Carrillo et al. (2020) *Int J Res Ex Phys*. 15(2):35-53.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

International Journal of Research in Exercise Physiology

Original Research Article

Quantifying Heat Stress of Sauna Suits during Physical Activity and Examining the Effects of Heat Acclimation on Physiological Responses in Hypoxic Conditions: a Preliminary Explorative Study on Cross-Adaptation

Sadie N. Carrillo[1], Eder Pina[1], Christina A. Buchanan[1], Lance C. Dalleck[1]
[1]High Altitude Exercise Physiology Program, Western State Colorado University, Gunnison, CO, USA

ABSTRACT

Purpose: The purpose of this study was two-fold: to analyze thermal stress of sauna suits during low-moderate exercise; and to examine the effects of a two-week heat acclimation training with a sauna suit on physiological responses in hypoxic conditions in active males**. Methods**: 4 physically active males (M=24 ± 2.7 yrs) completed a two-week, heat acclimation period using a sauna suit. Hypoxic testing took place pre- and post- heat acclimation, involving 30 minutes of sitting while being exposed to simulated altitude (~4000 meters). Heart rate (HR), oxygen saturation (SpO_2), blood pressure (BP), and symptoms of Acute Mountain Sickness were all measured. Subjects also completed 2 thermal stress tests, involving jogging for 45 minutes at their Ventilatory Threshold-1 with and without a sauna suit. Core temperature, HR, and SpO_2 were measured during the thermal stress tests. **Results:** Significant differences ($p<0.05$) were found for mean arterial pressure comparing pre- to post- hypoxic tests with an average improvement of 9.22 ± 5.18 mm/Hg. No statistical mean differences were found for the other variables measured during the hypoxic tests, even though they all improved post- heat acclimation. Significant differences were found for area under the curve for core temperature comparing thermal stress test trials with an average increase in area under the curve of 42.53 ± 16.16 °F/min. There were no significant main effects for the other variables measured during the thermal stress tests but did show decrements that are expected with heat exposure**. Conclusion**: The results of this novel study support the use of a sauna suit as a form of heat acclimation to enhance physiological responses at altitude.

Keywords: Cross-tolerance, maximal exercise test, heat tolerance, thermal stress, heat acclimation

Introduction

Hippocrates once said, "Give me the power to produce fever, and I will cure all disease" [4]. The use of heat for health purposes has been used for many years with the Chinese and Japanese among the earliest people to use hot springs for therapeutic purposes[4]. The history of heat is quite extensive and the literature surrounding heat along with its risks and benefits is vast. The understanding and use of heat has evolved over the years with different innovations to acquire the benefits of heat including, saunas, steam rooms, and sauna suits. Studies have shown that when paired with exercise, heat can improve certain metabolic factors like enhanced sweating and skin blood flow response, plasma volume expansion, better cardiovascular stability, a lowered metabolic rate, and acquired thermal tolerance[30, 31]; as well as others like enhanced oxygen uptake and reduced blood lactate at a given power output[36,46], muscle glycogen sparing[8,46], and increased ventricular compliance[20].

An important part of research in the exercise science field is to find new ways to improve performance or improve ability to perform in imperfect environmental conditions, such as altitude. Populations that may benefit from these new methods of training may include athletes traveling to altitude for their sport, or military personnel being moved to remote locations that may be at higher altitudes. A common, imperfect condition is high altitude because of the stress it puts on the body. The effects of acute altitude exposure are an increase in ventilation, an increase in heart rate (HR), an increase in diuresis contributing to a decrease in plasma volume, and an increase in blood lactate[1]. However, altitude acclimatization may also elicit certain beneficial adaptations like increased red blood cells, increased capillary volume, increased lung size, which contribute to increased oxygen utilization [5]. Altitude training has become a popular training method for athletes who want to perform well in both normoxic and hypoxic conditions[5]. However, altitude training can be expensive, time-consuming, and not always practical/accessible. This has led researchers to look for alternative methods for achieving physiological adaptations that can improve performance. This has included alternative altitude training methods from the traditional chronic exposure of altitude in the live high, train high (LH-TH) model. Some examples of alternative methods are live high, train low (LH-TL), hypoxic sleeping chambers/tents, and elevation training masks. However, most of these are still costly and time-consuming and may not be practical for everyone.

Recently, the literature has pointed to the theory of cross-tolerance as another efficient method of attaining performance adaptations in normoxic and hypoxic conditions [11,18,22,23,44]. Cross-tolerance is defined as acclimatization to one environmental stressor aiding in the adaptation or increase of protection against another environmental stressor[44]. Deriving from this theory are cross-acclimatization, which is an adaptation that is caused by a natural environment, and cross-acclimation, which is the adaptation from a simulated environment[11]. A couple interesting pairings have been researched including cold to hypoxia and heat to hypoxia cross-adaptation, with the more popular pairing being heat to hypoxia cross-adaptation[44]. Heat acclimation has been shown to elicit some favorable adaptations including enhanced sweating and skin blood flow response, plasma volume expansion, better cardiovascular stability, a lowered metabolic rate, and acquired thermal tolerance[31]. These adaptations may be why heat to hypoxia cross-adaption has the potential to work. Plasma volume expansion could theoretically combat the decrease in plasma volume seen with acute exposure to altitude. In addition, better cardiovascular stability may potentially aid in protection against an increased HR and oxidative stress on the cardiovascular system that occurs with altitude exposure. It is for these reasons that heat to hypoxia may be an optimal pairing due to the ways heat adaptations can combat common problems seen with exposure to altitude or hypoxic conditions.

This idea of cross-acclimation is still novel and not well understood with only a handful of studies on heat to hypoxia cross-acclimation[11,18,22,23,44]. With so little research regarding heat to hypoxia cross-acclimation more research on the topic would be beneficial to gain greater understanding about the topic and its uses. Additionally, research has only focused on using heat chambers for acclimation to heat and has not examined other methods of heat acclimation (i.e. sauna suits) [11,18,22,23,44]. Different modalities may be better suited for a certain situation. For example, military personnel may not have access to heat chambers where they are stationed but heat training could still be beneficial for them. Thus, the purpose of this experimental study was two-fold: to analyze thermal stress of sauna suits during low-moderate exercise; and to examine the effects of two weeks of heat acclimation training on physiological responses in hypoxic conditions in recreationally active males.

METHODS

Subjects

This study included 4 active males who gave written consent to participate. Subject descriptive statistics are included in Table 1. Subjects were acclimatized to the elevation of Gunnison, Colorado (2,348 m), where all testing took place. All subjects were considered low risk according to ACSM guidelines. We excluded subjects who had poor circulation, abnormal blood pressure, those previously acclimated to extreme altitudes or heat, subjects with digestion issues, and elite athletes (performing >10 h/wk of exercise training) from this study. The Institutional Review Board (IRB) at Western State Colorado University reviewed and approved this research project.

Table 1: Physical attributes of subjects

Parameter	Mean ±SD
Age (yr)	**24 ± 2.7**
Height (cm)	**175.8 ± 7.0**
Weight (kg)	**69.38 ± 12.6**
VO_2 max (mL/kg/min)	**60.5 ±4.3**

Experimental Design

This study was a repeated measure, experimental design. Subjects were asked to come into the High-Altitude Performance Lab on the Western State Colorado University campus on 5 separate occasions spanning over a three-week period, with sessions lasting 75 minutes or less. See Figure 1: experimental design flowchart. All subjects received the treatment of exercising in a sauna suit.

