Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum 28 August, 2012 Perth Convention & Exhibition Centre

Edited by R.P. Thornton & L.J. Wright

Published by:

Bushfire Cooperative Research Centre

Level 5 340 Albert Street

East Melbourne 3002 Australia

Citation: R. P. Thornton & L.J. Wright (Ed) 2013, 'Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum' 28 August 2012, Perth Australia, Bushfire CRC

Welcome from Editors

It is our pleasure to bring to you the compiled papers from the Research Forum of the AFAC and Bushfire CRC Annual Conference, held in the Perth Exhibition and Convention Centre on the 28th of August 2012.

These papers were anonymously referred. We would like to express our gratitude to all the referees who agreed to take on this task diligently. We would also like to extend our gratitude to all those involved in the organising, and conducting of the Research Forum.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Research Forum focuses on the delivery of research findings for emergency management personnel who need to use this knowledge for their daily work.

Not all papers presented are included in these proceedings as some authors opted to not supply full papers. However these proceedings cover the broad spectrum of work shared during this important event.

The full presentations from the Research Forum and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton and Lyndsey Wright

June 2013

ISBN: 978-0-9806759-6-2

Disclaimer:

The content of the papers are entirely the views of the authors and do not necessarily reflect the views of the Bushfire CRC or AFAC, their Boards or partners.

Assessing the validity of tympanic temperature to predict core temperature of firefighters in different environmental conditions

Peter Langridge[1], Anna Ruzic[1], Brianna Larsen[2], Cara Lord[2], Brad Aisbett[2]
[1]Country Fire Authority 8 Lakeside Drive, Burwood East 3135
[2]Centre for Exercise and Sports Science (C-ESS)School of Exercise and Nutrition Sciences
Deakin University 221 Burwood Highway, Burwood 3125

Abstract

The present study examined the validity of tympanic temperature measurements as a predictor of core temperature on the fireground in different environmental conditions. Fifty-one volunteer firefighters participated in the study across four different conditions, the conditions consisted of; 1) passive (i.e., no intervention) cooling in cold ambient temperatures (0-6°C); 2) cooling (through water immersion) in cool ambient temperatures (10-12ºC); 3) cooling (through water immersion) in warm ambient temperatures (21.5°C); and, 4) passive cooling in warm ambient temperatures (22°C). Firefighters wore full structural personal protective clothing while performing common firefighting duties including search and rescue tasks for 20-40 minutes. There was no difference between core and tympanic temperature immediately post-exercise across any condition. However, for all conditions, tympanic temperature dropped significantly faster than core temperature from 0 minutes, and remained significantly lower ($p < 0.05$) than core temperature from nine to 20 minutes post-training. The results show that there is no consistent difference between core and tympanic temperature during recovery from a simulated firefighting task across a range of different ambient conditions. Agencies should, accordingly, prioritize investigating other practical markers of core temperature as part of a broader heat stress management plan for firefighters.

 R.P. Thornton & L.J. Wright (Ed) 2013, 'Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum' 28 August 2012, Perth Australia, Bushfire CRC

Introduction

Firefighting is a physically demanding occupation, in which firefighters are required to perform short bouts of intense physical activity for extended periods of time (Barr et al. 2009; Rhea et al. 2004). Upon deployment to a fire, firefighters face life-threatening dangers including flames, radiant heat and collapsing structures, as well as physiological hazards in the form of smoke inhalation and heat stress (IAFF, 2003). In Australia, heat stress is one of the top three leading causes of injury for firefighters from South-Eastern Australian fire agencies (Aisbett et al. 2007). Factors influencing firefighter heat stress include; high physical demand of tasks, exposure to radiant heat and flames, and the retention of body heat due to wearing of personal protective clothing (IAFF, 2003).

