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Comparison of active cooling devices to passive cooling for rehabilitation of firefighters performing exercise in thermal protective clothing: A report from the Fireground Rehab Evaluation (FIRE) trial

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Abstract

Background—Thermal protective clothing (TPC) worn by firefighters provides considerable protection from the external environment during structural fire suppression. However, TPC is associated with physiological derangements that may have adverse cardiovascular consequences. These derangements should be treated during on-scene rehabilitation periods.

Objective—The present study examined heart rate and core temperature responses during the application of four active cooling devices, currently being marketed to the fire service for on-scene rehab, and compared them to passive cooling in a moderate temperature (approximately 24°C) and to an infusion of cold (4°C) saline.

Methods—Subjects exercised in TPC in a heated room. Following an initial exercise period (BOUT 1) the subjects exited the room, removed TPC, and for 20 minutes cooled passively at room temperature, received an infusion of cold normal saline, or were cooled by one of four devices (fan, forearm immersion in water, hand cooling, water perfused cooling vest). After cooling, subjects donned TPC and entered the heated room for another 50-minute exercise period (BOUT 2).

Results—Subjects were not able to fully recover core temperature during a 20-minute rehab period when provided rehydration and the opportunity to completely remove TPC. Exercise duration was shorter during BOUT 2 when compared to BOUT 1 but did not differ by cooling intervention. The overall magnitude and rate of cooling and heart rate recovery did not differ by intervention.

Conclusions—No clear advantage was identified when active cooling devices and cold intravenous saline were compared to passive cooling in a moderate temperature after treadmill exercise in TPC.

Keywords

Cardiovascular strain; Thermal Stress; Performance; Firefighter; Heat strain

Introduction

Thermal protective clothing (TPC) worn by firefighters provides considerable protection from the external environment (e.g. heat, flame) during structural fire suppression and heavy rescue activities. The evolution of TPC from a long outer coat and high boots to a shorter outer-coat combined with outer-pants has increased the level of protection but also reduces work time and speeds dehydration^{1, 2}. In addition to the thermal burden, TPC also provides a barrier to heat loss, primarily the evaporation of sweat, resulting in an imbalance of heat production and heat loss and subsequent heat strain³.

The result of work in TPC can lead to multiple physiological derangements that must be identified and treated. The resulting hypohydration, cardiovascular strain, and heat strain after work in TPC must be reduced (by allowing rest and cooling), particularly between repeated fire suppression periods, to avoid compromising operational capability and firefighter safety. Since firefighters may be required to perform multiple bouts of work at a single incident, it is imperative that these recovery periods, known as fireground rehab, be implemented to decrease the chance of short- and potentially long-term negative health effects⁴. Multiple studies have examined various active and passive devices to cool firefighters following work in TPC⁵⁻⁹. One study demonstrated that active cooling by forearm immersion reduces cardiovascular and thermal strain and increases work time in firefighters wearing TPC and self-contained breathing apparatus (SCBA) when compared to cooling by a fan coupled with a water mist or passive cooling¹⁰. However, the rehab procedures in the Selkirk (2004) study were performed in a 35°C chamber which would simulate outdoor fireground rehab on a very warm day.

Much of the industrialized world lies in the temperate regions between the tropics and the polar circles and exceedingly warm temperatures may only exist a few weeks to months each year. Given a finite number of personnel available to perform fire suppression at any given incident and that finances available for equipment purchases are not limitless in the fire service, it is important to understand if the benefits available from active vs. passive cooling in a warm environment are realized when working in cooler environments. Therefore, the present study examined heart rate and core temperature responses during the application of four active cooling devices, currently being marketed to the fire service, and compared them to passive cooling in a moderate temperature condition (approximately 24°C) and to an intravenous infusion of cold (4°C) normal saline.

Methods

The University of Pittsburgh Institutional Review Board approved this prospective laboratory trial.

