Comparison of Active Cooling Devices with Passive Cooling for Rehabilitation of Firefighters Performing Exercise in Thermal Protective Clothing: A Report from the Fireground Rehab Evaluation (FIRE) Trial

David Hostler, PhD, Steven E. Reis, MD, James C. Bednez, MS, Sarah Kerin, Joe Suyama, MD

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 physiologic derangements that may have adverse cardiovascular consequences. These derangements should be treated during on-scene rehabilitation periods. **Objective.** To examine heart rate and core temperature responses during the application of four active cooling devices, currently being marketed to the fire service for on-scene rehabilitation, and compare them with passive cooling in a moderate temperature (approximately 24°C) and with an infusion of cold (4°C) saline. **Methods.** Subjects exercised while they were wearing TPC in a heated room. Following an initial exercise period (bout 1), the subjects exited the room, removed the 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, or water-perfused cooling vest). After cooling, the subjects donned the TPC and entered the heated room for another 50-minute exercise period (bout 2). **Results.** The subjects were not able to fully recover core temperature during a 20-minute rehabilitation period when provided rehydration and the opportunity to completely remove the TPC. Exercise durations were shorter during bout 2 when compared with bout 1 but did not differ by cooling intervention. The overall magnitudes and rates 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 with passive cooling in a moderate temperature after treadmill exercise in TPC. **Key words:** cardiovascular strain; thermal stress; performance; firefighter; heat strain; cooling

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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 not only 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 strain.[3]

Doing work while wearing TPC can lead to multiple physiologic 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 effects.[4] Multiple studies have examined various active and passive devices to cool firefighters following work in TPC.[5–9] 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 with cooling by a fan coupled with a water mist or passive cooling.[10] However, the rehabilitation procedures in the study by Selkirk et al.

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Address correspondence and reprint requests to: Dave Hostler, PhD, CSCS, Emergency Responder Human Performance Laboratory, University of Pittsburgh, Department of Emergency Medicine, 3600 Forbes Avenue, Suite 400A, Pittsburgh, PA 15213. e-mail: hostlerdp@upmc.edu

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were performed in a 35°C chamber,[10] 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 exist only a few weeks to months each year. Given that a finite number of personnel are 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 whether 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 with passive cooling in a moderate temperature condition (approximately 24°C) and with an intravenous (IV) 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 men, four women) were recruited and provided written informed consent. Thirteen subjects were firefighters, while the remaining subjects were fit individuals who were recruited from the university population and provided with the opportunity to become familiar with protective equipment. The subjects were compensated for their time at the midpoint and conclusion of the study. Prior to entering the protocol, the subjects reported to the laboratory for a physical examination and an exercise stress test (EST) conducted by a study physician. In addition to a physical examination, the subjects had body fat percentage measured by three-site skinfold analysis.[11] The inclusion criterion was age 18 to 45 years, and the exclusion criteria were existing heart or respiratory disease, medications known to alter cardiac response to exercise or thermoregulation, previous abdominal surgery, renal disease, Reynaud's disease, or other circulatory disease.

Exercise Stress Test

Prior to the first protocol visit, the subjects performed a modified Storer-Davis protocol graded EST on a Monark 828E cycle ergometer (Monark Exercise AB, Vansbro, Sweden) to determine aerobic capacity (VO_{2peak}) and cardiovascular function.[12] The female subjects were required to take a urine pregnancy test prior to each testing day and were excluded if a positive result was confirmed. The 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 BreezeSuite 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 12-lead electrocardiogram (ECG) was obtained every 3 minutes during the protocol and after exercise to screen for undiagnosed ischemic disease presenting during exercise. A cardiologist interpreted the 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 National Fire Protection Association (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 period.[4] 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.

The subjects reported to the laboratory 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 laboratory was heated to 35.1°C ± 2.7°C air temperature (mean ± standard deviation). The 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 U.S.A., Inc., Bellevue, WA) when the subject reported to the laboratory. The subjects were required to be well hydrated (USG $\leq$ 1.025). They were weighed nude on a digital balance. To ensure equivalent pre-exercise nutrition, they 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).

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

The 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 suppression.[10] The subjects initially walked at 4.5 km/h 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/h for 3 minutes to mimic exiting the fire structure followed by a 4-minute standing period to simulate having their SCBA cylinder changed. Following the standing period, the subjects again walked at 2.5 km/h on a 0% incline for 3 minutes, followed by a 20-minute bout of walking at 4.5 km/h 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). The subjects ended bout 1 when they completed the 50-minute protocol or when one of the following termination criteria was achieved: 1) respiratory rate >60 breaths/min; 2) heart rate exceeding the age-predicted maximum, i.e., (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 2 minutes during exercise.