Monitoring heat increases in firefighters is a health and safety priority, as heat stress can severely impair the physical and mental performance of firefighters (Pryor et al. 2011). Under high ambient temperatures, the body may experience exhaustion, mental confusion, disorientation, loss of consciousness, heart attack and in extreme cases, death (Binkley et al. 2002). Measurements of core temperature need to be obtained in order to identify the rapidly rising body temperature of firefighters at an incident (Pryor et al. 2011). Direct measurements of core body temperature using rectal thermometry is seen as the most accurate measurement for monitoring and assessing changes of core temperature (Mazerolle et al. 2010; Casa et al. 2007; Binkley et al. 2002). While using rectal thermometers may provide the most accurate measurement of core temperature, these devices are invasive and impractical to administer on the fireground. Gastrointestinal (GI) tablets, commonly known as core temperature tablets, are frequently used in research environments to transmit GI temperature readings to wireless data recording devices (Byrne & Lim 2007; Domitrovich et al. 2010; Casa et al. 2007). A study by Casa et al. (2007) compared common core temperature measuring devices including oral, gastrointestinal, axillary, aural, and temporal measurements to the well-validated measure of rectal temperature before, during and after exercise. It was concluded that ingestible GI tablets were the only measurement device that accurately predicted core body temperature (Casa et al. 2007). However, some studies suggest that core temperature tablets may produce inaccurate core temperature values when fluids are consumed (Domitrovich et al. 2010; Byrne & Lim 2007). To prevent such errors from occurring, the manufacturers instruct users to ingest the GI tablet at least six hours prior to the work bout in order for it to pass through the stomach and reach the small intestines, which is known to accurately reflect core temperature (HQinc, Palmetto, FL). This approach will limit false readings occurring with the consumption of cool fluids (Goodman et al. 2009; Wilkinson et al. 2008). Despite its ability to accurately measure core temperature, particularly when ingestion instructions are adhered to, core temperature tablets may not be the most practical way of obtaining core measurements on the fireground. The device requires advanced notice, limiting its use in emergency settings, as deployment times cannot easily be predicted. Further, the use of core temperature tablets may not be a cost effective strategy for monitoring firefighter's heat stress given the expense of each tablet (approximately AUD $70 per tablet).

In contrast to the limitations of the GI temperature device, tympanic temperature measurements taken by inserting the device into the ear canal is an inexpensive, commercially available and practical method of assessing body temperature (Ganio et al. 2009). Using tympanic temperature devices allows medical personnel on the fireground to take quick and easy temperature measurements when firefighters temporarily exit a hazardous environment. Currently, ambulance officers and medical personnel use tympanic temperature devices on the fire ground to predict the core temperature of firefighters (Ambulance Victoria, 2012). The use of these devices in predicting core temperature has been questioned by a number of studies (e.g., Casa et al. 2007; Pryor et al. 2011; Gagnon et al. 2010; Ganio et al. 2009). The existing literature from the medical, sporting and emergency service fields suggests that tympanic temperature measurements commonly underestimate core temperature (Ganio et al. 2009; Pryor et al. 2011; Amoateng-Adjepong et al. 1999). Therefore, this study aims to quantify the extent of this under-prediction to evaluate whether tympanic temperature has any utility as a core temperature marker device on the fireground.

Methods

Participants

Volunteer firefighters from the Country Fire Authority (CFA) participated in this study. The CFA is the overarching volunteer firefighting organization responsible for fire suppression throughout Victoria. The participants were recruited through flyers distributed at CFA brigade meetings by local Health and Safety advisors. The requirements and potential risks associated with the study were explained to each participant prior to the commencement of testing. Written informed consent was required of each participant. To be included in the study, participants had to be active members of the CFA, without cardiovascular or gastrointestinal conditions, and have no plans for magnetic resonance imaging (MRI) or airplane travel three days post testing (the latter two criteria being contraindications for the core temperature tablets; BMedical, 2010). Ethical approval for all procedures was secured from the Deakin University Human Research Ethics Committee prior to the commencement of testing.