On the first session, after obtaining informed consent, subjects were screened using the Western State Colorado University's Screening Questionnaire for Research Involving Exercise to confirm that all subjects were rated as low risk before any exercise testing. Participants who were not at low risk were informed that they could not participate further in the study. If they were low risk and cleared to be in the study following screening and questionnaires, anthropometric measurements and a VO_2max test were included in the first session. The first session took between 45 minutes to one hour to complete. The second session was 24 to 48 hours after the first session and consisted of the hypoxic test. This session lasted for approximately one hour. The third session consisted of the first trial of two physiological thermal stress testing days. During this first physiological thermal stress testing day, subjects performed 45 minutes of moderate intensity exercise (HR corresponding to their ventilatory threshold 1) on a treadmill in thermoneutral conditions. HR, SpO_2, core temperature, blood pressure, and water loss were measured during this session. All subjects completed this first physiological thermal stress test without a sauna suit, in typical exercise clothing (i.e. running shorts and exercise shoes). The fourth session was 2 to 4 days following the previous session and was the second trial of the physiological thermal stress test using the same measurements mentioned above in the previous session, this time with the addition of a sauna suit (Kutting Weight, LLC., Los Angeles, CA) over their exercise clothing. They then continued with their typical exercise regimen for two weeks training with a sauna suit.

Subjects were asked to keep track of how many days of working out in a sauna suit they completed during the two weeks of training.

The subjects also checked in with research personnel often to make sure workouts were completed and there was adherence to wearing a sauna suit. After the two week acclimation period was complete, subjects were asked to come in for their fifth and final testing session. This last session consisted of the same hypoxic test as the second visit to analyze differences pre to post heat acclimation protocol.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

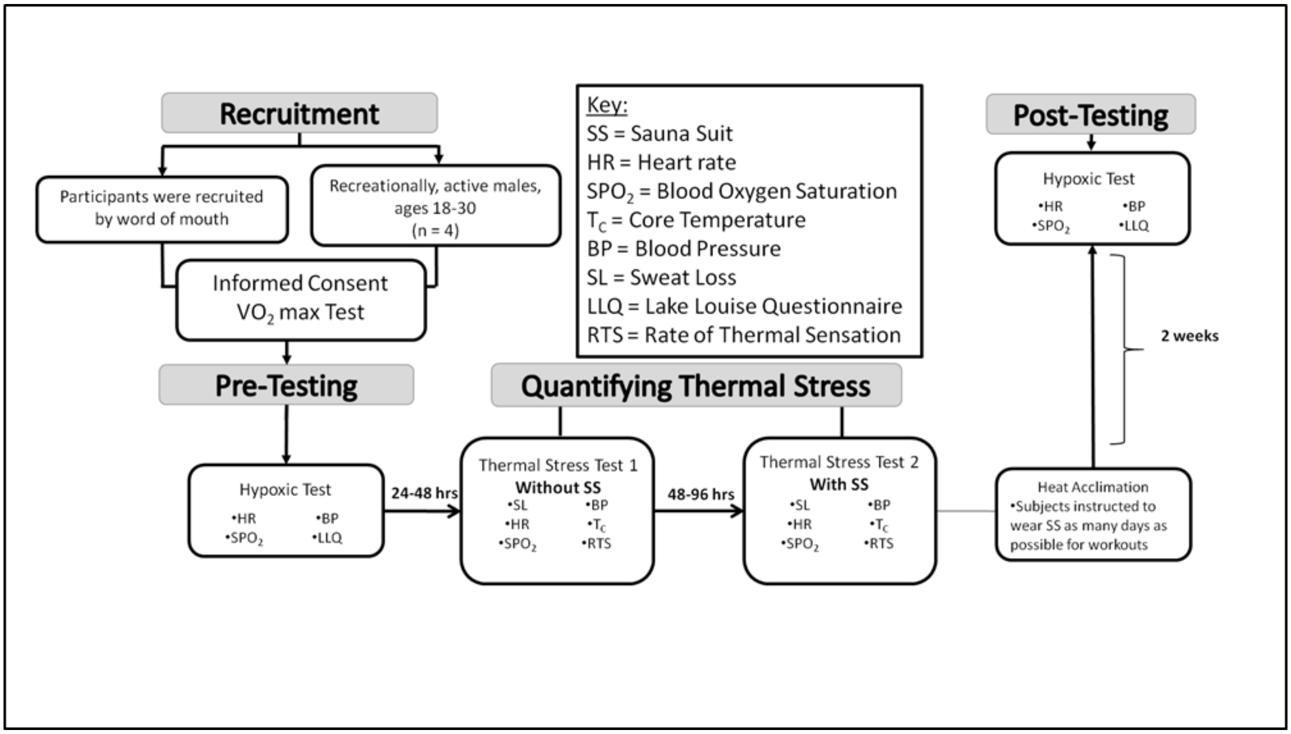

Figure 1. Experimental Design Flow Chart.

Procedures

VO_2max. Prior to the VO_2max test session, subjects were instructed about what was expected of them to prepare for the session. Instructions included: to come to the test well-hydrated, not participate in any strenuous exercise at least 24 hours prior to the session, and to refrain from drinking an excessive amount of caffeine (any amount exceeding individual's typical daily amount). Additional instructions were given to subjects when they arrived for the testing session. These additional instructions included: instruction and familiarization of the Rate of Perceived Exertion Scale (RPE; a modified Borg Scale, rating 1 through 10), to use hand signals to notify researchers about the need to stop the test whether it was due to fatigue or possible adverse responses to the test (i.e. chest pain, light headedness, nausea, etc). Before the official start of the test, subjects performed an exercise warm-up period of three minutes at their desired speed with no incline on a treadmill (Trackmaster, Full Vision, INC, Newton, KS). Participants were instructed to put on a mask with a breathing valve to collect expired gases for analyzation. Expired gas was collected and analyzed through a metabolic cart (Parvo Medics, Sandy, UT, USA). Participants were asked to jog at a speed that they know that they could maintain for thirty minutes on a surface with no incline while research personnel increased the incline 1% per minute. At the end of each minute HR, SpO_2, and RPE were measured and recorded. Protocols for these measurements are described below. The test continued until the subject became fatigued and voluntarily stopped or other symptoms prohibited further exercise. After testing, participants went through an exercise cool-down for at least five minutes walking or until HR was near resting values. The main criteria for determining if VO_2max was achieved included: a definite plateau of VO_2. Other criteria that was used to determine the achievement of VO_2max was a respiratory exchange ratio (RER) greater than or equal to 1.1, achieved a HR within a range of ten beats of their predicted HR maximum, an RPE of ten, and a test lasting longer than 8 minutes. Using this list of criteria 100% of the subjects achieved their VO_2max.

