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NAVAL HEALTH RESEARCH CENTER

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SUMMARY

Problem

Hypothermia may occur with prolonged exposure to cold air or water. Recovery from hypothermia involves isolating the individual from the cold environment and utilizing a rewarming strategy. In a military field situation, it is difficult to employ the latest clinical rewarming strategy. The current major rewarming strategies fall into three groups: 1) passive rewarming, 2) active external heating, and 3) active internal heating. Controversy continues as to the best rewarming procedure for use in the field.

Objective

The primary objective of this research was to compare the effectiveness of three field rewarming procedures: 1) United States Marine Corps (USMC) issue extreme cold weather sleeping bag; 2) USMC bag with external heat applied using a Heatpac device (Alcatel Innova, Norway); and 3) USMC bag with external heat applied using the Heatpac and internal heat applied with a Humipac (prototype Alcatel Innova, Norway) attachment which supplies warm humidified breathing air.

Approach

Measurements including rectal (T_{re}), esophageal (T_{es}), mean weighted skin temperatures (T_{msk}), heart rate (HR), and oxygen uptake ($\dot{V}O_2$) were recorded on six male subjects on three separate days within a one week period in the sequential conditions as outlined (1, 2, 3) above, but in random order. The subjects fasted for 10 hours prior to each test and the study was conducted each time at the same time of day to control for circadian rhythms. After a blood pressure check, each subject wearing swim suit/shorts only, lowered themselves into a cold water bath (12.1°C ± 1.3) and sat on a chair with the water level up to the apex of the sternum. Recorded cooling time began once the subject was seated. The subject remained in cold water until either his rectal temperature dropped 1°C from baseline, he requested to get out, or after an elapsed time of 85 minutes. During immersion, HR, T_{re}, T_{es}, and skin temperatures were recorded every five minutes. At the end of immersion (before exiting the cold water bath) $\dot{V}O_2$ was determined and body temperatures were again recorded. The subject then exited the tank, dried off, changed into dry shorts, and entered the sleeping bag. One of the three rewarming strategies was then employed. Skin temperatures were recorded every five minutes throughout rewarming. $\dot{V}O_2$ was determined at 15, 45, 90, and 120 minutes of rewarming.

Results

Rewarming for 120 minutes with all three methods (sleeping bag alone = SB; Heatpac in sleeping bag = HP; Heatpac with Humipac in sleeping bag = HHP) was associated with significant ($p<0.01$) and progressive increases in T_{re}, T_{es}, and T_{msk}. Also, $\dot{V}O_2$ decreased significantly ($p<0.01$) in all three conditions with no differences noted. External heating using the HP appeared to suppress the rise in core temperature as indicated by the changes in T_{re} and T_{es}. The T_{msk} with HHA was higher than with the SB. Using the HHA, the core temperatures were higher or similar to the temperatures associated with the SB or HP. The HHA warms the skin surface more than the SB and raises core temperature more than the HP. When significant differences are computed for T_{es}, T_{re}, and T_{msk}, the HHA is either similar or faster at rewarming than the SB or HP. In addition, T_{es}, T_{re}, and T_{msk} were similar or higher for the HHA than the SB or HP.

Conclusions

The Heatpac with the Humipac attachment supplying warm, humidified air may be the preferred rewarming device for use in the field, but further research under actual field conditions is necessary.

INTRODUCTION

Hypothermia may occur with prolonged exposure to cold air or water (1,2,3). Recovery from hypothermia involves removing the individual from the cold environment and utilizing a rewarming strategy. Three major rewarming strategies include: 1) passive rewarming, 2) active external heating, and 3) active internal heating. Controversy continues regarding the best rewarming procedure for use in the field.

During passive rewarming, the individual is removed from cold air or water, dried off, placed in a sleeping bag, and allowed to shiver until fully recovered. Provided that the cold stress has been sufficiently removed, it is assumed that the body can spontaneously generate sufficient heat to rewarm itself (2).

Rapid external rewarming is the application of direct heat to the external body surfaces. Rewarming is thus facilitated by heat generated from external sources. Examples of rapid external rewarming include: warm water baths, heat cradles, diathermy, and liquid heated suits (2,3).