At the end of bout 1, the subjects exited the heated room and doffed the TPC. The 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. They received a 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*) marketed to the fire service (Cool Draft Blue, Cool Draft Scientific, Bellaire, OH), 3) an ice-water–perfused hand-cooling device (*hand*) that applies a slight vacuum distal to the wrist was marketed to the fire service (CoreControl, AVAcore Technologies, Inc., Ann Arbor, MI), 4) an IV infusion (*IV*) of cold (4°C) normal saline, 5) passive cooling (*passive*) in a room maintained at 24.0°C ± 1.4°C, or 6) an ice-water–perfused cooling vest (*vest*) (empty mass = 0.6 kg) worn during the rehabilitation period that was marketed to the fire service (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 prewetted as per the manufacturer's recommendation. The *fan* was placed 2.1 meters from the subject and the low speed was selected. This produced a wind speed of approximately 7.2 km/h. The water temperature in the *arm* reservoir was 14.3°C ± 2.7°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 slake thirst and wet the oral mucosa. Heart rate and core temperature were monitored every 5 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 be spent cooling passively to prevent overcooling.

Following cooling, the 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 were monitored until recovered. At the conclusion of all six trials, the subjects were asked to complete a brief questionnaire about their perceptions of and preferences for the cooling devices.

Physiologic Measures

The subjects were fitted with a heart rate monitor (Polar Electro–USA, Lake Success, NY) placed around the chest. Core temperature was measured with an indigestible pill and radio receiver (HQ Inc, Palmetto, FL). The subjects took the pill eight hours before arrival to minimize the confounding influence of recently consumed food or fluid that would occur if the pill were still positioned in the stomach or upper portion of the small bowel.[13] This device provides a core temperature measurement that is intermediate to rectal and esophageal temperature.[14]

Data Analysis

Vital signs, core temperatures, and durations of exercise were compared by analysis of variance (ANOVA) (device × time). Cooling magnitudes and rates were compared by one-way ANOVA. Post hoc analyses were performed with Tukey's test. Analyses were performed with SPSS version 11 for Mac (SPSS Inc., Chicago, IL) with significance set at $p \leq 0.05$.

TABLE 1. Subject Demographics and Morphometrics

	Height (cm)	Weight (kg)	BMI (kg/m^2)	Body Fat (%)	Age (yr)	VO_{2peak} (mL/kg/min)	Cholesterol (mg/dL)	Triglycerides (mg/dL)
Women (*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
Men (*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 are presented as mean ± standard deviation.
*Different from women, p < 0.05.
BMI = body mass index; VO_{2peak} = aerobic capacity (peak oxygen consumption).

RESULTS

The subjects had normal EST and resting 12-lead ECG results. Subject morphometrics and baseline characteristics are shown in Table 1. The male subjects were taller and heavier. However, no differences were noted in body mass index (BMI) or percentage of body fat. Overall, the subjects possessed moderate cardiorespiratory capacity, and mean fasting total cholesterol and triglyceride levels 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 but became ill just prior to entering rehabilitation. One subject dropped out of the trial without explanation, resulting in the loss of one trial.

Changes during Exercise

The durations 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 rehabilitation was shorter than that in 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 temperatures and heart rates were compared before and after bout 1 and bout 2. A main effect of time was seen for core temperature ($F = 283.2$, $p < 0.001$) (Fig. 1A). Core temperature rose during bout 1, exceeding 38.0°C on average. Partial recovery to baseline core temperature was achieved during rehabilitation, and the core temperature then rose again during bout 2. A post hoc analysis revealed that the 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 the end of bout 1 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 Rehabilitation

The magnitudes (°C) and rates (°C/min) of cooling during the 20-minute rehabilitation period did not differ by device (Table 3). The proportion of subjects achieving the goal rehabilitation temperature of 37.5°C varied between groups, ranging from 31% (*passive*) to 67% (*IV*) (Table 3). Serial core temperatures during rehabilitation are shown in Fig. 2. Although the overall magnitudes 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 with *IV* when compared with *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 rehabilitation 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 rehabilitation entered rehabilitation with higher core temperature than those achieving goal temperature ($F = 253.2$, $p < 0.001$) (Fig. 3). However, the temperatures when entering rehabilitation did not

