International Journal of Research in Exercise Physiology

Original Research Article

Physiological responses during acute, high intensity functional training: normal vs. hot environmental conditions

Kimberly Allan[1], Ryan M. Weatherwax[2], Lance C. Dalleck[1]

[1]Applied Exercise Science and Performance Program, Western Colorado University, Gunnison, CO, USA
[2]Department of Health and Exercise Science, Southern Oregon University, Ashland, OR, USA

Abstract

Introduction: Compelling evidence confirms that regular exercise improves health and reduces the risk of chronic diseases. Only 1 in 4 adults meet exercise guidelines. The common reported barriers include a "lack of time or enjoyment". High intensity functional training (HIFT) is a time efficient modality combining resistance training and high intensity cardiorespiratory exercise. Additionally, substantial evidence shows heat acclimation can improve thermoregulation, attenuate physiological strain, reduce heat illness and enhance endurance and other cardiometabolic outcomes. Therefore, the purpose of this study was to determine the physiological, metabolic, and perceptual responses during HIFT with and without artificial heat exposure. **Methods:** 19 healthy adults (age=19-43 years) completed an acute bout of HIFT in both a normal (NORM) and hot (HOT) environment with physiological, metabolic, and perceptual measures obtained for each session. **Results:** Paired t-tests revealed multiple HIFT session physiological and metabolic responses were significantly higher ($p<0.05$) in HOT compared to NORM conditions, respectively: overall session HR (151 ± 25.9 bpm vs. 144.1 ± 27.2 bpm), % HR reserve (65.9 ± 6.6% vs. 60.7 ± 7.5%), % oxygen uptake reserve (63.2 ± 5.2% vs. 59.1 ± 5.9%), metabolic equivalents (8.8 ± 1.4 METs vs. 8.4 ± 1.4 METs), energy expenditure per minute (10.4 ± 1.9 kcal/min vs. 9.8 ± 1.9 kcal/min), overall HIFT session energy expenditure (311.6 ± 59.5 kcal vs. 294.1 ± 57.1 kcal). Overall, core temperature in HOT was 0.4% greater than in NORM (100.2 ± 0.9° vs. 99.9 ± 0.6°, $p<0.05$). Paired t-tests revealed both HIFT rating of perceived exertion (7.1 ± 1.4 vs. 6.5 ± 1.4) and HIFT thermal comfort rating (3.3 ± 1.0 vs. 2.3 ± 0.7) scores were significantly higher ($p<0.05$) in HOT vs NORM conditions. **Conclusion:** Quantifying the acute physiological and metabolic responses to HIFT provides health and exercise professionals insight into of the safety and effectiveness of this type of exercise. An acute bout of HIFT in HOT conditions can elicit greater physiological and metabolic responses relative to NORM. Therefore, adding heat to a HIFT session represents an additional variable, beyond volume and/or intensity that can modify the training stimulus. In summary, HIFT may be an effective, safe, and time-efficient exercise modality for many populations.

Keywords: exercise recommendations, physical activity, and resistance training.

Introduction

Compelling evidence confirms that regular exercise improves health and reduces the risk of many chronic diseases, which has led to exercise recommendations published worldwide[1-2]. However, only one in four adults meet these recommended guidelines with "lack of time or enjoyment" as a commonly reported barriers[3-4]. High intensity interval training (HIIT), defined as brief bouts of vigorous cardiorespiratory exercise interspersed with short periods of low intensity cardiorespiratory exercise or rest, has been proposed as a time-efficient modality[5]. Investigations examining various intensity and interval protocols have shown HIIT improves health and fitness as well as reduces disease risk[6]. Despite the time-efficiency and effectiveness of HIIT, there are concerns the higher intensities may compromise adherence and motivation to the exercise due to perceived discomfort[7]. High intensity functional training (HIFT) is another time-efficient modality of exercise, differentiated from HIIT by the inclusion of resistance exercises along with high intensity cardiorespiratory exercise[8]. These functional exercises typically involve whole-body, universal movement patterns performed across multiple planes, such as squats, deadlifts, cleans, snatches, pull-ups, and vertical jumps[8]. In comparison to standard worldwide exercise recommendations, preliminary data on perceptions of HIFT found that participants reported greater enjoyment, were more likely to adhere to a program, and spent significantly less time exercising[9].

Furthermore, this modality offers significant translatability to various physical settings as the exercises use minimal equipment and space, reducing the barriers of needing access to a fitness facility[8]. In populations with risk factors or currently with metabolic diseases, HIFT can improve oxygen capacity, insulin resistance, metabolic risk factors, and muscular strength[10-11]. In apparently healthy populations, HIFT can also improve cardiorespiratory fitness[12], as well as enhance muscular strength and power[13]. Willis and colleagues[14] measured energy expenditure and quantified the intensity of HIFT and found that a 40-minute session of HIFT, including warm-up and cooldown, expended an average of 485 kcal and the participant's average heart rate (HR) was 80% of maximum. Indeed, HIFT has the potential to meet the weekly recommended energy expenditure to improve health outcomes, especially if performed several times per week[1].