Active internal rewarming involves administering heat directly to the "core" of the body, which is usually considered the contents of the trunk beneath the skeletomuscular and adipose shell (2). Examples include: peritoneal dialysis, mediastinal irrigation, extracorporeal circulation, hemodialysis, and intragastric or colonic lavage (2,3). These methods involve surgical procedures and are not practical in a field setting. However, an active internal technique for the field is the breathing of warm, humidified air. Warm moist air is also used in hospitals to help rewarm surgical patients (4,5,6,7,8). The problem is that most of the devices are bulky, heavy, and impractical to use in the field. While investigating a field device used to provide warm humidified air, Sterba (9) had a problem with excessive inspiration temperature.

One study (9) concluded that only passive heating should be done in the field, while others (8,10,11,12,13,14,15) contend that active external, or active internal (5,6,7,8,16,17,18) strategies should be employed. One problem with active external or internal rewarming is that shivering may be decreased, resulting in slower rewarming (13,19). The purpose of this study was to compare the effectiveness of three field rewarming procedures: 1) United States Marine Corps (USMC) issue extreme cold-weather sleep-ing bag, 2) cold-weather sleeping bag with external heat applied using a Heatpac device, and 3) cold-weather sleeping bag while breathing warm, humid air from a Heatpac with Humipac (prototype) attachment.

METHODS

Six male subjects participated in this study. The physical characteristics of the subjects are presented in Table 1.

Table 1. Physical characteristics of the subjects

Subject	Age (yrs)	Height (cm)	Weight (kg)	Body Fat (%)
1	34	186.1	93.6	17.6
2	35	170.2	70.6	9.0
3	25	184.2	89.8	23.1
4	35	181.6	89.6	16.9
5	29	168.9	80.6	17.9
6	29	175.9	106.3	24.4
Mean±SD	31±2	177.8±3.0	88.4±4.9	18.1±2.2

Medical Screening

Subjects were informed of the nature, purpose, and potential risks of the experimental procedures, and they signed informed consent and privacy act statements. All subjects underwent medical screening, which included a medical history questionnaire, body composition assessment, and clearance to participate by a medical officer. Height and weight were determined by standard methods. Body density was determined using skinfolds from three sites: chest, abdomen, and mid-thigh (20). Body fat was determined from body density using the Siri equation (21).

Measurement Systems

A Polar Vantage XL monitor (Polar USA, Inc., Stamford, CT 06902) was used to determine heart rate. Core temperatures were measured using sterile disposable Sher-I-Temp thermistors. Skin temperatures were measured using silver skin thermocouples. A Grant 1200 series (12-Bit) Squirrel Meter/Logger was used to record core and skin temperatures.

Oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were determined using open-circuit spirometry. Expired gas was collected for 1.5 minutes in a Collins 100 liter plastic bag connected to a Hans-Rudolph two-way valve. Expired air was analyzed for O_2 and CO_2 using Amatek S-3A/I oxygen and CD-3A carbon dioxide analyzers (Amatek, Pittsburgh, PA), respectively. Expired gas volume was measured using a gas meter (Rayfield Equipment, Waitsfield, VT). Blood pressure was measured using a digital blood pressure monitor (Carolina Biological Supply Co.).

Experimental Protocol

Each subject reported to the laboratory on three separate days within a one-week period. The influence of circadian rhythms on body temperature was controlled by conducting each test at the same time of day (22). Rewarming methods were presented to each subject in random order. The three methods included passive heating (shivering in the sleeping bag), active external heating (shivering in the sleeping bag with external heat provided by a Heatpac), and active internal heating (shivering in the sleeping bag with Heatpac plus Humipac attachment). The testing protocol consisted of 15 minutes of rest in air at room temperature (23°C), cold water immersion (12.1°C) for up to 85 minutes, four to eight minutes of transition to the rewarming bag, and rewarming for 120 minutes. Measurements included rectal (T_{re}), esophageal (T_{es}), and mean weighted skin temperatures (T_{msk}) (23), as well as heart rate (HR) and oxygen uptake ($\dot{V}O_2$).

Subjects fasted for 10 hours prior to each test. Upon arrival to the laboratory, body weight was recorded. Each subject then inserted a rectal thermistor to a depth of 20 cm. An esophageal probe was inserted to heart level. Skin thermistors were placed on the forehead, right cheek, Baseline measurements of blood pressure, T_{re}, T_{es}, skin temperatures, HR, and $\dot{V}O_2$ were recorded after 15 minutes of rest at room temperature (23°C) immediately before cold-water immersion. Each subject then lowered himself into the cold water bath (12.1°C ± 1.3) and sat on a chair with the water level up to the apex of the sternum. Recorded cooling time began once the subject was seated. The subject remained in cold water until either his rectal temperature dropped 1°C from baseline, he requested to get out, or after a total elapsed time of 85 minutes. During immersion, HR, T_{re}, T_{es} and skin temperatures were recorded every five minutes. At the end of immersion (before exiting the cold-water bath), $\dot{V}O_2$ was determined, and body temperatures were recorded again.