TABLE 2. Work Duration and Change in Body Mass for Bout 1 and Bout 2

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 ± 11.6	0.61 ± 0.29	28.1 ± 12.5	0.54 ± 0.29
Fan (18)	39.2 ± 6.5	0.69 ± 0.34	28.6 ± 9.3	0.60 ± 0.34
Hand (17)	40.1 ± 6.4	0.68 ± 0.30	28.6 ± 12.3	0.61 ± 0.41
IV (16)	42.7 ± 5.4	0.69 ± 0.32	33.3 ± 11.1	0.72 ± 0.38
Passive (18)	39.7 ± 7.1	0.63 ± 0.35	26.7 ± 10.8	0.75 ± 0.56
Vest (18)	39.4 ± 7.4	0.69 ± 0.41	31.2 ± 10.6	0.63 ± 0.48

Data are presented as mean ± standard deviation. The bout 2 duration is shorter than that for bout 1 (p < 0.001). No device differences were detected.
IV = intravenous (saline).

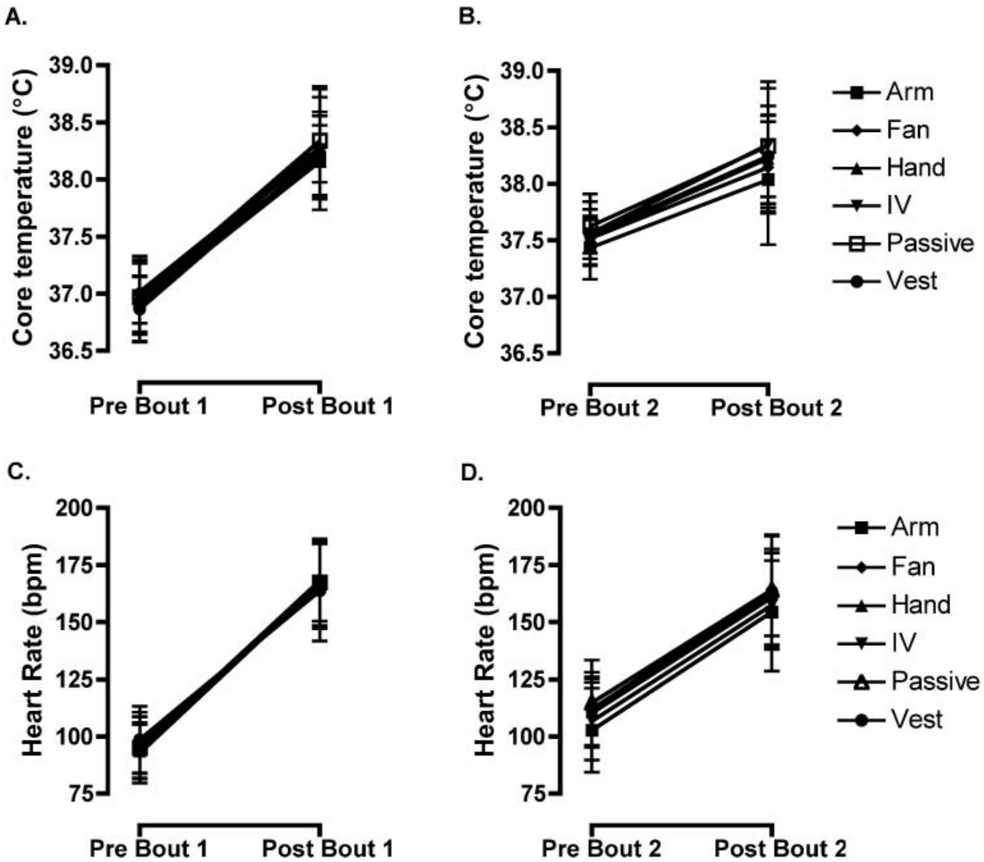

FIGURE 1. Core temperature response during exercise before (**A**) and after (**B**) rehabilitation. Also shown is heart rate response during exercise before (**C**) and after (**D**) rehabilitation. For both temperature and heart rate, all time comparisons showed a difference ($p < 0.001$) except post–bout 1 and post–bout 2. No device differences were identified. IV = intravenous (saline).

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 rehabilitation (Fig. 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 for *passive* when compared with *arm* ($p = 0.006$), *hand* ($p = 0.012$), and *IV* ($p = 0.013$). All time points during rehabilitation differed from rehabilitation time 0 ($p < 0.001$). Overall, heart rate recovered rapidly in the first 5 minutes, and no differences were noted between rehabilitation 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.

TABLE 3. Cooling Characteristics during a 20-Minute Rehabilitation Period

	Subjects Achieving Goal Temperature (%)	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

The data shown are the proportion of subjects achieving the target temperature of 37.5°C, the magnitude (°C) of cooling, and the rate (°C/min) of cooling. The magnitude and rate of cooling are expressed as mean ± standard deviation. No device differences were detected.
IV = intravenous (saline).