Substantial evidence exists that heat acclimation can improve thermoregulation, attenuate physiological strain, and reduce risk of heat illness[15], which may result in increased endurance and other beneficial metabolic alterations[16]. Additionally, heat acclimation has been shown to induce heat shock proteins, which help protect skeletal muscle by regulating inflammatory responses within the body[17]. Heat acclimation may also enhance performance in both cool and temperate conditions and can act as a training tool for competitive athletes in-season[15] or provide workplace performance benefits for tactical athletes[18]. Heat acclimation can be achieved through several modalities, including but not limited to environmental chambers, saunas, or sauna suits. Van de Velde et al.[19] found a significant increase in VO_2max (50.4 $\pm$ 8.8 to 54.7 $\pm$ 8.3 mL·kg^{-1}·min^{-1}, $p<0.05$) when using sauna suits over a 6-week training intervention at a moderate cardiorespiratory intensity. Similarly, McCleave and colleagues[20] found a 3.3% improvement in 15-km cycling time trial following 3 weeks of heat training using an environmental chamber compared to training without heat exposure. Therefore, it is speculated that HIFT with heat exposure might conceivably contribute to greater health and performance outcomes, including improved cardiorespiratory and muscular fitness.

HIFT has become increasingly popular in recent years. However, few studies have evaluated the physiological and metabolic responses to HIFT, and, to our knowledge, there is not current research examining these responses during heat exposure when performing HIFT or other resistance-related exercises. Quantifying the acute physiological responses, metabolic responses, and muscle activation to HIFT and heat exposure may provide health and exercise professionals with a better understanding of the safety and effectiveness of this type of exercise and use of environmental training. Therefore, the purpose of this study was to determine the physiological, metabolic, and perceptual responses, along with muscular activation, during HIFT with and without artificial heat exposure.

Methods

Participants

Participants between the ages of 18-45 years were recruited from the local university and community via advertisement and word-of-mouth. Inclusion criteria required participants to be low risk for heart disease as classified by the American College of Sports Medicine[21], and were also required to be able to complete two HIFT sessions in different environmental conditions: normal room temperature (NORM) and under hot conditions (HOT). Participants were excluded from the study if they had a diagnosis of or currently being treated for heart, liver, kidney, or neurological disease, had any musculoskeletal or orthopedic conditions that limit exercise participation, any previous self-reported heat injury, or were pregnant or planning to become pregnant during the study. This study was conducted on the Western Colorado University campus (2347m). Prior to the beginning of this study, participants provided written informed consent. This study was approved by the Western Colorado University Institutional Review Board [HRC-2023-01-01-R06].

Experimental Design

In this cross-over experimental study, participants were randomly assigned by a computer-generated sequence into an initial

NORM group and HOT group. Prior to the experimental protocols, baseline testing was completed under the supervision of a well-trained exercise physiologist to obtain anthropometric and maximal oxygen uptake (VO_2max) measures. After baseline testing, participants completed a familiarization period of the experimental protocols. Week 1 of familiarization consisted of a movement screen to assess the participant's capabilities of multi-planar, functional movements (squat, hinge, lunge, push, pull, carry, rotation, and plank). Corrections and modifications were advised, then movements were rehearsed to ensure proper, safe exercise. If proper movement was not attained within Week 1, this familiarization was extended until satisfaction before progression. Week 2 of familiarization consisted of learning the structured routine adding appropriate resistance to the functional movements using bodyweight or portable modalities such as suspension bands, medicine balls, kettlebells, dumbbells, elastic bands, and stability balls. Additionally, participants were familiarized with the required effort level, with a target range of 7-10 using the Modified Borg CR10 rating of perceived exertion (RPE) scale. Following the adaptive period, participants visited the laboratory one time per week for two consecutive weeks and completed the NORM and HOT conditions in randomized order. The week between experimental conditions allowed for a washout and recovery period prior to the remaining experimental condition.

Procedures

Anthropometric Measures

Height and mass were measured to the nearest 0.5 cm and 0.1 kg, respectively, using a stadiometer and medical grade scale (Tanita-WB3000).

Resting Physiological Measures and Cardiorespiratory Fitness Testing

A graded exercise test (GXT) using individualized protocols on a treadmill was completed to determine VO_2max using a metabolic analyzer (Parvo Medics TrueOne 2.0, Salt Lake City, UT, USA). Before each exercise test, the metabolic analyzer was calibrated in accordance with manufacturer guidelines. Prior to the commencement of the GXT, 5 min of seated rest were performed to obtain seated heart rate (HR) using a chest strap and radiotelemetry (Polar Electro, Woodbury, NY, USA) and resting metabolic rate was determined as the average breath-by-breath VO_2 during the final min of the seated rest. After the 5 min of seated rest, participants performed an exercise warm-up at a self-selected pace for 4 min For the GXT, participants chose a self-selected pace to complete the test and the incline was increased by 1% each minute until volitional exhaustion was reached. Breath-by-breath and HR data were continuously recorded and RPE (Modified Borg CR10 Scale) was monitored each minute. Breath-by-breath data were averaged for every 15 sec. The final two consecutive 15 sec data were averaged to represent the data at VO_2max. Participants were confirmed to be at VO_2max if two of the following were present: (1) A plateau (ΔVO_2 < 150 mL/min) in VO_2 with increases in workload, (2) maximal respiratory exchange ratio (RER) > 1.1, and (3) maximal HR within 10 beats/min of the age-predicted maximum.

