVERSITY-LEVEL TRACK ATHLETES

Dylan T. Dahlquist [1,2,*], Brad P. Dieter [3], James Brotherhood [1,2], and Michael S. Koehle [1,2,4]

[1] School of Kinesiology, University of British Columbia, Vancouver, BC, Canada.
[2] Athletics and Recreation, University of British Columbia, Vancouver, BC, Canada.
[3] Marcros Inc., Spokane, WA, USA.
[4] Division of Sport & Exercise Medicine, University of British Columbia, Vancouver, BC, Canada

*Corresponding author: dyl.dahlquist@gmail.com

ABSTRACT

Background: Sporting events are commonly held in environments that differ from an athlete's typical training environment, impacting performance. To maximize performance and tolerance of said environments, athletes often employ adaptation strategies in natural or controlled-stress settings prior to competition. The purpose of this case study was to determine if post-exercise sauna bathing could augment performance in University-level track and field athletes competing in temperate [TEMP] as well as hot and humid environments [HOT]. **Methods:** Two male runners partook in a three-week heat acclimation (HA) protocol. Athletes completed a total of 16 post-exercise sauna sessions (total time: 600 minutes at ~40-50^{o}C, 5-10% humidity) and 2 heat chamber runs (90 minutes at ~12-15 kmph and a constant 38.5^{o}C, 5-10% humidity). Blood was sampled pre- and post-HA to assess plasma volume (PV) percent change (Δ). **Results:** PV increased by 13.5% and 4.9% following HA. Both athletes had lifetime personal bests in the 5-km in the TEMP competition, posting an average improvement of 1.3±0.8% from their previous personal best. Of the two athletes, one competed at the HOT competition in 2015 for the 10-km and ran 1:40.4 faster in 2016, reducing their time to completion by 5.0%. **Conclusions:** Post-exercise sauna bathing could be a practical and time-efficient method to enhance track and field athlete performance in 5- and 10-km events in both temperate and hot conditions.

Keywords: Heat Acclimation; Cross Tolerance; Extreme Conditions

INTRODUCTION

Major national and international sporting events are commonly held in environments that are highly stressful for intense exercise, such as in heat and humidity (*e.g.,* 2016 and 2020 Summer Olympics) and/or in extreme cold (*e.g.,* 2014 Scarpa ISMF World Ski Cup). Combined stress from heat and cold can even occur within one event (*e.g.,* triathlon or Western States 100). Un-compensated heat stress without proper dissipation of thermal load can lead to hyperthermia and death, and training or competing in hot weather can severely hamper one's performance by 2-57% in team sports [1-3]. Furthermore, moderate (11-18^{o}C) to severe (-20-10^{o}C) cold exposure can severely hamper an individual's performance in simple cognitive tasks including memory, vigilance, decision making, dexterity, reaction time and grip strength [4-7]. Thus, athletes usually try to adapt to natural [8, 9] or controlled-stress settings [10] prior to competition, to maximize performance and tolerance of those environments.

A rapid onset of acclimation occurs over the course of 6 days that involves a reduction in heart rate, resting and working core and skin temperatures, as well as an improvement in thermal comfort and an expansion in plasma volume (PV) [11, 12]. This increase in PV is one of the key drivers of an increase in performance after heat acclimation (HA). This performance benefit is derived from an increase in cardiac output, resulting in a higher maximal oxygen uptake per given effort level [13]. During chronic stimuli to thermal stress (12-14 days), there will be an alteration in sudomotor and vasomotor responses, such as: a reduction in sweating onset, an increase in the amount and rate of sweating, a change in mineral concentration in said sweat and an improved redistribution of blood flow to the peripheries for heat exchange [11, 12]. It is still unknown if HA and/or acclimatization protocols lasting ≥30 days would provide further benefits.