Analyzation of thermal stress. Subjects came into the lab twice to participate in a thermal stress test. During the first physiological thermal stress test, subjects completed 45 minutes jogging at a HR corresponding to their ventilatory threshold 1 (VT1) on a treadmill without a sauna suit in their typical exercise clothing. They were instructed to come well-hydrated and not participate in any strenuous exercise at least 24 hours prior to the session. In order to quantify the thermal stress on the body a variety of measurements were taken. HR, SpO_2, and rating of thermal sensation (RTS) were taken every 2 minutes throughout the exercise protocol. Core temperature was take as often as possible throughout the test, with attempts of readings every minute. Water loss was also measured pre- and post- exercise protocol. The second thermal stress test session was 2 to 4 days following the first thermal stress test. For this session, subjects wore a sauna suit over their exercise clothing. All subjects were monitored throughout each thermal stress testing session for adverse responses to exercise or heat.

Hypoxic test. The hypoxic test consisted of passively sitting for 30 minutes, while being connected to the hypoxic system (GoOxygen hypoxic system, VacuMed, Ventura, CA 93003). This system simulated an altitude of ~4000 m (~13,000ft). Subjects were monitored throughout the test. HR and SpO_2 were measured every two minutes. Blood pressure was take pre-test, at minute 10, 20 and 30 during the test. A Lake Louise Questionnaire was given pre- and post- test to check for symptoms of AMS. After the test was completed, subjects were removed from the system. Subjects were checked for adverse symptoms before being cleared to leave the session.

Heat acclimation protocol. Subjects were warned about the possible adverse effects of wearing the sauna suits. This included increased HR, increased core temperature, fatigue, dehydration, weight loss, or dizziness and in rare instances heat illness. Subjects were also instructed to drink an adequate amount of water, while exercising in the sauna suit. They were also asked to report adverse effects immediately to research personnel. Subjects were also strictly instructed to maintain their pre-existing exercise training for two weeks. Subjects were asked to wear a sauna suit during as many days throughout the two weeks of exercise training. Subjects were asked to record how many days they completed during the two weeks of training. Research personnel checked with subjects often to make sure workouts were completed and there was adherence to wearing a sauna suit.

Heart rate and oxygen saturation. HR was measured using a HR monitor chest strap (Polar Electro, Kempele, FI). SpO_2 was measured using a pulse oximeter (Gurin Products, Tustin, CA, USA).

Blood pressure. Blood pressure was taken with a sphygmomenter (Medline Industries, Mundelein, Il) and stethoscope (Littmann stethoscope, 3M, St, Paul, MN, USA). The sphygmmentor was placed on the left arm and lined up with the brachial artery. The stethoscope was placed on the brachial artery right below the sphygmomentor. The sphygmomenter was inflated to 200 mmHg and pressure was released at rate of approximately 4 mmHg per second. Where the pressure was when first Korotkoff sound was heard was recorded as the systolic blood pressure, while the pressure where the last Korotkoff sound was heard was recorded as the diastolic blood pressure. After determining the diastolic blood pressure the remaining pressure in the sphygmomenter was released. This blood pressure was then converted to mean arterial pressure (MAP) for statistical analysis.

Core temperature. Core temperature was measured with a small, jellybean sized, temperature sensor pill (HQ Inc., Palmetto, FL), which the subjects ingested two hours before the session, and a core temperature analyzer (HQ Inc., Palmetto, FL). It was the subjects' preference to use water to swallow or not use water. This pill monitored core temperature for approximately 4-6 hours.

Water loss. Water loss was measured with a simple difference in body weight pre to post session. Subjects were asked to keep on running shorts but remove all other clothing for weight measurements. Weight was taken with a scale prior to testing and following cool-down procedure after thermal stress testing after hydration status was taken. The difference in weight was deemed "water loss" weight. Subjects did not intake any fluids during the exercise testing session. Kilograms lost was converted to $L \cdot hr^{-1}$ for statistical analysis.

Statistical Analysis

Data was analyzed using SPSS Version 24.0 (IBM-SPSS, Chicago, IL) and GraphPad Prism (GraphPad Software, La Jolla, CA). Graphpad Prism was used to analyze differences for area under the curve for a couple variables of the thermal stress test and all other statistical analyses were run using SPSS Version 24.0. The difference in performance in the hypoxic exercise tests and thermal stress tests, for all variables, were analyzed using paired samples t-tests. Differences in variables between testing sessions over time were analyzed using two-way repeated measures ANOVA. Level of significance for all tests was set at $p < 0.05$

Results

The testing protocols and the addition of a sauna suit to current training programs were well tolerated for all four recruited subjects. Overall, there was excellent adherence, with all subjects completing all pre- and post- testing sessions and completing six or more days of training (mean 6.5 days; range, 6-7 days) in the two-week heat training period.

Quantifying Thermal Stress Analysis

Heart rate, oxygen saturation, mean arterial pressure, and water loss. Paired t-tests were conducted to evaluate the impact of performing moderate exercise with the addition of a sauna suit on HR, SpO_2, MAP, and water loss. Paired t-tests showed no significant differences ($p>0.05$) from thermal stress test trial 1 performed without a sauna suit and trial 2 performed with a sauna suit for these variables. Means and mean differences for each variable for each thermal stress test trial are located in Table 3. Mean differences were calculated from subtracting the mean of trial 2 from the mean of trial 1.

Table 3. Variables in Thermal Stress Test, Mean ± SD.

Dependent Variables	Trial 1: NS	Trial 2: SS	Mean Difference
Heart Rate (bpm)	139.11 ± 14.43	146.27 ± 18.20	-7.16 ± 5.01
Peripheral Oxygen Saturation (%)	90.35 ± 1.07	89.71 ± 1.79	0.64 ± 1.35
Mean Arterial Pressure (mm/Hg)	88.44 ± 5.31	88.22 ± 4.10	0.22 ± 2.96
Water Loss ($L \cdot hr^{-1}$)	0.93 ± 0.11	1.11 ± 0.29	-0.17 ± 0.23

Two-way repeated measures ANOVAs showed statistically significant main effects of time point ($p< 0.05$) for HR [$F(1.57,4.70) = 13.57$, $p = 0.064$, partial $\eta^2 = 0.82$], MAP [$F(2,6) = 7.05$, $p = 0.027$, partial $\eta^2 = 0.70$], and water loss [$F(1,3) = 112.76$, $p = 0.002$, partial $\eta^2 = 0.97$]. However, no significant main effect of time point was found for SpO_2 ($p > 0.05$). Also, no significant main effects were found between trials ($p > 0.05$), nor an interaction of trials and time point for HR, SpO_2, MAP, and water loss ($p > 0.05$). However, HR did increase more in the second trial even though no statistical difference was found. Figure 2 shows depiction of the differences in HR between trials.