Study Design and Population

Eighteen subjects (14 males, 4 females) were recruited and provided written informed consent. Thirteen subjects were firefighters while the remaining subjects were fit individuals recruited from the university population and provided with the opportunity to become familiar with protective equipment. Subjects were compensated for their time at the midpoint and conclusion of the study. Prior to entering the protocol, subjects reported to the lab for a physical exam and an exercise stress test conducted by a study physician. In addition to a physical exam, subjects had body fat percentage measured by three site skinfold analysis¹¹. Inclusion criteria were age 18–45 years while the exclusion criteria were existing heart or respiratory disease, medications known to alter cardiac response to exercise or thermoregulation, previous abdominal surgery, renal disease, Reynoud's disease or other circulatory disease.

Exercise Stress Test (EST)

Prior to the first protocol visit, subjects performed a modified Storer-Davis protocol graded exercise stress test on a Monark 828E cycle ergometer (Vansbro, Sweden) to determine aerobic capacity ($\text{VO}_{2\text{max}}$) and cardiovascular function¹². Female subjects were required to take a urine pregnancy test prior to each testing day and excluded if a positive result was confirmed. Subjects were asked to refrain from caffeine, tobacco, alcohol, and exercise 12 hours before the stress test. During testing, an open circuit spirometer (MedGraphics Cardiorespiratory Diagnostic System with Breeze Suite Software, St. Paul, MN) calculated breath by breath analysis of oxygen consumption (VO_2). The electronic analyzers were calibrated prior to each exercise test using standard reference gases. A twelve-lead ECG was obtained every three minutes during the protocol and post exercise to screen for undiagnosed ischemic disease presenting during exercise. A cardiologist interpreted test results to identify ischemic changes or other electrocardiographic evidence of underlying cardiovascular disease that would result in exclusion from the protocol.

Testing Protocol

The testing protocol was designed to mimic an extended period of fire suppression that complied with the NFPA 1584: Standard on the Rehabilitation Process for Members During Operations and Training Exercises which recommends that firefighters use a maximum of two breathing air cylinders before submitting to on-scene rehabilitation (approximately 50 minutes total including the cylinder change) prior to a second work period⁴. Other than the group assignment of cooling received during rehabilitation, all testing days were identical. The order of the cooling regimen was predetermined by random assignment.

Subjects reported to the lab between 0800 and 1100 hours on six separate occasions, each visit separated by at least one week, to perform an exercise protocol in TPC. The lab was heated to $35.1 \pm 2.7^\circ\text{C}$ air temperature. Subjects were instructed to abstain from any food intake the morning of testing and were asked to refrain from alcohol, nicotine and caffeine for at least 12 hours before testing. Urine specific gravity (USG) was measured using a hand-held refractometer (ATAGO Ltd, Bellevue, WA) when the subject reported to the lab. Subjects were required to be well hydrated ($\text{USG} \leq 1.025$). Subjects were weighed nude on a digital balance. To assure equivalent pre-exercise nutrition, subjects received a standardized diet of 1 g/kg of body weight of carbohydrates of meal replacement bars (Clif Bar, Berkeley CA) and 400–600 ml of water one hour before testing. Midway through testing, this meal replacement bar was withdrawn from sale and a substitute with comparable nutrition content was used (Powerbar Harvest, Glendale, CA).

Subjects were dressed in standard station wear (cotton-poly long pants, 100% cotton t-shirt) prior to donning the uniform and TPC. Subjects donned standardized thermal protective clothing consisting of turnout pants and coat (Body guard, Lion Apparel, Dayton OH), Nomex® hood, rubber bunker boots (Servus, Rock Island, IL), polycarbonate helmet (Paul Conway, Dayton, OH), and leather gloves. Subjects wore SCBA (Firehawk®, MSA, Pittsburgh, PA). The SCBA mask was worn during the protocol but left open to room air. After donning TPC and SCBA, subjects stood on the treadmill while baseline measures of heart rate, respiratory rate, and core temperature were taken.

