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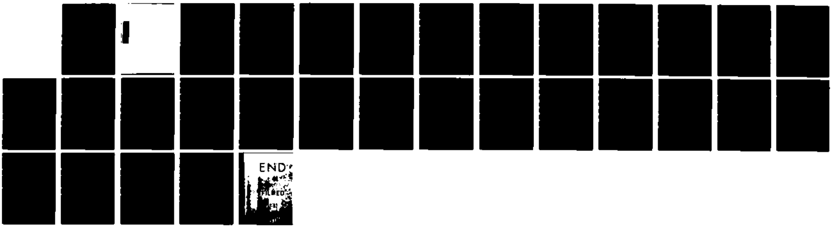

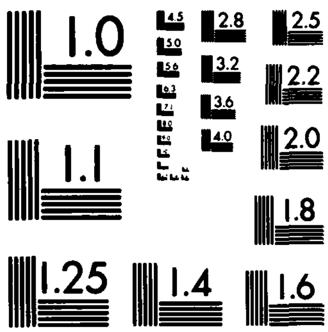

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Navy Clothing and Textile Research Facility (NCTRF) physiologically evaluated the Navy's cold-weather clothing by exposing subjects wearing either the A1 (Extreme-Cold-Weather) clothing ensemble or the A2 (Buoyant, Intermediate-Cold-Weather) clothing ensemble to various environmental temperatures. The environmental temperatures in which the clothing was tested included: 5°F (-15°C), -10°F (-23.3°C), -30°F (-34.4°C), and -40°F (-40°C) for evaluation of

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) the A1 ensemble; and 39°F (3.9°C), 20°F (-6.7°C), 0°F (-17.8°C) and -10°F (-23.3°C) for evaluation of the A2 ensemble. An additional exposure to -40°F was undertaken to compare responses with the Army Arctic gear, and an exposure to 70°F (21.1°C) while standard Navy utility clothing was worn served as a control. Exposures were 3 hours in duration, the first hour of which the subject sat quietly, followed by 1 hour of exercise at 3.5 mph, and again 1 hour of rest. Based on mean skin temperature responses, the results indicate that none of the test garments would keep an inactive person warm for prolonged periods of time (>4.0 hours). Predicted tolerance times ranged from 1.3 hours at -40°F to 3.7 hours at 5°F with the A1 ensemble. Individuals wearing the Army Arctic gear would have been expected to have double the tolerance time at -40°F than those with the Navy clothing. Exercise interspersed with the rest periods would significantly increase exposure time, the extent of which would depend upon the work/rest schedule. (U)

TABLE OF CONTENTS

A

LIST OF ILLUSTRATIONS

LIST OF TABLES

PHYSIOLOGICAL EVALUATION OF A1 (EXTREME-COLD-WEATHER) AND A2 (BUOYANT, INTERMEDIATE-COLD-WEATHER) JACKETS

INTRODUCTION

Since the Navy's cold-weather clothing had been modified by Navy Clothing and Textile Research Facility (NCTRF) personnel, a physiological evaluation of the resulting prototypes was necessary. The A1 (Extreme-Cold-Weather) Jacket, along with entire ensemble, was designed to protect against cold temperatures as low as -40°F, while the A2 (Buoyant, Intermediate-Cold-Weather) ensemble was expected to be worn in temperatures no lower than 0°F.

Evaluation of any cold-weather ensemble should proceed according to the following rationale: (a) the initial heat loss through the clothing should be determined while the subject is sitting quietly with minimal activity in a cold environment and wearing the entire clothing ensemble which would normally be worn under such climatic conditions; (b) following a reasonable period of sitting, during which thermal equilibrium would normally be established if no heat were lost or gained by the individual, a metabolic heat load should be produced by having the fully clothed subject perform moderate work in the same environment; (c) after working, the individual should again sit quietly for a period of time equal in duration to sequence (a). During this time, the metabolic heat lost by the subject through the clothing will again be determined. Depending upon the nature of the clothing's material (for instance, whether it is permeable or impermeable to water vapor transfer), heat loss will occur more or less rapidly than that which occurred in sequence (a).

PROCEDURES AND METHODS

Procedures

Eight Army enlisted personnel volunteered to participate in this study after having the nature of the study and its suspected risks explained to them. Prior to each exposure to the cold conditions, the subjects were weighed, rectal probes were inserted, and thermocouples and EKG electrodes were affixed. After donning the appropriate clothing, the subjects then entered the environmental chamber, which was set at one of the following climatic conditions.

A. For evaluation of the A1 (Extreme-Cold-Weather) Jacket,

1. 5°F (-15°C), wind speed 5 mph (wind chill 0°F);
2. -10°F (-23.3°C), wind speed 3 mph (wind chill -10°F);
3. -30°F (-34.4°C), wind speed 1.8 mph (wind chill -30°F);
4. -40°F (-40°C), wind speed 2.1 mph (wind chill -40°F).

