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Human Kinetics
CRITICALLY APPRAISED TOPIC

Does Dehydration Affect the Adaptations of Plasma Volume, Heart Rate, Internal Body Temperature, and Sweat Rate During the Induction Phase of Heat Acclimation?

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Clinical Scenario: Exercise in the heat can lead to performance decrements and increase the risk of heat illness. Heat acclimation refers to the systematic and gradual increase in exercise in a controlled, laboratory environment. Increased duration and intensity of exercise in the heat positively affects physiological responses, such as higher sweat rate, plasma volume expansion, decreased heart rate, and lower internal body temperature. Many heat acclimation studies have examined the hydration status of the subjects exercising in the heat. Some of the physiological responses that are desired to elicit heat acclimation (ie, higher heart rate and internal body temperature) are exacerbated in a dehydrated state. Thus, euhydration (optimal hydration) and dehydration trials during heat acclimation induction have been conducted to determine if there are additional benefits to dehydrated exercise trials on physiological adaptations. However, there is still much debate over hydration status and its effect on heat acclimation. ***Clinical Question:*** Does dehydration affect the adaptations of plasma volume, heart rate, internal body temperature, skin temperature, and sweat rate during the induction phase of heat acclimation? ***Summary of Findings:*** There were no observed differences in plasma volume, internal body temperature, and skin temperature following heat acclimation in this critically appraised topic. One study found an increase in sweat rate and another study indicated greater changes in heart rate following heat acclimation with dehydration. Aside from these findings, all 4 trials did not observe statistically significant differences in euhydrated and dehydrated heat acclimation trials. ***Clinical Bottom Line:*** There is minimal evidence to suggest that hydration status affects heat acclimation induction. In the studies that met the inclusion criteria, there were no differences in plasma volume concentrations, internal body temperature, and skin temperature. ***Strength of Recommendation:*** Based on the Oxford Centre for Evidence-Based Medicine Scale, Level 2 evidence exists.

Keywords: hydration, physiological adaptations, heat exposure

Clinical Scenario

Exercise in the heat can lead to performance decrements and increase the risk of heat illness.[1,2] Heat acclimation refers to the systematic and gradual increase in exercise in a controlled, laboratory environment with hot environmental conditions and is an impactful strategy that can be used to optimize performance and safety when exercising in the heat.[1] Higher sweat rate, plasma volume expansion, decreased heart rate, and lower internal body temperature are observed following heat acclimation, and these adaptations decrease the risk of heat illness and increase exercise performance in the heat.[1–3] Heat acclimation induction protocols typically occur over the course of 5 to 14 days (<7 d, short term; 7–14 d, medium term; and >14 d, long term) and produce a variety of physiological gains in performance.[1,3] Many heat acclimation studies have examined the hydration status of the subjects exercising in the heat[4–8] and it is well known that hydration status impacts physiological and performance responses in the heat.[9] Some of the physiological responses that are desired to elicit heat acclimation (ie, higher heart rate and internal body temperature) are exacerbated in a dehydrated state.[10] Thus, euhydration (optimal hydration) and dehydration trials during heat acclimation induction have been conducted to determine if there are additional benefits to dehydrated exercise trials on plasma volume, heart rate, internal body temperature, skin temperature, and sweat rate. However, there is still much debate over hydration status and its effect on heat acclimation.

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Focused Clinical Question

Does dehydration affect the adaptations of plasma volume, heart rate, internal body temperature, skin temperature, and sweat rate during the induction phase of heat acclimation?

Search Strategy

Terms Used to Guide Search

Our key terms included the following: hydration, heat, environment, acclimation, thermoregulation, and exercise.