TABLE 4. Subject Impressions of and Preferences for Cooling Devices

Question	*Passive*	*Vest*	*IV*	*Forearm*	*Hand*	*Fan*
Which of the following cooling methods *felt* 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

IV = intravenous (saline).

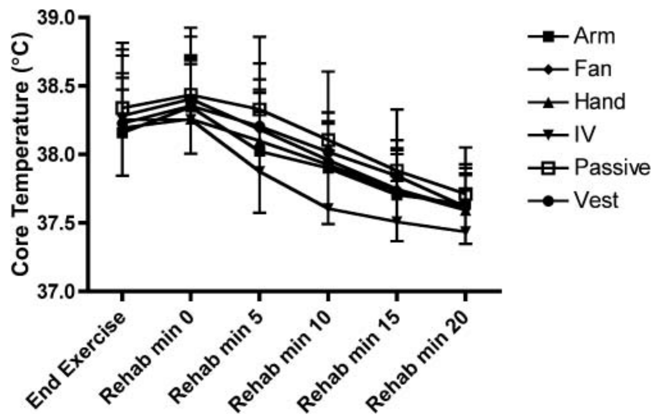

FIGURE 2. Core temperature response during rehabilitation. Intravenous (*IV*) cooling was faster than *fan* ($p = 0.0004$), *passive* ($p < 0.001$), and *vest* ($p = 0.001$). All time points showed a difference, except minute 15 and minute 20.

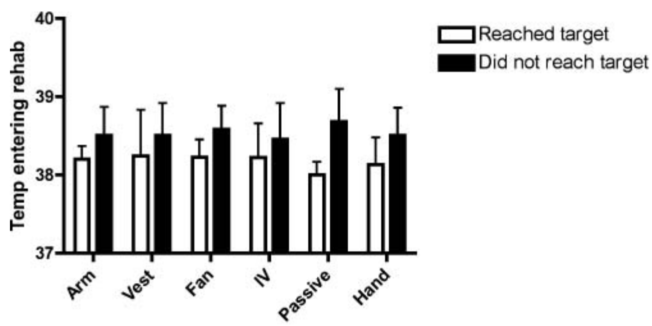

FIGURE 3. Core temperature at rehabilitation minute 0 for subjects ultimately reaching the core temperature of 37.5°C (*open bars*) and those not reaching target temperature (*closed bars*). The groups were different ($p < 0.001$). No device differences were identified.

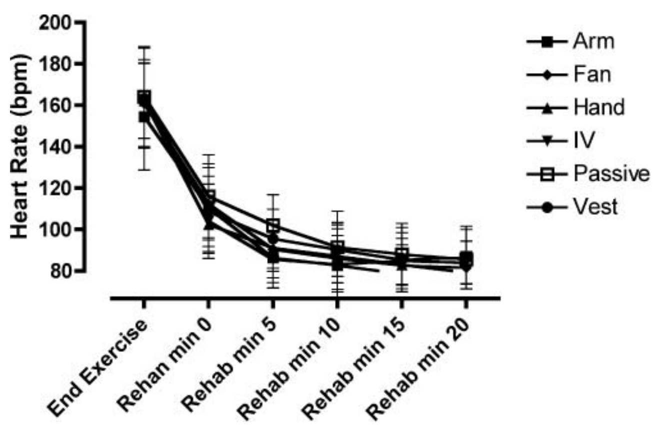

FIGURE 4. Heart rate response during rehabilitation. *Passive* cooling was slower than *arm* ($p = 0.006$), *hand* ($p = 0.012$), and intravenous (*IV*) cooling ($p = 0.013$). Heart rate was lower at all time points when compared with that at minute 0 ($p < 0.001$). Minutes 10, 15, and 20 did not show a difference.

DISCUSSION

This study compared four active cooling devices with cold IV saline and passive cooling in a 24°C room. This study is unique in that it examined 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 rehabilitation period when provided rehydration and the opportunity to completely remove TPC for passive cooling. Additionally, the active cooling devices did not enhance firefighter recovery following work in TPC when compared with the passive cooling when resting in a 24°C room.

