International Journal of Innovative Research in Medical Science (IJIRMS)
Volume 02 Issue 01 January 2017, ISSN No. – 2455-8737
Available online at - www.ijirms.in

Open Access Journal www.ijirms.in ISSN - 2455-8737

Novel Cooling Device Enhances Autonomic Nervous System Recovery from Live Fire Training: A Pilot Study

Rohan C. Edmonds[1], Andrea F. Wilkinson[2], Patricia C. Fehling*[3]

[1]Visiting Assistant Professor, Health and Exercise Sciences,

[2]Research Assistant, First Responder Health and Safety Laboratory,

[3] Professor, Health and Exercise Sciences, Skidmore College, 815 North Broadway, Saratoga Spring, NY 12866

Abstract:

Background: *The occupation of firefighting is strenuous and dangerous. Firefighters perform demanding work while wearing heavy, insulative PPE. Thus, heat stress is a constant concern. The fire service has protocols to allow for rest, rehydration, and cooling. However, finding cooling techniques that are effective and convenient remains a challenge for many departments. The aim of this study was to determine the effectiveness of a novel cooling device during firefighting training drills.*

Methods: *Firefighters reported to REHAB during a day-long training class, and were randomly assigned to wear the dhamaSPORT cooling band in cooling mode or off mode. During the required REHAB, heart rate and perceived measures of comfort were assessed on 41 volunteer firefighters. Additionally, a sub-group of 12 firefighters wore a continuous heart rate monitoring system to assess autonomic balance changes during cooling vs. control.*

Results: *There was a significant reduction in the perceptual measures when wearing the cooling band, and there is enhanced improvement of the autonomic nervous system balance evidenced by a decrease in RMSSD, indicating a decrease in parasympathetic tone following firefighting. However, this reduction was less in the cooling group. The results of this study indicate that the wearable cooling band improves perceptual measures and hastens autonomic nervous system recovery. Additional testing is warranted to assess the long-term impact on firefighters' health and recovery from firefighting duties, training, or actual fire calls.*

Keywords: ***Thermal strain, Heart rate variability, Firefighters.***

1. Introduction

Heat stress, dehydration, and high levels of cardiovascular strain are ubiquitous concerns for firefighters. Firefighters must perform their work while wearing heavy, insulative personal protective equipment (PPE) that protects against burn and thermal injury, as well as from exposure and abrasion, but this PPE also imposes a considerable physiological burden. Firefighting PPE is heavy, approximately 22 kg, and it is restrictive, making work harder.

Thus, PPE greatly increases metabolic work and heat production. Furthermore, PPE interferes with the body's ability to dissipate heat. The combination of radiant heat loads, heavy work, and encapsulating PPE results in uncompensable heat stress. Heat stress presents challenges directly, but it also exacerbates dehydration, which can negatively affect a firefighter's cognition and increase cardiovascular strain, **[1]** further endangering the first responders.

Core temperature of firefighters can increase quickly due to high metabolic heat production and an inability to dissipate the heat that is generated, thus leading to uncompensable heat stress. **[2,3]** Research has shown that core temperatures can increase by 1.0-1.5°C during short bouts of firefighting, and by as much as 1.8°C with repeated bouts.**[2]** Further, research indicates that an increase in 1.2°C results in a much larger effect on heart rate responses than dehydration of approximately 3% of body mass loss.**[4]** Increases in core temperature are most profound during prolonged firefighting activity, including firefighting training in which firefighters perform multiple evolutions of firefighting activity.**[2]** Although core temperatures rise quickly, and sometimes dangerously high during firefighting activity, core temperature recovery rates are much slower. Research has

**Corresponding Author- Patricia C. Fehling*

shown that it can take 50-80 minutes for heart rate to return to baseline post firefighting. **[2, 3]**

Heat stress is a known challenge of firefighting and managing heat stress is critical to ensuring that firefighters can work effectively and safely. **[2, 5]** The National Fire Protection Association (NFPA) recommends that firefighters undergo on-scene rehabilitation (REHAB) during actual emergencies and training exercises. **[6]** Incident scene REHAB has been defined as an intervention to mitigate the physical, physiological, and emotional stresses of firefighting; Incident scene REHAB is utilized to lessen physiological strain, provide an opportunity for recovery, and to ensure a safe return to work protocol. **[1]** REHAB provides time for rest, recovery, cooling, rehydration and the monitoring of vital signs. Cooling is a primary goal of incident scene REHAB and multiple cooling methods have been used to mitigate heat stress. **[1, 7]** However, operationally it is still a challenge to provide cooling in an effective and feasible manner.

