Portable prehospital methods to treat near-hypothermic shivering cold casualties

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Abstract

Objectives To compare the effectiveness of a single-layered polyethylene survival bag (P), a single-layered polyethylene survival bag with a hot drink (P+HD), a multi-layered metalized plastic sheeting survival bag (MPS: Blizzard Survival), and a multi-layered MPS survival bag with four large chemical-heat pads (MPS+HP: Blizzard Heat) to treat cold casualties.

Methods Portable cold casualty treatment methods were compared by examining core and skin temperature, metabolic heat production and thermal comfort during a 3-h, 0°C cold-air exposure in seven shivering, near-hypothermic men (35.4°C). The hot drink (70°C, ~400ml, ~28kJ) was consumed at 0, 1 and 2 h during the cold-air exposure.

Results During the cold-air exposure, core-rewarming and thermal comfort were similar on all trials ($P = 0.45$ and $P = 0.36$, respectively). However, skin temperature was higher (10-13%, $P < 0.001$, large effect sizes $d > 2.7$) and metabolic heat production lower (15-39%, $P < 0.05$, large effect sizes $d > 0.9$) on MPS and MPS+HP than P and P+HD. The addition of heat pads further lowered metabolic heat production by 15% (MPS+HP vs. MPS, $P = 0.05$, large effect size $d = 0.9$). The addition of the hot drink to polyethylene survival bag did not increase skin temperature or lower metabolic heat production.

Conclusions Near-hypothermic cold casualties are rewarmed with less peripheral cold stress and shivering thermogenesis using a multi-layered MPS survival bag compared with a polyethylene survival bag. Prehospital rewarming is further aided by large chemical heat pads but not by hot drinks.

Key words: Rewarming; Hypothermia; Thermogenesis; Multiple Trauma; Frostbite; Wilderness Medicine.

Introduction

To prevent hypothermia related mortality it is vital to develop portable methods to attenuate heat loss that casualties and first-responders can use as part of prehospital care whilst they await more sophisticated medical facilities.[1,2] Multiple-layering that includes a vapor proof barrier and insulation has recently been highlighted as important for cold protection.[3,4] Unfortunately, being cumbersome and heavy (2.5 kg), the methods used in these studies have limited portability. A more portable cold protection method option is a survival bag constructed of multiple layers of metalized plastic sheeting (MPS: Blizzard Survival weight 0.4 kg). The effectiveness of this survival bag to protect shivering human cold casualties' compared with other vapor proof barriers remains unknown. Portable heat sources that may benefit cold casualties are limited to chemical heat pads and the ingestion of hot drinks, as body-to-body contact is ineffective in rewarming shivering cold casualties.[5] Although a recommended practice to support shivering,[1] no study has investigated whether hot drink ingestion has thermally beneficial effects for cold casualties. As cold drinks reduce core temperature and subjective thermal discomfort during exercise-induced hyperthermia[6] it might be hypothesized that hot drinks may increase core temperature and thermal comfort in shivering cold casualties'. Large chemical heat pads are more effective than spontaneous thermogenesis to rewarm persons with inhibited shivering;[7] however, it remains unclear if they are effective to rewarm shivering cold casualties. This study's objective was therefore to compare the effectiveness to treat cold casualties of a single-layered polyethylene survival bag, a single-layered polyethylene survival bag with a hot drink, a multi-layered metalized plastic sheeting survival bag, and a multi-layered MPS survival bag with four large chemical-heat pads.

Methods

Study Design

A crossover study was performed where participants completed all trials in a random order. Randomisation was completed by SJO (www.randomizer.org). The study received University Ethics Committee approval.

Participants

Seven healthy men (mean ± SD: age, 21 ± 3 years; height, 178 ± 5 cm; nude body mass, 70.5 ± 5.2 kg; body fat, 10 ± 3%) volunteered for the study after giving written informed consent. Participants reported no infection, and did not take medication or nutritional supplements six weeks before or during the study. To standardize nutritional status and physical activity, participants completed a food and activity diary for the 24 h before the first trial, which they then repeated before each subsequent trial. In the 24 h before each trial, participants also consumed water equal to 35 ml per kilogram body mass, and refrained from alcohol and exhaustive exercise.