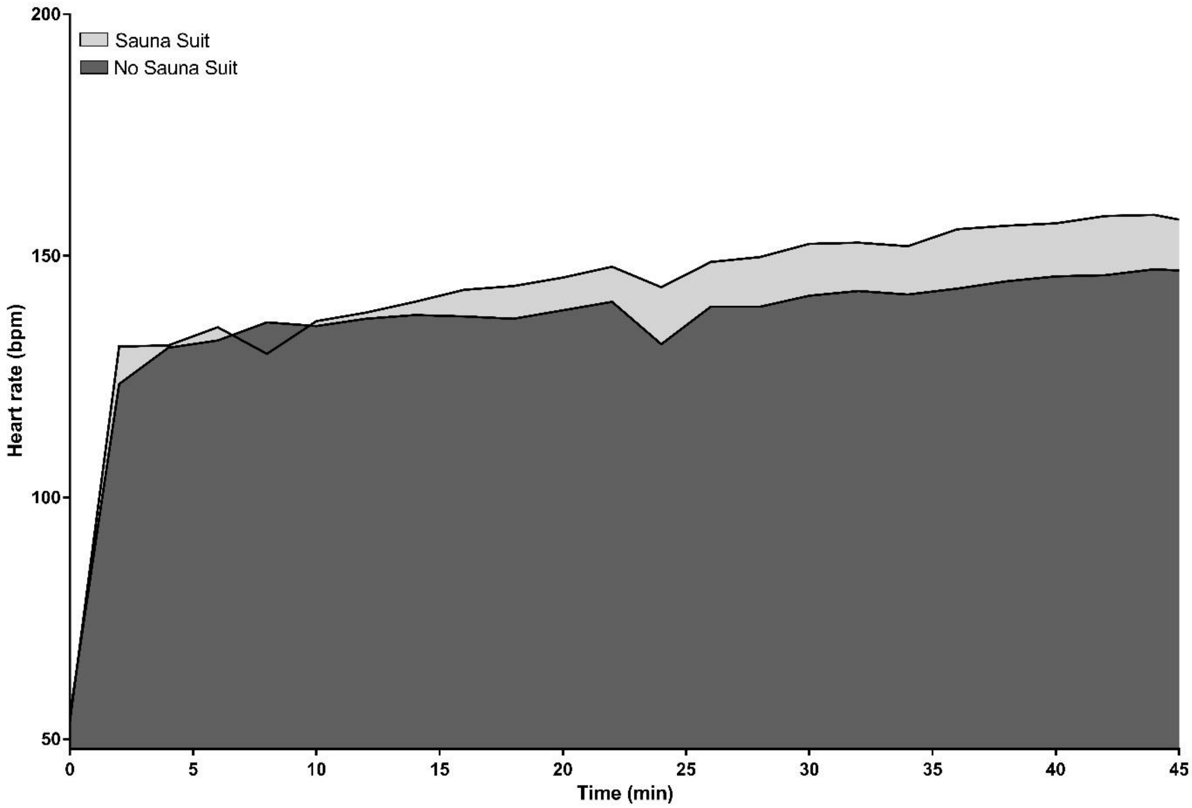

Figure 2. A depiction of differences in area under the curve for heart rate. Trial 1 was performed without a sauna suit, while trial 2 was performed with a sauna suit. No significant difference was found between trials for area under the curve for heart rate ($p > 0.05$).

Core temperature. A paired t-test was performed to examine differences for area under the curve for core temperature throughout the thermal stress test trials. The paired samples t-test showed a significant difference ($p < 0.05$) for area under the curve for core temperature [$t(3)= 5.26$]. The mean increase in area under the curve for core temperature was 42.53 ± 16.16 ˚F/min with a 95% confidence interval with a range of 16.8 to 68.25 ˚F/min. A difference for area under the curve between trials is depicted in Figure 3.

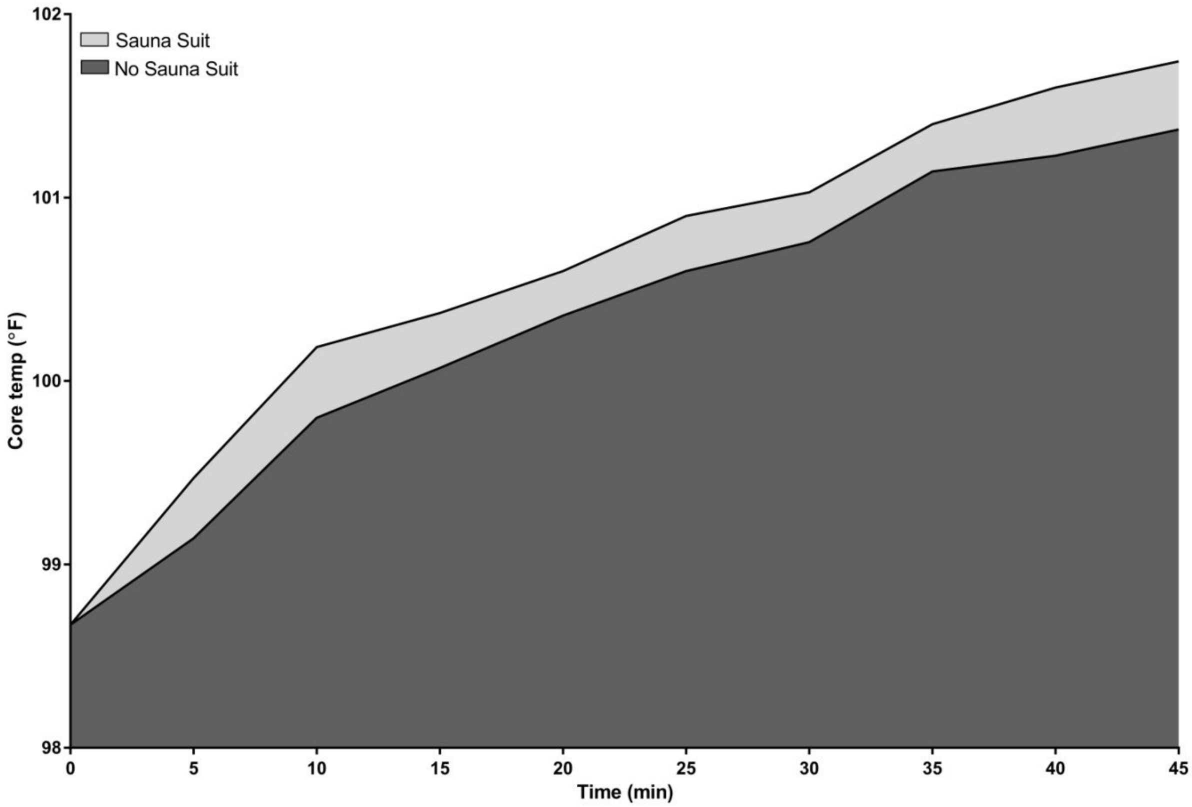

Figure 3. Depiction of differences in area under the curve for core temperature. Trial 1 was performed without a sauna suit, while trial 2 was performed with a sauna suit. There was a significant increase ($p < 0.05$) in area under the curve for trail 2 compared to trial 1.

Cross-Adaptation

Heart rate and oxygen saturation**.** Paired samples t-tests showed no significant differences ($p > 0.05$) between pre- and post- hypoxic tests for HR nor SpO_2.Two-way repeated measures ANOVAs showed no significant main effects of pre- and post- hypoxic tests ($p > 0.05$), and time point ($p > 0.05$), nor an interaction of pre- and post- hypoxic tests and time point ($p > 0.05$) for HR and SpO_2.

