NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 9-90

EFFICACY AND SAFETY OF PRE-HOSPITAL REWARMING TECHNIQUES TO TREAT ACCIDENTAL HYPOTHERMIA

LCDR JOHN A. STERBA, MC, USNR

MAY 1990

NAVY EXPERIMENTAL DIVING UNIT

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Inhalation rewarming (IR) and peripheral rewarming (PR) were evaluated for reducing after drop and accelerating rewarming rates following cooling to clinical hypothermia. Wearing dry suits in an ice bath, eight subjects were cooled to termination criteria (rectal or esophageal temperatures (Tr and TE) = 35.0°C). Rewarming in rescue sleeping bags was in windy, cold air (2°C). After drop (AD) was characterized by duration to minimum Tr and Te plus recovery time to Tr and Te values at the onset of rewarming. Rewarming rates 30 and 60 minutes past maximum AD for Te and Tr were measured. By ANOVA, IR and PR evaluated separately or combined did not significantly influence AD duration, AD recovery, or rewarming rates. Maximum AD: Tr = 35.0 ± 0.0(SE)°C, Tr = 34.9 ± 0.1(SE)°C. With hazards identified (PR: carbon monoxide = 300-600 ppm and IR: burning the face) and no physiological benefit, IR and PR are not recommended for pre-hospital treatment of mild hypothermia.

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I. INTRODUCTION

Controversy exists as to the ideal pre-hospital method for rewarming the accidental hypothermia victim in the field. Some authors recommend active external rewarming (1-5) while others recommend active internal rewarming for the treatment of accidental hypothermia (6-10). Conflicting results comparing the continued drop in body core temperature during rewarming (i.e. after drop) between active external and internal rewarming (6,8,11) may be explained by the differences in protocols for rewarming in human and animal model experimentation. Criticism of previous studies investigating pre-hospital rewarming techniques include insufficient number of subjects, lack of control condition (e.g. breathing cold air), and not measuring esophageal temperature which reflects cardiac temperature. These criticisms were addressed in this study investigating the benefit of adding peripheral rewarming and/or inhalation rewarming with the hypothermic subject in a rescue sleeping bag in a windy, cold air environment.

II. METHODS

Eight, healthy U.S. Navy divers from the Navy Experimental Diving Unit (NEDU) volunteered as subjects in these studies. Physical characteristics (mean ± SD) were age: 31.8 ± 4.6 yr, weight: 84.1 ± 9.7 kg, height 182.4 ± 7.0 cm, percent body fat: 22.5 ± 4.5%, body surface area: 2.06 ± 0.12 m^2. Preceding exposure to cold water to lower body core temperature, subjects avoided medications, alcohol, tobacco, and physical exertion. Diet was not modified (e.g. carbohydrate or lipid loading) beyond ensuring an adequate breakfast and hydration prior to cold water exposure. A minimum of 48 hours elapsed between five cold water exposures for each subject. None of the subjects had any history of cold related disorders (e.g. hypothermia, frostbite or nonfreezing cold injury). This experimental protocol was approved by the Review Committee for Protection of Diver Subjects at NEDU.

Esophageal body core temperature (Te) was measured by a swallowed thermistor (Hi-Lo Temp, 9 FR., model 90050, Mallinckrodt Critical Care, Glens Falls, NY) passed through the nose and held at 43 cm from the nares. At this level in the esophagus, indirect measurement of the cardiac temperature can be made (11-12). A rectal thermistor (YSI model 401, Yellow Springs, OH) was inserted 15 cm into the rectum and taped in place. Immediately proximal to the inhalation rewarming mask, inspiratory temperature was measured (YSI model 401). Temperature sensing accuracies were ± 0.1°C for all thermisters compared to calibrated quartz and electronic thermometers traceable to the National Bureau of Standards. Temperatures were monitored every 30 sec during cooling and rewarming using an automated on-line Diver Monitoring System (DMS) described elsewhere (13).