After completion of the cold-water immersion, the subject climbed out of the water tank, dried off, changed into dry shorts, and climbed into the sleeping bag placed on a gurney. Transition time into the bag ranged from four to eight minutes. Skin temperatures, T_{re}, and T_{es} were recorded at five minute intervals throughout rewarming. $\dot{V}O_2$ was determined at 15, 45, 90, and 120 minutes of rewarming.

Rewarming Systems

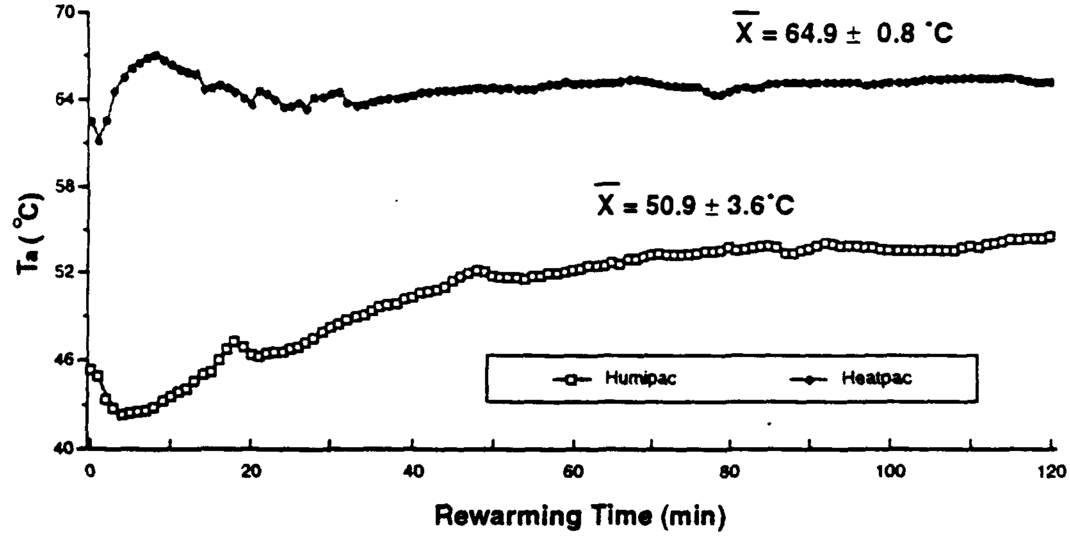
The rewarming systems included: 1) the sleeping bag (SB), 2) sleeping bag with Heatpac (HP) (Alcatel Innova, Norway), and 3) sleeping bag with Heatpac plus Humipac attachment (HHA) (prototype Alcatel Innova, Norway). The sleeping bag was a USMC extreme cold weather bag II, weighing 4.3 kg and rated for temperatures to -50°F. Insulation consisted of waterfowl feathers, down, and polyester batting.

The Heatpac (HP) is a portable heater weighing 750 g. It utilizes heat from a slow-burning stick of charcoal, assisted by a battery- (size "D" dry cell, 1.5 V) driven fan. The fan pulls air into the unit and pushes it out via heat tubes or tentacles. A catalytic converter removes carbon monoxide and other gases from the burning charcoal. When in use, four heat tubes or tentacles are attached to the HP. The HP is placed inside the sleeping bag near the feet, with the exhaust vented outside of the bag. Inside the bag, two tentacles are placed along the sides of the body, while the other two tentacles are placed on the inside of each thigh.

The Heatpac with Humipac attachment (HHA) is a prototype device that weighs 2.0 kg. Air flows from the HP through the Humipac attachment to a face mask from which the subject inhales and exhales. The Humipac attachment is a double-tube cylinder (one tube inside the other). The inner chamber is lined with a moisture-absorbent material. A 100 ml plastic reservoir is connected to the inner chamber. The reservoir is filled with water, then "squeezed," pushing water into an inner chamber. The moisture-absorbent material then becomes saturated; absorption capacity is 200 g. During operation, warm air flows through the chamber and becomes saturated with water.