Effective cooling strategies are critical for the fire service and many other occupational groups that encounter heat stress. In order to be widely adopted, these cooling technologies must be able to be transported easily and deployed in a field setting with minimal need for additional personnel resources. New wearable technology (dhamaSPORT cooling band) has been developed that permits prolonged cooling through a wrist band. The patented technology is light-weight (125 g), rechargeable, and provides constant cooling of 7.2°C (45°F) (on the coolest setting) to the underside of the wrist for up to 120 minutes. The purpose of this pilot study was to investigate the effect of the dhamaSPORT cooling band during recovery from live fire training on perceptual measures, heart rate, and autonomic nervous system balance. Secondarily, we sought to understand the feasibility of deploying this wearable technology during large-scale training exercises. It was hypothesized that when the firefighters wore the cooling band in recovery, heart rate and perceptual measures would recover at a faster rate with the device in cooling mode compared to off mode.

2. Materials and Methods

2.1 Participants

Participants in this study were firefighting volunteers who were part of a firefighting training class that was conducted at a County Fire and Rescue Training facility in Virginia during the month of June. Forty-one firefighters volunteered to participate in this study. A subset of 10 firefighters agreed to wear a specialty t-shirt with an embedded heart rate (HR) monitor to measure autonomic nervous system balance. Prior to the commencement of the study, all participants read and completed an Informed Consent and Health History. This study was approved by the Skidmore College Institutional Review Board and conformed to the ethical guidelines outlined in the Belmont Report.

2.2 Study Design and Protocol

This study was a randomly assigned, non-blinded, descriptive study. Participants were placed into three teams of firefighters to perform multiple drills throughout the day. All teams performed two firefighting scenarios (evolutions) before being assigned to the REHAB station. During each firefighting scenario, teams were assigned to perform standard drills that are used for training recruit firefighters; such as, deploying to various locations, forcing doors open, pulling a charged hoseline through a hot and smoke-filled room, searching and rescuing (rescuing weighted dummies), crawling with hand tools, and throwing ladders to all sides of building.

2.3 Data Collection

After the team of recruit firefighters completed two training evolutions, they doffed their PPE and entered the REHAB station. The REHAB building was approximately 50-75 feet from burn building and was open to the outdoors (via large, open garage doors). Participants were seated in chairs at tables during their time in REHAB. There was a large fan located in the back of the building that was turned on during the entire data collection period. The ambient conditions at 8:45 am were 24.3°C and overcast, with 78% humidity and winds of 4.6 miles per hour. At 11:15 am it was 26.4°C and sunny, with 69% humidity and winds of 3 miles per hour.

Upon entry to REHAB, a dhamaSPORT Band was placed on the wrist of each participant and was either turned on (COOLING) (on highest setting) or was left in the off (CONTROL) position. The condition of COOLING or CONTROL, was randomly assigned prior to data collection. HR and perceptual measurements were obtained upon entry into REHAB and every 5 minutes, for a total of 15 minutes. A subset of firefighters also had heart rate variability (HRV) measures obtained during this period.

2.4 Cooling Band

The dhamaSPORT is a cooling band that provides personal cooling to the underside of the wrist (Figure 1). This wearable technology uses a patented ClimaCon® technology to deliver constant cooling at 7.2°C (45°F) on the highest setting to the underside of the wrist. The cooling band is light-weight and can easily be transported with fire apparatus or with ambulances that are assigned to provide REHAB on scene or stored and used at a training facility.

Corresponding Author- Patricia C. Fehling

Figure 1. dhamaSPORT™ cooling band

2.5 Measurements

Heart rate measurements were obtained via a finger pulse oximeter (accV-rate model 5000GL). Thermal Sensation and Thermal Comfort were obtained at baseline, upon entry to REHAB, and at minutes 5, 10 and 15 during REHAB. Participants were also asked to provide anonymous written feedback on their perceptions of the cooling band. Thermal Sensation was assessed using an 8-point scale that advances in 0.5 increments; a rating of 0.0 indicates unbearably cold, while an 8.0 is unbearably hot. The Thermal Comfort scale indicates how comfortable the participate feels. On this scale, a 1.0 depicts comfortable, while a 5.0 indicates extremely uncomfortable.