During the cooling phase, the subject was cooled in ice water (1°C) in a one-man immersion tank. Wearing a dry suit (Viking, model Pro, Viking America, Solon, OH), a light weight undergarment (Thinsulate, model M-200, Diving Unlimited International, San Diego, CA), and thin long underwear, the subject assumed a head-out immersion position. Hands and feet were out of the ice water, thus avoiding any risk of nonfreezing cold injury to the digits. The neck and back of the head were exposed to the cold water, but kept dry with a thin latex dry suit hood. The limit of cooling was 35.0°C, Tr or Te, which is the commonly accepted lower limit for cold exposure experiments (14) and also the upper limit of clinical mild hypothermia (15).

Transfer of the subjects by stretcher from the ice water to the cold room a few feet away took 3 minutes avoiding muscular contraction which can induce body core temperature after drop. The cold room atmosphere was monitored for oxygen and carbon dioxide with a fresh cold air supply preventing oxygen from falling below 20% or carbon dioxide from rising above 1%. The air in the cold room was well-mixed using a refrigeration fan.

During the rewarming phase, the following rewarming techniques were evaluated with the subjects wearing thin long underwear: two rescue sleeping bags, designed for field rewarming from hypothermia. Bag 1 was the Thermal Recovery Capsule (model LGS-TRC-A, Lifeguard Systems, Inc., Hurley NY) and Bag 2 was the Heat Pac Rescue Bag (A.B. Russell, Waitsfield, VT) both having 7.6 cm of uncompressed loft equalling 12.2 clo of insulation (16). Both bags were used cold, being left in the cold room (2°C) prior to placing the subject in either bag on top of a stretcher.

Bag 2 is designed to also be actively heated using the Heat Pac (A.B. Russell) charcoal-fueled heat generator. This small device delivers heated fresh air by a battery operated fan and two, 1 m long baffles surrounding the chest, axilla and neck of the subject inside Bag 2. The exhaust from the charcoal heater contains high concentrations of carbon monoxide (CO) which was carried out of the bag and cold room by lengthening the exhaust tube.

Preliminary studies measured the CO levels during simulated rewarming of a mannequin in Bag 2 within a two-man tent. Concentration of CO was measured at the mannequin's mouth and chest, inside the tent, and from the exhaust hose. Measurements were also made with the exhaust hose unattached or if the single D cell battery was installed upside down, which spins the Heat Pac fan in the opposite direction.

Inhalation rewarming used a portable device (Heat Treat, Thermogensis, Victoria, B.C., Canada) which delivers humidified, heated air by a facemask. Maximum tolerated inspiratory temperature was maintained at 45°C.

The five field rewarming techniques listed in Table 1 allowed evaluation of one variable at a time: (a) Bag 1 vs. Bag 2, both cold, (b) Bag 2 cold vs. Bag 2 with peripheral rewarming (PR), (c) Bag 2 cold vs. Bag 2 cold with inhalation rewarming (IR), (d) Bag 2 cold vs. Bag 2 with PR, and (e) Bag 2 cold vs. Bag 2 with PR and IR. These various rewarming techniques were randomized among the subjects to control for any ordering effect. Experiments were conducted at the same hour of the day to avoid any potential influence of circadian rhythm. The actual time and body core temperatures when the subject was hoisted out of the ice water marked the beginning of the rewarming period. After drop (AD) was characterized by duration (AD dur) to minimum Tr and Te plus recovery time (AD rec) to Tr and Te values at the onset of rewarming. Rewarming rates 30 and 60 min past maximum AD for Te and Tr were determined by least squares analysis. Mean values and standard deviations for grouped data from all eight subjects are reported. Any differences between the five exposures was determined by analysis of variance (ANOVA) with a paired Student's T-test for individual comparisons. Statistically significant differences in Tr and Te during the cooling phase and the effects of PR and/or IR plus differences between Bag 1 and Bag 2 on maximum AD, AD dur, AD rec, and rewarming rates for both Tr and Te were accepted at $p < 0.05$.

III. RESULTS

Table 1 lists the five exposures which allowed comparisons of PR, IR and the two rescue bags. In the cooling phase shown in Table 2, there are no significant differences in initial Tr (37.1°C) and Te (37.0°C). With termination criteria of 35.0°C for either Tr or Te, mean values of final body temperature were slightly above 35.0°C (Tr = 35.4°C, Te = 35.5°C). These final temperatures define the onset of the AD during the rewarming phase.

