Dalleck et al. (2019) ***Int J Res Ex Phys*****. 15(1):87-96.**

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

International Journal of Research in Exercise Physiology

Original Research Article

Post-Exercise Passive Heating Strategies with Hot Water Immersion and Sauna Suits Improve VO_2max, Running Economy, and Lactate Threshold

Lance C. Dalleck[1], Bryant R. Byrd[1], Jonathan W. Specht[1], Angelo K. Valenciana[1]

[1]High Altitude Exercise Physiology Program, Western Colorado University, Gunnison, CO, USA

ABSTRACT

Aim: The purpose of this study was to examine the effects of post-exercise passive heating strategies (sauna suit and hot water immersion) on VO_2max, economy, and lactate threshold. **Methods:** Following recruitment, participants were randomized into one of three groups: 1) exercise training alone – control (N=10), 2) exercise training with post-exercise hot water immersion (N=10), and exercise training with post-exercise sauna suit (N=10). At baseline and post-program participants completed a running economy protocol and maximal exercise testing protocol to measure VO_2max and lactate threshold. The running economy protocol consisted of three consecutive 5-minute stages: stage 1 = 4.6 mph, stage 2 = 5.0 mph, and stage 3 = 5.4 mph. Ventilatory thresholds (VT1 and VT2) were also obtained during the maximal exercise testing protocols. The running economy and maximal exercise testing protocols were performed two times (at both baseline and post-program) to quantify the biological variability of VO_2max, economy, and lactate threshold. **Results:** After 3wk, mean VO_2max changes in the sauna suit and hot water immersion groups were significantly greater ($p < 0.05$) when compared to the control group. Similarly, following the 3wk intervention, lactate threshold changes in the sauna suit and hot water immersion groups were significantly more favorable ($p < 0.05$) when compared to the control group. In the hot water immersion group, there were significant within-group improvements ($p < 0.05$) in economy between baseline and 3wk for all three stages. In the control group, 50% (4/8) of individuals were categorized as responders (change in VO_2max ($\Delta > 3.2\%$)) and 50% (4/8) were categorized as non-responders ($\Delta \leq 3.2\%$). In the hot water immersion and sauna suit groups, the incidence of VO_2max responders were significantly ($p < 0.05$) greater when compared to the control group. In fact, there were 100% VO_2max training responsiveness (7/7 and 9/9) in the hot water immersion and sauna suit groups, respectively. **Conclusions:** Both post-exercise passive heating strategies were equally effective at increasing VO_2max and lactate threshold values. In addition, post-exercise hot water immersion was a more effective strategy at improving running economy relative to wearing a sauna suit after exercise.

KEYWORDS: Endurance performance, Environmental Stress, Heat acclimation, Thermal stress

Introduction

Endurance exercise can be defined as the ability to perform any type of cardiorespiratory exercise (e.g., cross-country skiing, cycling, running, hiking, swimming) for an extended period of time[1]. The complex integration of multiple physiological functions may limit an individual in the pursuit of these endurance exercises. Yet, despite its multifaceted nature, endurance performance is characterized by one simple requirement—the necessity to sustain repeated skeletal muscle contraction. Whether it be an elite athlete, recreational runner or previously inactive individual, the ability to maintain repeated skeletal muscle contraction, and thus overall potential for performance in endurance exercise, can be explained by a similar set of physiological attributes: VO_2max, lactate threshold, and economy.