A subgroup (n=10) of the recruits also wore a heart rate monitor (Zephyr Bioharness), which continuously monitored HR throughout the training day. Three specific five-minute time periods were analyzed for HRV: prior to any firefighting activity as a baseline measure, once in the last 10 minutes of a REHAB visit with the dhamaSPORT turned on (COOLING) and once in the last 10 minutes of a REHAB visit with the dhamaSPORT turned off (CONTROL). Analysis of HRV data was completed using Kubios HRV software (v2.1, University of Kuopio, Finland) and focused solely on the root mean square of successive differences in RR intervals (RMSSD) as it is a well-recognized marker of vagal activity in a variety of populations. **[8,9]** After visual inspection, all artifact and ectopic beats were replaced using Kubios's intrinsic cubic spline interpolation. **[10]**

2.6 Statistics

Changes in HR during REHAB of the entire group (n=41) are reported as mean ± S.E., and difference between condition (COOLING vs. CONTROL) and over time (3 visits to REHAB) were assessed using a repeated measures analysis of variance. Likewise, perceptual data were reported as mean ± S.E., with differences between conditions examined using an independent samples t-test. Statistical analysis of the HRV subgroup data (mean HR and RMSSD) was assessed over time using a Friedman's non-parametric one-way analysis of variance, and was reported as mean ± S.E.

3. Results

3.1 Heart Rate and Perceptual Measures of Entire Group

Heart rate and perceptual measures were obtained from the group of 41 firefighters participating in this study. There was no significant difference in HR between conditions (COOLING and CONTROL) at any time point throughout the protocol ($p>0.05$) (Figure 2). Thermal sensation was similar between conditions upon entry into REHAB, at 5 minutes into REHAB, and at 15 minutes into REHAB (Figure 3a). Likewise, thermal comfort was similar between conditions upon entry into REHAB, at 10 minutes into REHAB, and at 15 minutes into REHAB (Figure 3b). However, thermal sensation at 10 minutes into REHAB was significantly lower ($p=0.02$) during REHAB with COOLING compared to CONTROL (Figure 3a). Likewise, thermal comfort was significantly lower ($p=0.01$) at 5 minutes during REHAB with COOLING compared to CONTROL (Figure 3b).

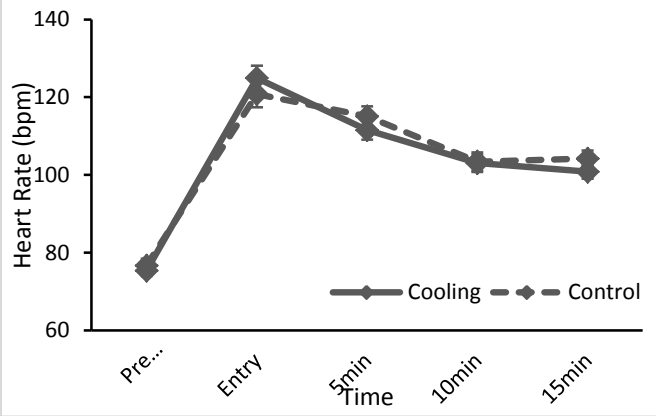

Figure 2. Mean heart rate (+SE) of the entire group (n=41) at rest and during REHAB with COOLING and CONTROL.

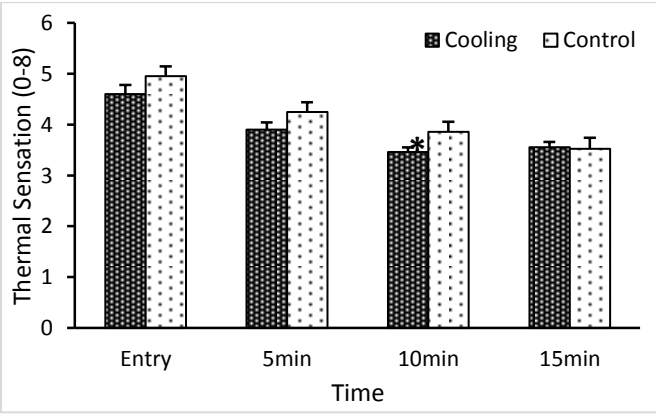

Figure 3a. Mean thermal sensation scores (+SE) of the entire group (n=41) during REHAB with COOLING and CONTROL.