Mean arterial pressure**.** A paired samples t-test revealed a significant difference between pre- and post- hypoxic tests ($t(3) = 3.56$, $p < 0.05$). The mean improvement in mean arterial pressure from pre- to post- hypoxic test was 9.22 ± 5.18 mm/Hg with a 95% confidence interval with a range of 0.98 to 17.46 mm/Hg. Another set of paired t-tests were performed to examine differences in the three times point measures of MAP from the pre- to post- hypoxic tests. It was revealed that time point 10 and time point 20 were significant between test ($p < 0.05$, $t(3) = 4.39$, and $p < 0.05$, $t(3) = 3.41$, respectively) with 95% confidence intervals with a range of 2.57 to 16.10 mm/Hg and 0.67 to 19.66 mm/Hg, respectively. However, time point 30 was not significantly different ($p > 0.05$). A depiction of the differences for test points between tests for MAP is located in Figure 5.A two-way repeated measures ANOVA showed significant differences between tests ($p<0.05$, $F=12.70$, partial $\eta^2 = 0.81$). However, no significant differences were found between time points, nor an interaction between tests and time points ($p>0.05$).

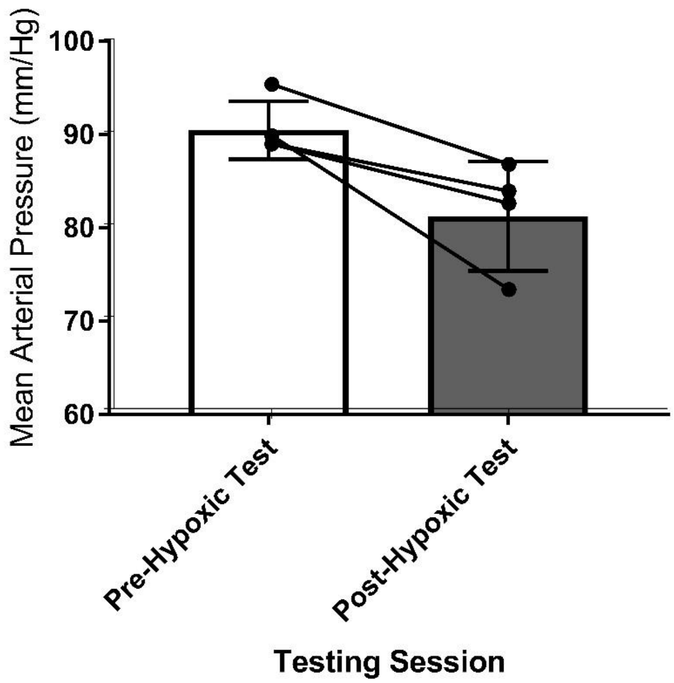

Figure 4. Depiction of the mean MAP for each hypoxic test. Individual responses indicated by the connecting dots between tests.

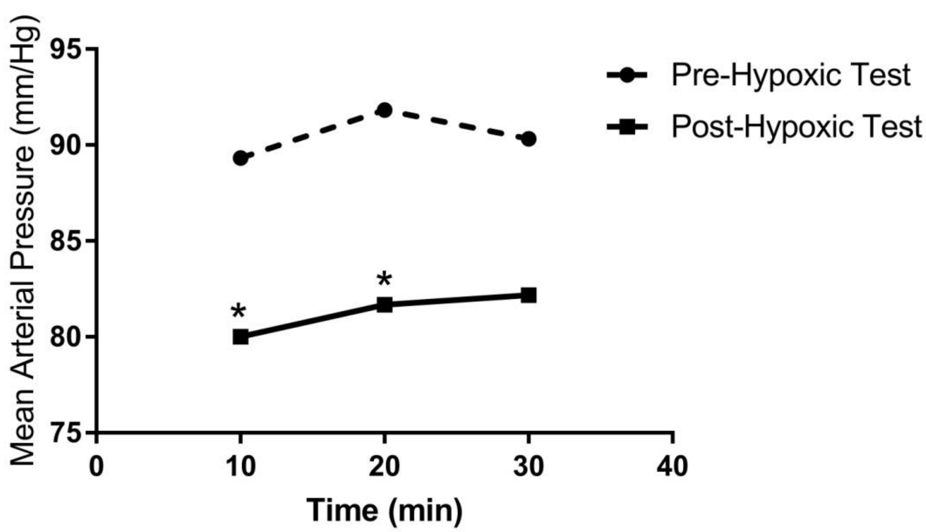

Figure 5. A depiction of the change in MAP during pre- and post- hypoxic tests.
* signifies a significant difference between the time point pre- to post- hypoxic test.

Lake Louise Questionnaire scores. Figure 6 shows a depiction of Lake Louise Questionnaire scores for the diagnosis of Acute Mountain Sickness. There was no incidence of severe AMS. However, there was a decrease (n=1) in the incidence of mild AMS from pre- to post- hypoxic tests.

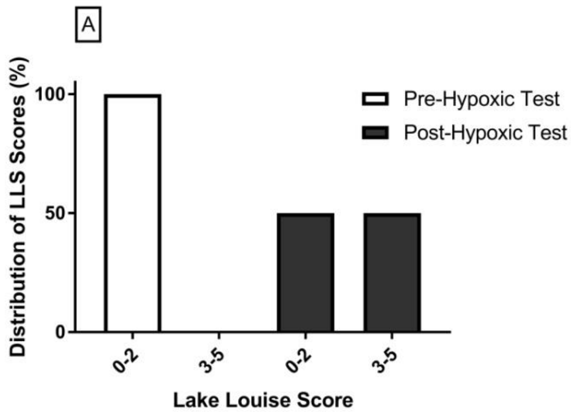

Figure 6. A depiction of Lake Louise Questionnaire scores for each hypoxic test trial. Graph A depicts the test scores pre- and post- hypoxic test number 1. Graph B depicts the test scores pre- and post-hypoxic test number 2.

Discussion

The main findings of this study concerning the acute thermal stress of wearing a sauna suit during moderate exercise are 1) there was a significant amount of thermal stress added during moderate-intensity exercise with the addition of a sauna suit, indicated by a significant increase in core temperature, and 2) moderate-intensity exercise with a sauna suit did show added physiological stress indicated by increased HR, MAP, and water loss, as well as a decrease in SpO_2, even though the differences were not significant. The main findings of this study with regard to examining cross-adaptation were 1) training with a sauna suit over a two-week period can significantly improve MAP during acute exposure to simulated altitude, and 2) training with a sauna suit did show improved physiological responses in regards to HR and SPO_2, even though effects were not significant. Heat acclimation has a variety of uses and is well studied; however, the training adaptations to exercise training with a sauna suit on physiological measurements in hypoxic conditions has not been scientifically explored. The results of this novel study support the use of a sauna suit as a form of heat acclimation to enhance physiological responses at altitude indicated by an increase is MAP.

Acute Thermal Stress

Heart rate, oxygen saturation, and mean arterial pressure**.** The results of the current study follow the general trend that is expected with exercise performed in hot conditions[30]. HR is known to increase significantly amount (~8 bpm) more when exercising in the heat compared to cool temperature[30], which was what was observed in the current study with a mean increase of 7.16 ± 5.01 bpm, even though there were no statistically significant differences between the thermo-neutral and sauna suit bouts of moderate-intensity exercise. In addition, oxygen uptake is known to be decreased (~18%) during exercise in heat [30,12], which follows the same trend seen in the current study with SpO_2 measurements. SpO_2 had a mean decrease of 0.64 ± 1.35% in the present study. MAP has been shown to decrease during bouts of exercise in the heat compared to exercise in thermo-neutral environments[30], which what was seen in the current study with an average decrease of 0.22 ±2.96 mm/Hg.