Subjects performed a treadmill exercise protocol modified from a previous study of firefighter response to cooling devices that was designed to simulate the aerobic demands of fire suppression¹⁰. Subjects initially walked at 4.5 km/hr on a 2.5% incline to mimic the exertion of fire suppression. After 20 minutes the treadmill was lowered to a level position and the speed was decreased to 2.5 km/hr for three minutes to mimic exiting the fire structure followed by a four minute standing period to simulate having their SCBA cylinder changed. Following the

standing period, the subjects again walked at 2.5 km/hr on a 0% incline for three minutes followed by a 20 minute bout of walking at 4.5 km/hr on a 2.5% incline to simulate returning to the fire structure for a second period of fire suppression. Total protocol length was 50 minutes (BOUT 1). Subjects ended BOUT 1 when they completed the 50-minute protocol or when one of the following termination criteria were achieved 1) respiratory rate > 60 breaths per min, 2) heart rate exceeded age predicted maximum (220-age) + 10 bpm, 3) core temperature > 39.5° C, 4) unsteady gait making it unsafe to continue treadmill exercise, or 5) subject request. Heart rate, respiratory rate, and core temperature were recorded every two minutes during exercise.

At the end of BOUT 1, subjects exited the heated room and doffed TPC. Subjects were immediately weighed nude. They were then redressed in the uniform with a dry shirt and instructed to rest in the semi-fowler position for a 20-minute period. Subjects received rehydration volume of room temperature water equal to the mass lost during exercise.

Cooling was applied through one of the following: 1) a forearm and hand immersion device (ARM) marketed to the fire service (Kore Kooler™, Morning Pride, Dayton, OH), 2) a cooling fan (FAN) (Cool Draft Blue, Cool Draft Scientific, Bellaire, OH), 3) an ice-water perfused hand cooling device (HAND) that applies slight vacuum distal to the wrist (CoreControl™, AVAcore Technologies, Inc., Ann Arbor, MI), 4) an intravenous (IV) infusion of cold (4°C) normal saline, 5) passive cooling (PASSIVE) in a room maintained at $24.0 \pm 1.4^{\circ}\text{C}$, or 6) an ice-water perfused cooling vest (VEST) (empty mass = 0.6 kg) worn during the rehab period (Cool Shirt® Personal Cooling System, Shafer Enterprises, Inc., Stockbridge, GA).

Both the HAND and VEST devices had the reservoirs filled with ice water immediately before use. The cooling vest was pre-wetted as per the manufacturers recommendation. The FAN was placed 2.1 meters from the subject and the low speed selected. This produced a wind speed of approximately 7.2 km/hr. Water temperature in the ARM reservoir was $14.3 \pm 2.7^{\circ}\text{C}$. Cold saline was infused through an 18-gauge catheter placed in a forearm vein. A volume equal to the mass lost through sweating during BOUT 1, less 50 mL, was infused with a pressure bag. The remaining 50 mL was provided as room temperature water to slack thirst and wet the oral mucosa. Heart rate and core temperature were monitored every five minutes during cooling. The Institutional Review Board required that active cooling be stopped when the subject reached a target core temperature of 37.5°C and the remainder of the period spent cooling passively to prevent overcooling.

Following cooling, subjects were again weighed nude, donned the uniform, TPC, and SCBA and returned to the heated room. A second 50-minute period of treadmill exercise was administered (BOUT 2). At the conclusion of the second phase all subjects doffed gear, were weighed a final time, and monitored until recovered. At the conclusion of all six trials, subjects were asked to complete a brief questionnaire about their perceptions and preferences for the cooling devices.

Physiological Measures

Subjects were fitted with a heart rate monitor (Polar Electro – USA, NY) placed around the chest. Core temperature was measured with an indigestible pill and radio receiver (HQ Inc, FL). Subjects took the pill eight hours before arrival to minimize the confounding influence of recently consumed food or fluid if the pill were still positioned in the stomach or upper portion of the small bowel¹³. This device provides a core temperature measurement that is intermediate to rectal and esophageal temperature¹⁴.