B. For evaluation of the A2 (Buoyant, Intermediate-Cold-Weather) Jacket,

1. 39°F (3.9°C), wind speed 3 mph (wind chill 39°F);
2. 20°F (-6.7°C), wind speed 7.5 mph (wind chill 10°F);
3. 0°F (-17.8°C), wind speed 2.75 mph (wind chill 0°F);
4. -10°F (-23.3°C), wind speed 3 mph (wind chill -10°F).

C. For control testing with utility clothing,

70°F (21.1°C), 50% r.h., no wind.

D. For comparison with the Army Arctic gear,

-40°F (-40°C), wind speed 2.1 mph (wind chill -40°F).

The subjects remained in the arctic chamber for 3 hours. During the first hour, they sat quietly on chairs located near the center of the chamber. They were asked to remain as still as possible, but were permitted to move about if their hands or feet became cold. After 60 minutes had elapsed, the subjects walked on a motor-driven treadmill set at 3.5 mph with no grade for an additional 60 minutes. Following the exercise, the subjects again were told to sit quietly for another 60 minutes.

The following clothing was worn during the 10 exposures.

A. For evaluation of A1 (Extreme-Cold-Weather) Jacket,

1. T-shirt, shorts, socks;
2. Thermal underwear;
3. Navy work uniform (shirt and trousers);
4. A1 ensemble including jacket, trousers, hat and hood;
5. Army Arctic mittens and mitten insert;
6. Army Arctic boots.

Total weight = 8.66 kg (19.1 lbs).

B. For evaluation of A2 (Buoyant, Intermediate-Cold-Weather) Jacket,

1. At 39°F,

   a. T-shirt, shorts, socks;
   b. Navy work uniform;
   c. A2 jacket and hat;
   d. Leather gloves with wool insert;
   e. Shoes.

   Total Weight = 3.39 kg (7.46 lbs).

2. At 20°, 0°F and -10°F,

   a. T-shirt, shorts, socks;
   b. Navy work uniform;
   c. A2 jacket, trousers and hat;
   d. Army Arctic mittens with liner;
   e. Army Arctic hood;
   f. Army Arctic boots.

   Total weight = 7.84 kg (17.25 lbs).

C. For control testing with utility clothing,

1. T-shirt, shorts, socks;
2. Navy work uniform;
3. Shoes.

Total weight = 1.73kg (3.81 lbs).

D. For comparison with Army Arctic gear,

1. T-shirt, shorts, socks;
2. Long underwear;
3. Navy work uniform;
4. Full Arctic gear, including field pant liner and field pants, wool shirt, field jacket liner, field jacket, Arctic liner, Arctic shell, Arctic parka liner, Arctic parka, leather glove liners and leather gloves, Arctic mitten inserts, liner and mittens, Arctic cap and hood;
5. Arctic boots.

Total weight = 12.28 kg (27.0 lbs).

Measurements

The rectal probe, which was made by placing a copper-constantan thermocouple into a soft rubber catheter, was inserted ∿4 inches into the rectum. Ten uncovered thermocouples were affixed to the following sites: big toe, calf, medial thigh, lateral thigh, upper back, chest, upper arm, lower arm, index finger and cheek. Mean skin temperature ($\bar{T}_{sk}$) was calculated by averaging the appropriately weighted skin surface area sites. Every 5 minutes throughout the duration of the 3-hour test, heart rate (HR) was measured on a Beckman dynagraph recorder, while rectal (T_{re}) and skin temperatures were recorded on a Kaye digital output recorder.

Mean body temperature was calculated as: $\bar{T}_b = 0.8\ (T_{re}) + 0.2\ (\bar{T}_{sk})$, °C. The hourly rate of body heat storage was calculated as: $S = [0.97x\ wt\ x\Delta\bar{T}_b] \div$ Body Surface Area, W/m^2.

Oxygen uptake ($\dot{V}O_2$) was measured during the rest and work periods of each exposure. The $\dot{V}O_2$ values could be used as an indication of the increased metabolic heat produced both by the wearing of the heavy clothing and the increase in shivering during exposures in which the clothing itself could not keep the individual sufficiently warm. Oxygen uptake was determined by having the subject breathe for 2 minutes through a low-resistance valve into a Douglas bag. The expired air was analyzed for O_2 content by an Applied Electrochemistry Oxygen Analyzer and for CO_2 content by a Beckman LB-2 CO_2 Analyzer. The volume was then measured in a Tissot spirometer and converted to STPD values. $\dot{V}O_2$ was determined from 3 to 6 times during each exposure: during rest 1 at 25 and 50 minutes, during work at 25 and 50 minutes, and during rest 2 at 25 and 50 minutes.