High-Intensity Functional Training: NORM and HOT Testing Sessions

Core temperature was measured via a core temperature pill (HQInc., CorTemp®, TEMP SENSOR) that was consumed two hours prior to the HIFT testing sessions. Core temperature was measured to ensure the body core temperature did not go above 102° Fahrenheit (F). Core temperature was measured at rest, after warmup, after each as many rounds as possible (AMRAP) and rest period, and at the end of the cooldown. The HR was measured and recorded at the same time points for each participant. The environmental temperature was continuously monitored throughout both the NORM and HOT conditions. Heat exposure duration and magnitude were consistent with previous heat research that has been demonstrated to be safe[22].

Each HIFT condition followed the same protocols and procedures with the environmental temperature being the only difference. In summary, all participants completed a 10-minute monitored warmup consisting of a quadruped series, straight leg series, and dynamic series prior to each HIFT session. The conditioning phase of the HIFT session consisted of four 6-min sets with 3-min rests between sets. Each set included a round of an aerobic priming exercise, lower body resistance exercise, upper body resistance exercise, and core strengthening exercise (Figure 1). Participants were asked to perform AMRAP of these 4 exercises within the 6-min set. All participants performed the same number of prescribed repetitions within each exercise, but the amount of resistance was individualized to achieve a session RPE between 7-9. There was a work to rest ratio programmed to be 2:1 with total work time was ~24 min and total rest time was ~12 min After each HIFT intervention, a self-regulated cool down was completed. Individual perception of heat exposure (Figure 2) was measured at rest, after warmup, after each AMRAP and rest period, and at the end of the cooldown to determine how the participants felt in the hot room intervention.

Elapsed Exercise Time (Min)	Exercise Description	Work Time	Rest Time
Warm Up Min 0	**Quadruped Series:** Fire Hydrants, Donkey Kicks, Donkey Whips, Hip Circles (FWD/BWD), Cat/Cow, Forward Reach, Shoulder Flexion, Sprinklers **Straight Leg Series:** Straight Leg Raise, Hip Abduction, Hip Adduction, the Dab, Glute Bridge **Dynamic Series:** Hip Gates, Cradles, Quad Reach, Forward Lunge Twist and Reach, Lateral Lunge + Curtsy, Reverse World's Greatest, Hamstring Sweeps, Tin Soldiers, Inchworms	10 min	
AMRAP Set 1 Min 10	20 Jumping Jacks 6 Goblet Squats 8 TRX Push Ups 10 total Plank Toe Taps	6 min	
Rest Interval Min 16			3 min
AMRAP Set 2 Min 19	20 Squat Jacks 6 total DB Step Ups 8 TRX Rows 10 total MB Russian Twists	6 min	
Rest Interval Min 25			3 min
AMPRAP Set 3 Min 28	20 total High Knees 6 BB Deadlifts 8 DB Push Press 10 total Plank Knee to Elbow	6 min	
Rest Interval Min 34			3 min
AMRAP Set 4 Min 37	20 KB Swings 6 Box Jumps 8 DB Zottman Curls 20 second High Plank	6 min	
Rest Interval Min 43			3 min

Figure 1. HIFT workout.

Thermal Comfort Index	
1	Neutral - I feel Comfortable
2	Slightly Warm
2.5	Moderately Warm
3	Warm - Middle of the Road
3.5	Warmer
4	Very Warm
4.5	Hot
5	Very HOT!

Figure 2. Thermal Comfort Index.

Exercise intensity and metabolic calculations

Individual heart rate reserve (HRR) was determined as the difference between resting and maximal HR values. Percent HRR was calculated by subtracting resting HR from the HIFT HR response, dividing by HRR, and then multiplying the quotient by 100. Individual HIFT $\%VO_2R$ (difference between resting VO_2 and maximum VO_2)

was estimated via %HRR based on a prediction equation [$\%VO_2R = 11.893 + (\%HRR)(0.778)$, $R^2=0.491$, $p<0.01$] developed with previously published data from our laboratory[11]. The metabolic equivalent (MET) for HIFT exercise was determined by dividing the exercise VO_2 by the obtained seated VO_2 for the HIFT workout portion (warm-up and cool-down metabolic data was omitted in this analysis). Energy expenditure (kcal/session) for the HIFT session was calculated by multiplying the above-calculated MET equivalent of HIFT by individual resting VO_2 and then individual body mass. This value was then divided by 1000, multiplied by 5 (the assumption was made for an energy cost of 5 $kcal\cdot L^{-1}$ of oxygen), and last multiplied by the length of the HIFT session.

Statistical Analysis

Measures of centrality and spread are presented as mean ± SD. Paired samples t-tests were used to compare within-group differences for all physiological, metabolic, and perceptual outcome variables between NORM and HOT conditions. Significance level was set at $p<0.05$ for all analyses. GraphPad Prism version 10.2.2 was used for the analyses.

Results

Of the twenty-two participants recruited, nineteen (11 women and 8 men) completed both the NORM and HOT sessions; one participant did not complete due to loss of contact, one due to an injury outside of the study, and one due to moving to a new state. Descriptive characteristics (mean ± SD) of the participants are shown in Table 1. Environmental conditions during testing sessions were as follows: NORM (room temperature: 65.4 ± 0.3° F, humidity: 7 ± 2.3%) and HOT (room temperature: 110.9 ± 3.8° F, humidity: 14.8 ± 3.4%). The HOT room temperature ranged from 107°-113° F.

Table 1. Descriptive characteristics of participants.