A combination of increased training volume, steady-state exercise, and interval workouts is the most common approach to improvement of the triad of VO_2max, lactate threshold and economy. However, one drawback to this strategy is an increased risk of overtraining and injury. An alternative strategy to improve performance is exposure to an environmental stressor, such as hypoxia or heat. In fact, there is some preliminary evidence that exercise in conjunction with passive heat exposure provides endurance-related health benefits. For instance, it has been demonstrated that 3 weeks of post-exercise sauna bathing elicits an improvement in cardiorespiratory fitness, most likely due to an increase in plasma volume[2]. More recently, it was shown that 6 days of moderate-intensity exercise training followed by hot water immersion improved endurance performance[3]. However, to our knowledge, there is no research investigating the effects of post-exercise hot water immersion on VO_2max, lactate threshold and economy. Additionally, hot water immersion may be inconvenient for some and therefore it is plausible post-exercise passive heat exposure via wearing a sauna suit may provide individuals with a more practical and portable heat exposure alternative. The purpose of this study was to examine the effects of post-exercise passive heating strategies (sauna suit and hot water immersion) on VO_2max, economy, and lactate threshold. It was hypothesized that incorporating post-exercise heat exposure and hot water immersion into the overall training paradigm will elicit improvements in VO_2max, economy, and lactate threshold.

Methods

Participants

Low risk (N=30) men and women (18 to 50 years of age) were recruited. Inclusionary criteria included no more than one cardiometabolic risk factors (i.e., elevated blood pressure, blood lipids, and/or blood glucose) and willingness to complete the intervention along with baseline and post-program testing.

Experimental design

Following recruitment, participants were

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

randomized into one of three groups: 1) exercise training alone – control (N=10), 2) exercise training with post-exercise hot water immersion (N=10), and exercise training with post-exercise sauna suit (N=10). At baseline and post-program participants completed a running economy protocol and maximal exercise testing protocol to measure VO_2max and lactate threshold. The running economy protocol consisted of three consecutive 5-minute stages: stage 1 = 4.6 mph, stage 2 = 5.0 mph, and stage 3 = 5.4 mph. Ventilatory thresholds (VT1 and VT2) were also obtained during the maximal exercise testing protocols. The running economy and maximal exercise testing protocols were performed two times (at both baseline and post-program) to quantify the biological variability of VO_2max, economy, and lactate threshold.

Exercise Training Intervention

All participants completed a standardized 3wk exercise training program (Table 1):

Monday/Wednesday/Friday

- 3 days/wk of moderate-intensity continuous training performed at VT1

Tuesday

- 1 day/wk of high-intensity, interval training performed at 100% VO_2max

Thursday

- 1 day/wk of steady-state training performed VT2

All exercise-training sessions included a 5-minute warmup and cool-down performed at an RPE of 2 on the 0-10 RPE scale.
Interval bouts were interspersed with 2.5-minute active recovery.

Table 1. Intervention and progression details for the 3wk exercise training program.

Wk	Monday	Tuesday	Wednesday	Thursday	Friday
1	20min at VT1	4 x 1min at 100% VO_2max	20min at VT1	10min at VT2	20min at VT1
2	25min at VT1	6 x 1 min at 100% VO_2max	25min at VT1	15min at VT2	25min at VT1
3	30min at VT1	8 x 1 min at 100% VO_2max	30min at VT1	20min at VT2	30min at VT1

Hot water immersion and sauna suit protocols

In the two treatment groups, participants either 1) sat in a hot tub (temperature: ~102° F) with only their head above the water surface OR 2) wore a full-body sauna suit (Kutting Weight hoodie and pants) for 30min immediately post-exercise for 3 days/wk following Monday, Wednesday, and Friday training sessions. Participants ingested core temperature sensors on two occasions during week #1 of the intervention to ensure the hot water immersion and sauna suit protocols were safe and to identify possible underpinning mechanisms of how these treatments were beneficial to improvement of VO_2max, running economy, and lactate threshold.

Statistical Analyses

All analyses were performed using SPSS Version 25.0 (IBM Corporation, New York, NY, USA) and GraphPad Prism 7.0. (San Diego, CA). Measures of centrality and spread are presented as mean ± standard deviation (SD). All baseline-dependent variables were compared using general linear model (GLM) ANOVA and, where appropriate, Tukey post hoc tests. Primary outcome measures included mean changes in VO_2max, economy, and lactate threshold (i.e., % VO_2max). Within-group comparisons were made using paired t-tests. Other between-group 3wk changes were analyzed using GLM-ANOVA and, where appropriate, Tukey post hoc tests. The assumption of normality was tested by examining normal plots of the residuals in ANOVA models. Residuals were regarded as normally distributed if Shapiro-Wilk tests were not significant[4]. The probability of making a Type I error was set at $p<0.05$ for all analyses.