It is well established that work in chemical protective clothing 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 duties.[17] The NFPA has recognized the importance of fireground rehab by elevating NFPA 1584 from a guideline to a standard in the most recent revision.[4] 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 conditions.[10]

In a previous study of rehabilitation in a warm environment (35°C), active cooling blunted the rise in core temperature and extended work time when compared with passive cooling, but could not correct the physiologic derangements (e.g., tachycardia, heat strain) within a 20-minute rehabilitation period.[10] There are few studies comparing active cooling devices with 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 with rehabilitation 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 physiologic response following rehabilitation, or in overall magnitude or rate of cooling during rehabilitation. Small advantages in the speed of recovery were identified in some of the devices employed during rehabilitation. 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 cooling.[18] 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 IV saline resulted in the earliest return of core temperature, although the magnitude of cooling was not different from those of other less invasive methods. Unlike the normothermic subjects participating in previous studies, the hyperthermic subjects in this study reported intense discomfort in the upper extremity and shoulder during the infusion, making this an unattractive rehabilitation tool for the mildly hyperthermic firefighter.

Alternative rehabilitation 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 anastomoses (AVA) of the distal upper extremity. In a previous study of rehabilitation in a warm environment with a similar exercise protocol to that of the present report, forearm and hand immersion was superior for extending work time and blunting the hyperthermic response when compared with both passive cooling and a fan coupled with a fine water mist.[10] Another study of hand and forearm cooling used three 20-minute work periods with intervening 20-minute rehabilitation periods at room temperature to investigate the capacity of 10°C and 20°C water to correct the hyperthermic response of exertion in TPC; the results demonstrated that hand immersion in 10°C water, as well as forearm and hand immersion in both 10°C and 20°C water, conferred lower core temperature during the bout of exercise following cooling.[7] However, these cooling trials were not different from the passive condition or hand immersion in 20°C water 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 periods 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 temperature.[6]

The present study did not identify a clear benefit in core temperature reduction for either hand cooling or forearm immersion when compared with passive cooling in a 24°C room, although a more rapid heart rate recovery was noted in the *arm* and *hand* groups when compared with passive cooling. The starting water temperature used in the present report was comparable to that of both studies but may be considerably cooler than what is available on the fireground. Our study differs from that of Selkirk et al. principally by changing the rehabilitation climate from warm and humid to more temperate conditions, thereby improving the radiative and evaporative processes of passive cooling and by completely removing TPC.[10] 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 in a large water tank to provide a constant heat sink,[7] whereas in another study, the subjects immersed their forearms in a calorimeter with an approximate volume of 36 liters.[10] 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 that 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 by Zhang et al. compared the same device with passive cooling after 40 minutes of treadmill and upper body exercise.[9] 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 postexercise cooling in hot, humid conditions in athletes reported whole-body fanning to be most effective at extracting heat when compared with 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 a hot (31.2°C), humid (70% relative humidity [RH]) room, clothed only in short pants, making it difficult to translate to fireground rehab practices. Another study found that using a fan coupled with removing the TPC coat blunted the rise of core temperature when compared with simply unbuckling the coat during the rest phase.[5] 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 rehabilitation in the warm environment, a misting fan partially restored core temperature during rest periods but was not as effective as forearm immersion.[10]

While fans are readily available on the fire scene, the misting fan marketed for fireground rehab exists only as a rehabilitation tool and cannot be employed for fire suppression. We chose to examine a large cooling fan without using the misting attachment based on their widespread availability. While a standard fire service fan cannot employ the fine water mist, the use of the misting feature should take environmental conditions into consideration. In the 2004 study by Selkirk et al., the misting fan likely improved convective heat loss but may have inhibited evaporative heat loss by raising the local RH by 20%.[10] The lack of clear benefit when compared with passive cooling does not recommend its routine use on the fireground when conditions are temperate. However, the subjects had a clear preference for the fan, 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 practical only in the rehabilitation setting. However, there was no clear benefit over passive cooling in 24°C air.

LIMITATIONS

Several potential limitations 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 field.[21] Subjects completely removed the TPC ensemble during the rehabilitation 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 because of 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 infusion of only a few hundred milliliters of cold saline during the IV condition. We have previously shown that hyperhydration induced with 30 mL/kg of IV normal saline prior to work in chemical protective clothing is well tolerated,[24] so larger volumes could have been provided during the rehabilitation 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 cooling.[18] 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 rehabilitation period is typical in Western Pennsylvania but may not be universal. A longer rehabilitation 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 2004 study by Selkirk et al. has clearly shown that passive cooling is not acceptable when rehabilitation is performed in a warm environment.[10] 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 with passive cooling in a temperate environment.

CONCLUSION

The present study is the first to demonstrate no clear advantage between active cooling devices, cold IV saline, and passive cooling in a moderate temperature after treadmill exercise while subjects were wearing TPC. On average, the subjects were not able to fully recover core temperature during a 20-minute rehabilitation period when provided with fluids and the opportunity to completely remove the TPC. There may not be an advantage to employing active cooling devices for 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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