* $p<0.05$ between conditions

Corresponding Author- Patricia C. Fehling

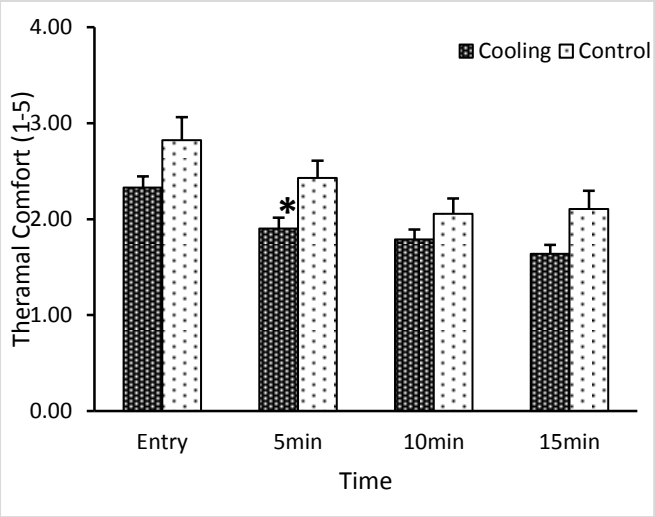

Figure 3b. Mean thermal comfort scores (+SE) of the entire group (n=41) during REHAB with COOLING and CONTROL.
* p<0.05 between conditions

3.2 Heart Rate Variability of Subgroup

As seen in Figure 4a, mean HR was significantly elevated in REHAB vs pre-firefighting in both conditions (COOLING, p=0.01; CONTROL, p=0.01) (Figure 4a). Because the HRV analysis was performed during a 5-minute window in the last 10 minutes of recovery, the HR in recovery in the subgroup was lower than the initial HR seen in recovery in the entire group. However, as in the entire group, the HR did not differ between conditions in this subgroup. Importantly, RMSSD was significantly reduced from pre-firefighting to REHAB in both conditions (COOLING, p=0.000; CONTROL, p=0.000) (Figure 5a).

The percentage change in mean HR was similar (p=0.527) from pre-firefighting to REHAB in both conditions (Figure 4b). However, the percentage change in RMSSD was significantly less (p=0.011) from pre-firefighting to REHAB with the COOLING (percentage change = -20.8±8.6%) than from pre-firefighting to the REHAB with the CONTROL (-39.8±8.2%) (Figure 5b).

When viewed visually, the perceptual measures from the subgroup appeared to mirror the larger group. However, likely due to the smaller sample size, there were no significant differences in thermal sensation (p>0.05) (Figure 6a) and thermal comfort (p>0.05) (Figure 6b) between each REHAB condition for the subgroup with HRV measures. Written feedback indicated that the firefighters liked wearing the cooling band and found it convenient to use.

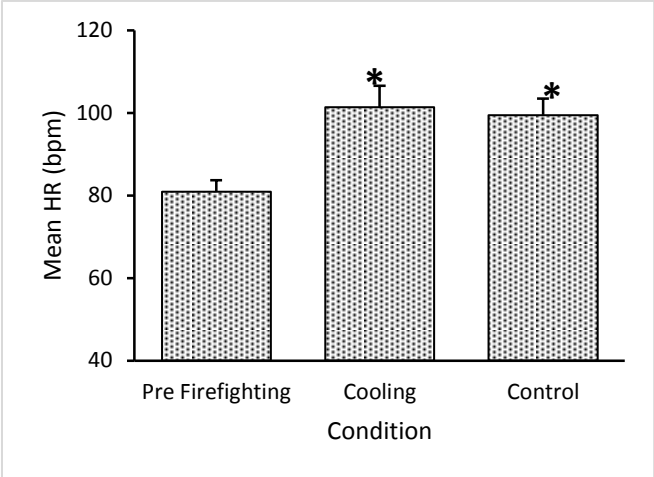

Figure 4a. Mean heart rate (+SE) of the HRV subgroup (n=10) pre-firefighting and during the last 10 min of REHAB with COOLING and CONTROL.
* p<0.05 compared to pre-fighting