Results

All analyses and data presented in the results are for those participants who completed the investigation. The physical and physiological characteristics for participants at baseline and 3wk are presented in Table 2. The exercise intervention and treatments were well-tolerated for the 24 of 30 participants who completed the study. Six participants were unable to complete the study for the following reasons: illness (N=3), personal reasons (N=2), and unknown (N=1). Overall, there was excellent adherence (≥ 94%) to the total number of prescribed training sessions within each group. After 3wk, mean VO_2max changes in the sauna suit and hot water immersion groups were significantly greater ($p < 0.05$) when compared to the control group. Similarly, following the 3wk intervention, lactate threshold changes in the sauna suit and hot water immersion groups were significantly more favorable ($p < 0.05$) when compared to the control group. In the hot water immersion group, there were significant within-group improvements ($p < 0.05$) in running economy between baseline and 3wk for all three stages; however, the mean running economy changes from baseline to 3wk were similar ($p > 0.05$) across all groups for all stages.

Table 2. Physical and physiological characteristics at baseline and 3wk for control, sauna suit, and hot water immersion groups. (Values are mean ± SD).

	Control group (N=8)		Sauna suit group (N=7)		Hot water immersion group (N=9)	
Parameter	**Baseline**	**3wk**	**Baseline**	**3wk**	**Baseline**	**3wk**
Age (yr)	26.6 ± 11	—	24.8 ± 17	—	22.9 ± 11	—
Height (cm)	165 ± 29	—	168.6 ± 30	—	177.7 ± 3	—
Body mass (kg)	64.7 ± 30.2	64.7 ± 31.7	65.1 ± 38.8	64.3 ± 36.7	72.9 ± 39.4	72.8 ± 36.4
Economy – stage 1 ($mL·kg^{-1}·min^{-1}$)	24.3 ± 2.3	23.1 ± 4.4	24.5 ± 3.4	24.0 ± 2.4	24.8 ± 1.8	22.3 ± 3.8*
Economy – stage 2 ($mL·kg^{-1}·min^{-1}$)	27. 6 ± 3.9	26.5 ± 4.5	28.2 ± 2.4	27.3 ± 3.0	28.0 ± 1.9	26.1 ± 3.4*
Economy – stage 3 ($mL·kg^{-1}·min^{-1}$)	29.7 ± 3.8	29.0 ± 5.8	31.2 ± 1.7	29.6 ± 3.5	30.2 ± 2.2	28.1 ± 3.5*
Lactate threshold (% VO_2max)	59.8 ± 4.4	62.8 ± 5.4*	57.3 ± 4.0	65.2 ± 4.7*†	58.6 ± 6.9	67.0 ± 7.7*†
VO_2max ($mL·kg^{-1}·min^{-1}$)	39.4 ± 15.2	40.5 ± 15.9	42.2 ± 10.6	45.5 ± 12.9*†	46.3 ± 25.4	49.7 ± 26*†

* Within-group change is significantly different from baseline, $p < 0.05$; † Change from baseline is significantly different from control group, $p < 0.05$.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

Core temperature responses

The core temperature responses during 20 minutes of moderate-intensity continuous training performed at VT1 and 30 minutes post-exercise for all groups are shown in Figure 1. The area under the curve for core temperature during the 20 minutes of exercise were similar ($p > 0.05$) across groups. However, throughout the 30-minute post-exercise time period, area under the curve for core temperature were greater ($p < 0.05$) for the hot water immersion and sauna suit groups relative to the control group. Core temperature area under the curve for hot water immersion and sauna suit groups were comparable ($p > 0.05$). These findings have two important implications. First, it demonstrates that the passive heating strategies (i.e., 30-minute post-exercise hot water immersion or sauna suit) were equally sufficient to increase core temperature. Second, the passive heating strategies, while adequate to raise core temperature, still remained below levels (i.e., < 102° F) that might increase risk of heat illness.