Water loss. With mechanical work, like exercise, heat is created and must be dissipated to maintain homeostasis[24]. However, with a greater increase in body temperature which is seen with exercise in the heat, can cause a greater sweat production and water loss in order for the body to attempt to cool itself; about 1 liter of sweat loss for each hour of exercise in hot conditions[24]. This is in line with the current study where subjects lost more weight through sweat production indicated by a mean difference in body weight loss of 0.17 ± 0.23 $L \cdot hr^{-1}$ between trials and an overall sweat loss of 1.11 ± 0.23 $L \cdot hr^{-1}$.

Core temperature. In order for heat adaptations to occur a sufficient amount of thermal stress must be applied to the body[27]. Most protocols require a 10 to 12 day heat acclimation protocol in a heat chamber with at least 40˚C temperature, and 25% humidity to achieve optimal heat acclimation[11,18,22,23,44]. Heat acclimation must occur in order to protect the body from increased body temperature. A study by Périard et al.[30] found that temperature remained significantly higher throughout exercise in a hot condition compared to exercise in a thermoneutral condition, which follows the trend of the present study. In the present study, it was shown that there was a significant amount of thermal stress added by the sauna suit during moderate exercise, which shows that sauna suits may be a practical modality to achieve heat acclimation. A mean difference between area under the curve for trial 1 performed without a sauna suit and trial 2 performed with a sauna suit was on average 42.53 ± 16.16 ˚F/min. A 95% confidence interval with a range of 16.8 to 68.25 ˚F/min is wide, but does not overlap zero, which shows that there is the likely effect of an increase in core temperature with the addition of a sauna suit to moderate exercise. Also, effect size is another good indicator on how meaningful or impactful the results could be on the true population and helps to answer the question "How well does an intervention work in a range of contexts?". A partial eta squared of 0.90 shows there is a large effects size and that sauna suits are likely helpful in adding significant thermal stress during a bout of moderate exercise.

Cross-Adaptation

Heart rate and oxygen saturation. The trends of HR and SpO_2 found, even though not statistically significant, in the current study are in line with other cross-acclimation studies[18,23]. Heled et al.[18] found that HR decreased by 9 bpm at the onset of blood lactate and SpO_2 was improved by on average 1.5% at a pace of 7 km/h during a maximal graded exercise test at a simulated altitude of 2400 meters after a 10 day heat acclimation protocol. Similarly, Lee et al.[23] found that following a 10-day heat acclimation period that mean HR was decreased by ~9 bpm with improved mean SpO_2 by 2% during exercise two separate exercise bouts at a simulated altitude of 3300 meters. This is consistent with the current study, which found that HR decreased on average 5 bpm and SpO_2 improved on average 2.2%, but neither were statistically significant. The difference in simulated altitude may explain the more significant improvements in HR and SpO_2 during hypoxic exposure. Both studies previously mentioned[18,23], performed their hypoxic testing at approximately 2500 meters and 3300 meters, respectively, while the current study performed their hypoxic testing on average at approximately 4000 meters, with subjects being acclimatized to 2350 meters. This could account for the differences in results between studies.

A study by Gibson et al.[11] had similar results in regards to HR and SpO_2 during their resting portion of their hypoxic testing, which is a more comparable to the method used for hypoxic testing in the current study. Gibson et al.[11] found no significant differences between pre- and post- hypoxic tests during a 10 minute rest period for HR and SpO_2, which is in line with the findings of the current study. The methodology of the hypoxic test may also be a contributing factor of the differences in HR and SpO_2 responses between the current study and the literature.

Mean arterial pressure. The five known studies concerning heat to hypoxia cross-adaptation did not specifically look into the effect of heat acclimation on blood pressure during a bout of hypoxia[11,18,22,23,44]. The current study had a novel finding that MAP was significantly improved during the post- hypoxic test following a two-week period of training with a sauna suit. A 95% confidence interval for mean MAP with a range of 0.98 to 17.46 mm/Hg indicate the likely mean changes from pre to post- hypoxic tests in MAP. An effect size of 0.81 for differences between pre- and post- hypoxic tests analyzed with a two-way repeated measures ANOVA shows a large effect size, meaning the results are beneficial. These results show that that two-weeks of heat training seem to be helpful for improving MAP during acute exposure to altitude. An improvement in MAP may be important because in may improve the pressure gradient in the pulmonary circuit allowing for better oxygen diffusion from the lungs. Better oxygen diffusion could consequently improve common physiological responses seen at altitude, ventilation and heart rate and may even decrease symptoms of AMS.

Acute Mountain Sickness. Improvements in other variables during the exposure to hypoxia may have helped to decrease the prevalence of symptoms of AMS. However, with such a small sample size, the improvement ended up only being one person improving the category of AMS from mild AMS to no diagnosis of AMS. However, this is an overall 25% improvement for the present study. If this same percentage can be shown in a larger population, it may hold more value.

Mechanisms

Thermoregulation. When the body is exposed to heat during exercise, thermoregulatory functions become critical for survival and maintenance of physical activity. There are multiple strategies that the human body uses in order to maintain physiological homeostasis when exposed to heat. During physical activity, heat starts to accumulate in the body through mechanical work and energy production. When the amount of heat being produced is at a rate faster than the heat can dissipate, there is a rise in core temperature[24]. This mechanism gives the explanation for a significant increase in area under the curve for core temperature in the second thermal stress test trial performed in a sauna suit. It is also known that heat exposure and heat stress causes a reduction of stroke volume and increased HR in order to attempt to maintain cardiac output[18], which would explain the trend found in the present study of an increase in HR during the second thermal stress test trial compared to the first. Also, during physical activity the main cooling mechanism is evaporative heat loss, mainly through sweating, which can account for >80% of heat dissipation[24]. This is in line with the trend that was shown in the current study with greater water/sweat loss in the second thermal stress test trial. All of these expected responses present in this study suggest that exercise in a sauna suit elicits enough thermal stress to produce increased thermoregulatory responses.

Hypoxic factor 1 alpha and heat shock proteins. Hypoxic factor 1 alpha (HIF1α) is a protein complex that plays an essential role in the body's response to low oxygen concentration, or hypoxic conditions[47]. Its pathway can be activated during times of oxidative stress, which could be exercise and heat, through an up-regulation of heat shock proteins[47]. Heat shock proteins are upregulated when the body is put under heat stress[22]. Once activated, HIF1α will move into the nucleus of the cell and form a transcription complex with hypoxic inducible factor 1 beta (HIF1β) and transcribe certain target genes that aid in the protection against oxidative stress[11]. These target genes will be used to make new proteins. A few important target genes of HIF1α are EPO, VEGF, and inducible nitric oxide synthase (iNOS)[47]. VEGF is one of the major regulators of angiogenesis, while EPO stimulates the production of red blood cells[47]. With these adaptations of angiogenesis and increased red blood cell formation, there would likely be an improvement in HR and SpO_2, which is what was seen in the current study, and thus the increased ability to deliver oxygen and nutrients to working tissues. The last important target gene is iNOS, which is responsible for the production of nitric oxide, a potent vasodilator[32], that can help to improve blood pressure in times of oxidative stress, which is what was found in the present study. Because HIF1 α plays such a huge role in protective adaptations, it could be assumed that activation of HIF1 α through heat stress would be beneficial in protecting cells against subsequent bouts of oxidative and heat stress.