Experimental Procedures

In four trials, participants were made near-hypothermic by cold-water immersion, after which they completed a 3-h 0°C cold-air exposure in an environmental chamber using one of four cold casualty treatments: a single-layered polyethylene survival bag (P: 3-mil (~0.08 mm thick) polyethylene, weight 0.25 kg, packed size 24x15x1 cm: Figure 1A), a single-layered polyethylene survival bag with a hot drink (P+HD), a multi-layered MPS survival bag (MPS:

Blizzard Survival bag, weight 0.39 kg, packed size 21x11x4 cm: Figure 1B), and a multi-layered MPS survival bag with four large chemical heat pads (MPS+HP: Blizzard Survival Heat bag, weight 1.90 kg, packed size 30x25x7 cm; surface area of each large chemical heat pad 24x30 cm). The fifth trial was a control (CON) where participants remained seated in an ambient temperature 20°C, relative humidity (RH) 41%).

After an overnight fast, participants arrived at 0800 h. After voiding, anthropometric and body composition measures of height, body mass and body fat were obtained (InBody230, Biospace, South Korea). Urine was analysed for specific gravity (Atago, Japan). Participants then fitted a rectal thermistor 12 cm beyond the anal sphincter (2020 Series, Grant, UK) and began a 30-min seated rest dressed in a tracksuit, swim shorts, t-shirt, socks and shoes. On the cold stress trials, participants were then immersed up to the axilla in 13.0 ± 0.1°C stirred water wearing swim shorts until core temperature reached 36°C. After, participants were carefully dried, dressed in dry shorts, socks and gloves, and fitted with skin thermistors. Participants then entered an environmental chamber and after 5-min seated were given, and instructed how to use, one of the portable cold casualty field methods. Participants remained seated for the 3 h in the environmental chamber (0°C, RH 40% and wind velocity 0.2 m/s: Delta Environmental Systems, UK). On CON, participants were fitted with rectal and skin thermistors and sat for the same duration as in the cold-air exposure trials but were free to choose their attire. During all trials participants consumed flavoured water from an insulated container equal to 6 ml per kg of body mass at 0, 60 and 120 min. The flavoured water contained negligible energy content (~7 kJ per 100 ml). Pilot testing confirmed that the 15-min drinking period meant the average drink temperature consumed was 70°C on P+HD and 36°C on all other trials. During the trials, core and skin temperature was measured continuously via thermometry. Mean skin temperature was calculated by an equation adjusted for regional proportions.[8] Metabolic heat production and energy expenditure were determined by indirect calorimetry techniques and equations[9,10] as described in detail previously.[11] Thermal discomfort was determined by perceived thermal comfort (McGinnis 13-point scale, 1 = so cold I am helpless, 7 = comfortable, 13 = so hot I am sick and nauseated)[12] and pain sensation to cold (10-point scale, 1 = barely cool to 10 = unbearable pain)[13]. Following cold-air exposure, participants were rewarmed in 40°C water and monitored for 2 h.

Statistical Analyses

Based on the typical standard deviation of 0.6°C and 9 W/m^2 (co-efficient of variation ~3% and 7%, respectively),[11] and using standard alpha (0.05) and beta values (0.8), a sample size of seven was estimated (G*Power, Version 3.1.2) to have adequate statistical precision to detect a 0.8°C and 12 W/m^2 difference in skin temperature and metabolic heat production between any two conditions during the cold-air exposure (two-tailed). The main outcome measures, skin temperature and metabolic heat production, were averaged using the arithmetic mean for each hour and compared between trials by two-way fully repeated-measures analyses of variance (ANOVA). Significant main effects and interactions were explored by one-way repeated measures ANOVA, uncorrected Fisher's LSD and Tukey's post hoc tests. The meaningfulness of the differences between cold casualty treatment methods were quantified by Cohen's *d* effect sizes, which can be interpreted as small (0.2), medium (0.5), and large (0.8).[14] A one-way repeated measures ANOVA was also used to compare baseline, cold-water immersion time, and physiological responses at the start the cold-air exposure. Thermal discomfort was analyzed by Friedman test. Statistical significance was accepted at $P < 0.05$. All statistical analyses were completed using a computerized statistical software package (GraphPad Prism version 6, GraphPad Software, USA).