Procedure

Each participant attended a one-hour pre-training briefing on the day of experimentation. Once informed consent was provided, each participant was given a core temperature tablet to ingest (Jonah™ Tablet, Respironics, Bond, Oregon). The core temperature tablet was provided at least six hours prior to the beginning of the training session to ensure the tablet had moved through the stomach and into the lower intestines (Byrne & Lim 2007). Participants returned to the experimentation site between 5:00 pm and 6:00 pm and were fitted with the remaining equipment (see Measurements and Equipment section, below). Participants wore full personal protective equipment which consisted of structural ensemble (PBI Gold and Nomex, Stewart & Heaton, Australia), FirePro fire resistant gloves (Allglove Industries, Australia), treated leather work boots (Taipan, Australia) and a structural helmet (Pacific, Australia), with a net weight of approximately 10 kg. Participants also carried, and may have used, fire safety goggles (UVEX, Germany). Clothing worn under personal protective equipment was not recorded. Participants were divided into four different post-work subgroups to determine the efficacy of tympanic temperature measurement across a range of different conditions. The conditions consisted of; 1) passive (i.e., no intervention) cooling in cold ambient temperatures (0-6°C); 2) cooling (through water immersion) in cool ambient temperatures (10-12ºC); 3) cooling (through water immersion) in warm ambient temperatures (21.5°C); and, 4) passive cooling in warm ambient temperatures (22°C). In the 'cooling (through water immersion)' conditions, participants sat with their arms submerged in water (12-15°C) for either 15 or 20 minutes (see Measurements and Equipment section, below) post-exercise. It should be noted that the same cohort of participants participated in conditions three and four. After being fitted with equipment, participants were fitted with self contained breathing apparatus (SCBA) and air cylinders. Participants in condition one were divided into pairs by site commanders and entered a smoke filled building where they performed common firefighting duties for between 20 and 40 minutes. Participants were required to exit the building when their (or their partner's) air cylinders signaled 'low'. The remaining three conditions (two, three and four) were divided into teams of five, where they then performed common firefighter search and rescue tasks for 20 minutes in a heated building, temperature range 60°C to 124°c. In these instances, teams were required to exit the building between 20 and 22 minutes of exposure. For all groups, the time at which the firefighters exited the building was labeled '0 minutes' and reflects when post-training measurements commenced.

Measurements and Equipment

Weight and height were measured using standard body weight scales (A and D, Japan) and a portable stadiometer (SECA, Brooklyn, New York), respectively. In condition one, core temperature was recorded on a wireless data logger (Vitalsense, Respironics, Bond, Oregon), which received measurement of core temperature from the ingested tablet at one minute epochs throughout the training simulation and post-training. The data logger was carried in the firefighter's pockets through the duration of the training simulation. The remaining three conditions utilized a wireless CorTemp Data Recorder, which also tracked heart rate from a Polar chest strap (Polar RSD 800sd, Polar Electro, Oy, Finland). Researchers documented manual core temperature and heart rate readings from the recorders at set intervals. Participants in condition one wore a heart rate monitor chest strap and receiver watch (Polar RSD 800sd, Polar Electro, Oy, Finland) during- and post- training. Heart rate data in all trials was concealed from participants throughout the trials to ensure heart rate was not consciously manipulated (e.g., through self-pacing, slower breathing). In the post-exercise cooling in cold ambient temperatures group (condition one), tympanic temperature was measured post-training at three-minute intervals until 15 minutes had elapsed, using the Braun Thermoscan® Pro 4000 tympanic thermometer (Braun, United Kingdom). The remaining three groups recorded tympanic temperature every five minutes for 20 minutes post-exercise. All measurements were taken from the participants left ear by the same researcher to ensure consistent collection techniques. In condition one, each participant also wore a global positioning unit (GPS; Spi Elite, GPSports, Australia) in order to measure activity, heart rate and distance travelled every second. As SCBA was carried on the back, the GPS harness was retrofitted to be worn on the chest in a harness which looped around the participants' shoulders.