Parameter	Women (N=11)	Men (N=8)	Combined (N=19)
Age (years)	22.1 ± 3.3	25 ± 8.2	23.3 ± 5.9
Height (cm)	166.4 ± 4.6	179.3 ± 9.1	171.8 ± 9.3
Weight (kg)	65.2 ± 9.6	77.3 ± 12.7	70.3 ± 12.3
Activity Level (1-5)	3.5 ± 0.9	3.6 ± 0.9	3.5 ± 0.9
Resting Heart Rate (bpm)	64.2 ± 4.8	60.8 ± 5.6	62.7 ± 5.3
Maximal Heart Rate (bpm)	197.9 ± 3.3	195 ± 8.2	196.7 ± 5.9
Resting Oxygen Uptake ($mL\cdot kg^{-1}\cdot min^{-1}$)	3.5 ± 1.7	3.5 ± 1.4	3.5 ± 1.6
Maximal Oxygen Uptake ($mL\cdot kg^{-1}\cdot min^{-1}$)	42.3 ± 5.5	49.4 ± 8.9	45.3 ± 7.8

Note: Values are mean ± SD. Every participant completed both NORM and HOT interventions. Activity level on a scale of 1-5 (1 = Sedentary, 2 = Lightly Active, 3 = Moderately Active, 4 = Highly Active, 5 = Extremely Active).

Acute Physiological and Metabolic Responses

Acute cardiovascular and physiological responses (mean ± SD) to HIFT are presented in Table 2. Paired t-tests revealed multiple HIFT session physiological and metabolic responses that were significantly higher ($p<0.05$) in HOT compared to NORM conditions, respectively: overall session HR response (151 ± 25.9 bpm vs. 144.1 ± 27.2 bpm; Figure 3), %HRR (65.9 ± 6.6% vs. 60.7 ± 7.5%; Figure 4), %VO_2R (63.2 ± 5.2% vs. 59.1 ± 5.9%), METs (8.8 ± 1.4 METs vs. 8.4 ± 1.4 METs), averaged energy expenditure per minute (10.4 ± 1.9 kcal·min^{-1} vs. 9.8 ± 1.9 kcal·min^{-1}), overall HIFT session energy expenditure (311.6 ± 59.5 kcal vs. 294.1 ± 57.1 kcal). Furthermore, core temperature in HOT was 0.4% greater than in NORM (100.2 ± 0.9 vs. 99.9 ± 0.6, $p<0.05$; Figure 5). Paired t-tests revealed both HIFT rating of perceived exertion (7.1 ± 1.4 vs. 6.5 ± 1.4) and HIFT thermal comfort rating (3.3 ± 1.0 vs. 2.3 ± 0.7) scores were significantly higher ($p<0.05$) in HOT vs NORM conditions, respectively.

Table 2. Acute physiological and metabolic responses to HIFT.

Parameter	NORM (N=19)	HOT (N=19)
HR (bpm)	144.1 ± 27.2	151 ± 25.9*
Range	173.4 - 82.2 (91.21)	174.5 - 85.3 (89.2)
%HRR	60.7 ± 7.5	65.9 ± 6.6*
Range	71.7 - 42.6 (29.1)	76 - 53.4 (22.7)
%VO_2R	59.1 ± 5.9	63.2 ± 5.2*
Range	67.7 - 45.1 (22.6)	71 - 53.4 (17.6)
METs	8.4 ± 1.4	8.8 ± 1.4*
Range	10.8 - 4.8 (6)	11.4 - 5.5 (5.9)
EE (kcal·min^{-1})	9.8 ± 1.9	10.4 ± 1.9*
Range	13.5 - 5.3 (8.2)	14.2 - 6.1 (8.1)
EE (kcal·session^{-1})	294.1 ± 57.1	311.6 ± 59.5*
Range	403.6 - 159 (244.6)	425.4 - 182.4 (243)
Average CT (°F)	99.9 ± 0.6	100.2 ± 0.9*
Range	100.4 - 98.8 (1.7)	101.2 - 98.8 (2.4)

Note: Values are mean ± SD. Range is Max. - Min. (Range). (HR, heart rate; %HRR, percentage heart rate reserve; %VO_2R, percentage oxygen uptake reserve; METs, metabolic equivalents; EE, energy expenditure; kcal, kilocalories; CT, core temperature). *Denotes statistical significance, $p < 0.05$.

Figure 3. Mean heart rate response throughout a HIFT Session (**HOT** vs. **NORM**).