- **P**atient/Client Group: regularly trained active males
- **I**ntervention/Assessment: heat acclimation exercise sessions for 3+days
- **C**omparison: euhydration trial and dehydration trial
- **O**utcome: plasma volume, heart rate, internal body temperature, skin temperature, and sweat rate

Table 1 Summary of Study Design and Articles Retrieved

Level of evidence	Study design	Reference
2	Randomized controlled trial	Pethick et al[6]
2	Randomized controlled trial	Neal et al[11]
2	Randomized controlled trial	Schleh et al[5]
2	Randomized controlled trial	Garrett et al[12]

Source of Evidence Searched

- PubMed
- Scopus
- SPORTDiscus

Inclusion Criteria

- Regularly trained active males
- At least one of the following dependent variables were included as dependent variables: plasma volume, heart rate, internal body temperature, skin temperature, and sweat rate
- There was an intervention of euhydration and dehydration
- Heat acclimation exercise sessions for 3+ days
- Full articles were published

Exclusion Criteria

- Heat acclimatization trials
- Studies not available in the English language

Results of Search

In the initial search, 5 out of 265 studies were recognized. Four of 5 studies met the inclusion criteria. One excluded study did not include the intervention of euhydration and dehydration. The study designs were 1 cross-sectional and 3 crossover studies. Each study was evaluated using the 2011 Oxford Centre for Evidence-Based Medicine (See Table 1).

Best Evidence

The studies in Table 2 were identified as the best evidence available for this critically appraised topic. All 4 studies had a level 2 evidence rating, because they were randomized control clinical trials, and the participant's VO_2max was ≥53 $mL·kg^{-1}·min^{-1}$ to identify them as "active" and "trained." At least one of following variables, including plasma volume, heart rate, internal body temperature, skin temperature, and sweat rate, was the dependent variable in all 4 studies. There were no differences in plasma volume, internal body temperature, and skin temperature following heat acclimation in all 4 studies. This is an indication that hydration status might not affect adaptations to heat acclimation.

Clinical Bottom Line

There is minimal literature assessing the effects of hydration status on heat acclimation induction. In the studies that met the inclusion criteria, there were no differences in plasma volume, internal body temperature, and skin temperature between euhydration and dehydration trials following heat acclimation.[5,6,11,12]

Table 2 Characteristics of Included Studies

Article	Pethick et al[6]	Neal et al[11]	Schleh et al[5]	Garrett et al[12]
Design	RCT (cross-sectional study)	RCT (balanced crossover design)	RCT (random crossover design)	RCT (random crossover design)
Participants	24 subelite male athletes Age, 28 (6) y BM, 74.4 (8.3) kg VO_2max, 61.2 (7.0) $mL·kg^{-1}·min^{-1}$	8 trained male athletes Age, 21 (3) y BM, 77.3 (4.89) kg VO_2max, 56.9 (7.2) $mL·kg^{-1}·min^{-1}$	13 recreationally active males Age, 23 (1) y BM, 81.4 (2.2) kg VO_2max, 53.3 (1.7) $mL·kg^{-1}·min^{-1}$	9 trained males Age, 27 (7) y BM, 74.6 (4.4) kg VO_2peak, 60.0 (7.0) $mL·kg^{-1}·min^{-1}$
Intervention investigated	EUH (–0.2% [0.7%] BML) and DEH (2.2% [0.5%] BML) groups performed 90-min exercise with isothermal method in 35°C and 57% RH for 5 d. Plasma volume and resting T_{int} were measured prior to and following heat acclimation.	EUH (0.6% [0.7%] BML) and DEH (2.7% [0.8%] BML) groups performed 90-min exercise with isothermal method in 39°C and 56% RH for 8 d. Adaptations in plasma volume, HR, T_{int}, T_{skin}, and sweat loss were measured by heat stress test prior to and following heat acclimation. HST was consisted of 60 min at 35% of peak power output in 39°C and 53% RH.	EUH (1.4% BML) and DEH (2.4% BML) groups performed for 3 d of 90-min exercise at 50% VO_2max in 40°C and 30% RH. Plasma volume, HR, T_{skin}, and sweat rate were measured by heat stress test prior to and following heat acclimation. HST was consisted of 90 min at 50% VO_2max in 40°C and 30% RH.	EUH (–0.3% [0.6%] BML) and DEH (1.9% [0.6%] BML) groups performed 5 d of 90 min with isothermal method in 35°C and 60% RH. Plasma volume, HR, T_{int}, and T_{skin} were measured by HST prior to and following heat acclimation. HST was consisted of 90 min at 40% of peak power output in 35°C and 60% RH.
Outcome measures	Plasma volume Resting T_{int}	Plasma volume HR T_{int} T_{skin} Sweat loss	Plasma volume HR T_{skin} Sweat rate	Plasma volume HR T_{int} T_{skin}