Statistical Analysis

A two-way repeated measures analysis of variance (ANOVA) test, with time and device (core or tympanic temperature) as the within participant factors, was used to detect differences between the device at each time point post-training. If the ANOVA detected a difference, simple effects analysis was used to identify where the differences lay. All statistics were calculated using Statistic Package for the Social Sciences (SPSS, V.18, Champaign, Illinois). Statistical significance was set at $p \leq 0.05$ and all data was presented as mean ± standard deviation unless otherwise stated.

Results

Participant Demographics

	Condition One	Condition Two	Conditions Three and Four
Age (years)	39 ± 10	27 ± 11	47 ± 10
Height (cm)	177.4 ± 6.0	176.6 ± 7.7	178.0 ± 7.0
Weight (kg)	88.3 ± 14.1	85.69 ± 19.41	91.6 ± 15.2
n	16	22	19

Values are mean ± standard deviation.

Table 1. Participant Demographics

Firefighting training simulation

In condition one, each participant spent approximately 30 – 40 minutes performing the firefighting training simulation in which a number of common firefighting duties, including search and rescue, were undertaken. Individual time spent during the simulated training varied due to rate of air consumed and the subsequent need to exit when their air cylinder signaled low. For the remaining three groups (conditions two, three and four), 20 to 22 minutes was spent in the heated simulated firefighting environment.

Detailed activity data was also obtained for condition one, and serves as a reasonable estimate of the work performed across all four conditions. While the individual tasks during the simulation could not be captured, the intensity of the work simulation as a whole was predominantly above 70% of age predicted heart rate maximum (HR_{max}). The American College of Sports Medicine (ACSM, 2000) classifications of work intensities would categorize the in-simulation heart rates achieved as moderate- to hard- intensity work (above 50% HR_{max}). Small periods of hard to maximal and very light work intensities were also recorded. Average heart rate throughout the entire training simulation was 128 ± 25 beats·min^{-1}. The distance travelled throughout the simulation was 2.1 ± 0.7 km.

Post-Training

Relationship between core and tympanic temperature at specific time points

In condition one, core temperature remained constant between 37.5°C and 38°C across all of the six recovery time points (Figure 1). In contrast, tympanic temperature steadily dropped across the 15 minute rest period, and was significantly lower than core temperature at the nine-, 12, and 15 minute time points. The differences between core and tympanic temperature increased at each successive time point up to 12 minutes, ranging from 0.7 ± 0.9°C immediately post-exercise to 2.2 ± 1.3°C at 12 minutes post simulation. At 15 minutes post-simulation, the tympanic temperature was 2.0 ± 1.1°C lower ($p < 0.001$) than the corresponding core temperature. In conditions two, three and four, there was a significant interaction between temperature measuring device and time ($p < 0.001$). There was no difference between core and tympanic temperature immediately post-exercise ($p = 0.578$, 0.445 and 0.908, respectively). However, for all conditions, tympanic temperature dropped significantly faster than core temperature from 0 to 5 minutes, and remained significantly lower than core temperature at time points 5, 10, 15 and 20 ($p < 0.05$; Figure 1). In condition two, the biggest difference between devices arose at the 5-minute mark, with core temperature being 1.1 ± 0.5°C higher than tympanic temperature. The magnitude of this difference then slowly decreased across the remaining 15 minutes so that at 20 minutes core temperature was 0.6 ± 1.0°C higher ($p = 0.023$) than tympanic. In condition three and four, the discrepancy between the two devices remained relatively constant between 5 and 20 minutes, ranging between 0.6 ± 0.4°C and 0.7 ± 0.5°C ($p < 0.001$).