During rewarming with the HHA, a temperature probe was placed directly above the area where the warm, humidified air first exits the HHA. The mean near-inspired air temperature exiting the HHA was 50.9 ± 3.6°C (Fig. 1). The air then travels through a 10 cm rubber neck, through a two-way valve, and into the face mask. Preliminary studies on the HHA (unpublished data) reflect actual inspired air temperatures 2° to 6°C less than temperature coming directly out of Humipac. For this study, the range of air temperature entering the mouth ranged from 45.4 to 47.9°C.

Fig. 1 Heatpac Tentacle and Humipac Near-inspired Air Temperature



Note: Actual inspired air temperature is predicted to be 45.4-47.9°C (authors unpublished data).

In this study, the charcoal fuel element was ignited at the start of immersion, allowing the HP and HHA to warm up for at least 40 minutes. In all tests, the HP or HHA was set on its highest temperature setting. The HP produced air temperatures of 64.9 ± 0.8°C (Fig. 1).

During rewarming, the HHA is placed on the subject's chest. The subject's nose and mouth are covered by a standard oral-nasal mask, and the subject inhales warm, humid air. Exhalation is vented to the atmosphere by a two-way valve attached to the mask. The main body of the HHA generates heat to the chest area. The HHA has a cloth cover over the HP and Humipac. During each test the relative humidity of the air going to the subject from the HHA was checked before and after application, and was constant at 100 percent. All experiments were conducted at an environmental temperature of 23°C.

Statistical Analysis

Data were analyzed using repeated measures multivariate analysis of variance (MANOVA). The alpha level was set at 0.05. The rate of rewarming was calculated using the rewarming slope (regression line) of the three rewarming methods.

RESULTS

Cold-water immersion ranged from 40 to 85 minutes (71.1 ± 15.0 min). During immersion, T_{re} and T_{es} initially increased above baseline values in all subjects. After 5 to 15 minutes of cold-water immersion, T_{re} and T_{es} began to decrease. However, at the end of cold-water immersion, T_{re} and T_{es} remained above baseline values in five and three of 18 tests, respectively. T_{re} decreased 1°C in four tests whereas T_{es} decreased in one test (Table 2).

Table 2. Baseline to end of immersion changes (n=18 tests)

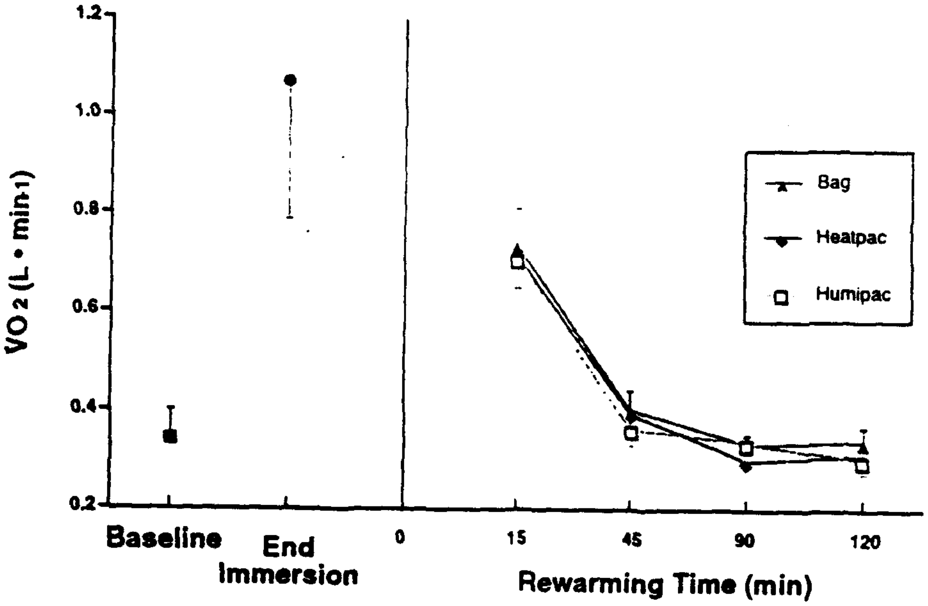
Measurement	Baseline	End of Immersion	Difference
T_{re} (°C)	37.0 ± 0.2	36.6 ± 0.6	0.4 ± 0.5
T_{es} (°C)	36.8 ± 0.2	36.5 ± 0.6	0.3 ± 0.5
T_{sk} (°C)	29.1 ± 1.1	18.8 ± 1.3	10.4 ± 2.9*
$\dot{V}O_2$ (l·min^{-1})	0.35 ± 0.05	1.08 ± 0.29	0.73 ±0.28*
HR (bpm)	68 ± 10	77 ± 8	9 ± 14