In the Figure, the mean esophageal body temperature for all five experimental conditions is shown for both cooling and rewarming phases to illustrate the after drop (AD), AD duration time (AD dur), and AD recovery time (AD rec). In Table 3, there were no differences in the AD for all five exposures, Tr = 35.0°C and Te = 34.9°C. Likewise, in Table 4, there were no differences for AD duration and AD recovery times between all five experimental conditions for either Tr or Te. Table 5 illustrates the rewarming rates at 30 and 60 min past the AD which were also not significantly different between experimental conditions for either Tr or Te.

To summarize, there were no differences between the two rescue bags, and no effect to decrease AD indices or improve rewarming rates with PR and/or IR in subjects cooled to a minimum body core temperature ethically allowed for human experimentation.

Regarding carbon monoxide (CO) levels measured on a mannequin under normal operations over a two-hour period (n=7), the Heat Pac charcoal burning unit produced trace carbon monoxide (CO) levels at the mouth (2.0 ppm), chest (4.0 ppm), and inside the tent (1.5 ppm) compared to control background measurements (1.1 ppm). The CO from the heater exhaust hose outside the tent was initially over 600 ppm, but stabilized over a two-hour period between 300-400 ppm. With the exhaust hose disconnected, which happened inadvertently a few times due to poor connector design, the CO level at the mannequin's chest ranged from 305 to 410 ppm and at the mouth, 125 to 238 ppm. Reversing the battery caused the chest CO level to initially rise to 600 ppm and mouth to 208 ppm, but combustion slowly went out over 10-20 min. Igniting the charcoal insert with an integral fuse caused the tent to fill with smoke with CO levels between 300-400 ppm. Failure rate for the fire to go out with the charcoal inserts was 27% (n=30). The unit's exhaust hose was only 30 cm long, requiring an extension to be added to take the exhaust out the sleeping bag and tent. The exhaust connector with the unit was replaced with a permanent connector to prevent CO poisoning during manned experiments.

Numerous unsafe characteristics of the Heat Treat IR device were observed: (a) explosive ignition of the propane canister burned the arms of three operators, (b) the unit became too hot to handle and melted the plastic flooring, (c) difficulty to control inhalation temperature resulted in a mild first degree burn of the face in one subject, despite constant monitoring in a laboratory setting, and (d) high dyspnea was noted by all eight subjects due to water from condensation restricting airflow in the breathing tubes.

Bag 2 (Heat Pac) was unanimously preferred over Bag 1 (Thermal Recovery Capsule) due to having draw strings to limit air pockets within the bag, having litter-carrying straps, being adaptable to surround a victim already in a thick sleeping bag, and the outer covering being made of very durable water-proof materials. Bag 2 is made in green and orange colors, orange being preferred for Arctic use for high visibility. Bag 1 could not limit drafty voids inside the bag, could not easily accept another inner sleeping bag, and did not have litter-carrying straps.

IV. DISCUSSION

Most authors agree that rapid peripheral rewarming is the treatment of choice in accidental hypothermia (1,3,17-21). However, rapid peripheral rewarming may lead to potential complications from peripheral vasodilation leading to ventricular fibrillation (18,22-24) and cardiac arrest (25) from sudden cooling of the myocardium as well as hypovolemic shock secondary to a reduced central blood volume (22-23). The risk of hypovolemic shock due to diuresis and fluid redistribution is especially severe in hypothermia of slow-onset (7). This has lead to the recommendation that hypothermia of slow onset should be treated by slow rewarming whereas rapid rewarming is felt to be safe for hypothermia of rapid onset (23,26). Ventricular fibrillation and rewarming hypovolemic shock are potential problems that may go undetected and be difficult to manage in the remote setting without pre-hospital medical training, vital signs interpretation, and cardiac monitoring.

To avoid the risks of peripheral rewarming, core rewarming techniques have been proposed to deliver heat to the central organs and blood volume, thus avoiding peripheral vasodilation. Core rewarming methods found to be effective, but only useful in the hospital setting, include peritoneal lavage or dialysis using warm fluids (27), extracorporeal circulation rewarming (28-29), thoracotomy with warm fluids bathing the heart (30), endotracheal intubation with either warm air ventilation (31) or combined with warmed intravenous fluids (32).