Results

Baseline physiological responses and cold-water immersion times

At the start of the trials, body mass, body fat, urine specific gravity, resting core temperature and metabolic heat production were similar (70.5 ± 5.2 kg, $P = 0.41$; 10 ± 3%, $P = 0.55$; 1.023 ± 1.004, $P = 0.69$; 36.7 ± 0.2 °C, $P = 0.73$; 52 ± 14 W/m^2, $P = 0.88$). Cold-water immersion time was similar on all the cold stress trials (32 ± 17 min, $P = 0.55$).

Cold-air exposure thermal responses

At the start of the cold-air exposure core and skin temperature and metabolic heat production were similar ($P = 0.12$, $P = 0.38$ and $P = 0.69$, respectively). Irrespective of cold casualty treatment method employed, core temperature was similar during the 3-h cold-air exposures ($P = 0.33$). Core temperature declined to a low of 35.4 ± 0.3°C within the first 20 min and then returned to within normal control core temperatures by the third hour of cold-air exposure ($P = 0.38$).

Core temperature rewarming was achieved by different thermal and metabolic effects that suggest lower cold stress with MPS and MPS+HP than P and P+HD (Figure 2, Table 1). Lower peripheral cold stress was clear from the 2.5 to 3.1°C higher skin temperature with MPS and MPS+HP than P and P+HD (10-13%, $P < 0.001$, large effect sizes $d > 2.7$, Figure 2A, Table 1). Throughout the cold air exposure skin temperature was higher on MPS and MPS+HP than P and

P+HD in the first ($P < 0.05$), second ($P < 0.01$) and third hours ($P < 0.01$). Skin temperature was lower than CON throughout all cold-air exposures trials ($P < 0.01$).

Metabolic heat production was lower when cold casualties used MPS and MPS+HP than P and P+HD (15-38%, $P < 0.05$, large effect sizes $d > 0.9$, Figure 2B, Table 1). Further, when participants used MPS and MPS+HP, metabolic heat production was not different to CON in the second and third hour of the cold-air exposure ($P = 0.21$ and 0.80, respectively). In contrast, metabolic heat production was greater than CON in the third hour of the cold-air exposure when participants used P and P+HD ($P = 0.01$ and < 0.001, respectively). The addition of heat pads further lowered metabolic heat production by 15% (MPS+HP vs. MPS, $P = 0.05$, large effect size $d = 0.9$). Energy expenditure responses were similar to metabolic heat production (Figure 2C, Table 1). The addition of the hot drink to polyethylene survival bag did not increase skin temperature or lower metabolic heat production.

Subjective thermal discomfort was not statistically different between cold casualty treatments (thermal comfort $P = 0.36$, pain sensation to cold $P = 0.14$, Figure 3); however, MPS+HP was the only treatment where thermal discomfort was not greater than CON.

Discussion

This study compared the effectiveness of portable prehospital field methods to treat near-hypothermic (35.4°C) shivering cold casualties in 0°C environment. Core temperature rewarming was accomplished (~1°C) by all methods within 3 hours. The prehospital methods, however, accomplished rewarming with a different peripheral cold stress and shivering thermogenesis. Near-hypothermic cold casualties were rewarmed with less peripheral cold stress and shivering thermogenesis using a multi-layered, MPS survival bag compared with a polyethylene survival bag. Prehospital rewarming was further aided by large chemical heat pads. The differences in skin temperature and metabolic heat production observed between the prehospital methods should be considered meaningful and clinically relevant based on the observed large or very large effect size statistics. The differences between methods in the present study are also relatively large, 2 to 3-fold greater, when compared to another recent cold casualty study that evaluated the benefit of wet clothing removal or the addition of a vapour barrier.[4]