* $p<0.05$

Rewarming Responses

All subjects shivered vigorously during the initial stages of rewarming. However, the intensity of shivering decreased with gradual rewarming of the body. Rewarming for 120 minutes with all three methods was associated with significant ($p<0.01$) and progressive increases in T_{re}, T_{es}, and T_{sk}. As rewarming progressed, $\dot{V}O_2$ decreased significantly ($p<0.01$) in all three rewarming treatments, but no difference between treatments occurred (Fig. 2).

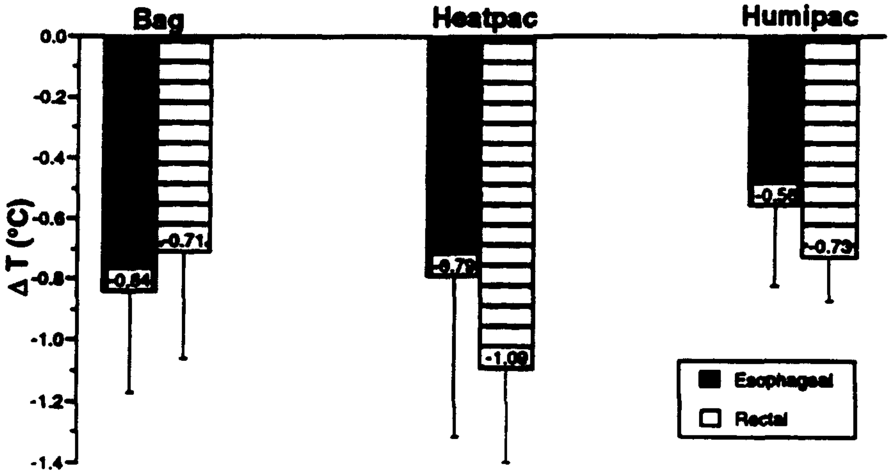
Fig. 2 Oxygen Uptake During Three Rewarming Protocols



Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

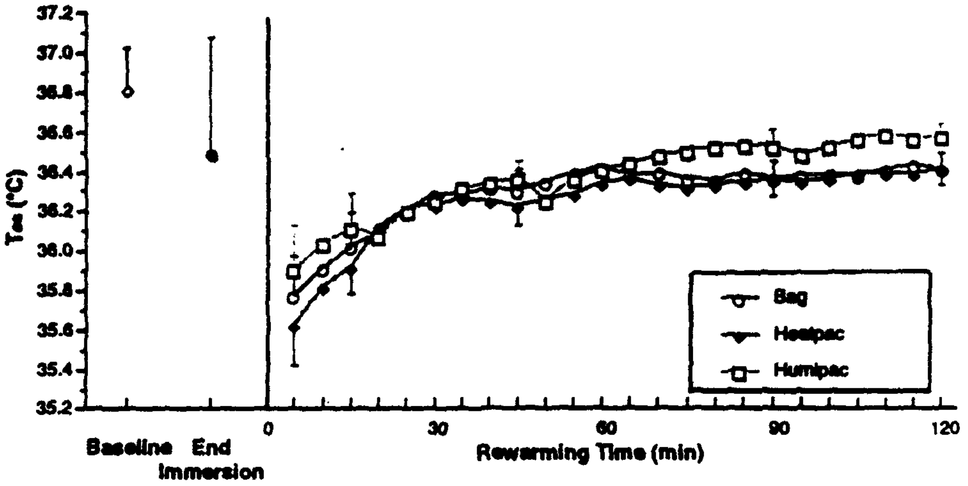
Afterdrop in T_{es} was 0.6 ± 0.3°C with the HHA, 0.8 ± 0.5°C with the HP, and 0.8 ± 0.3°C with the SB. Afterdrop in T_{re} was 0.7 ± 0.4°C with the SB, 0.7 ± 0.2°C with the HHA, and 1.1 ± 0.3°C with the HP (Fig. 3). No significant differences in afterdrop were found among the three rewarming methods in T_{re} or T_{es}.