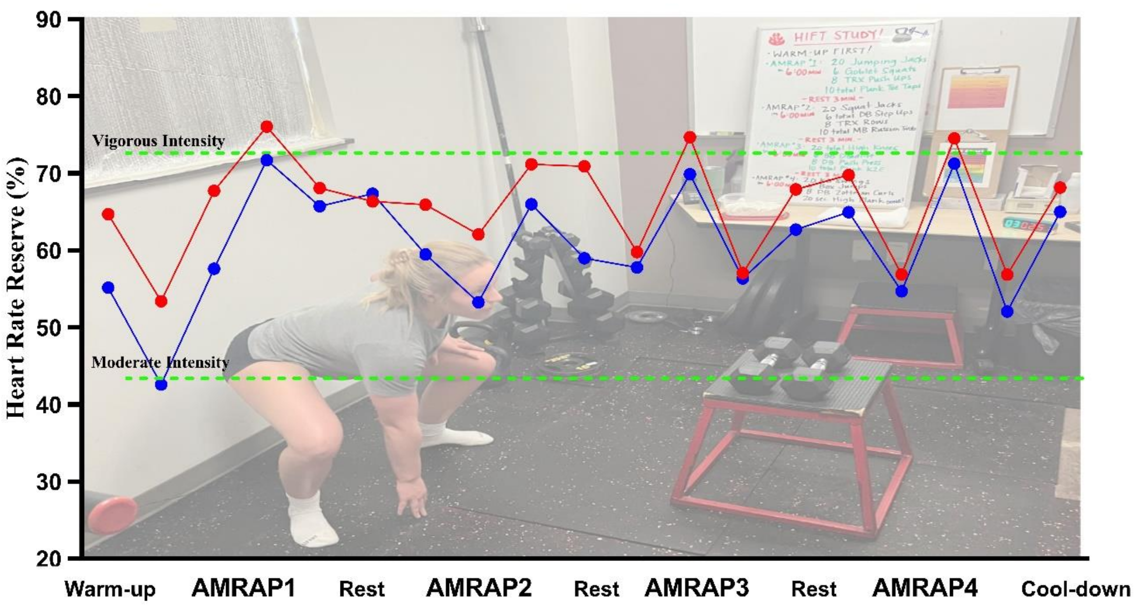

Figure 4. Mean % heart rate reserve response throughout a HIFT Session (**HOT** vs. **NORM**).

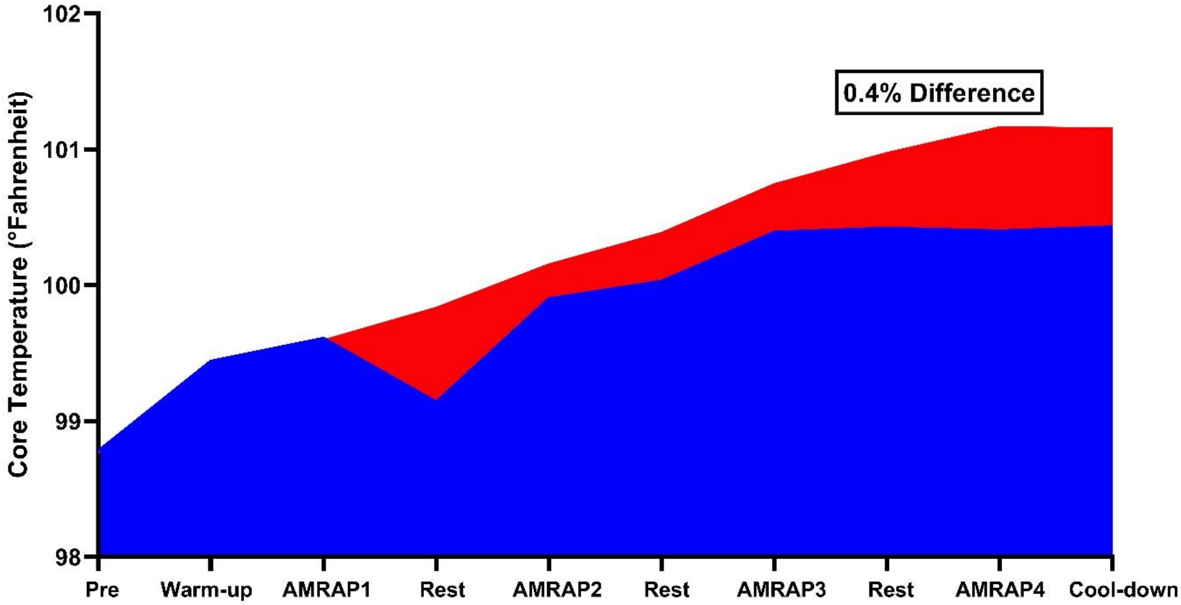

Figure 5. Mean core temperature response throughout a HIFT Session (**HOT** vs. **NORM**).

Perception Ratings and Rounds Completed of HIFT.

Perception ratings and rounds completed (mean ± SD) during HIFT are presented in Table 3. Paired t-tests revealed higher RPE (7.1 ± 1.4 vs. 6.5 ± 1.4, $p<0.05$) and Thermal Comfort Rating (3.3 ± 1.0 vs. 2.3 ± 0.7, $p<0.05$) scores in HOT vs. NORM. No statistical significance was found for rounds of HIFT completed in HOT vs. NORM (196.3 ± 23.4 vs. 212.3 ± 28.6, p=0.06). Nevertheless, on average 16 fewer repetitions were performed during the HOT session, which coincides with the perception ratings of HIFT in HOT conditions being more challenging.

Table 3. Perception ratings and rounds completed of HIFT.

Parameter	NORM (N=19)	HOT (N=19)
Session RPE	6.5 ± 1.4	7.1 ± 1.4*
Range	7.7 - 4.4 (3.3)	8 - 5.1 (2.9)
Session Heat Index	2.3 ± 0.7	3.3 ± 1.0*
Range	3.3 - 1 (2.3)	4.5 - 1 (3.5)
Number of Rounds Completed (total reps)	212.3 ± 28.6	196.3 ± 23.4
Range	249.7 - 185.6 (64.2)	221.6 - 172.8 (48.8)

Note: Values are mean ± SD. (RPE, rating of perceived exertion, scale of 1-10, 1 is light activity, 10 is maximal; Heat index, scale of 1-5, 1 is neutral, 5 is very hot; AMRAP 1, 44 total reps; AMRAP 2, 44 total reps; AMRAP 3, 44 total reps; AMRAP 4, 54 total reps; 186 total reps for 1 rounds of HIFT session). *Denotes statistical significance, $p < 0.05$.