To the authors' knowledge, this is the first study, to provide empirical evidence, that a hot drink provides no rewarming benefit to a shivering cold casualty. As participants consumed approximately 1.3 L of 70°C flavoured water, which likely represents the upper limits of what is practically portable, this study highlights that hot drinks have limited application for the treatment of cold casualties, and does not support prehospital accidental hypothermia guidelines to administer hot drinks to hypothermic patients. Instead guidelines should emphasize the consumption of sugary drinks irrespective of temperature.[1]

Limitations

In this study, participants were not blind to each prehospital method which may have influenced their reports of thermal discomfort. Rectal core temperature assessment has received recent criticism for monitoring cold casualties during rewarming because it is slower at responding than the esophageal method.[1] The choice of a rectal thermistor in this study is less problematic as the interest was not to determine the precise temperature but to compared differences between prehospital methods. Further, skin temperature and metabolic heat production were the main outcome measures and not rewarming determined by core temperature. The performance of prehospital methods used in this study remains unclear in persons other than uninjured healthy young men (e.g. women, children, elderly or injured persons). Encouragingly, it is likely that the differences between prehospital methods observed in uninjured healthy young men would be similar or even greater in persons other than uninjured healthy young men as they are at greater cold-injury risk because of thermoregulatory disadvantages (i.e. greater surface area, smaller total body mass and musculature, and impaired peripheral vasoconstriction and thermogenesis in older and injured persons).[15]

Practical implications

The multi-layered MPS survival bag with heat pads should be the first choice to treat all casualties. Where it is not possible to carry the MPS survival bag with heat pads, the multi-layered MPS survival bag without heat pads should be chosen due to its superior performance compared to the single-layered, vapor-proof polyethylene survival bag.

Conclusions

In conclusion, near-hypothermic cold casualties are rewarmed with less peripheral cold stress and shivering thermogenesis using a multi-layered MPS survival bag compared with a polyethylene survival bag. Prehospital rewarming is further aided by large chemical heat pads but not by hot drinks.

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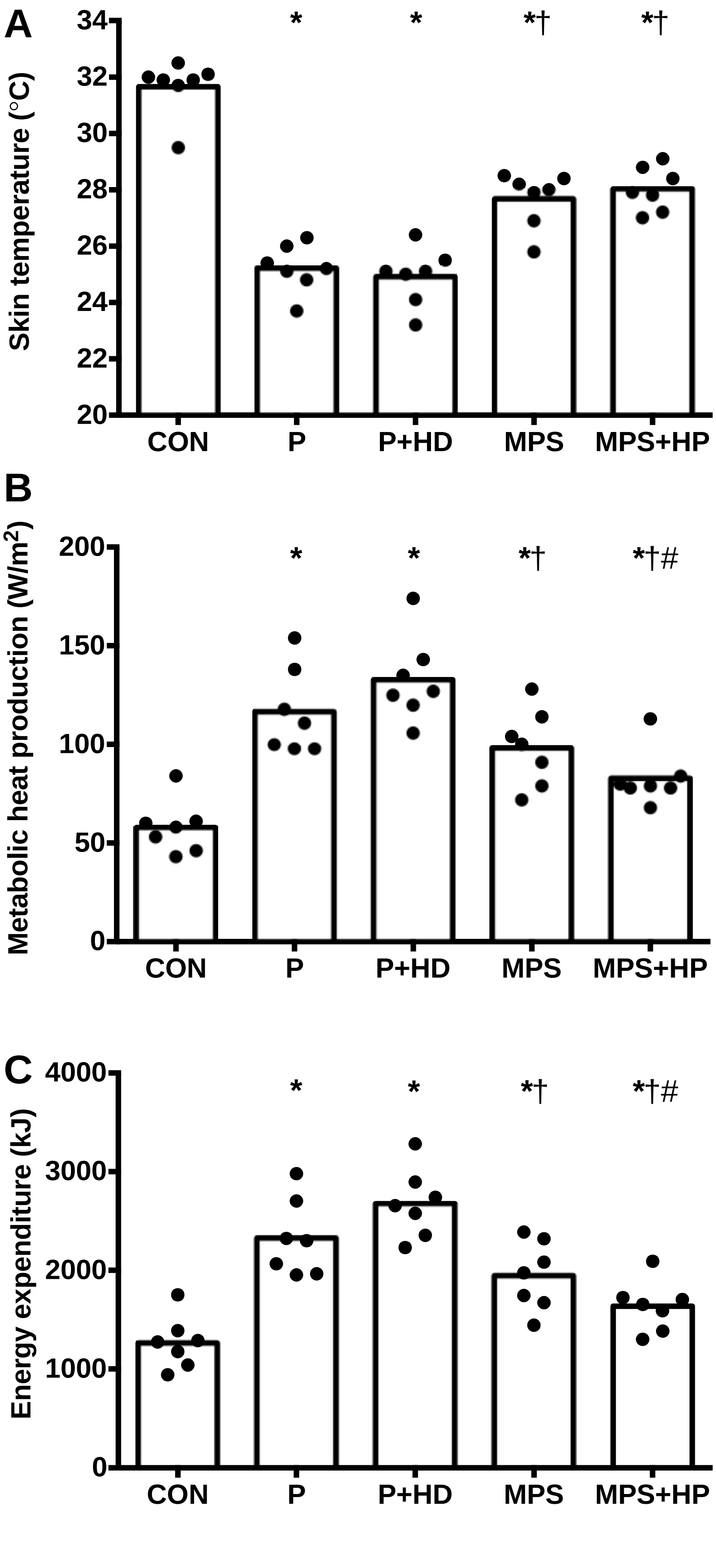
Figure legends