Fig. 3 Esophageal and Rectal Temperature Afterdrop



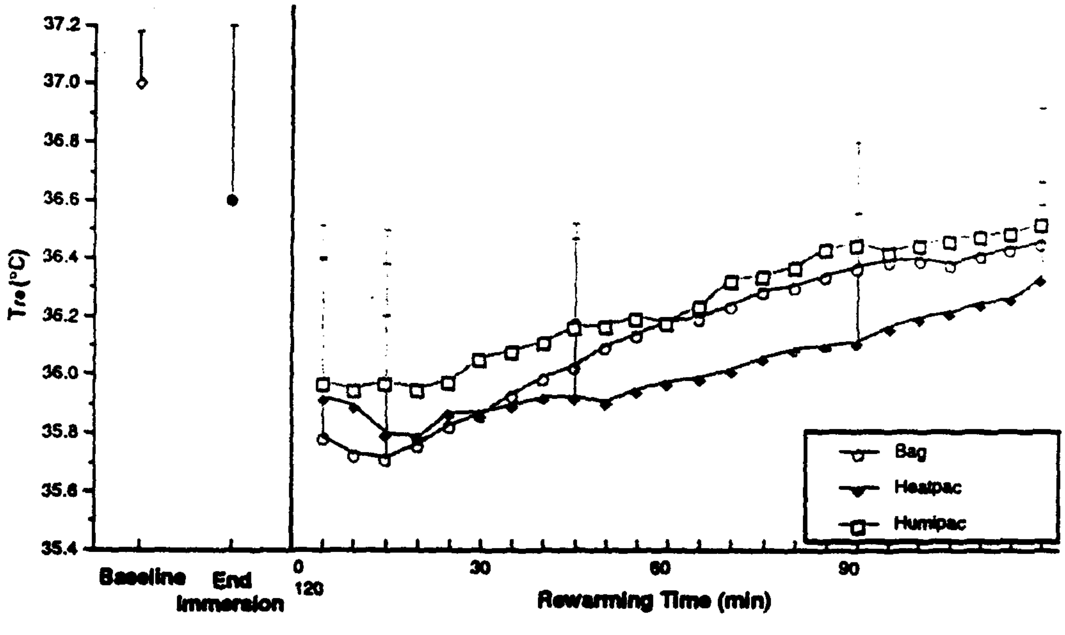
Analysis of the interaction effect between rewarming time and rewarming method reveals that rewarming occurred faster with HHA compared to HP ($p<0.01$) and SB ($p<0.01$). With the application of the HHA, HP, and SB, T_{es} rewarmed at 1.4°C·hr^{-1}, 1.2°C·hr^{-1}, 1.1°C·hr^{-1} respectively (Fig. 4). With the application of the SB, HHA, and HP, T_{re} rewarmed at 2.0°C·hr^{-1}, 1.6°C·hr^{-1}, and 1.2°C·hr^{-1} respectively (Fig. 5). The application of the SB method rewarmed subjects significantly faster ($p<0.01$) than HP.