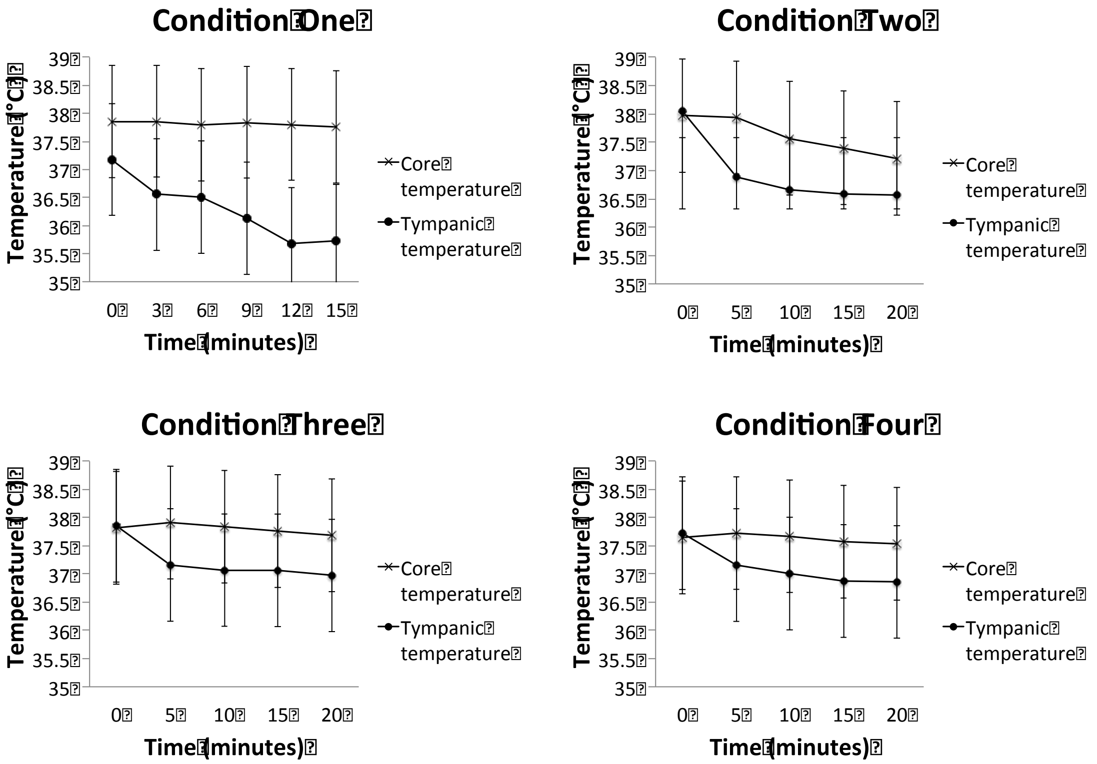

Figure 1: Tympanic and core temperature following 20-40 min of simulated structural firefighting work. Please note that tympanic and core temperatures differ significantly after minute nine in Condition One and from five minute s of Conditions two to four.

Discussion

The major finding of this study was that there was no consistent difference between core and tympanic temperature during recovery from a simulated firefighting task across a range of different ambient conditions and with or without limb cooling. The variations in the difference between core and tympanic temperature measurement post-training severely undermines the utility of tympanic temperature for heat stress detection in firefighters.

Firefighters in all conditions had lower tympanic temperature readings than core temperature for the majority of the post-training period (Figure 1). However, tympanic measurements were temporarily not different to core temperature immediately after exiting the hot environment. This could be due to the 0-minute tympanic measurement being recorded prior to the ear canal being cooled by a cooler external environment (Pryor et al. 2012; Byrne & Lim 2007). Indeed, significant differences between core and tympanic temperature were identified from 5 minutes post exit from the training simulation.