VO_2max responders and non-responders

The incidence of VO_2max responders and non-responders to the intervention for all groups are shown in Figure 2. In the control group, 50% (4/8) of individuals were categorized as responders (change in VO_2max ($\Delta > 3.2\%$)) and 50% (4/8) were categorized as non-responders ($\Delta \leq 3.2\%$). In the hot water immersion and sauna suit groups, the incidence of VO_2max responders were significantly ($p < 0.05$) greater when compared to the control group. In fact, there were 100% VO_2max training responsiveness (7/7 and 9/9) in the hot water immersion and sauna suit groups, respectively.

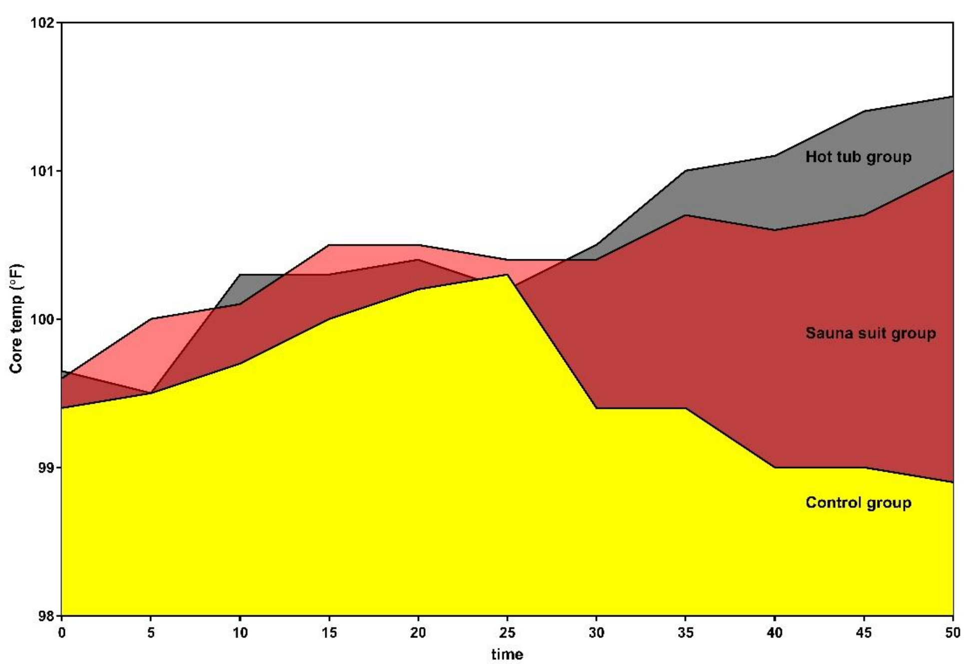


Figure 1. Core temperature area under the curve for the control (yellow), sauna suit (red), and hot water immersion (gray) groups during 20 minutes of moderate-intensity continuous training performed at VT1 and 30 minutes post-exercise.