Figure 1 Polyethylene survival bag (A) and a multi-layered metallized plastic sheeting survival bag (B: Blizzard Survival bag).

Figure 2 Mean thermal responses to a 3-h cold-air exposure (0°C) when shivering cold casualties are use a single-layered polyethylene survival bag (P), a single-layered polyethylene survival bag with a hot drink (P+HD), a multi-layered MPS survival bag (MPS: Blizzard Survival bag), and a multi-layered MPS survival bag with four large chemical heat pads (MPS+HP: Blizzard Survival Heat bag). The fifth trial was a control (CON) where participants remained seated in an ambient temperature 20.2 ± 1.7°C, relative humidity (RH) 41 ± 6%). Data are presented as individual responses (displayed as dot plots) and mean (as boxes). Statistical annotation are from post hoc multiple comparison tests to examine differences between treatment methods, * indicates difference to CON ($P < 0.05$), † indicates difference to P and P+HD ($P < 0.05$). # indicates difference to MPS ($P < 0.05$).



A
B
C
Skin temperature (°C)
Metabolic heat production (W/m²)
Energy expenditure (kJ)
34
32
30
28
26
24
22
20
200
150
100
50
0
4000
3000
2000
1000
0
CON
P
P+HD
MPS
MPS+HP
*
*†
*†#

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Figure 3 Mean thermal discomfort responses to a 3-h cold-air exposure (0°C) when shivering cold casualties are use a single-layered polyethylene survival bag (P), a single-layered polyethylene survival bag with a hot drink (P+HD), a multi-layered MPS survival bag (MPS: Blizzard Survival bag), and a multi-layered MPS survival bag with four large chemical heat pads (MPS+HP: Blizzard Survival Heat bag). The fifth trial was a control (CON) where participants remained seated in an ambient temperature 20.2 ± 1.7°C, relative humidity (RH) 41 ± 6%). Data are presented as individual responses (displayed as dot plots) and median (as boxes). Statistical annotation are from post hoc multiple comparison tests to examine differences between treatment methods, * indicates difference to CON ($P < 0.05$).