Since ambient heat stress impacts almost all physiological systems, studies have therefore examined how heat stress-induced adaptations could improve performance in cool [14], normothermic [15] and hypoxic [16, 17] conditions. Until recently, most athletes either needed to visit a tropical environment or use a highly technical, expensive, environmental chamber to adapt to hot environments. Even when athletes have access to the latter, the traditional 90-minute exposure, for five consecutive days in 35-40^{o}C, 40% humidity can be poorly tolerated by athletes since it can lead to blunting of their ability to recover and properly taper since most short-term heat acclimation protocols are undertaken shortly prior to competition and/or travel [18]. Secondly, such a protocol can alter athletes' habitual training or be of insufficient duration since full acclimation can takes more than 14 days [11]. Thus, scientists have started utilizing various passive heat stressors to practically and efficiently adapt athletes [19].

Three studies have shown that post-exercise sauna bathing (~90^{o}C) for 30 min, with a total of 10-13 sessions over a ~1.5-3-week period can increase PV by ~7-18% and significantly lower heart rate in moderately or well-trained athletes [20-22]. Intriguingly, a recent study of cross-adaptation [14, 23] demonstrated this effect with a passive heat acclimation (HA) protocol independent of exercise [24]. Researchers demonstrated that a short, 11-day period of sitting in a hot ambient condition (48-50^{o}C, 50% humidity) for 60 minutes/day, significantly improved the participants' skeletal muscle contractility in both cool (24^{o}C, 40% humidity) and hot (44-50^{o}C, 50% humidity) conditions (≥ 9-17%) [24].

The current state of the literature on practical methods (e.g., using a sauna at a local recreational center) to adapt to the heat remain scarce and inconsistent. Therefore, the purpose of this case study was to assess a practical and economically efficient HA protocol that could be used by athletes competing in a very hot, humid environmental condition. A secondary purpose was to determine if athletes would also have a boost in their performance in temperate conditions.

Background & Athletes

Two trained University-level male track and field athletes (age: 22±1 years; weight: 68.5±0.5 kg) partook in this field-based post-exercise sauna protocol to acclimate to the heat in preparation for a major track and field competition in Alabama, U.S.A. [HOT]. At the time of the post-exercise sauna protocol, athletes had been running for a Division 1 Collegiate Track Program for 2 and 3 years, with a total of 10±2 years of competitive running. Training and the post-exercise sauna protocol was undertaken during the months of April (avg weather: 11.7°C, 78% humidity) and May (avg weather: 14.4°C, 74% humidity) in Vancouver BC, Canada. Each athlete was healthy, cleared to run by their medical doctor and had no history of heat-related illness. Both athletes subjectively informed the researchers that they routinely performed poorly in race situations in the heat. Each athlete approved and provided verbal consent for participating in all protocols as part of the demands of their sport [25] and provided further written informed consent for the publication of this case study.

Post-exercise Sauna Protocol

Athletes completed 16 periodized post-exercise sauna sessions (total time: 600 minutes) and 2 heat chamber runs (90 minutes at ~12-15 kph) over a course of 31 days in preparation for one race each in cool (TEMP: 12-14°C, 90% humidity) and hot, humid environments (HOT: 28-29°C, 70% humidity). Recovery days, which consisted of no sauna exposure, were strategically implemented prior to competition to minimize fatigue and maximize recovery following the initial acclimation phase (Day 1 to Day 13). Acclimation Days 1 to Days 13 were completed continuously since daily heat stress for acclimation purposes appears to be superior to a non-continuous protocol [26]. There was no sauna or heat exposure during travel days. Sauna temperature was ~40-50°C (with humidity between 5 and 10%) according to the facility utilized by the athletes. The heat chamber was set at a constant 38.5°C with 5-10% humidity (Weiss-Technik, 2014, WPH1504-1-30-WC-SSR-X; Heuchelheim, Germany). Athletes reported to a local laboratory to acquire pre- and post- HA blood samples to assess the changes in hematocrit (Hct) and hemoglobin (Hb). Hct and Hb were utilized to determine the relative percent change in PV (Δ) via the equation developed by Dill and Costill [27]: Δ PV (%) = $100x((Hb_{pre}/Hb_{post})x(100\text{-}Hct_{post})/(100\text{-}Hct_{pre})\text{-}1)$. Baseline measurements for both athletes were taken prior to training on the same date and time of day. The second blood sample varied between athletes. One athlete provided the second blood sample the day after TEMP (16 days post-baseline). The other athlete provided the second blood sample four days following CHAMP (32 days post-baseline). Time of day was not controlled for the second blood sample. Times are presented in minutes:seconds.milliseconds. An overview of the protocol, duration of each session and blood sampling time-periods can be seen in Figure 1.