In 1972, inhalation rewarming through voluntary inspiration of warm, humidified oxygen was first proposed by Lloyd, et al (33) as a first aid measure for central rewarming. Lloyd (33-34) also first proposed that the clinical benefit of inhalation rewarming may be due to the elimination of respiratory heat loss rather than additional heat supplied. However, this assumption was not proven from observations he made from an unspecified number of hypothermic patients in a hospital setting. Since then, many studies have been done which both support (6,8,11,35) and refute (9,36-37) the assumption that inhalation rewarming influences the rewarming rate by heat being delivered to the central body core. Differences in experimental protocol may explain the disparity of results and current confusion over inhalation rewarming. Such differences include: various inhalation rewarming water temperatures (6,8,11,38), inhalation temperatures (8,36) and room air temperatures during rewarming (8), delays in rewarming possibly affecting after drop (11,35,38), varying amounts of insulation worn by a subject during inhalation rewarming, and incomparable body core temperatures made at various sites (6,8,11,38).

Other deep body temperatures measured to determine the effectiveness of rewarming techniques have included rectal and tympanic membrane temperature. Rectal temperature, known to lag behind the response of esophageal temperature to thermal stresses (39), is not an ideal temperature to evaluate rewarming strategies. If the rectal probe is not inserted far enough, 15 cm being considered standard, cold venous blood returning from the lower extremities surrounding the distal rectum may underestimate the rectal temperature. Tympanic membrane temperature, reflecting brain temperature, is influenced by the scalp and external ear temperature (40). Environmental temperature changes during cooling and rewarming may alter the tympanic membrane temperature, without affecting the brain temperature. To date, it has not been demonstrated that the tympanic temperature reflects the temperature of the tissues of the thermoregulatory center, the hypothalamus.

Esophageal temperature, known to represent cardiac temperature (11,41), is an ideal temperature for environmental thermoregulation studies (12,40). Esophageal temperature, by measuring the central, thoracic temperature is useful to determine the influence of either peripheral rewarming or inhalation rewarming on body core temperature after drop and rewarming rate. However, in the three studies supporting inhalation rewarming, esophageal temperature was measured in only one subject (6,11) or in an unspecified number of patients (33-34). Romet and Hoskin (37) demonstrated that inhalation rewarming did not have any effect on the esophageal temperature after drop or rewarming rate compared to shivering alone. This study evaluated both shivering and inhalation rewarming with breathing room air (21°C) as the control (37).

Our study attempted to simulate the field conditions of a cold, windy environment breathing cold air as the control. However, there was <u>no</u> significant effect of inhalation rewarming to raise Te, minimize after drop, or accelerate rewarming rates. In addition, the Heat Pac peripheral rewarming device did not influence AD indices or rewarming rates. Presently, there is no effective method commercially available to actively rewarm the hypothermic victim in the field. Current recommendations emphasize nutritionally supporting the mildly hypothermia victim to best facilitate shivering and non-shivering thermogenesis plus maximizing insulation to limit convective and conductive heat loss (42-43). Present research is evaluating radio frequency and portable extracorporeal rewarming techniques to actively rewarm hypothermic victims in the field (42-43).

Although inhalation and peripheral rewarming techniques might indeed be helpful for victims of more severe hypothermia, the risk of carbon monoxide poisoning from the Heat Pac charcoal burning device is unacceptably high. Air purity standards for occupational exposure to carbon monoxide are 20 ppm by the U.S. Navy and 10 ppm by federal specification (FED SPEC BB-A-1034) (44). The levels of CO from the Heat Pac device are far above these safe exposure limits if the exhaust hose inadvertently disconnects, the charcoal insert is lighted inside a tent, or the battery is placed in backwards. Likewise, the risk of the Heat Treat inhalation rewarming unit burning the operator and patient is very high.

IV. CONCLUSION AND RECOMMENDATIONS

In the absence of any physiological benefit of peripheral rewarming and inhalation rewarming, used separately or combined, to reduce after drop or improve rewarming rates, plus the safety hazards described above, these techniques cannot be recommended for the pre-hospital management of mild hypothermia. Bag 2 (Heat Pac) would be ideal for use as an outer rescue sleeping bag by using an inner, thick sleeping bag to maximize insulation. Bag 2, in the orange color, should be vacuum-packaged with an Arctic-grade, high-loft down sleeping bag and a vapor barrier to limit body moisture from reducing the insulation of the down bag. Since Bag 1 (Thermal Recovery Capsule) would be too thin to use alone, and cannot easily accept another inner sleeping bag, it is not recommended for use.