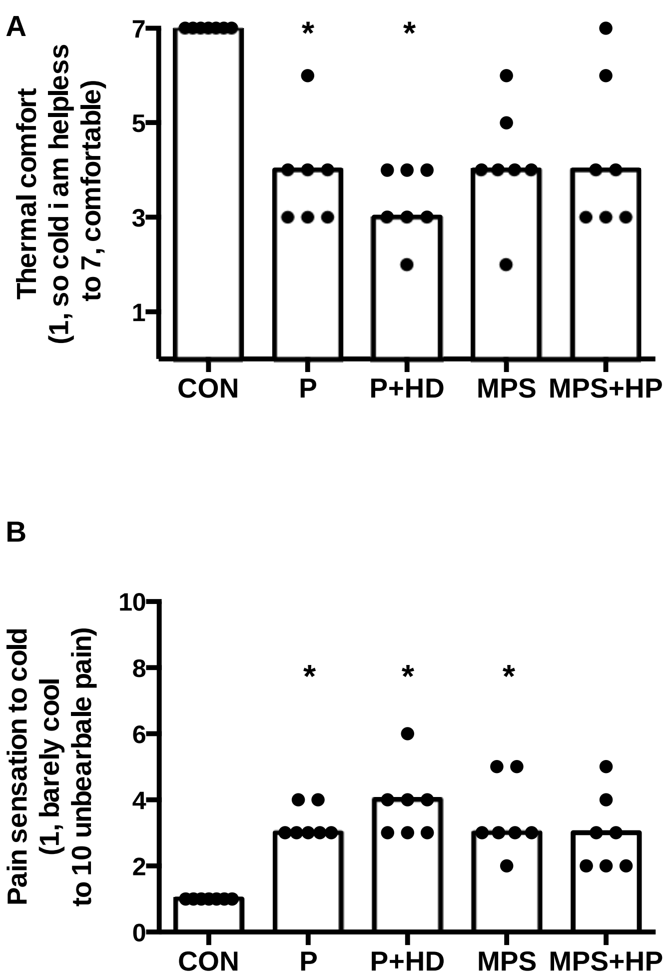

Table 1. Differences in thermal responses and energy expenditure to a 3-h cold-air exposure (0°C) when shivering cold casualties use a single-layered polyethylene survival bag (P), a single-layered polyethylene survival bag with a hot drink (P+HD), a multi-layered MPS survival bag (MPS: Blizzard Survival bag), and a multi-layered MPS survival bag with four large chemical heat pads (MPS+HP: Blizzard Survival Heat bag)

	Mean absolute difference	95% confidence interval of difference	Relative difference (%)	Cohen's *d* effect size
Skin temperature (°C)				
P+HD vs. P	-0.3	-0.7 to 1.3	-1	-0.3 (small)
*MPS vs. P	2.5	1.4 to 3.5	10	2.7 (large)
*MPS+HP vs. P	2.8	1.2 to 4.4	11	3.4 (large)
*MPS vs. P+HD	2.8	1.6 to 3.9	11	2.8 (large)
*MPS+HP vs. P+HD	3.1	1.8 to 4.4	13	3.4 (large)
MPS+HP vs. MPS	0.4	-1.3 to 2.0	1	0.3 (small)
Metabolic heat production (W/m^2)				
P+HD vs. P	16	-10 to 42	14	0.7 (medium)
*MPS vs. P	-18	-42 to 5	-15	-0.9 (large)
*MPS+HP vs. P	-34	-63 to -5	-29	-1.8 (large)
*MPS vs. P+HD	-35	-48 to -21	-26	-1.7 (large)
*MPS+HP vs. P+HD	-50	-69 to -31	-38	-2.7 (large)

*MPS+HP vs. MPS	-15	-37 to 6	-15	-0.9 (large)
Energy expenditure (kJ)				
*P+HD vs. P	349	-105 to 803	15	1.0 (large)
*MPS vs. P	-380	-871 to 110	-16	-1.0 (large)
*MPS+HP vs. P	-34	-1204 to -179	-30	-2.1 (large)
*MPS vs. P+HD	-35	-1013 to -445	-27	-2.1 (large)
*MPS+HP vs. P+HD	-50	-1379 to -684	-39	-3.4 (large)
*MPS+HP vs. MPS	-15	-729 to 108	-16	-1.0 (large)

Note: * indicates statistical difference ($P < 0.05$) determined by uncorrected Fisher's LSD post hoc test. The 95% confidence interval of difference is from Tukey's post hoc test.