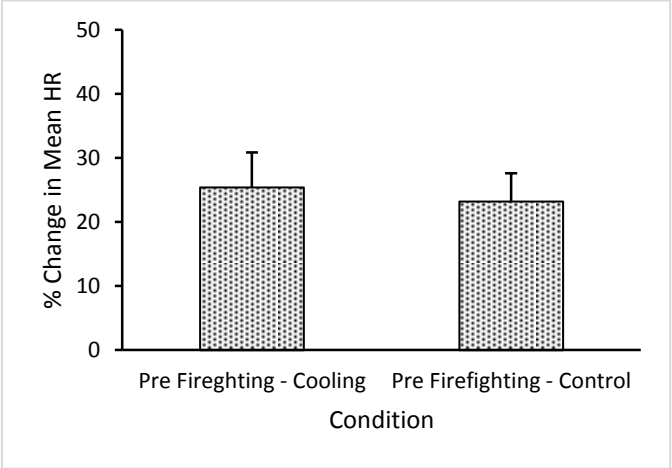

Figure 4b. The percentage change (+SE) in mean HR of the HRV subgroup (n=10) from rest to REHAB with the COOLING and CONTROL during REHAB.

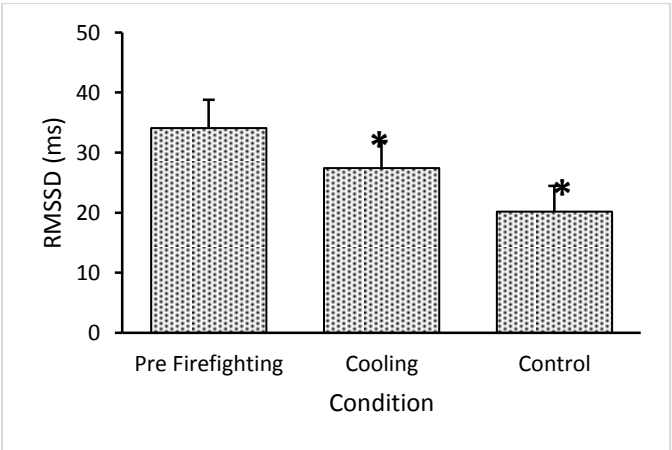

Figure 5a. RMSSD (+SE) of the HRV subgroup (n=10) at rest and during REHAB with COOLING and CONTROL.
* p<0.05 compared to pre-fighting

Corresponding Author- Patricia C. Fehling

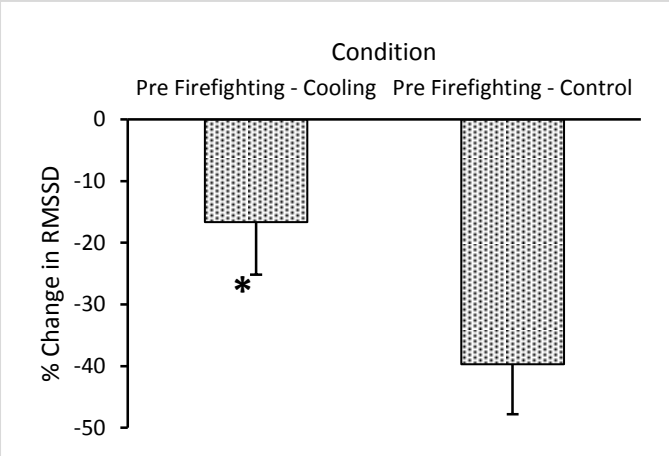

Figure 5b. The percentage change (+SE) in RMSSD of the HRV subgroup (n=10) from rest to REHAB with the COOLING and CONTROL during REHAB.
* $p<0.05$ between conditions

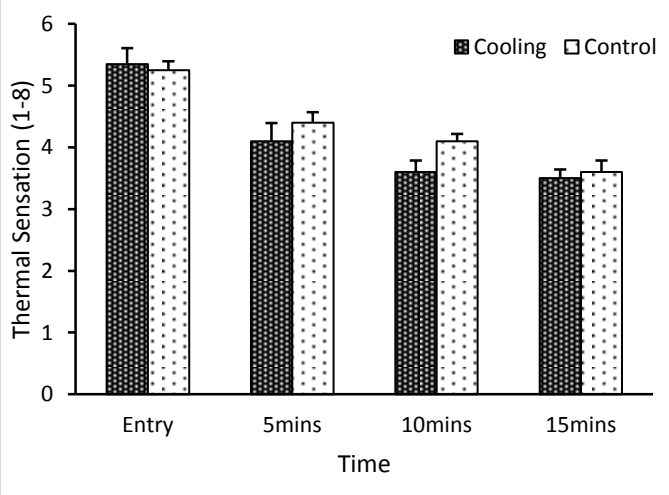

Figure 6a. Mean thermal sensation scores (+SE) of the HRV subgroup (n=10) during REHAB with COOLING and CONTROL.