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Table 1

Key

Experimental Conditions

Bag 1 (cold)	Bag 1(c)
Bag 2 (cold)	Bag 2(c)
Bag 2 (warm)	Bag 2(w).
Bag 2 (cold) & inhalation rewarming	Bag 2(c)+IR
Bag 2 (warm) & inhalation rewarming	Bag 2(w)+IR

Table 2

Cooling Phase

Rectal Temperature (Tr), Esophageal Temperature (Te)

(mean ± SD, n=8)

	Bag 1(c)	Bag 2(c)	Bag 2(w)	Bag 2(c)+IR	Bag 2(w)+IR	Mean ± SE	Significance
Initial Temp							
Tr	37.3 ± 0.3	37.2 ± 0.4	37.0 ± 0.6	37.0 ± 1.0	37.2 ± 0.2	37.1 ± 0.1	NS
Te	37.0 ± 0.4	36.9 ± 0.2	36.9 ± 0.3	37.0 ± 0.3	37.0 ± 0.2	37.0 ± 0.0	NS
Final Temp							
Tr	35.4 ± 0.3	35.4 ± 0.4	35.3 ± 0.4	35.4 ± 0.6	35.4 ± 0.5	35.4 ± 0.0	NS
Te	35.6 ± 0.6	35.4 ± 0.6	35.3 ± 0.5	35.5 ± 0.5	35.5 ± 0.4	35.5 ± 0.1	NS

Table 3

Rewarming Phase, Afterdrop (°C)

(mean ± SD, n=8)

	Bag 1(c)	Bag 2(c)	Bag 2(w)	Bag 2(c)+IR	Bag 2(w)+IR	Mean ± SE	Significance
Tr	35.1 ± 0.4	35.1 ± 0.6	35.0 ± 0.6	35.0 ± 0.7	35.0 ± 0.6	35.0 ± 0.0	NS
Te	35.1 ± 0.7	34.9 ± 0.7	34.9 ± 0.5	35.1 ± 0.6	34.9 ± 0.4	34.9 ± 0.1	NS

Table 4

AD Duration and AD Recovery Time (min)

(mean ± SD)

	Bag 1(c)	Bag 2(c)	Bag 2(w)	Bag 2(c)+IR	Bag 2(w)+IR	Mean ± SE	Significance
AD Duration							
Tr	16:30 ± 07:15	23:49 ± 20:18	18:09 ± 09:25	21:19 ± 14:21	23:15 ± 15:29	20:37 ± 01.26	NS
Te	07:39 ± 02:59	12:30 ± 04:55	11:15 ± 01:58	07:04 ± 03:35	05:25 ± 01:36	08:47 ± 01:20	NS
AD Recovery Time							
Tr	41:17 ± 20:43	26:36 ± 11:41	46:56 ± 24:36	41:43 ± 20:30	45:45 ± 21:14	40:28 ± 03:38	NS
Te	28:21 ± 12:40	29:09 ± 07:41	29:00 ± 09:38	17:43 ± 07:36	23:15 ± 18:37	25:29 ± 02:14	NS

Table 5

Rewarming Rates (°C/hr)

(mean ± SD)

	Bag 1(c)	Bag 2(c)	Bag 2(w)	Bag 2(c)+IR	Bag 2(w)+IR	Mean ± SE	Significance
30 minute rate							
Tr	0.62 ± 0.34	0.68 ± 0.48	0.60 ± 0.53	0.82 ± 0.48	0.80 ± 0.68	0.70 ± 0.04	NS
Te	1.42 ± 0.62	1.36 ± 0.54	1.57 ± 0.73	2.11 ± 1.00	1.89 ± 1.20	1.67 ± 0.13	NS
60 minute rate							
Tr	0.54 ± 0.28	0.64 ± 0.27	0.74 ± 0.35	0.68 ± 0.39	0.66 ± 0.50	0.65 ± 0.03	NS
Te	0.95 ± 0.32	0.87 ± 0.31	1.20 ± 0.46	1.09 ± 0.40	1.17 ± 0.46	1.06 ± 0.06	NS