Data analysis

Vital signs, core temperature, duration of exercise were compared by ANOVA (device x time). Cooling magnitude and rate were compared by oneway ANOVA. Post hoc analyses were performed with Tukey's test. Analyses were performed with SPSS v11 for Mac (Chicago, IL) with significance set at $p \leq 0.05$.

Results

Subjects had normal ECG and resting 12-lead ECG. Subject morphometrics and baseline characteristics are shown in Table 1. Male subjects were taller and heavier. However, no differences were noted in BMI or percent body fat. Overall, subjects possessed moderate cardiorespiratory capacity and mean fasting total cholesterol and triglycerides were within normal limits. One subject dropped out of the study after being diagnosed by his primary care physician with a chronic illness unrelated to the study resulting in the loss of two tests. One subject began a trial becoming ill just prior to entering rehab. One subject dropped from the trial without explanation resulting in the loss of one trial (Table 2).

Changes during exercise

The duration of exercise in BOUT 1 and BOUT 2 did not differ by device ($F = 1.23$, $p = 0.293$) (Table 2). However, the average duration of exercise in BOUT 2 following rehab was shorter than BOUT 1 ($F = 64.5$, $p < 0.001$). The loss of mass exceeded 0.5 kg per bout but did not differ by bout or device (Table 2).

Core temperature and heart rate were compared before, and after, BOUT 1 and BOUT 2. A main effect of time was seen for core temperature ($F = 0.283.2$, $p < 0.001$) (Figure 1A). Core temperature rose during BOUT 1 exceeding 38.0°C on average. Partial recovery to baseline core temperature was achieved during rehab then rose again during BOUT 2. A post hoc analysis revealed that end of BOUT 1 and end of BOUT 2 temperatures were not different. All other time point comparisons during exercise differed ($p < 0.001$). No differences in core temperature were seen between devices ($F = 2.08$, $p = 0.067$) nor was there a device*time interaction ($F = 0.378$, $p = 0.984$).

Similar results were seen for heart rate response during exercise. There was a main effect of time ($F = 396.3$, $p < 0.001$) with all post hoc time point comparisons during exercise differing ($p < 0.001$) except end of BOUT1 and end of BOUT 2 ($p = 0.083$). No differences were seen between devices ($F = 0.942$, $p = 0.453$) nor was there a device*time interaction ($F = 0.351$, $p = 0.989$).

Changes during rehab

The magnitude (°C) and rate (°C/min) of cooling during the 20-minute rehab period did not differ by device (Table 3). The proportion of subjects achieving the goal rehab temperature of 37.5°C varied between groups ranging from 31% (Passive) to 67% (IV) (Table 3). Serial core temperatures during rehab are shown in Figure 2. Although the overall magnitude of cooling did not differ, when considering the serial measurements across 20 minutes, there was an effect of both device ($F = 7.57$, $p < 0.001$) and time ($F = 59.2$, $p < 0.001$). Post hoc comparisons indicated that more rapid cooling occurred in the IV group when compared to FAN ($p = 0.004$), VEST ($p = 0.001$), and PASSIVE ($p < 0.001$). The post hoc analysis for time indicated that all time points compared during rehab differed ($p < 0.002$) except minute 15 and minute 20 ($p = 0.097$). No device*time interaction was noted ($F = 0.373$, $p = 0.995$).

Subjects not recovering below 37.5°C during the 20-minute rehab entered rehab with higher core temperature than those achieving goal temperature ($F = 253.2$, $p < 0.001$) (Figure 3).

However, the temperature when entering rehab did not differ by device ($F = 1.23$, $p = 0.295$). A post hoc subgroup analysis of subjects achieving target temperature and those who did not also failed to reveal any difference in devices.