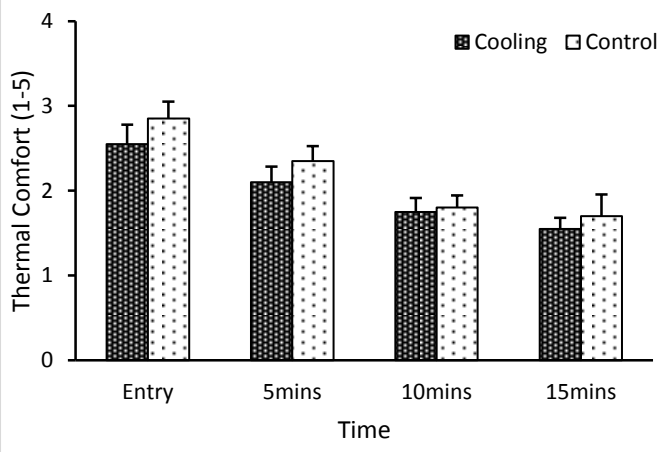

Figure 6b. Thermal comfort scores (+SE) of the HRV subgroup (n=10) during REHAB with COOLING and CONTROL.

4. Discussion

Heat stress is a critical concern for firefighters. New technology offers a potential way to help mitigate heat stress and hasten recovery from exercise-induced heat stress while wearing protective clothing. Primary findings of this pilot study show that a wearable cooling band (dhamaSPORT) improves perceptual measures of recovery; has no effect on HR recovery; and positively impacts autonomic nervous system balance as evidenced by a blunted reduction in RMSSD. The lower RMSSD in recovery indicates a decrease in parasympathetic tone implying an increase in sympathetic drive. The attenuated decrease in RMSSD in recovery in the cooling condition reflects a faster return towards baseline, suggesting enhanced recovery using the dhamaSPORT cooling band.

Because firefighters perform strenuous work while wearing heavy protective clothing, the combination of high metabolic heat production and impaired thermoregulation results in uncompensable heat stress that hastens fatigue, impairs performance, and may lead to heat illness. Incident REHAB is a strategy designed, in part, to provide recovery, rehydration, and cooling for fighter fighters. However, effective cooling may not always be available on-scene. One of the challenges faced during on-scene operations is the ability to provide cooling in a convenient and personalized way. The newly developed wearable cooling band developed by Dhama USA has the potential to provide convenient cooling and aid in recovery of firefighters. The cooling band provides a patented ClimaCon® technology to provide constant cooling to 7.2°C (45°F) (on the highest setting). The wrist is an important area for cooling because blood flow to the skin increases dramatically during exercise and forearm blood flow has been shown to approximately 6-fold during exercise. **[11]**

We measured the recovery of firefighters using perpetual measures, HR, and HRV following actual training exercises at a training academy. Previous research has shown that HR reaches near maximal levels during firefighting activity, but generally recovers toward baseline within 15 minutes of firefighting activity.**[3]** Smith et al. documented HR in REHAB following firefighting drills in live fire trainings; this study reported that within 15 minutes of REHAB, HR significantly decreased.**[12]** Further findings from Barr et al. reported a decrease in HR by approximately 22 beats per minute within the first 10 minutes of REHAB among those who entered REHAB with a HR greater than 100 beats per minute, thus supporting the findings of Horn et al. and Smith et al. [**3,6,12,13]**

Hostler et al. examined HR and core temperature responses following exercise in thermal protective clothing; four active cooling devices were compared and it was reported that there was no advantage to the use of these active cooling

Corresponding Author- Patricia C. Fehling

devices versus passive cooling in moderate temperature (approximately 24°C).**[7]** Colburn et al. compared cooling devices following a 20-minute live fire training evolution, found no benefit to cooling vests in comparison to passive cooling in an air-conditioned medical trailer and found only a slightly higher cooling rate with forearm immersion was found when cooling in a moderate ambient setting.**[14]**

Our findings are similar to previous studies. **[1,12]** We reported HR of approximately 120 bpm as firefighters entered REHAB and a reduction in HR to about 100 bpm during REHAB. Although we found no difference in HR recovery between COOLING and CONTROL, we did find improved perceptual measures in the group with COOLING. Further, we found that in the last 10 minutes of REHAB there was not as much of a reduction in RMSSD in the COOLING group. The blunted decrease in RMSSD indicates a faster return of cardiac autonomic balance.