Practical Applications

A variety of populations may benefit from these new methods of training to help performance at altitude. These populations may include athletes traveling to altitude for their sport, or military personnel being moved to remote locations that may be at higher altitudes, and also the average traveler. Altitude training has become a popular training method for athletes who want to perform well in both normoxic and hypoxic conditions[5]. However, altitude training may not always be appropriate and can be expensive, time-consuming, and not always practical/accessible. Heat training may be a great substitute for traditional altitude acclimation depending on the methodology. However, using a heat chamber to elicit heat adaptations presents the same problems of being costly and not always practical/accessible. If heat training with sauna suit can be shown to improve physiological responses to altitude exposure and decrease the prevalence of AMS symptoms, it can help to combat some of the problems seen with other methodologies. Sauna suits are fairly inexpensive, compared to hypoxic training devices or heat and hypoxic chambers. With that fact combined with heat acclimation taking on average 10 days[11], heat training with a sauna suit would be a great asset to those populations with time and financial constraints or even the average person that may be at risk for experiencing AMS symptoms when travelling.

Limitations and Future Research

Possible limitations in the present study include sample size, heat acclimation protocol, equipment reliability, as well as little being known concerning the individual variability of responsiveness to heat training. We were statistically underpowered with such a small sample size. With a larger sample size, it is possible that a significant trend can be found that can already be shown with the insignificant results found in the present study. Also, our subject pool was not as homogenous mostly due to the fact of being from different exercise backgrounds (i.e. mountain sports, middle-distance running, and long-distance running). Furthermore, our heat acclimation protocol was fairly short with subjects exercising in a sauna suit for about 6 days. This may not have provided the necessary thermal stress needed to elicit all adaptations. Also, with the use of a novel hypoxic machine, there was some variability between hypoxic tests, which may have affected our results. Lastly, it should be said that differences in individual response is a common occurrence in other training studies and should be kept in mind when interpreting the findings[28,29]. Looking toward the future, research would need to expand the knowledge of sauna suits being used as a practical method for heat training to improve performance both in normoxic and hypoxic conditions. Research could also focus on how sauna suits affect not only core temperature but skin temperature as well. Also, research could focus on a direct comparison of sauna suits or heat chambers for heat acclimation and beneficial performance adaptations. Lastly, establishing a dose-response relationship in regard to sauna suit use and performance benefits and analyze the responsiveness of heat acclimation.

Conclusion

In conclusion, the results of this novel study support the use of a sauna suit as a form of cross-adaptation to enhance physiological responses at altitude. Heat acclimation is well studied [6,12-15,30,31,40]; however, the training adaptations to exercise training with a sauna suit on physiological measurements in hypoxic conditions has not been sufficiently explored. Training in sauna suits were shown to help with the improvement of MAP during acute exposure to high altitude and this may have a valuable impact on those travelling to altitude. However, further research is warranted to explore the effectiveness of sauna suits as a tool for cross-adaptation for other physiological responses.

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. Bärtsch, P., & Gibbs, J. S. R. (2007). Effect of altitude on the heart and the lungs. *Circulation*, *116*(19), 2191-2202.
2. Beall, C. M. (2007). Two routes to functional adaptation: Tibetan and Andean high-altitude natives. *Proceedings of the National Academy of Sciences*, *104*(suppl 1), 8655-8660.
3. Bean, W. B., & Eichna, L. W. (1943). Performance in relation to environmental temperature. Reactions of normal young men to simulated desert environment. *Federation Proceedings. Federation of American Societies for Experimental Biology*, *2*(3), 144–58.
4. Bierman, W. (1942). The history of fever therapy in the treatment of disease. *Bulletin of the New York Academy of Medicine*, *18*(1), 65.
5. Chapman, R. F., Karlsen, T., Resaland, G. K., Ge, R. L., Harber, M. P., Witkowski, S., ... & Levine, B. D. (2014). Defining the "dose" of altitude training: How high to live for optimal sea level performance enhancement. *Journal of applied physiology*, *116*(6), 595- 603.
6. Charkoudian, N. (2003). Skin blood flow in adult human thermoregulation: How it works, when it does not, and why. *Mayo Clinic Proceedings*, *78*(5), 603-612.
7. Ely, B. R., Lovering, A. T., Horowitz, M., & Minson, C. T. (2014). Heat acclimation and cross tolerance to hypoxia: bridging the gap between cellular and systemic responses. *Temperature*, *1*(2), 107-114.
8. Febbraio, M. A., Snow, R. J., Hargreaves, M., Stathis, C. G., Martin, I. K., & Carey, M. F. (1994). Muscle metabolism during exercise and heat stress in trained men: effect of acclimation. *Journal of Applied Physiology*, *76*(2), 589–597.
9. Fujii, N., Honda, Y., Ogawa, T., Tsuji, B., Kondo, N., Koga, S., & Nishiyasu, T. (2012). Short-term exercise-heat acclimation enhances skin vasodilation but not hyperthermic hyperpnea in humans exercising in a hot environment. *European Journal of Applied Physiology*, *112*(1), 295–307.
10. Gibson, O. R., Taylor, L., Watt, P. W., & Maxwell, N. S. (2017). Cross-adaptation: Heat and cold adaptation to improve physiological and cellular responses to hypoxia. *Sports Medicine*, *47*(9), 1751–1768.
11. Gibson, O. R., Turner, G., Tuttle, J. A., Taylor, L., Watt, P. W., & Maxwell, N. S. (2015). Heat acclimation attenuates physiological strain and the HSP72, but not HSP90α, mRNA response to acute normobaric hypoxia. *Journal of Applied Physiology*, *119*(8), 889–899.
12. González-Alonso, J., & Calbet, A. L. (2003) Reductions in systemic and skeletal muscle blood flow and oxygen delivery limit maximal aerobic capacity in humans. *Circulation, 107,* 824-830.
13. González-Alonso, J., Calbet, A. L., & Nielsen, B. (1998). Muscle blood flow is reduced with dehydration during prolonged exercise in humans. *The Journal of Physiology*, *513*(3), 895–905.
14. González-Alonso, J., Crandall, C. G., & Johnson, J. M. (2008). The cardiovascular challenge of exercising in the heat: Hyperthermia challenge to cardiovascular regulation and homeostasis. *The Journal of Physiology*, *586*(1), 45–53.
15. González-Alonso, J., Teller, C., Andersen, S. L., Jensen, F. B., Hyldig, T., & Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *American Physiological Society, 86(3),* 1032-1039.
16. Hargreaves, M., Dillo, P., Angus, D., & Febbraio, M. (1996). Effect of fluid ingestion on muscle metabolism during prolonged exercise. *Journal of Applied Physiology*, *80*(1), 363–366.
17. Hauser, A., Schmitt, L., Troesch, S., Saugy, J. J., Cejuela Anta, R., Faiss, R., ... Millet, G. P. (2015). Similar hemoglobin mass response in hypobaric and normobaric hypoxia in athletes. *Medical & Science in Sports & Exercise, 48(4),* 734-741.
18. Heled, Y., Peled, A., Yanovich, R., Shargal, E., Pilz-Burstein, R., Epstein, Y., & Moran, D. S. (2012). Heat acclimation and performance in hypoxic conditions. *Aviation, Space, and Environmental Medicine*, *83*(7), 649–653.
19. Horowitz, M. (1998). Do Cellular Heat acclimation responses modulate central thermoregulatory activity? *Physiology*, *13*(5), 218–225.
20. Horowitz, M., Shimoni, Y., Parnes, S., Gotsman, M. S., & Hasin, Y. (1986). Heat acclimation: Cardiac performance of isolated rat heart. *Journal of Applied Physiology*, *60*(1), 9–13.