Similar results were seen for heart rate during rehab (Figure 4). There is a main effect of both device ($F = 4.90$, $p < 0.001$) and time ($F = 54.5$, $p < 0.001$). Post hoc analysis revealed that heart rate recovered more slowly in PASSIVE when compared to ARM ($p = 0.006$), HAND ($p = 0.012$), and IV ($p = 0.013$). All time points during rehab differed from rehab time 0 ($p < 0.001$). Overall, heart rate recovered rapidly in the first five minutes and no differences noted between rehab minutes 10, 15, and 20. No device*time interaction was noted ($F = 0.653$, $p = 0.871$).

When asked which cooling modality felt best, the 17 subjects completing all six trials were largely split between FAN and VEST (Table 4). When asked which device they believe most lowered their core temperature, the responses were split across VEST, IV, and FAN. However, when given the choice, 64.7% indicated they would choose FAN as their preferred method of cooling on the fireground.

Discussion

This study compared four active cooling devices to cold intravenous saline and passive cooling in a 24°C room. This study is unique in that it examines a large number of cooling modalities currently marketed to the fire service in a controlled laboratory setting. On average, subjects were not able to recover to a core temperature below 37.5°C during a 20-minute rehab period when provided rehydration and the opportunity to completely remove TPC for passive cooling. Additionally, active cooling devices did not enhance firefighter recovery following work in TPC when compared to passive cooling when resting in a 24°C room.

It is well established that work in chemical protective and TPC results in hypohydration and cardiovascular stress^{15, 16}. If uncorrected, continued heat stress may lead to exertional heat illness including heat exhaustion and heat stroke. Additionally, heat stress sequelae may contribute to the increased cardiovascular events seen in firefighters performing fire suppression duties¹⁷. The National Fire Protection Association (NFPA) has recognized the importance of fireground rehab by elevating NFPA 1584 from a guideline to a standard in the most recent revision⁴. However, other than one scientific study of firefighter cooling in the warm environment there is a paucity of research in this area using operationally relevant work times and conditions making it difficult to create evidence-based practices that can be applied to a wide range of operations and environmental conditions¹⁰.

In a previous study of rehab in a warm environment (35°C), active cooling blunted the rise in core temperature and extended work time when compared to passive cooling but could not correct the physiologic derangements (e.g. tachycardia, heat strain) within a 20-minute rehab period¹⁰. There are few studies comparing active cooling devices to passive cooling in a controlled moderate temperature environment such as could be created with an air-conditioned vehicle or portable shelter which are commonly employed on the scene. When compared to rehab in moderate temperatures, the data in the present investigation indicate that no device is superior to passive cooling in terms of subsequent exercise duration or physiological response following rehab, or in overall magnitude or rate of cooling during rehab. Small advantages in the speed of recovery were identified in some of the devices employed during rehab. However, the clinical and operational significance of faster recovery is uncertain.

The optimal rate of cooling during fireground rehab is not known, although from an operational standpoint it can be argued that the most rapid return of core temperature to baseline levels is desirable for situations requiring crews to rotate back into an incident. We have previously

investigated the effect of a rapid infusion of cold saline in normothermic volunteers and reported that administration of 30 ml/kg of cold fluid into a peripheral arm vein produces approximately 1°C of core cooling¹⁸. Increasing availability of cold saline in the prehospital setting for induction of therapeutic hypothermia following cardiac arrest makes this potential therapy available for other applications. In this report, we found that cold intravenous saline resulted in the earliest return of core temperature although the magnitude of cooling was not different from other less invasive methods. Unlike previous studies in normothermic subjects, hyperthermic subjects reported intense discomfort in the upper extremity and shoulder during the infusion making this an unattractive rehab tool for the mildly hyperthermic firefighter.