Participant Characteristics

Athlete characteristics from their 2015 and 2016 training/competition years can be seen in Table 1.

Figure 1. Schematic of Sauna Protocol

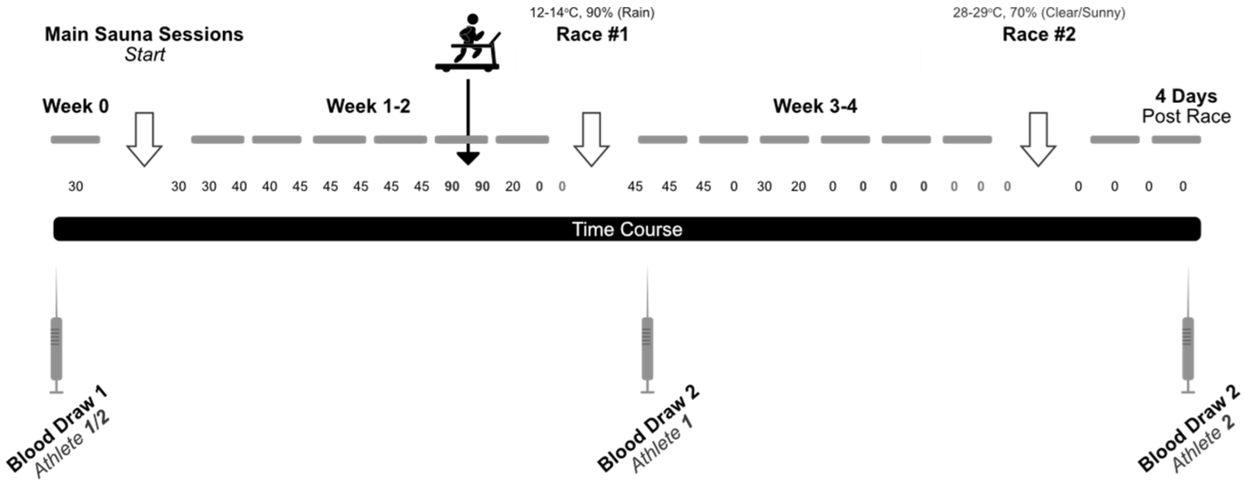

Table 1. Subject Characteristics

Subject (#)	Athlete #1	Athlete #2
Age (years)	23	21
Weight (kg)	69	68
Height (cm)	182	180
Years of Running	7	6
Years of Competing at University Level	2	3
# of Races Ran in 2014	10	15
# of Races Ran in 2015	15	12
# of Races Ran in 2016	15	20
Low Volume Training Week (km)	113	100
High Volume Training Week (km)	160	150
Avg Training Volume in 2014 (km)	129	110
Avg Training Volume in 2015 (km)	145	120
Avg Training Volume in 2016 (km)	153	130

Performance Results in 5,000 and 10,000m Race in Hot and Cold Climates

Following the entire post-exercise sauna protocol, one athlete increased their PV by 4.9%. The other athlete increased their PV by 13.5% and provided their second blood sample after being exposed to 11 post-exercise sauna sessions [total time: 415 minutes] and two heat chamber runs (the day following TEMP). Both athletes had lifetime personal bests (1.3±0.8% average decrease in 5-km times) in the TEMP competition, two weeks into the protocol, running 14:33.3 (-00:16.4 faster than previous personal best; -1.8%) and 14:20.1 (-00:06.0 faster than previous personal best; -0.7%). Following 3 weeks and 6 days, athletes competed in the 5- and 10-km race at the HOT competition; running 14:53.4 and 14:47.9, and 31:11.8 and 32:03.6, respectively. Of the two athletes, one athlete in the 10-km event had competed in the same event at HOT the year prior (2015). They ran 1:40.4 faster in