(continued)

Table 2 (continued)

Article	Pethick et al[6]	Neal et al[11]	Schleh et al[5]	Garrett et al[12]
Main findings	Plasma volume was not different in EUH (+4.8% [10.2%]) and DEH (+1.7% [10.1%]) following heat acclimation ($P > .05$). Resting T_{int} was not different in EUH (37.3°C [0.3°C]) and DEH (37.4°C [0.3°C]) following heat acclimation ($P > .05$).	Plasma volume, HR, T_{int}, T_{skin}, and sweat loss were not different in EUH and DEH following heat acclimation. (Data in article represented by figures.)	Sweat rate increased greater following heat acclimation with DEH (1.9 [0.1] L·h^{-1}) compared with EUH (1.8 [0.1] L·h^{-1}) ($P = .02$). There were no differences in plasma volume (EUH, 4.4% [2.5%]; DEH, 7.1% [1.8%]), HR (EUH, 167.4 [3.7] bpm; DEH, 164.1 [4.4] bpm), and T_{skin} (EUH, 37.6 [0.2]; DEH, 37.4 [0.1]) between EUH and DEH ($P > .05$).	Plasma volume (EUH, 4% [3%]; DEH, 8% [3%], $P = .06$), T_{int} (EUH, −0.2°C; DEH, −0.4°C, $P = .52$), and T_{skin} (EUH, −0.3°C; DEH, −0.4°C, $P = .15$) were not different in EUH and DEH following heat acclimation. However, HR with DEH demonstrated a greater extent of change (−19 bpm) compared with EUH (−10 bpm) following heat acclimation ($P = .05$).
Level of evidence	2	2	2	2
Validity score[a]	6	7	7	6
Conclusion	Dehydration did not affect adaptations in plasma volume and resting T_{int} following heat acclimation.	Dehydration did not affect adaptations in plasma volume, HR, T_{int}, T_{skin}, and sweat loss following heat acclimation.	Dehydration did not affect plasma volume, HR, and T_{skin} following heat acclimation. However, sweat rate increased greater following heat acclimation with dehydration.	Dehydration did not affect adaptations in plasma volume, T_{int}, T_{skin}, and sweat loss following heat acclimation. However, HR decreased greater following heat acclimation with dehydration.

Abbreviations: BM, body mass; BML, body mass loss; bpm, beats per minute; DEH, dehydration; EUH, euhydration; HR, heart rate; HST, heat stress test; RCT, randomized controlled trial; RH, relative humidity; T_{int}, internal body temperature; T_{skin}, skin temperature; VO_2max, maximal oxygen consumption; VO_2peak, peak oxygen consumption.

[a]Validity score was measured by PEDro scale.

Strength of Recommendation

Based on the Oxford Centre for Evidence-Based Medicine Scale, Level 2 evidence exists.