Discussion

To our knowledge, the present study is the first to investigate the physiological and metabolic responses of HIFT in NORM vs. HOT environmental conditions. The main findings of this novel study shed light on the ability of HIFT in heat to (1) elicit an increase in both heart rate and core temperature response and (2) increase the perception of exercise intensity and thermal comfort when compared to the literature. The data suggest that HIFT acutely falls within the high end of moderate and into vigorous intensity exercise when intensity is quantified based on %HRR and %VO_2R[21]. Furthermore, participants performed roughly 150 minutes of HIFT throughout this entire study and had no adverse events such as muscular injury or any heat events, such as light headedness and dizziness. With a group mean session energy expenditure achieved in less than 1 hour of 311.6 ± 59.5 and 294.1 ± 57.1 kcal for HOT and NORM, respectively, we confirm that HIFT is a viable way to increase daily energy expenditure[23-24]. Based on these findings, HIFT, along with training in heat, may be a way to further augment training without the risk of injury and may be considered a safe modality of exercise.

Willis et al.[14] measured energy expenditure by analyzing the oxygen demands of exercise during a HIFT session and found that energy expenditure was highly influenced by the duration of the session, with <10, 15, 20, 35, and 45 min equating to a range of energy expenditures of ~60–170, ~175–200, ~260–320, ~465–580 and ~460–605 kcal, respectively. A recent study by Smith and colleagues[11] implemented a similar HIFT protocol as the current investigation to determine the effects on energy expenditure, VO_2max, and blood lactate levels in individuals with metabolic syndrome. They found that HIFT elicited a higher energy expenditure per minute (8 ± 2 $kcal\cdot min^{-1}$) and higher total session energy expenditure (270 ± 77 $kcal\cdot session^{-1}$) when compared to other exercise modalities, such as HIIT or traditional steady-state exercise. These results are comparable to the current findings in which 294.1 ± 57.1 and 311.6 ± 59.5 total kcals for each session in the NORM and HOT conditions, respectively.

Since numerous protocols and designs of HIFT have been implemented previously, it is important to acknowledge that differences in the length of session and timing of exercise may influence the average minute energy expenditure throughout the exercise bout. In four studies involving varying length and designs of HIFT for both males and females, session averaged caloric expenditures were found to be 7.5 $kcal\cdot min^{-1}$ for 45 min[25], 9.7 $kcal\cdot min^{-1}$ for 15 min[26], 10.8 $kcal\cdot min^{-1}$ for 44 min[14], and 15.1 $kcal\cdot min^{-1}$ for 35 min[27]. These findings highlight that as session duration decreases, there is a greater energy expenditure per minute that can occur, likely due to less fatigue accumulated over a shorter duration. These results are comparable to our findings, with a 45-minute HIFT session in the NORM condition yielding an energy expenditure of 9.8 ± 1.9 $kcal\cdot min^{-1}$ and 294.1

± 57.1 kcal·session^{-1}) and in the HOT condition showing slightly elevated results of 10.4 ± 1.9 kcal·min^{-1} and 311.6 ± 59.5 kcal·session^{-1}.

The human body has intrinsic regulatory mechanisms to cope with heat exposure, including perspiration and vasodilation of the blood vessels[28] allowing the bloodstream to transport heat generated from within the body to the skin surface and then the heat is released to the surrounding environment[29]. Heat exposure can improve these responses and improve heat tolerance. McCleave et al.[20] found that after 6-wks of heat exposure, improvements in 15-km cycling time trial (652 ± 76 vs 629 ± 67 s, $p<0.05$) and power output (298 ± 6 to 315 ± 6W, $p<0.05$) were obtained. However, the adaptations to heat acclimation are lost relatively quick without continued heat exposure (~2.5% decay per day[30] yet it has been shown that recovery periods from the heat exposure are needed. Therefore, Pryor et al.[30] examined how much recovery is needed throughout heat acclimation. Sixteen participants were randomized into a temperate exercise group and intermittent heat exercise group and performed a cycling session every 5th day for 25 days. They found that heart rate, perceived exertion, fatigue, and thermal sensation were lowered after initial heat exposure, and these levels were maintained throughout the 25 days. These findings suggest performing HIFT in heat every 5 days might be sufficient for maintaining favorable adaptations.

It has been shown that with exercise-heat acclimation, both regional blood flow and cardiac output increase to maintain adequate blood flow to the skin for thermoregulation, support blood flow to metabolically active tissues, and can lower core temperature both at rest and during exercise[31]. During HIFT, heat produced in contracting muscles causes internal body temperature to rise until heat dissipation responses are activated. Core temperature initially increases rapidly and then rises more slowly until heat loss equals heat production. This elevation is largely dependent upon the environmental condition and is proportional to the individual metabolic rate. In the current study, as participants began exercising, core temperature gradually increased throughout the HIFT session in the NORM and HOT environments from 98.8 to 100.4°F and 98.8 to 101.2°F, respectively.