2016 than their previous year, beating their time to complete the 10-km race by 5.0% (33:40.0 and 32:03.6, respectively).

DISCUSSION

This case study supports the limited data available on heat acclimation, and that utilizing a highly ecological method that repeated post-exercise sauna exposure can improve race performance in trained athletes competing in hot (28-29°C) and humid (~70% RH) conditions. Importantly, the effects observed in the present study are not trivial in the context of sport, especially elite sport, as the improvements in this case study were as large as 5% in one athlete. What makes this report novel is that this case study was conducted in a real-world setting (training, acclimation and competition), which also provides ecological validity to the study. Furthermore, it supports the notion of the possibility of cross-acclimation [14, 23]; where both athletes had a lifetime personal best in cool weather (12-14°C and 90% RH), improving the time to complete a 5-km by 1.3±0.8%. Lastly, PV expansion occurred in both athletes following the acclimation by an average of 6.9%, indicating that successful HA was obtained and provides insights into the amount of physiological adaptation that occurs from post-exercise sauna exposure.

To our knowledge, published research investigating the ability of a passive HA protocol to enhance performance is currently limited to 27 studies [20-22, 24, 28-50], and of those, only eleven utilized a sauna for its heat source. Moreso, only six have been performed in trained athletes using a sauna; and of the six, only two included performance testing following HA. Scoon et al [21] showed that over the course of three weeks (~13-15 sessions) of post-workout sauna exposure for 31±5 min at 89.9±2.2°C increased run time-to-exhaustion by 32% [21]. This correlated with a ~2% reduction in time to finish a 5-km time trial. Our case study supports this notion in the competition setting by demonstrating that one athlete improved their 10-km race time by 1:40.4, reducing their time to completion by 5.0%. This improvement could have been associated with the increase in PV, which increased by 6.9% [13]. In line with these findings, Bartolome et al. [33] found a significant improvement in maximal oxygen uptake following three weeks of passive heat acclimation using a dry sauna in semi-professional football players. Additionally, HA has been shown to improve running economy [15], pacing strategies [3] and individuals' ability to dissipate thermal load [51], which simultaneously bolsters fatigue resilience and performance.

The reported temperature used for HA in the current case study was significantly lower than that used by previous protocols [21], but yielded similar expansions in PV and improvements in performance. These findings could be explained by the longer HA course used in the current study, the continuous (daily) protocol and/or the longer total duration of heat exposure. This longer duration acclimation protocol coincides with a another study showing benefits at lower ambient conditions; the research group showed that over a 11-day period of passive exposure to 48-50°C (50% humidity) for 60 minutes/day, the participants' skeletal muscle contractility was increased during a maximal voluntary contraction in both cool (24°C, 40% humidity) and hot (44-50°C, 50% humidity) conditions (≥ 9-17%) [24]. Total time accumulated by the subjects was 660 minutes, which aligns with the total time for the athletes in the current case study. Despite this, we did not take any measurements that could assess a plausible increase in skeletal muscle contractility. Thus, future research should assess a plausible dose-response in time accumulated and intensity of thermal stress on force production.