Implications for Practice, Education, and Further Research

The results of the 4 studies included in this critically appraised topic demonstrate that hydration status does not change physiological adaptations in plasma volume, internal body temperature, and skin temperature. While heat acclimation protocols can vary, the studies that met the inclusion criteria had exercise trials in the heat from 3 to 8 days. The study to show differences in sweat rate had the shortest heat acclimation protocol. Trials were held over a 3-day period, which included exercising in the heat for 90 minutes 3 times a day.[5] Plasma volume and heart rate remained unchanged. Sweat rate was the only variable that had changes between dehydrated (1.5 [0.1] to 1.9 [0.1] L·h^{-1}) and euhydrated trials (1.6 [0.1] to 1.8 [0.1] L·h^{-1}, $P = .02$). In addition, only 1 study demonstrated greater changes in heart rate with dehydration trials following heat acclimation compared with preheat acclimation heart rate. However, the absolute heart rate values were not different between euhydration and dehydration trials following heat acclimation. As all 4 studies did not show changes in plasma volume, internal body temperature, and skin temperature, and 2 out of 3 studies did not indicate the differences in heart rate, between euhydrated and dehydrated trials, which indicates that intentional dehydration does not influence effectiveness of heat acclimation. When designing a heat acclimation protocol, researchers need to keep in mind the target population and ultimate training goal to optimize heat acclimation. Each study included healthy, aerobically fit participants. As hydration status has not been demonstrated to attenuate or enhance the ability to acclimate to the heat, the maintenance of euhydration is considered optimal to prevent athletes from the risk of heat illness and decreases in performance during heat acclimation induction.

References

1. Périard 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. PubMed ID: 25943654 doi:10.1111/sms.12408
2. Armstrong LE, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc*. 2007;39(3):556–572. PubMed ID: 17473783 doi:10.1249/MSS.0b013e31802fa199
3. Tyler CJ, Reeve T, Hodges GJ, Cheung SS. The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports Med*. 2016;46(11):1699–1724. PubMed ID: 27106556 doi:10.1007/s40279-016-0538-5
4. Daanen HAM, Racinais S, Périard JD. Heat acclimation decay and re-induction: a systematic review and meta-analysis. *Sports Med*. 2018;48(2):409–430. PubMed ID: 29129022 doi:10.1007/s40279-017-0808-x
5. Schleh MW, Ruby BC, Dumke CL. Short term heat acclimation reduces heat stress, but is not augmented by dehydration. *J Therm Biol*. 2018;78:227–234. PubMed ID: 30509641 doi:10.1016/j.jtherbio.2018.10.004
6. Pethick WA, Murray HJ, McFadyen P, Brodie R, Gaul CA, Stellingwerff T. Effects of hydration status during heat acclimation on plasma volume and performance. *Scand J Med Sci Sports*. 2019;29(2):189–199. PubMed ID: 30317666 doi:10.1111/sms.13319

7. Patterson MJ, Stocks JM, Taylor NA. Whole-body fluid distribution in humans during dehydration and recovery, before and after humid-heat acclimation induced using controlled hyperthermia. *Acta Physiol*. 2014;210(4):899–912. PubMed ID: 24330400 doi:10.1111/apha.12214
8. Garrett AT, Creasy R, Rehrer NJ, Patterson MJ, Cotter JD. Effectiveness of short-term heat acclimation for highly trained athletes. *Eur J Appl Physiol*. 2012;112(5):1827–1837. PubMed ID: 21915701 doi:10.1007/s00421-011-2153-3
9. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39(2): 377–390. PubMed ID: 17277604 doi:10.1249/mss.0b013e31802ca597
10. Armstrong LE, Maresh CM, Gabaree CV, et al. Thermal and circulatory responses during exercise: effects of hypohydration, dehydration, and water intake. *J Appl Physiol*. 1997;82(6): 2028–2035. PubMed ID: 9173973 doi:10.1152/jappl.1997.82.6.2028
11. Neal RA, Massey HC, Tipton MJ, Young JS, Corbett J. Effect of permissive dehydration on induction and decay of heat acclimation, and temperate exercise performance. *Front Physiol*. 2016;7:564. PubMed ID: 27932993 doi:10.3389/fphys.2016.00564
12. Garrett AT, Goosens NG, Rehrer NJ, et al. Short-term heat acclimation is effective and may be enhanced rather than impaired by dehydration. *Am J Hum Biol*. 2014;26(3):311–320. PubMed ID: 24469986 doi:10.1002/ajhb.22509