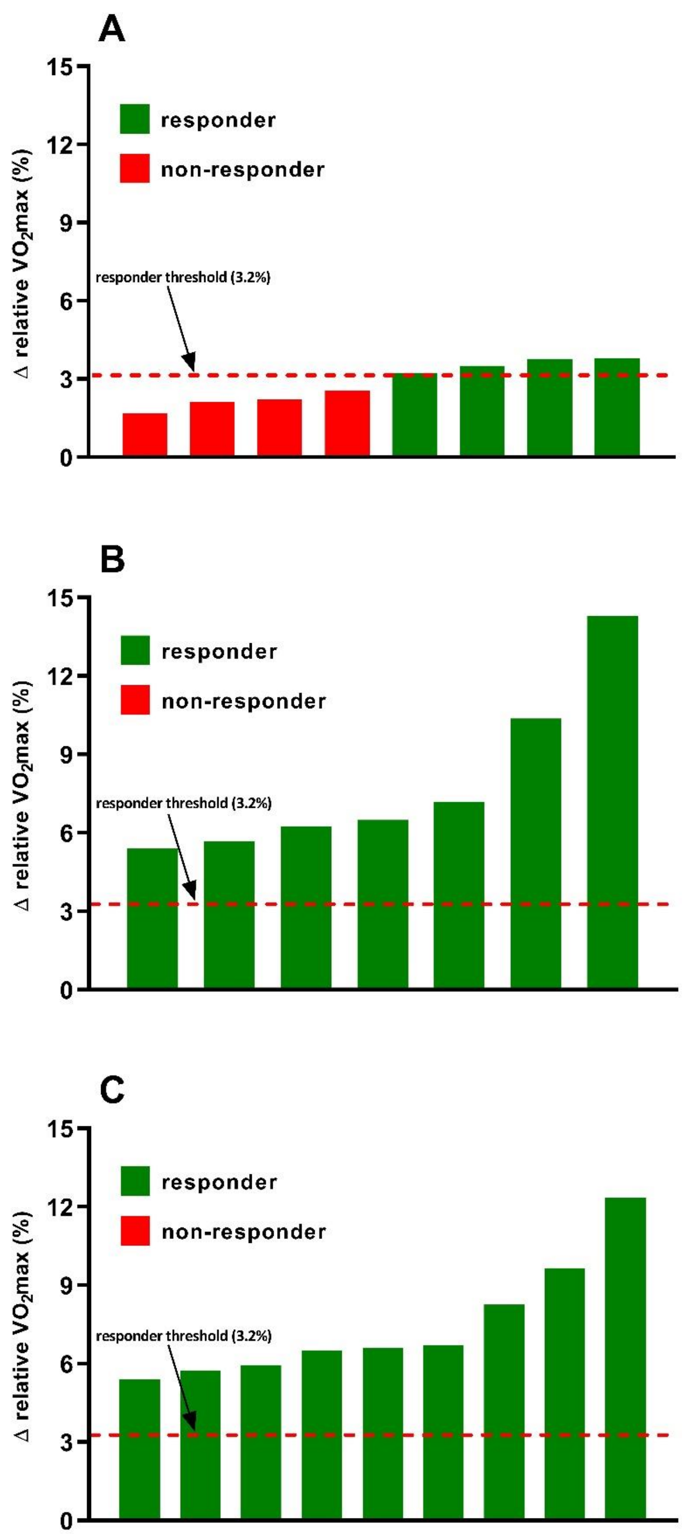
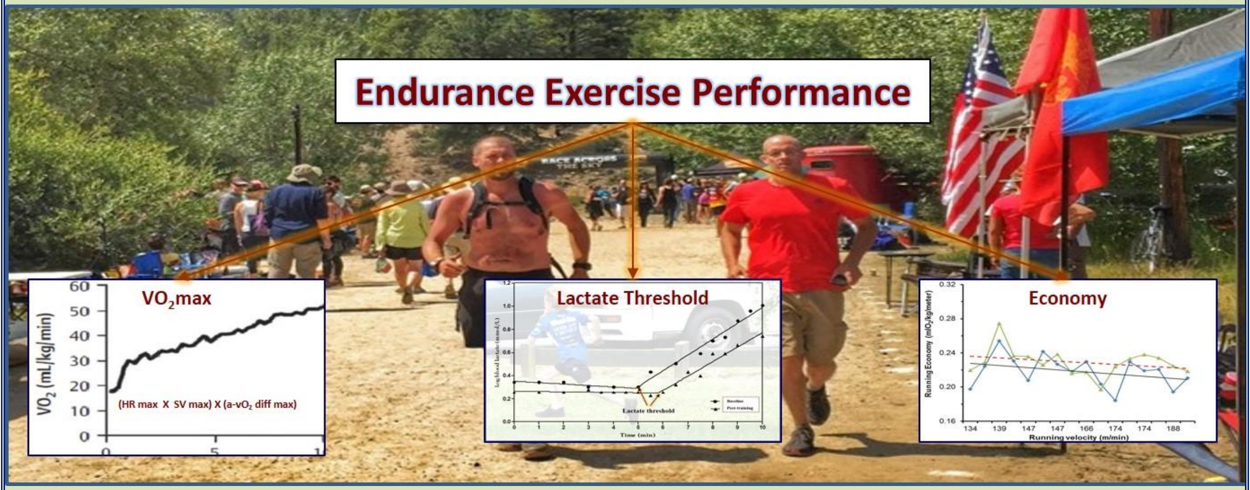