In addition to the benefits shown in performance in hot environments, heat acclimation/acclimatization has potential ergogenic effects in temperate conditions due to cold-induced vasoconstriction, dehydration and a diminished ability to sweat [52]. Lorenzo and colleagues (2010) first investigated this by subjecting 12 trained cyclists to a maximal oxygen uptake test, time trial performance and lactate threshold test following 10 days of HA in cool (13^{o}C, 30% humidity) and hot (38^{o}C, 30% RH) conditions. Following HA, PV increased by 6.5±1.5% and led to a 5% and 8% increase in maximal oxygen uptake in cool and hot conditions, respectively. Performances in the time trial, which consisted of total amount of work performed in 60 minutes, were bolstered by 5% and 8% in cool and hot conditions, respectively. Lastly, HA increased power output and lactate threshold by 5% both in cool and hot conditions. A follow-up study showed similar findings when assessing the effects of a 10-day heat acclimation protocol on thermoneutral maximal oxygen uptake in 22 amateur cyclists [53]. The authors reported a significant 4.9% increase in maximal oxygen uptake 4 days following the last heat acclimation session. In support of these results, recent reviews and meta-analyses have confirmed the potential for cross-acclimation [16, 54]. Although not as substantial findings as Lorenzo and colleagues, we saw a 1.3±0.8% increase in time trial performance in both athletes in similar conditions (TEMP: 12-14^{o}C, 90% humidity). The discrepancies here could partially be related to the humidity in both conditions. It was roughly 90% RH at TEMP and ~70% at HOT, compared to the 30% seen in Lorenzo et al. This in turn, would target the beneficial sudomotor adaptations that occur with long-term heat exposure, and diminish one's ability to evaporate sweat [55]. Although our track athletes had a plausible higher thermal tolerance, the uncompensated heat stress imposed by the high humidity could explain the smaller improvement in time trial performance as compared to previous studies in highly trained cyclists where humidity was lower [15].

Limitations

This case study has limitations that limit the extent to which the current findings might apply to the larger population. One of the primary limitations to the current case study is the inability to quantify improvements in race performance that could have been attributed to training or attributed to prior experience at the competitions. Secondly, the performance environment was not controlled due to TEMP and HOT being conducted at real world track and field competitions. A third limitation to the current case study is the difference in timing of the blood samples. The athlete with the highest PV expansion provided their second blood sample one day following the TEMP race, which was 15 days following the start of the sauna protocol. The second athlete provided their subsequent blood sample 16 days later (31 days after the first sauna session). Thus, differences in hydration and the stage to which they were acclimated could have altered the findings. The discrepancies could be further explained by the timing of the second blood sample in respect to the cessation of their last exercise session (whether that be training or competition); since a single session of intense exercise (such as a race) can plausibly alter 24 hour post-exercise PV by 10% [56]. Lastly, hydration status was not tightly monitored throughout the protocol; athletes were requested to hydrate *ad libitum* and dehydration could have confounded the PV changes [57]. Despite these limitations, the intervention did appear to improve performance, suggesting that the ecological validity of HA in real-world scenarios is plausible.

CONCLUSION

Post-exercise sauna interventions may be a practical and time-efficient method to enhance track and field athlete performance competing in 5- and 10-km events in both cool and hot conditions. These data indicate that post-exercise sauna exposures could be an easily implementable intervention for athletes who compete in environments with temperature-related stressors. As such, future research should investigate practical HA strategies to understand optimal training load, heat exposure, heat progression and other relevant parameters in relation to HA.

Acknowledgements

We would like to sincerely thank UBC Varsity Athletics and UBC Varsity Track & Field / Cross Country Athletes & Coaches. Lastly, a massive thank you to Lululemon Athletica's Whitespace Innovation team for granting us access to their well-equipped facility that housed the environmental chamber.

Conflicts of Interest

None.