One objective of HIFT is to optimize movement efficiency within relatively short periods of time to improve muscular strength, power, flexibility, and sport-specific performance. Heat exposure can be strategically utilized for athletes who begin their training in the winter season, such as track and field, but compete in warmer environments during their competitive season. Heat acclimation typically occurs within 7 to 14 days and can improve fluid balance, skeletal muscle metabolism, thermoregulatory mechanisms (i.e., increased sweating efficiency and enhanced skin blood flow at a given core temperature), as well as cardiovascular stability[30,32]. Due to the beneficial effects on human thermoregulatory capacity, heat acclimation is recommended to reduce the risk of heat injury or heat-related events during athletic practice or competition in hot environments[33]. Furthermore, for tactical athletes (i.e., fire fighters, law enforcement, or military personnel) train to perform the various fitness demands of their job and HIFT in combination with heat may be an advantageous training protocol since the design of HIFT workouts is boundless. A workout can vary in duration, work-to-rest ratios, variations in the order of exercises and number of repetitions, as well as the amount of resistance applied. With this in mind, HIFT can emulate the different aerobic and strength parameters (i.e., climbing, carrying, jumping, and crawling) and can improve operational readiness that a tactical athlete may require. Indeed, the incorporation of heat to a HIFT training session can provide advantageous adaptations to thermal comfort and physiological responses to help with performances for tactical athletes in hot environments. Future research should focus on within session variation with directly measured VO_2, continuous heart rate monitoring and comparison to traditional exercise training methods, along with more practical applications to simulate hot environments without a heat chamber.

Limitations

The main limitation to the current investigation is the use of a regression equation to estimate training session VO_2 data and energy expenditure data. A considerable limitation of the current investigation is the use of a heat chamber to implement the HIFT training in the hot environment. While it is speculated these conditions might be able to be replicated outside of a laboratory setting with increasing the heating mechanism within a room or use of environmentally hot environments, ecological validity of these findings is not known. unexpected limitation was the ceiling height of the environmental chamber used which caused some participants greater than 180 cm in height to have to modify some of the exercises in the HIFT session. Lastly, as noted by McDougle and colleagues[34], comparison of the current HIFT protocol to previous work is challenging due to limited consistency in HIFT workout structure within the literature.

Conclusion

Quantifying the acute physiological and metabolic responses to HIFT provides health and exercise professionals with a better understanding of the safety and effectiveness of this type of exercise. Moreover, an acute bout of HIFT in HOT conditions can elicit greater physiological and metabolic responses relative to NORM. As such, the addition of heat to a HIFT session equates to adding volume and/or intensity without the actual wear and tear of doing so. In summary, HIFT may be an effective, safe, and time-efficient exercise modality for many populations.

References

1. Garber C E, Blissmer B, Deschenes MR, Franklin B A, Lamonte MJ, Lee I-M, Nieman DC, Swain DP. (2011). Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine & Science in Sports & Exercise*, *43*(7), 1334–1359.
2. World Health Organization, (2020) Global physical activity recommendations. Available form URL: https://www.who.int/newsroom/fact-sheets/detail/physical-activity.
3. Costello E, Kafchinski M, Vrazel J, Sullivan P. (2011). Motivators, Barriers, and Beliefs Regarding Physical Activity in an Older Adult Population. *Journal of Geriatric Physical Therapy*, *34*(3), 138–147.
4. Korkiakangas EE, Alahuhta MA, Laitinen JH. (2009). Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: A systematic review. *Health Promotion International*, *24*(4), 416–427.
5. Gillen JB, Gibala MJ. (2014). Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? *Applied Physiology, Nutrition, and Metabolism*, *39*(3), 409–412.
6. Gibala MJ, Little JP. (2020). Physiological basis of brief vigorous exercise to improve health. *The Journal of Physiology*, *598*(1), 61–69.
7. Ekkekakis P, Parfitt G, Petruzzello SJ. (2011). The Pleasure and Displeasure People Feel When they Exercise at Different Intensities: Decennial Update and Progress towards a Tripartite Rationale for Exercise Intensity Prescription. *Sports Medicine*, *41*(8), 641–671.
8. Feito Y, Heinrich K, Butcher S, Poston W. (2018). High-Intensity Functional Training (HIFT): Definition and Research Implications for Improved Fitness. *Sports*, *6*(3), 76.
9. Heinrich KM, Patel PM, O'Neal JL, Heinrich BS. (2014). High-intensity compared to moderate-intensity training for exercise initiation, enjoyment, adherence, and intentions: An intervention study. *BMC Public Health*, *14*(1), 789.
10. Nieuwoudt S, Fealy CE, Foucher JA, Scelsi AR, Malin SK, Pagadala M, Rocco M, Burguera B, Kirwan JP. (2017). Functional high-intensity training improves pancreatic β-cell function in adults with type 2 diabetes. *American Journal of Physiology-Endocrinology and Metabolism*, *313*(3), E314–E320.
11. Smith LE, Van Guilder GP, Dalleck LC, Harris NK. (2022). The Effects of a Single Session of High Intensity Functional Training on Energy Expenditure, VO2, and Blood Lactate. *Journal of Sports Science & Medicine*, *21*(4), 545–554.
12. Posnakidis G, Aphamis G, Giannaki CD, Mougios V, Aristotelous P, Samoutis G, Bogdanis GC. (2022). High-Intensity Functional Training Improves Cardiorespiratory Fitness and Neuromuscular Performance Without Inflammation or Muscle Damage. *Journal of Strength and Conditioning Research*, *36*(3), 615–623.
13. Cosgrove S.J., Crawford D.A., Heinrich K.M. Multiple fitness improvements found after 6-months of high intensity functional training. *Sports*. 2019;7:203.
14. Willis EA, Szabo-Reed AN, Ptomey LT, Honas JJ, Steger FL, Washburn RA, Donnelly JE. (2019). Energy Expenditure and Intensity of Group-Based High-Intensity Functional Training: A Brief Report. *Journal of Physical Activity and Health*, *16*(6), 470–476.
15. Périard JD, Racinais S, Sawka MN. (2015). Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports: Adaptations and mechanisms of heat acclimation. *Scandinavian Journal of Medicine & Science in Sports*, *25*, 20–38.
16. Tardo-Dino P, Taverny C, Siracusa J, Bourdon S, Baugé S, Koulmann N, Malgoyre A. (2021). Effect of heat acclimation on metabolic adaptations induced by endurance training in soleus rat muscle. Physiological Reports, 9(16).
17. Fatseas G. (2011). *The effects of heat acclimation on the induction of cytoprotective proteins and skeletal muscle protection* [UNSW Sydney].
18. Wise SR, Trigg SD. (2020). Optimizing Health, Wellness, and Performance of the Tactical Athlete. *Current Sports Medicine Reports*, *19*(2), 70–75.
19. Van de Velde S, St. Pierre I, Byrd BR, Fargo JS, Loring LB, Dalleck LC. (2016). Effects of Exercise Training with a Sauna Suit on Cardiovascular Health: a Proof-of-Concept Study. *International Journal of Research in Exercise Physiology*. 11. 1-10.
20. McCleave EL, Slattery KM, Duffield R, Saunders PU, Sharma AP, Crowcroft SJ, Coutts AJ. (2017). Temperate Performance Benefits after Heat, but Not Combined Heat and Hypoxic Training. *Medicine & Science in Sports & Exercise*, *49*(3), 509–517.
21. Liguori G, Feito Y, Fountaine C, Roy B. (2021) ACSM's guidelines for exercise testing and prescription. Eleventh edition. *American College of Sports Medicine*. Wolters Kluwer, Philadelphia.
22. Tyler CJ, Reeve T, Hodges GJ, Cheung SS. (2016). The Effects of Heat Adaptation on Physiology, Perception and Exercise Performance in the Heat: A Meta-Analysis. *Sports Medicine*, *46*(11), 1699–1724.
23. Grundy SM, Hansen B, Smith SC, Cleeman JI, Kahn RA, & for Conference Participants. (2004). Clinical Management of Metabolic Syndrome: Report of the American Heart