Figure 2. Inter-individual variability in VO_2max responses to the intervention in the (A) control group, (B) sauna suit group, and (C) hot water immersion group.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University



Maximal oxygen uptake – VO_2max: Maximum oxygen uptake (VO_2max) refers to the highest rate at which oxygen can be taken up and consumed by the body during intense exercise[5]. Traditionally, the magnitude of an individual's VO_2max has been viewed as one of the most important predictors of endurance performance. Indeed, a classic study performed more than 40 years ago in the early 1970's at Ball State University, confirmed the importance of VO_2max to endurance performance with findings indicating a strong correlation between VO_2max and 10-mile run times[6]. The ability of the cardiorespiratory system to transport oxygen to the exercising muscles refers the central component of VO_2max[1]. The role of the central component is for oxygen to be transported from the atmosphere and delivered to the muscles where it is utilized during mitochondrial respiration to produce ATP. The main central limitations to oxygen delivery are pulmonary diffusion, cardiac output, and blood volume and flow[5]. The ability of exercising muscles to extract and utilize oxygen, which has been transported by the cardiorespiratory system, refers to the peripheral component of VO_2max[1]. The potential sites for VO_2max limitation in the peripheral component include muscle diffusion capacity, mitochondrial enzyme (molecules that facilitate ATP production in mitochondria) levels, and capillary density[5].

Lactate threshold: Lactate threshold refers to the intensity of exercise at which there is an abrupt increase in blood lactate levels[1]. Many scientists consider the lactate threshold, relative to VO_2max and economy, to be the strongest predictor of endurance performance[7]. Additionally, the lactate threshold (compared to VO_2max and economy) appears to be the most responsive physiological parameter to endurance training[8]. In untrained endurance individuals, the lactate threshold occurs at approximately 50-60% of VO_2max. Following endurance training, individuals generally improve the lactate threshold to 75% of VO_2max; with values at 80-90% of VO_2max having been reported in elite, world-class endurance athletes[8]. The premier performance benefit of this training adaptation is that an individual is capable of maintaining a higher steady state exercise intensity (below the lactate threshold) during endurance exercise. This permits the endurance exerciser to maintain faster steady state tempos during training or racing, leading to improved endurance performance. In fact, research has consistently reported high correlations between the lactate threshold and performance in a variety of endurance events including running, cycling, and race-walking[8]. Furthermore, it has been proposed that the best predictor of endurance performance is the maximal steady state workload achieved near VO_2max[9].

Economy: The term economy is used to express the oxygen consumption required to perform a given exercise workload, whether it be cycling, running, or another form of endurance activity[10]. Differences in oxygen consumption between individuals at similar exercise workloads illustrate the individual variation found in exercise economy. Consequently, individuals with similar VO_2max values can have much different endurance performances depending on their economy of movement. In fact, high correlations between 10-km running performance and economy have been reported between runners with comparable VO_2max values[11]. Individual exercise economy is enhanced with endurance training and has been explained by improvements in biomechanical techniques in performing the specific physical activity[1].