Previous literature suggests that tympanic temperature readings are commonly below that of core temperature as the device is influenced by external factors such as ambient temperature, air movement and sweat (Gagnon et al., 2010; Hansen et al. 1993). The four conditions used in the research utilised different resting ambient temperatures and wind speeds, thus, we were able to observe differences in the variation between tympanic temperature and core temperature. In the present study, condition one had the lowest ambient temperature (0-6ºC and 10-12ºC, respectively) and higher wind speeds when compared to the other conditions, which may explain why the discrepancy between core and tympanic temperature was most exaggerated here. In conditions three and four, firefighters rested in a warmer ambient environment (21.5-22ºC) with no wind, which may explain why the magnitude of the difference between the two temperature measurement devices was slightly smaller (although still significantly significant). Limb cooling (in conditions two and three) did not appear to impact tympanic temperature any differently to the passive-cooling conditions.

The results indicated a consistently lower tympanic temperature ranging between 0.6ºC to 2.2ºC below recorded core temperature. Thus, using tympanic temperature as a guide for returning firefighters to active duties could be placing firefighters at risk (Pryor et al., 2012). Casa et al. (2007) found that peak tympanic temperature occurred at the same time as rectal temperature, but was 1.6ºC ± 0.6ºC lower. The study also showed a large mean difference of 1.9ºC between tympanic and rectal temperature for one subject (Casa et al. 2007). More recently, different study evaluating cooling methods in the Northern Territory reported that firefighters' tympanic temperature was, on average, 1.3ºC below GI temperature (Brearley et al. ND) following performing an outdoor work circuit. Given the variable level of under-prediction of core temperature by tympanic measures, it is possible that fire agencies who use tympanic measurement as to guide the re-deployment of firefighters could be putting personal at increased risk of heat stress. For instance, un-prediction of core temperature (by tympanic devices) could lead to firefighters being allowed to re-enter hazardous environments with dangerously elevated core temperatures. This has the potential to put the firefighter at risk of developing heat illness, which may subsequently impact the performance of their fire suppression duties and place other firefighters at undue risk. Therefore, other measures that could serve as a more accurate proxy for core temperature need to be considered. Heart rate, blood pressure and subjective ratings have been recently disregarded as accurate individual predictors of core temperature (Talbot 2012; Brearley et al. ND; Armstrong et al. 2010), so pursuing other indicators of thermal stress should be a top priority. Until a suit a reliable proxy measures have been developed, firefighters (and their health and safety advisors) will continue to rely on a range of markers together with their own professional judgment.

In conclusion, the current findings show that tympanic temperature devices do not accurately reflect firefighters' core temperature across different conditions. While tympanic temperature devices are easily implemented on the fire ground, true reflections of core temperature are not attainable from the device. Unfortunately, an accurate proxy measure of core temperature is not yet evident, so fire agencies must prioritize investigating other practical markers of core temperature as part of a broader heat stress management plan for firefighters.

References

Aisbett B, Larsen B, Nichols D (2011) Firefighter Health and Safety, Fire Note, Issue 80, 1-4.

Ambulance Victoria (2012) ‘Protocols’, Victoria, Australia.

Amoateng-Adjepong Y, Del Mundo J, Manthous CA, (1999) ‘Accuracy of an Infrared Tympanic Thermometer’, CHEST, 115(4); 1002-1005.

Armstrong LE, Johnson EC, Casa DJ, Ganio MS, McDermott BP, Yamamoto LM, Lopes RM, Emmanuel H (2010) ‘The American Football Uniform: Uncompensable Heat Stress and Hyperthermic Exhaustion’, Journal of Athletic Training, 45(2); 117-127.

Baladay GJ, Berra KA, Golding LA, Gordon NF, Mahler DA, Myers JN, Sheldahl LM, (2000) ACSM's Guidelines for Exercise Testing and Prescription. Philadelphia, PA: Lippincott Williams & Wilkins.

Barr D, Gregson W, Sutton L, Reilly T (2009) ‘A practical cooling strategy for reducing the physiological strain associated with firefighting activity in the heat’, Ergonomics, 52(4); 413-420.

Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE (2002) ‘ National Athletic Trainers’ Association Position Statement: Exertional Heat Illnesses’, Journal of Athletic Training, 37(3): 329-343.

Brearley M, Norton I, Trewin T, Mitchell C (n.d) ‘Fire fighter cooling in tropical field conditions’, Northern Territory: National Critical Care and Trauma Response Centre.

Bryne C, Lim C (2007) ‘The ingestible telemetric body core temperature sensor: a review of validity and exercise applications’ British Journal of Sports Medicine, 41, 126-133.

Byrne C, Lim CL (2007) ‘The ingestible telemetric body core temperature sensor: a review of validity and exercise applications’, British Journal of Sports Medicine, 41: 126-133

Casa DJ, Becker SM, Ganio MS, Brown CM, Yeargin SW, Roti MW, Siegler J, Blowers JA, Glaviano NR, Huggins RA, Armstrong LE, Maresh CM (2007) ‘Validity of Devices That Assess Body Temperature During Outdoor Exercise in the Heat’, Journal of Athletic Training, 42(3): 333-342.

Domitrovich JW, Cuddy JS, Ruby BC (2010) ‘Core-Temperature Sensor Ingestion Timing and Measurement Variability’, Journal of Athletic Training, 45(6); 594-600.

Gagnon D, Lemire BB, Jay O, Kenny GP (2010) ‘Aural Canal, Esophageal, and Rectal Temperatures During Exertional Heat Stress and the Subsequent Recovery Period’, Journal of Athletic Training, 45(2); 157-163.

Ganio MS, Brown CM, Casa DJ, Becker SM, Yeargin SW, McDermott BP, Boots LM, Boyd PW, Armstrong LE, Maresh CM (2009) ‘ Validity and Reliability of Devices That Assess Body Temperature During Indoor Exercise in the Heat’, Journal of Athletic Training, 44(2); 124-135.

Goodman DA, Kenefick RW, Cadarette BS, & Cheuvront SN (2009) ‘Influence of Sensor Ingestion Timing on Consistency of Temperature Measures,’ Med. Sci. Sports Exercise, 41(3); 597-602.

Hansen R, Daley W, Leelarthaepin B (1993) ‘the effect of facial airflow on the estimation of exercise core temperature by infrared tympanic thermometry’ Australian Journal of Science and Medicine in Sport, 25(1);26 – 31.

International Association of Fire Fighters, Project Heroes Task 1: A Review of Modern Fire Service Hazards and Protection Needs, Washington, D.C.: Occupational Health and Safety Division, IAFF; 2003.

Mazerolle SM, Scruggs IC, Cara DJ, Burton LK, McDermott BP, Armstrong LE, Maresh CM (2010) ‘Current Knowledge, Attitudes, and Practices of Certified Athletic Trainers Regarding Recognition and Treatment of Exertional Heat Stroke’, Journal of Athletic Training, 45(2); 170-180.

Pryor RR, Seitz JR, Morley J, Suyama J, Guyette FX, Reis SE, Hostler D (2012) ‘Estimating core temperature with external devices after evectional heat stress in thermal protective clothing’, Prehospital Emergency Care, Early Online: 1-6.

Rhea MR, Alvar BA, Gray R (2004) ‘Physical Fitness and Job Performance of Firefighters’, Journal of strength and Conditioning Research, 18(2); 348-352.

Talbot EA (2012) ‘The Effects of Rectal Temperature and Hydration Status on Perceptual Ratings in Dehydrating Males’, Honors Scholar Theses, Paper 276, http://digitalcommons.uconn.edu/srhonors_theses/276

Wilkinson DM, Carter JM, Richmond VL, Blacker SD, Rayson MP (2008) ‘The Effect of Cool Water Ingestion on Gastrointestinal Pill Temperature’, Official Journal of the American College of Sports Medicine, 523 – 528