References

1. Taylor L, Rollo I: Impact of altitude and heat on football. *Sports Science Exchange* 2014, 27:1-9.
2. Guy JH, Deakin GB, Edwards AM, Miller CM, Pyne DB: Adaptation to hot environmental conditions: an exploration of the performance basis, procedures and future directions to optimise opportunities for elite athletes. *Sports Med* 2015, 45:303-311.
3. Racinais S, Periard JD, Karlsen A, Nybo L: Effect of heat and heat acclimatization on cycling time trial performance and pacing. *Med Sci Sports Exerc* 2015, 47:601-606.
4. Dizmen C, Ken M, Chan A: The Effect of Temperature on Manual Dexterity, Reaction Time, and Optimum Grip-Span. *IMECS 2015* 2015, 2.
5. Flouris AD, Westwood DA, Cheung SS: Thermal balance effects on vigilance during 2-hour exposures to -20 degrees C. *Aviat Space Environ Med* 2007, 78:673-679.
6. Nimmo M: Exercise in the cold. *J Sports Sci* 2004, 22:898-915; discussion 915-896.
7. Taylor L, Watkins SL, Marshall H, Dascombe BJ, Foster J: The Impact of Different Environmental Conditions on Cognitive Function: A Focused Review. *Front Physiol* 2015, 6:372.
8. Pugliese L, Serpiello FR, Millet GP, Torre A: Training Diaries during Altitude Training Camp in Two Olympic Champions: an Observational Case Study. *Journal of Sports Science and Medicine* 2014, 13:666-672.
9. Bucheit M, Hammond K, Bourdon PC, Simpson BM, Garvican-Lewis LA, Schmidt SF, Gore CJ, Aughey RJ: Relative Match Intensities at High Altitude in Highly-Trained Young Soccer Players (ISA3600). *Journal of Sports Science and Medicine* 2015, 14:98-102.
10. Dehnert C, Bohm A, Grigoriev I, Menold E, Bartsch P: Sleeping in moderate hypoxia at home for prevention of acute mountain sickness (AMS): a placebo-controlled, randomized double-blind study. *Wilderness Environ Med* 2014, 25:263-271.
11. Periard JD, Racinais S, Sawka MN: Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. *Scand J Med Sci Sports* 2015, 25 Suppl 1:20-38.
12. Periard JD, Travers GJS, Racinais S, Sawka MN: Cardiovascular adaptations

supporting human exercise-heat acclimation. *Auton Neurosci* 2016, 196:52-62.

13. Luetkemeier MJ, Thomas EL: Hypervolemia and cycling time trial performance. *Med Sci Sports Exerc* 1994, 26:503-509.
14. Corbett J, Neal RA, Lunt HC, Tipton MJ: Adaptation to heat and exercise performance under cooler conditions: a new hot topic. *Sports Med* 2014, 44:1323-1331.
15. Lorenzo S, Halliwill JR, Sawka MN, Minson CT: Heat acclimation improves exercise performance. *J Appl Physiol (1985)* 2010, 109:1140-1147.
16. Buchheit M, Racinais S, Bilsborough J, Hocking J, Mendez-Villanueva A, Bourdon PC, Voss S, Livingston S, Christian R, Periard J, et al: Adding heat to the live-high train-low altitude model: a practical insight from professional football. *Br J Sports Med* 2013, 47 Suppl 1:i59-69.
17. Heled Y, Peled A, Yanovich R, Shargal E, Pilz-Burstein R, Epstein Y, Moran DS: Heat acclimation and performance in hypoxic conditions. *Aviat Space Environ Med* 2012, 83:649-653.
18. Leatherwood WE, Dragoo JL: Effect of airline travel on performance: a review of the literature. *Br J Sports Med* 2013, 47:561-567.
19. Casadio JR, Kilding AE, Cotter JD, Laursen PB: From Lab to Real World: Heat Acclimation Considerations for Elite Athletes. *Sports Med* 2017, 47:1467-1476.
20. Stanley J, Halliday A, D'Auria S, Buchheit M, Leicht AS: Effect of sauna-based heat acclimation on plasma volume and heart rate variability. *Eur J Appl Physiol* 2015, 115:785-794.
21. Scoon G, Hopkins W, Mayhew S, Cotter J: Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. *Journal of Science and Medicine in Sport* 2007, 10:259262.
22. Leicht AS, Halliday A, Sinclair LM, Auria SD, Buchheit M, Kenny GP, Stanley J: Heart rate variability responses to acute, and repeated post-exercise sauna in trained cyclists. *Appl Physiol Nutr Metab* 2018.
23. Tipton M: A case for combined environmental stressor studies. *Extrem Physiol Med* 2012, 1:7.
24. Racinais S, Wilson MG, Periard JD: Passive heat acclimation improves skeletal muscle contractility in humans. *Am J Physiol Regul Integr Comp Physiol* 2017, 312:R101-R107.
25. Winter EM, Maughan RJ: Requirements for ethics approvals. *J Sports Sci* 2009, 27:985.
26. Gill N, Sleivert G: Effect of daily versus intermittent exposure on heat acclimation. *Aviat Space Environ Med* 2001, 72:385-390.
27. Dill DB, Costill DL: Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *J Appl Physiol* 1974, 37:247-248.
28. Fenemor SP, Driller MW, Gill ND, Mills B, Casadio JR, Beaven CM: Practical application of a mixed active and passive heat acclimation protocol in elite male Olympic team sport athletes. *Appl Physiol Nutr Metab* 2022, 47:981-991.
29. Ashworth E, Cotter J, Kilding A: Post-exercise, passive heat acclimation with sauna or hot-water immersion provide comparable adaptations to performance in the heat in a military context. *Ergonomics* 2022:1-12.
30. Zapara MA, Dudnik EN, Samartseva VG, Kryzhanovskaya SY, Susta D, Glazachev