Alternative rehab modalities that are more commonly used in the fire service and are potentially easier to implement are forearm and hand immersion cooling. Both modalities take advantage of the extensive arteriovenous (AVA) anastomoses of the distal upper extremity. In a previous study of rehab in a warm environment with a similar exercise protocol as the present report, forearm and hand immersion was superior for extending work time and blunting the hyperthermic response when compared to both passive cooling and a fan coupled with a fine water mist¹⁰. Another study of hand and forearm cooling used three 20-minute work periods with intervening 20-minute rehab periods at room temperature to investigate the capacity of 10°C and 20°C water to correct the hyperthermic response of exertion in TPC demonstrated that hand immersion in 10°C water, and forearm + hand immersion in both 10°C and 20°C water conferred lower core temperature during the bout of exercise following cooling⁷. However, these cooling trials were not different than the passive condition or hand immersion in 20°C at the end of any cooling period. At least part of the observed benefit in that study can be attributed to an afterdrop cooling effect in the opening minutes of the second and third exercise period following immersion. However, another study of hand immersion cooling following simulated firefighting activities also failed to reveal an advantage of hand cooling over removing TPC, drinking cold water, and sitting at room temperature⁶.

The present study did not identify a clear benefit in core temperature reduction for either hand cooling or forearm immersion when compared to passive cooling in a 24°C room, although a more rapid heart rate recovery was noted in the ARM and HAND groups when compared to passive cooling. The starting water temperature used in the present report was comparable to both studies but may be considerably cooler than what is available on the fireground. Our study differs from Selkirk et al principally by changing the rehab climate from warm and humid to more temperate conditions thereby improving the radiative and evaporative processes of passive cooling and by completely removing TPC¹⁰. Our study also differs from previous reports by employing the actual device currently marketed to the fire service. In one study of forearm immersion cooling, the authors report that the subjects immersed the upper extremities into a large water tank to provide a constant heat sink⁷ while in another, the subjects immersed their forearms into a calorimeter with an approximate volume of 36 liters¹⁰. The device currently marketed to the fire service uses smaller water reservoirs placed in the arms of a folding chair and may have less capacity to absorb heat.

The hand cooling device used in the present study also takes advantage of the AVA in the hand by having the subject grip a metal cone which is perfused with cold water while a mild vacuum is placed on the hand and is purported to encourage maximal blood volume in the blood vessels. However, given that the vessels should be dilated when core temperature is high the value of placing a vacuum on the hand is uncertain. A recent study compared the same device to passive cooling after 40 minutes of treadmill and upper body exercise⁹. A significant, although small, additional change in rectal temperature was noted in the hand cooling arm of their study but this was not evident until cooling had been applied for 35 minutes. It is unlikely that most fireground rehab sectors will hold asymptomatic individuals for this length of time if manpower must be rotated back into the incident.

The fan is ubiquitous within the fire service. Large ventilations fans are found on nearly every fire service vehicle tasked with structural fire suppression. A recent study of post-exercise cooling in hot humid conditions in athletes reported whole body fanning to be most effective at extracting heat when compared to other devices including hand immersion and a liquid cooled garment.¹⁹ In that study, a larger fan was used and the subjects were cooled in the hot (31.2°C), humid (70% RH) room clothed only in short pants making it difficult to translate to fireground rehab practices. Another study found that a fan coupled with removing the TPC coat blunted the rise of core temperature when compared to simply unbuckling the coat during the rest phase⁵. However, it is not clear what portion of the observed result was attributable to the fan vs. the removal of the TPC coat. In the study of rehab in the warm environment, a misting fan partially restored core temperature during rest periods but was not as effective as forearm immersion¹⁰.

While fans are readily available on the fire scene, the misting fan marketed for fireground rehab exists only as a rehab tool and cannot be employed for fire suppression. We chose to examine a large cooling fan without using the misting attachment based on the widespread availability. While a standard fire service fan cannot employ the fine water mist, the use of misting feature should take environmental conditions into consideration. In Selkirk et al (2004), the misting fan likely improved convective heat loss but may have inhibited evaporative heat loss by raising the local relative humidity by 20%. The lack of clear benefit when compared to passive cooling does not recommend its routine use on the fireground when conditions are temperate. However, there was a clear preference for the fan by the subjects potentially indicating a perceptual benefit.