21. Kuennen, M., Gillum, T., Dokladny, K., Bedrick, E., Schneider, S., & Moseley, P. (2011). Thermotolerance and heat acclimation may share a common mechanism in humans. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology*, *301*(2), R524–R533.
22. Lee, B. J., Emery-Sinclair, E. L., Mackenzie, R. W., Hussain, A., Taylor, L., James, R. S., & Thake, C. D. (2014). The impact of submaximal exercise during heat and/or hypoxia on the cardiovascular and monocyte HSP72 responses to subsequent (post 24 h) exercise in hypoxia. *Extreme Physiology & Medicine*, *3*(15), 1-16.
23. Lee, B. J., Miller, A., James, R. S., & Thake, C. D. (2016). Cross acclimation between heat and hypoxia: Heat acclimation improves cellular tolerance and exercise performance in acute normobaric hypoxia. *Frontiers in Physiology*, *7*(78), 1-15.
24. Lim, C. L., Byrne, C., & Lee, J. K. W. (2008). Human thermoregulation and measurement of body temperature in exercise and clinical settings. *Annals of the Academy of Medicine, Singapore Academy of Medicine, 37,* 347-353.
25. Neal, R. A., Corbett, J., Massey, H. C., & Tipton, M. J. (2016). Effect of short-term heat acclimation with permissive dehydration on thermoregulation and temperate exercise performance. *Scandinavian Journal of Medicine & Science in Sports*, *26*(8), 875–884.
26. Nielsen, B., Hales, J. R., Strange, S., Christensen, N. J., Warberg, J., & Saltin, B. (1993). Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *The Journal of Physiology*, *460*(1), 467–485.
27. Pandolf, K. B. (1998). Time course of heat acclimation and its decay. *International journal of sports medicine*, *19*(S 2), S157-S160.
28. Patterson, M. J., Stocks, J. M., & Taylor, N. A. S. (2014). Whole-body fluid distribution in humans during dehydration and recovery, before and after humid-heat acclimation induced using controlled hyperthermia. *Acta Physiological*, *210*(4), 899–912.
29. Patterson, M. J., Stocks, J. M., & Taylor, N. A. S. (2004b). Humid heat acclimation does not elicit a preferential sweat redistribution toward the limbs. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology*, *286*(3), R512–R518.
30. Périard, J. D., Cramer, M. N., Chapman, P. G., Caillaud, C., & Thompson, M. W. (2010). Cardiovascular strain impairs prolonged self-pace exercise in the heat. *Experimental Physiology, 96,* 134-144.
31. Périard, J. D., Racinais, S., & Sawka, M. N. (2015). Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. *Scandinavian Journal of Medicine & Science in Sports*, *25*, 20–38.
32. Qiao, Y., Liu, Z., Yan, X., & Luo, C. (2015). Effect of intermittent hypoxia on neuro-functional recovery post brain ischemia in mice. *Journal of Molecular Neuroscience*, *55*(4), 923-930.
33. Rowell, L. B., Kraning, K. K., Kennedy, J. W., & Evans, T. O. (1967). Central circulatory responses to work in dry heat before and after acclimatization. *Journal of Applied Physiology*, *22*(3), 509–518.
34. Salgado, R. M., White, A. C., Schneider, S. M., & Mermier, C. M. (2014). A novel mechanism for cross-adaptation between heat and altitude acclimation: The role of heat shock protein 90. *Physiology Journal*, *2014*, 1–12.
35. Sato, F., Owen, M., Matthes, R., Sato, K., & Gisolfi, C. V. (1990). Functional and morphological changes in the eccrine sweat gland with heat acclimation. *Journal of Applied Physiology*, *69*(1), 232–236.
36. Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J., & Stachenfeld, N. S. (2007). American College of Sports Medicine position stand: Exercise and fluid replacement. *Medicine and Science in Sports and Exercise*, *39*(2), 377–390.
37. Sawka, M. N., Leon, L. R., Montain, S. J., & Sonna, L. A. (2011). Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. *Comprehensive Physiology*. *October 1(4),* 1883-1928.
38. Sawka M. N. & Noakes T. D. (2007). Does dehydration impair exercise performance? *Medicine & Science in Sports & Exercise*, *39*(8), 1209–1217.
39. Sawka, M. N., Pandolf, K. B., Avellini, B. A., & Shapiro, Y. (1983). Does heat acclimation lower the rate of metabolism elicited by muscular exercise? *Aviation, Space, and Environmental Medicine*, *54*(1), 27–31.

40. Van de Velde, S., Byrd, B.R., Fargo, J.S., Loring, L.B., Buchanan, C.A., & Dalleck, L.C. (2017). Acute metabolic responses of exercise with a sauna suit. *International Journal of Research in Exercise Physiology, 12(2*), 1-8.
41. Wagner, P. D., Gale, G. E., Moon, R. E., Torre-Bueno, J. R., Stolp, B. W., & Saltzman, H. A. (1986). Pulmonary gas exchange in humans exercising at sea level and simulated altitude. *Journal of Applied Physiology*, *61*(1), 260–270.
42. Waldhoer, T., & Klebermass-Screhof, K. (2015). The impact of altitude on birth weight depends on further mother- and infant-related factors: a population-based study in an altitude range up to 1600 m in Austria between 1984 and 2013. *Journal of Perinatology*, (9), 689.
43. White, A. C., Salgado, R. M., Astorino, T. A., Loeppky, J. A., Schneider, S. M., McCormick, J. J., … Mermier, C. M. (2016). The effect of 10 days of heat acclimation on exercise performance in acute hypobaric hypoxia (4350 m). *Temperature*, *3*(1), 176–185.
44. White, A., Salgado, R., Schneider, S., Loeppky, J., Astorino, T., & Mermier, C. (2014). Does heat acclimation improve exercise capacity at altitude? A cross-tolerance model. *International Journal of Sports Medicine*, *35*(12), 975–981.
45. Wilber, R. L. (2007). Application of altitude/hypoxic training by elite athletes. *Medicine and Science in Sports and Exercise*, *39*(9), 1610-1624.
46. Young, A. J., Sawka, M. N., Levine, L., Cadarette, B. S., & Pandolf, K. B. (1985). Skeletal muscle metabolism during exercise is influenced by heat acclimation. *Journal of Applied Physiology*, *59*(6), 1929–1935.
47. Ziello, J. E., Jovin, I. S., & Huang, Y. (2007). Hypoxic-inducible factor (HIF)-1 regulatory pathway and its potential for therapeutic intention in malignancy and ischemia. *Yale Journal of Biology and Medicine, 80,* 51-6.