5. Conclusion

We tested the ability of a new wearable technology to hasten recovery from firefighting activity. We found that the dhamaSPORT cooling band was convenient and easy to use during incident REHAB. Qualitative data indicated that firefighters felt that the dhamaSPORT cooling band was helpful and easy to use. Quantitative measures of perceptual ratings mirrored these qualitative findings. We found no beneficial effect on HR recovery with the dhamaSPORT band, but HRV measures suggested a quicker return to autonomic nervous system balance. These data suggest that the dhamaSPORT cooling band does assist with recovery and may be a useful tool in providing REHAB to firefighters. Furthermore, a reliance on HR measures alone may underestimate the advantages of different cooling techniques.

Acknowledgements

We would like to thank the Loudoun County Fire and Rescue for their assistance with this project. Specifically, Lieutenant Michael Smith, who is in charge of the Fire Training Unit. We would also like to acknowledge Dhama Innovations who provided cooling bands to support this study.

References

1. Haigh, C.A., Smith, D.L. (2015). Incident scene REHABilitation: a leadership challenge. Fire Engineering. 168(12): 49-55.
2. Horn, G., Blevins, S., Fernhall, B., Smith, D.L. (2013). Core temperature and heart rate responses to repeated bouts of firefighting activity. Ergonomics. 56(9): 1465-1473.
3. Horn, G., Gutzmer, S., Fahs, C.A., Petruzzello, S.J., Goldstein, E., Fahey, G., Fernhall, B., Smith, D.L. (2011). Physiological recovery from firefighting activities in REHABilitation and beyond. Prehospital Emergency Care. 15(2): 214-225.
4. Fehling, P.C., Haller, J.M., Lefferts, W.K., Hultquist, E.M., Wharton, M., Rowland, T.W., Smith, D.L. (2015). Effect of exercise, heat stress and dehydration on myocardial performance. Occupational Medicine. 65.4: 317-323.
5. Larsen, B., Snow, R., Williams-Bell, M., Aisbett, B. (2015). Simulated firefighting task performance and physiology under very hot conditions. Frontiers in Physiology. November 9 [Epub].
6. Barr, D., Haigh, C.A., Haller J., Smith, D.L. (2016). Medical monitoring during firefighter incident scene REHABilitation. Prehospital Emergency Care. March 8 [Epub].
7. Hostler D., Reis S.E., Bednez J.C., Kerin S., Suyama J. (2010). Comparison of active cooling devices with passive cooling for REHABilitiation of firefighters performing exercise in thermal protective clothing: a report from the Fireground REHAB Evaluation.
8. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Eur Heart J. 1996; 17: 354-381.
9. Edmonds, R., Burkett, B., Leicht, A., McKean, M. (2015). Effect of Chronic Training on Heart Rate Variability, Salivary IgA and Salivary Alpha-Amylase in Elite Swimmers with a Disability PLOS One
10. Tarvainen, M.P., Niskanen, J.P. (2008). Kubios HRV version 2.0 USER'S GUIDE.Kuopio, Finland: Biosignal Analysis and Medical Imaging Group (BSAMIG), University of Kuopio.
11. Johnson, J.M. Exercise and the cutaneous circulation. Exercise and Sport Sciences Reviews, 20:59–97, 1992.
12. Smith, D.L. Haller, J.M., Benedict, R., Moore-Merrell, L. (2016). Firefighter incident REHABilitation: interpreting heart rate responses. Prehospital Emergency Care. 20(1): 28-36.
13. Smith, D.L., DeBlois, J.P., Kales, S.N., Horn, G.P. (2016). Cardiovascular strain of firefighting and the risk of sudden cardiac events. Exercise and Sport Sciences Reviews. 44(3): 90-97.
14. Colburn, D., Suyama, J., Reis, S.E., Morley, J.L., Goss, F.L., Chen, Y.F., Moore, C.G., Hostler, D. (2011). A comparison of cooling techniques in firefighters after a live burn evaluation. Prehospital Emergency Care. 15(2): 226-32. (FIRE) trial. Prehos Emerg Care. 14:300-9.

Corresponding Author- Patricia C. Fehling