Cooling vests have been examined in firefighters during work in TPC^{6, 8, 20}. However, we are unaware of studies using a powered cooling vest for fireground rehab. Use of cooling vests during fire suppression activities requires the firefighter to carry the additional weight of the vest that may include phase change material, cold packs, or a battery to operate a pump. Powered devices, such as the liquid perfused vest examined in the present study, are only practical in the rehab setting. However, there was no clear benefit over passive cooling in 24°C air.

Limitations

There are several potential limitations that should be considered when interpreting these data or when implementing operational guidelines. Since this was a laboratory study we were able to measure core temperature which may not be possible in the field²¹. Subjects completely removed the TPC ensemble during the rehab period to facilitate weighing. This is not typically done on the fireground and will have enhanced the cooling enjoyed in the passive condition. However, firefighters can remove the TPC coat and push the TPC pants down over the boots while seated thereby exposing both the upper and lower extremities. Given the reported benefits of wearing short pants under TPC, the combination of short pants and partial removal of the TPC pants may further enhance passive cooling^{22, 23}.

We were not able to fully investigate the cooling effect of cold saline due to the requirement of only replacing the volume of fluid lost to sweating. Although an average of 700 mL of cold saline was provided, a few subjects had minimal sweat losses in all conditions of the study resulting in only a few hundred milliliters of cold saline being infused during the IV condition. We have previously shown that hyperhydration induced with 30 mL/kg of intravenous normal saline prior to work in chemical protective clothing is well tolerated²⁴ so larger volumes could have been provided during the rehab period. Although the discomfort would still be present, a larger infusion of cold saline would likely have resulted in greater cooling potentially returning the individual to the baseline core temperature within the allotted 20 minutes. Similarly, we

cannot comment on the effect of a large volume of room temperature saline although this may be an attractive therapy given the ability to replace even large volumes of fluid loss in a short period of time and it may provide a tangible amount of cooling¹⁸. However, given the discomfort that accompanied cold saline infusion in hyperthermic individuals we would not recommend this as a routine practice but rather one that should be investigated as a therapy for exertional heat illness.

There are other permutations of fireground rehab that we were not able to address in this single study. The 20-minute rehab period is typical in western Pennsylvania but may not be universal. A longer rehab period may allow for additional cooling and ultimately could demonstrate one device to be superior. Clearly, 20 minutes was not sufficient to provide full recovery of core temperature in our subjects. Additionally, there may be other devices with superior cooling properties that we were not able to study. We chose devices that are being directly marketed to the fire service and to some degree are being used in the field. Finally, the study by Selkirk et al (2004) has clearly shown that passive cooling is not acceptable when rehab is performed in a warm environment¹⁰. It is possible that the HAND, VEST, or IV groups would have performed as well as forearm immersion in the Selkirk study when employed in a hot environment. In spite of these limitations, this is the first study to examine a wide array of cooling modalities and compare them to passive cooling in a temperate environment.

Conclusion

The present study is the first to demonstrate no clear advantage between active cooling devices, cold intravenous saline, and passive cooling in a moderate temperature after treadmill exercise in TPC. On average, subjects were not able to fully recover core temperature during a 20-minute rehab period when provided fluids and the opportunity to completely remove TPC. There may not be an advantage to employing active cooling devices to firefighters when the external temperature is below 24°C or if such a temperature can be provided through the use of air-conditioned shelters or vehicles. Further studies are required to verify these findings in the field.

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Figure 1.

Core temperature response during exercise before (panel A) and after (panel B) rehab. Also shown is heart rate response during exercise before (panel C) and after (panel D) rehab. For both temperature and heart rate, all time comparisons different ($p < 0.001$) except post BOUT 1 and post BOUT 2. No device differences were identified.

Figure 2.