Association/National Heart, Lung, and Blood Institute/American Diabetes Association Conference on Scientific Issues Related to Management. *Circulation*, *109*(4), 551–556.
24. Myers J, Kokkinos P, Nyelin E. (2019) Physical Activity, Cardiorespiratory Fitness, and the Metabolic Syndrome. *Nutrients* 11, 1652.
25. Brisebois MF, Biggerstaff KD, Nichols DL. (2022). Cardiorespiratory responses to acute bouts of high-intensity functional training and traditional exercise in physically active adults. *The Journal of Sports Medicine and Physical Fitness*, *62*(2).
26. Morris CE, Wessel PA, Tinius RA, Schafer MA, Maples JM. (2019). Validity of Activity Trackers in Estimating Energy Expenditure During High-Intensity Functional Training. *Research Quarterly for Exercise and Sport*, *90*(3), 377–384.
27. Browne JD, Carter R, Robinson A, Waldrup B, Zhang G, Carrillo E, Dinh M, Arnold MT, Hu J, Neufeld EV, Dolezal BA. (2020). Not All HIFT Classes Are Created Equal: Evaluating Energy Expenditure and Relative Intensity of a High-Intensity Functional Training Regimen. *International Journal of Exercise Science*, *13*(4), 1206–1216.
28. Kovats RS, Hajat S. (2008). Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*, *29*(1), 41–55.
29. Baldwin JW, Benmarhnia T, Ebi KL, Jay O, Lutsko NJ, Vanos JK. (2023). Humidity's Role in Heat-Related Health Outcomes: A Heated Debate. *Environmental Health Perspectives*, *131*(5), 55001.
30. Pryor JL, Johnson EC, Roberts WO, Pryor RR. (2019). Application of evidence-based recommendations for heat acclimation: Individual and team sport perspectives. *Temperature (Austin, Tex.)*, *6*(1), 37–49.
31. Ely BR, Lovering AT, Horowitz M, Minson CT. (2014). Heat acclimation and cross tolerance to hypoxia: Bridging the gap between cellular and systemic responses. *Temperature (Austin, Tex.)*, *1*(2), 107–114.
32. Ganio MS, Brown CM, Casa DJ, Becker SM, Yeargin SW, McDermott BP, Boots LM, Boyd PW, Armstrong LE, Maresh CM. (2009). Validity and reliability of devices that assess body temperature during indoor exercise in the heat. *Journal of Athletic Training*, *44*(2), 124–135.
33. Kenny GP, Wilson TE, Flouris AD, Fujii N. (2018). Heat exhaustion. In Handbook of Clinical Neurology (Vol. 157, pp. 505–529). Elsevier.
34. McDougle JM, Mangine GT, Townsend JR, Jajtner AR, Feito Y. (2023). Acute physiological outcomes of high-intensity functional training: A scoping review. *PeerJ*, *11*, e14493.