Figure 3. The physiology of VO_2max, lactate threshold, and economy.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

Discussion

Despite its multifaceted nature, endurance performance is characterized by one simple requirement – the necessity to sustain repeated skeletal muscle contraction. Importantly, whether your client is a national-class athlete, recreational runner, or currently inactive individual, their ability to maintain repeated skeletal muscle contraction, and thus their overall potential for performance in endurance exercise, can be explained by a similar set of physiological attributes – VO_2max, lactate threshold, and economy of movement. However, it is ultimately the overall capacity and interaction of each of these parameters that determines individual peak endurance performance. A fundamental appreciation of these three critical performance-defining physiological parameters provides the requisite foundation for designing a comprehensive training program focused on optimizing endurance performance. (Figure 3) Next, we briefly examine the scientific evidence illustrating the powerful relationships that exist between VO_2max, lactate threshold, and economy values and endurances performance.

There is a strong relationship between VO_2max[6], lactate threshold[7], and economy[5] related to cardiorespiratory performance. Furthermore, there is a direct relationship between running economy based on VO_2max and lactate threshold values. VO_2max sets the upper limit for endurance performance and it has been found for every 1 point increase in VO_2max, individuals had a 10 second quicker 10 mile run[6]. Lactate threshold represents the %VO_2max in which an abrupt increase in blood lactate levels is seen. There is overwhelming evidence linking lactate threshold with endurance performance and this is especially true with running events[12]. Economy could be noted as the most important of the aerobic training 'triad' as it is a direct relationship to increases or decreases in VO_2max and lactate threshold, as well as biomechanical techniques in performance[1].

While it has been well established that VO_2max alone has a strong relationship with endurance performance, there should also be an understanding of the interplay between the VO_2max, lactate threshold, and economy 'triad' and overall endurance performance. For example, *client A* and *B* both have a VO_2max of 45 $ml \cdot kg^{-1} \cdot min^{-1}$. In theory, they should both be able to perform relatively similar in an endurance event (i.e. a half-marathon). However, *client A* and *B* have a lactate threshold that occurs at 50% and 75% of VO_2max, respectively. In this situation, *client A* would have a velocity of 3.9 mph (104.5 $m \cdot min^{-1}$) whereas *client B* would have a velocity of 5.8 mph (155.4 $m \cdot min^{-1}$) near their lactate threshold. Therefore, even though the VO_2max values are the same for both client, there is a large variability in performance due to *client B* being able to maintain a higher running velocity of 2 mph (53.6 m·min^{-1}). Consequently, it is not only important to have a high cardiorespiratory fitness, but also be able to sustain a high relative maximal capacity (lactate threshold at a high %VO_2max) to better enhance economy and performance. Understanding the mechanisms to improving the VO_2max, lactate threshold, and economy 'triad'; and recognizing the interplay between the 'triad' and overall endurance performance is critical to prescribing an evidence-based training protocol.

Conclusions

Alternative, evidence-based strategies to improve performance have become increasingly important to health and fitness professionals along with their clients. The use of cold water immersion has been studied extensively over the past decade. In contrast, there is relatively sparse research available on the effects of hot water immersion (and other forms of passive heat stress) on various performance-related measures. This study provides health and fitness professionals with important evidence on the use of different forms of passive heating strategies (hot water immersion and sauna suits) during the post-exercise timeframe, and how it impacts various markers of endurance performance, including VO_2max, economy, and lactate threshold. Here are the main findings and practical applications:

1. Both post-exercise passive heating strategies were equally effective at increasing VO_2max and lactate threshold values. In addition, post-exercise hot water immersion was a more effective strategy at improving running economy relative to wearing a sauna suit after exercise.
2. The improvements in endurance-related parameters were obtained with a minimal investment of additional training time. Total weekly time of passive heating exposure was 90 minutes, which was accumulated over three x 30-minute post-exercise sessions.
3. Overall, heat acclimation was achieved in a brief 3wk timeframe. Over 3wk, implementation of thrice-weekly post-exercise passive heating strategies elicited improvements in VO_2max, lactate threshold, and running economy that are typically achieved with increased training volume and/or intensity. The specific mechanisms underpinning the heat acclimation and concurrent improvements to endurance-related performance measures warrants further study but are likely partially mediated by upregulation of HIF1A (i.e., hypoxia inducible factor 1 subunit alpha).
4. Post-exercise passive heating strategies may be an alternative and viable training option for individuals who are prone to overtraining and/or injury.
5. Both post-exercise passive heating strategies were not only equally effective at improving endurance performance-related measures but also appear to be safe training paradigms. However, it's important to note several key aspects of the interventions. First, all hot water

immersion and sauna suit sessions followed moderate duration (i.e., 20 to 40 minutes) and moderate-intensity continuous exercise training. We do not recommend implementation of passive heating strategies after higher-intensity and/or longer training sessions as core temperature may likely be already elevated. Second, hot tub temperature was 102° F – we do not recommend higher water temperatures. Third, our duration of post-exercise passive heating strategies was limited to 30 minutes. We do not recommend longer post-exercise passive heating exposure until further research demonstrates a safe and effective positive dose-response relationship.

6. It is important for health and exercise professionals to recommend proper hydration practices. All participants were instructed to arrive hydrated for all training/intervention sessions. Additionally, participants were encouraged to drink plenty of fluids throughout exercise and also while engaging in the post-exercise passive heating protocols.

Competing interests

This investigation was supported financially by the American Council on Exercise (ACE). The American Council on Exercise (ACE) was not involved in development of the study design, data collection and analysis, or preparation of the manuscript. There are no other potential conflicts of interest related to this article

Address for Correspondence

Lance Dalleck, Ph.D., High Altitude Exercise Physiology Program, 600 N. Adams St., Western Colorado University, Gunnison, CO, United States, 81231. Phone: 970-943-3095;
Email: ldalleck@western.edu.

References

1. Robergs RA, and Roberts S. (1997). *Exercise Physiology: Exercise, Performance and Clinical Applications*. St Louis, Mo.: Mosby.
2. Scoon GS, Hopkins WG, Mayhew S, Cotter JD. Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. *J Sci Med Sport*. 2007;10:259–262.
3. Zurawlew MJ, Walsh NP, Fortes MB, Potter C. Post-exercise hot water immersion induces heat acclimation and improved endurance exercise performance in the heat. *Scand J Med Sci Sports*. 2016;26(7):745–754.
4. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Lawrence Erlbaum Associates: Hillsdale, NJ, USA, 1988; ISBN 978-0-8058-0283-2.
5. Bassett DR Jr, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sports Exerc*. 2000;32:70–84.
6. Costill DL. Metabolic responses during distance running. *J Appl Physiol*. 1970;28:251–255.
7. Wilmore JH, Costill DL. 1999. *Physiology of sport and exercise*. Champaign, Illinois: Human Kinetics.
8. McArdle WD, Katch FI, Katch VL. 1996. *Exercise physiology: Energy, nutrition, and human performance*. Baltimore, Maryland: Williams & Wilkins.
9. Weltman A. 1995. *The blood lactate response to exercise*. Champaign, Illinois: Human Kinetics.
10. Daniels J. A physiologist's view of running economy. *Med Sci Sports Exerc*. 1985;17:332–338.
11. Conley DL, Krahenbuhl G. Running economy and distance running performance of highly trained athletes. *Med Sci Sports Exerc*. 1980;12:357-360.
12. Faude O, Kindermann W, Meyer T. Lactate threshold concepts: how valid are they? *Sports Med*. 2009;39:469–490.