OS: Passive Whole-Body Hyperthermia Increases Aerobic Capacity and Cardio-Respiratory Efficiency in Amateur Athletes. *Health* 2020, 12:14-26.

31. Stevens CJ, Ross MLR, Carr AJ, Vallance B, Best R, Urwin C, Periard JD, Burke L: Postexercise Hot-Water Immersion Does Not Further Enhance Heat Adaptation or Performance in Endurance Athletes Training in a Hot Environment. *Int J Sports Physiol Perform* 2021, 16:480-488.
32. Pokora I, Sadowska-Krepa E, Wolowski L, Wyderka P, Michnik A, Drzazga Z: The Effect of Medium-Term Sauna-Based Heat Acclimation (MPHA) on Thermophysiological and Plasma Volume Responses to Exercise Performed under Temperate Conditions in Elite Cross-Country Skiers. *Int J Environ Res Public Health* 2021, 18.
33. Bartolome I, Siquier-Coll J, Perez-Quintero M, Robles-Gil MC, Grijota FJ, Munoz D, Maynar-Marino M: 3-Week passive acclimation to extreme environmental heat (100+/- 3 degrees C) in dry sauna increases physical and physiological performance among young semi-professional football players. *J Therm Biol* 2021, 100:103048.
34. Kirby NV, Lucas SJE, Cable TG, Armstrong OJ, Weaver SR, Lucas RAI: Sex differences in adaptation to intermittent post-exercise sauna bathing in trained middle-distance runners. *Sports Med Open* 2021, 7:51.
35. Allan JR, Wilson CG: Influence of acclimatization on sweat sodium concentration. *J Appl Physiol* 1971, 30:708-712.
36. Barley OR, Chapman DW, Mavropalias G, Abbiss CR: The Influence of Heat Acclimation and Hypohydration on Post-Weight-Loss Exercise Performance. *Int J Sports Physiol Perform* 2019:1-26.
37. Beaudin AE, Clegg ME, Walsh ML, White MD: Adaptation of exercise ventilation during an actively-induced hyperthermia following passive heat acclimation. *Am J Physiol Regul Integr Comp Physiol* 2009, 297:R605-614.
38. Bonner RM, Harrison MH, Hall CJ, Edwards RJ: Effect of heat acclimatization on intravascular responses to acute heat stress in man. *J Appl Physiol* 1976, 41:708-713.
39. Brazaitis M, Skurvydas A: Heat acclimation does not reduce the impact of hyperthermia on central fatigue. *Eur J Appl Physiol* 2010, 109:771-778.
40. Fox RH, Goldsmith R, Hampton IF, Lewis HE: The Nature of the Increase in Sweating Capacity Produced by Heat Acclimatization. *J Physiol* 1964, 171:368-376.
41. Henane R, Valatx JL: Thermoregulatory changes induced during heat acclimatization by controlled hypothermia in man. *J Physiol* 1973, 230:255-271.
42. Kanikowska D, Sato M, Sugenoya J, Iwase S, Shimizu Y, Nishimura N, Inukai Y: No effects of acclimation to heat on immune and hormonal responses to passive heating in healthy volunteers. *Int J Biometeorol* 2012, 56:107-112.
43. Leppäluoto J, Huttunen P, Hirvonen J, Väänänen A, Tuominen M, Vuori J: Endocrine effects of repeated sauna bathing. *Acta physiologica Scandinavica* 1986, 128:467-470.
44. Pallubinsky H, Schellen L, Kingma BRM, Dautzenberg B, van Baak MA, van Marken Lichtenbelt WD: Thermophysiological adaptations to passive mild heat acclimation. *Temperature (Austin)* 2017, 4:176-186.
45. Racinais S, Wilson MG, Gaoua N, Periard JD: Heat acclimation has a protective