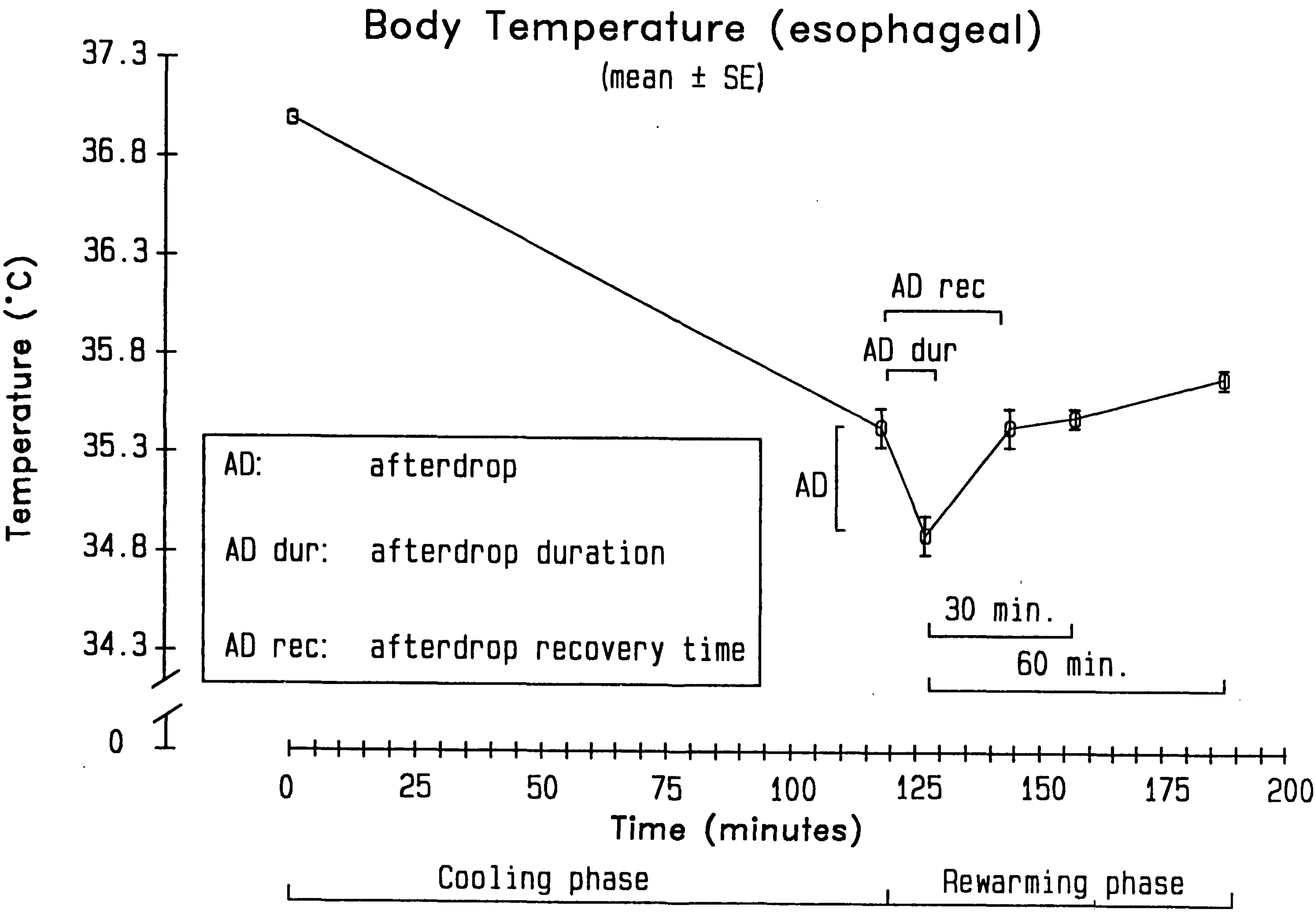

FIGURE 1. Esophageal body temperatures for all five experimental exposures with eight subjects (n = 40).