Core temperature response during rehab. IV cooling faster than FAN ($p = 0.0004$), PASSIVE ($p < 0.001$), and VEST ($p = 0.001$). All time points different except minute 15 and minute 20.

Figure 3.

Core temperature at rehab minute 0 for subjects ultimately reaching the core temperature of 37.5°C (open bars) and those not reaching target temperature (closed bars). Groups are different ($p < 0.001$). No device differences were identified.

Figure 4.

Heart rate response during rehab. PASSIVE cooling slower than ARM ($p = 0.006$), HAND ($p = 0.012$), and IV ($p = 0.013$). Heart rate lower at all time points when compared to minute 0 ($p < 0.001$). Minutes 10, 15, and 20 are not different.

Table 1

Subject demographics and morphometrics.

	Height (cm)	Weight (kg)	BMI (kg/m ²)	Body Fat (%)	Age	VO _{2peak}	Cholesterol (mg/dl)	Triglycerides (mg/dl)
Females (n=4)	157.7 ± 2.9	58.5 ± 6.7	22.2 ± 1.3	16.5 ± 7.5	25.5 ± 5.2	35.6 ± 2.4	179 ± 61	103 ± 61
Males (n=14)	176.2 ± 5.5*	80.2 ± 12.2*	26.0 ± 4.1	14.7 ± 7.0	31.1 ± 7.6	38.8 ± 7.7	181 ± 29	114 ± 102

Data presented as mean ± SD.

* different from females, $p < 0.05$.

Table 2

Work duration and change in body mass for Bout 1 and Bout 2 shown as mean $\pm$ SD (minutes). Bout 2 duration is shorter than Bout 1 ($p < 0.001$). No device differences were detected.

Device (n)	Bout 1 Duration (min)	Bout 1 Change in mass (kg)	Bout 2 Duration (min)	Bout 2 Change in mass (kg)
Arm (17)	38.4 $\pm$ 11.6	0.61 $\pm$ 0.29	28.1 $\pm$ 12.5	0.54 $\pm$ 0.29
Fan (18)	39.2 $\pm$ 6.5	0.69 $\pm$ 0.34	28.6 $\pm$ 9.3	0.60 $\pm$ 0.34
Hand (17)	40.1 $\pm$ 6.4	0.68 $\pm$ 0.30	28.6 $\pm$ 12.3	0.61 $\pm$ 0.41
IV (16)	42.7 $\pm$ 5.4	0.69 $\pm$ 0.32	33.3 $\pm$ 11.1	0.72 $\pm$ 0.38
Passive (18)	39.7 $\pm$ 7.1	0.63 $\pm$ 0.35	26.7 $\pm$ 10.8	0.75 $\pm$ 0.56
Vest (18)	39.4 $\pm$ 7.4	0.69 $\pm$ 0.41	31.2 $\pm$ 10.6	0.63 $\pm$ 0.48

Table 3

Cooling characteristics during a 20-minute rehab period. Shown is the proportion of subjects achieving target temperature of 37.5°C, the magnitude (°C), and rate (°C/min) of cooling. No device differences were detected.

	Subjects Achieving Goal Temp (%)	Temperature reduction (°C)	Cooling Rate (°C/min)
Arm	44	0.83 ± 0.30	0.054 ± 0.034
Fan	53	0.79 ± 0.34	0.041 ± 0.022
Hand	50	0.74 ± 0.33	0.040 ± 0.021
IV	67	0.86 ± 0.45	0.065 ± 0.055
Passive	31	0.76 ± 0.37	0.047 ± 0.031
Vest	53	0.76 ± 0.46	0.041 ± 0.022

Table 4

Subject impressions and preferences for cooling devices

Question	Passive	Vest	IV	Forearm	Hand	Fan
Which of the following cooling methods <i>felt</i> best?	3	6	0	0	0	8
Which of the following cooling methods reduced your temperature the most?	0	4	5	2	0	6
Which of the following methods would be your first choice on the fireground?	1	5	0	0	0	11