effect on the central but not peripheral nervous system. *J Appl Physiol (1985)* 2017, 123:816-824.

46. Shido O, Sugimoto N, Tanabe M, Sakurada S: Core temperature and sweating onset in humans acclimated to heat given at a fixed daily time. *Am J Physiol* 1999, 276:R1095-1101.
47. Shin YO, Lee JB, Min YK, Yang HM: Heat acclimation affects circulating levels of prostaglandin E2, COX-2 and orexin in humans. *Neurosci Lett* 2013, 542:17-20.
48. Stephens JM, Halson SL, Miller J, Slater GJ, Askew CD: Influence of body composition on physiological responses to post-exercise hydrotherapy. *J Sports Sci* 2018, 36:1044-1053.
49. Zurawlew MJ, Mee JA, Walsh NP: Heat Acclimation by Postexercise Hot-Water Immersion: Reduction of Thermal Strain During Morning and Afternoon Exercise-Heat Stress After Morning Hot-Water Immersion. *Int J Sports Physiol Perform* 2018:1-6.
50. Zurawlew MJ, Walsh NP, Fortes MB, Potter C: Post-exercise hot water immersion induces heat acclimation and improves endurance exercise performance in the heat. *Scand J Med Sci Sports* 2016, 26:745-754.
51. Ricardo JSC, Michael JC, Jonathan PM, Neil PW: Heat acclimation responses of an ultra-endurance running group preparing for hot desert-based competition. *European Journal of Sport Science* 2014.
52. Castellani JW, Young AJ: Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure. *Auton Neurosci* 2016, 196:63-74.
53. Waldron M, Jeffries O, Tallent J, Patterson S, Nevola V: The time course of adaptations in thermoneutral maximal oxygen consumption following heat acclimation. *Eur J Appl Physiol* 2019, 119:2391-2399.
54. Ely BR, Lovering AT, Horowitz M, Minson CT: Heat acclimation and cross tolerance to hypoxia: Bridging the gap between cellular and systemic responses. *Temperature (Austin)* 2014, 1:107-114.
55. Taylor NA: Human heat adaptation. *Compr Physiol* 2014, 4:325-365.
56. Gillen CM, Lee R, Mack GW, Tomaselli CM, Nishiyasu T, Nadel ER: Plasma volume expansion in humans after a single intense exercise protocol. *J Appl Physiol (1985)* 1991, 71:1914-1920.
57. Jimenez C, Melin B, Koulmann N, Allevard AM, Launay JC, Savourey G: Plasma volume changes during and after acute variations of body hydration level in humans. *Eur J Appl Physiol Occup Physiol* 1999, 80:1-8.