Fig. 4 Mean Esophageal Temperature During Rewarming



Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

Fig. 5 Mean Rectal Temperature During Rewarming

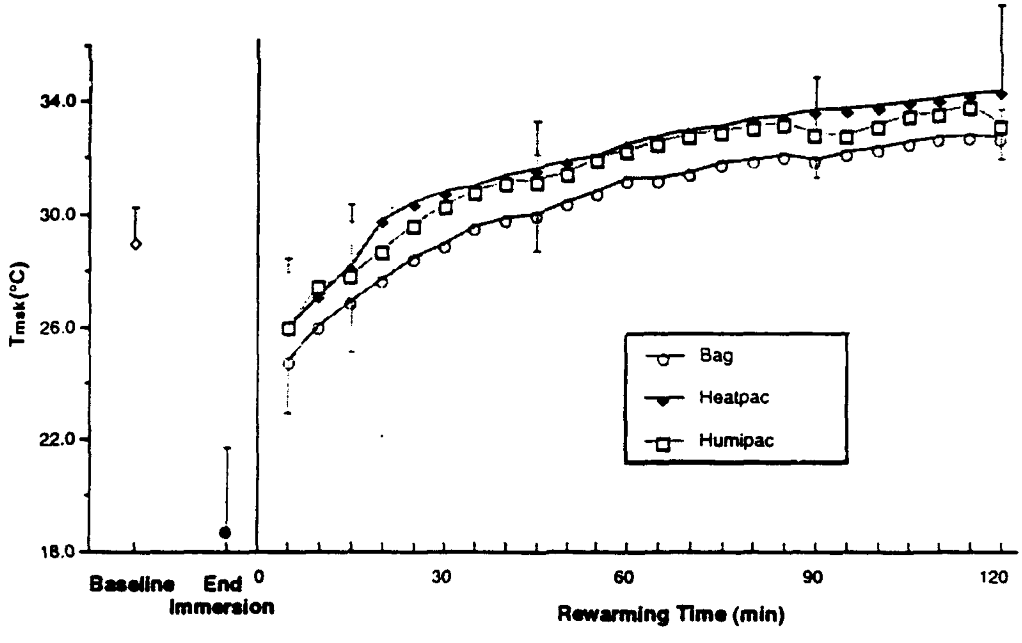


Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

With the application of the HHA, SB, and HP, the condition mean for T_{es} was 36.4 ± 0.2°C, 36.3 ± 0.2°C, and 36.3 ± 0.2°C, respectively. The T_{es} with the HHA was higher ($p<0.02$) than with the HP. The T_{es} condition mean for HHA was similar to T_{es} with the SB. With the application of the HHA, SB, and HP, the condition mean for T_{re} was 36.2 ± 0.4°C, 36.1 ± 0.3°C, and 36.0 ± 0.2°C, respectively. The T_{re} with the HHA was higher ($p<0.02$) than the T_{re} with the HP. The T_{re} condition mean for HHA was similar to T_{re} with the SB.

The rewarming rate for T_{msk} was similar among the three rewarming methods (Fig. 6). However, the condition mean for T_{msk} was 32.0 ± 1.4°C for HP, 31.6 ± 0.5°C for HHA, and 30.4 ± 1.2°C for SB; with the HP greater ($p<0.01$) than the SB, and the HHA ($p<0.05$) greater than the SB.

Fig. 6 Mean Skin Temperature During Rewarming



Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

DISCUSSION

This study compared three different strategies applicable to rewarming individuals in the field. Our analysis suggests the HHA is the most effective and safest rewarming method.

Investigators have shown that T_{es} is the more reliable estimation of core temperature (24,25). When using T_{es}, the findings suggest that the HHA rewarmed subjects faster and tended to have a lower (although not significant) afterdrop then either the HP or SB. An unknown portion of this afterdrop occurred prior to commencement of the treatments. Using a larger sample size in future studies may show a significant reduction in afterdrop for T_{es} in these different conditions.

External heating using the HP system significantly increased T_{msk}. However, the external heating appeared to suppress the rise in core temperature as indicated by the changes in T_{re} and T_{es}. The T_{msk} with HHA was higher than with the SB; with the HHA the core temperatures were higher or similar to the temperatures associated with the SB or HP. The HHA warms the skin surface more than the SB, and raises core temperature more than the HP. When significant differences are computed for T_{es}, T_{re}, and T_{msk}, the HHA is either similar or faster at rewarming than the SB or HP. In addition, the treatment for T_{es}, T_{re}, and T_{msk} were similar or higher for the HHA than the SB or HP.

CONCLUSION

In conclusion, the Heatpac with the Humipac attachment supplying warm, humidified air, may be the preferred rewarming device for use in the field, but further research is necessary.

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13. ABSTRACT *(Maximum 200 words)*

The Heatpac is currently used by the U.S. Marine Corps to warm cold-stressed infantry personnel in the field. Recently, this system has been modified so a small wetting chamber called Humipac can be attached to the Heatpac so personnel can breathe warm humidified air. The air is saturated to 95-99% humidity with a temperature range of 45.3 to 49.4°C. In a series of experiments using a USMC issue sleeping bag, we compared the effectiveness of the Heatpac vs. combined Heatpac/Humipac vs. rewarming by shivering. Subjects wearing only swimming trunks were placed in 12.8°C water for 1 hr. At the end of that period, any of the three interventions were randomly assigned. In all conditions, the subject was placed in a sleeping bag. HR, T_{re} and T_{es} temperatures, and metabolic rates were monitored during the cooling phase and for 120 min during the rewarming phase. Breathing the warm humidified air did not significantly alter the rate of body rewarming. In some cases, normal shivering induced as large an increase in core temperature as did the active interventions. Additional studies are underway to investigate the relative role that these various rewarming systems have on thermogenesis.

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