Statistical Procedure

All variables were analyzed with a two-factor analysis of variance using environment and activity as independent variables. Tukey's post-hoc multiple comparison procedure was used as a follow-up when significant ($p < 0.05$) F values were found.

RESULTS

A1 (Extreme-Cold-Weather) Jacket

Figure 1 presents the final hourly mean (±S.E.) values of T_{re} for all eight test subjects during testing in the four environments for evaluation of the extreme-cold-weather gear. As is evident for all exposures, T_{re} did not decrease significantly during the initial rest period compared with the value before the subject entered the climatic chamber. In all environments, including the control test at 70°F, the work period stimulated a similar rise in T_{re}. Moreover, in all environments, final T_{re} after the work period averaged ∿38.0°C. During the second rest period, T_{re} declined to ∿37.2°C, which represented an average decrease of 0.7°C in all environments.

As seen in Figure 2, mean skin temperature decreased as environmental temperatures decreased. The 60-minute value at 70°F was 29.9°C, then increased to 32.4°C following work, and decreased again to 30.6°C after another 60 minutes of rest. At 5° and -10°F, $\bar{T}_{sk}$ values were similar to each other, but significantly lower than the rest values of 70°F. The $\bar{T}_{sk}$ values following work, however, were similar to those at 70°F. As ambient temperature decreased further, $\bar{T}_{sk}$ decreased. At -30 and -40°F, $\bar{T}_{sk}$ during work remained less than 30°C. For all temperatures, there were no significant differences between the final $\bar{T}_{sk}$ at 60 minutes or 180 minutes.

Mean body temperature ($\bar{T}_b$), which is a weighted average of both rectal and skin temperatures, perhaps would best represent a value of body temperature during cold exposure. Figure 3 represents the mean (± S.E) values of $\bar{T}_b$ for the eight test subjects. At 70°F, $\bar{T}_b$ averaged 35.7°C after the first rest period, rose to 36.7°C during the work phase, and subsequently declined to 36.0°C following the second rest period. In the 5° and -10°F environments in which the A1 ensemble was evaluated, $\bar{T}_b$ after the first hour did not differ significantly from the control values. However, $\bar{T}_b$ was significantly lower after 60 minutes in the -30 and -40°F environments. During work, $\bar{T}_b$ in the 5°F and -10°F environments were similar to the control values. Again, by virtue of the lower $\bar{T}_{sk}$ values, the values during work at -30°F and -40°F were slightly lower than those obtained at 70°F. Following the second rest period, $\bar{T}_b$ was lower in all four environments compared with the 70°F value, with the lowest values found in the -30 and -40°F environments.

Heart rate values during exposure to all four experimental environments were no different from the control values at 70°F. HR averaged ∿80 beats/min during both rest 1 and rest 2, while it increased to ∿125 beats/min during the work period.

The rate of heat loss, as indicated by a negative rate of heat storage, was similar in all four test environments (Figure 4). In the 70°F climate, the individuals lost an average of -20.5 ± 3.3 W/m^2 of heat during the initial rest. The metabolic heat produced during the second hour caused a positive heat storage of 42.7 ± 5.5 W/m^2. During the final rest period, the rate of heat loss amounted to -30.9 ± 4.2 W/m^2. Compared with the control, the rate of heat loss during the first hour was significantly increased by 150-200% in the cold environments. However, because of large intra- and inter-individual variation, there was no significant difference among the four test environments in the rate of heat loss for each hour of exposure. In addition, there was no evidence that the rate of cooling occurred at a more rapid rate following the exercise period, since the rates of heat loss in the first hour were similar to those experienced during the third hour.

As the ambient temperature declined, the values of $\dot{V}O_2$ during rest 1 and 2 increased significantly from the control values (70°F), as seen in Table I, indicating an increase in metabolic rate in response to the lowered temperatures. At -40°F, $\dot{V}O_2$ was increased by 63% over the resting value at 70°F. During work, $\dot{V}O_2$ at temperatures $\leq$ 5°F was higher by 25-33% than at 70°F. The second rest period showed values similar to the first rest period in that a significant rise in $\dot{V}O_2$ was evident at temperatures -5°F and below.

Army Arctic Gear

No difference between the Army Arctic gear and the Navy Extreme-Cold-Weather clothing was noted in T_{re} during rest 1 and work at -40°F (see Figure 1). During the hour of inactivity in rest 2, however, T_{re} declined by 0.3°C more while the Navy clothing was worn.

While the Army Arctic gear was worn (Figure 2), mean skin temperature remained somewhat elevated during the -40°F exposure. The $\bar{T}_{sk}$ was 2 to 3°C higher during rests 1 and 2 and 4.0°C higher during work with the Army gear than when the Navy Extreme-Cold-Weather clothing was worn. These higher $\bar{T}_{sk}$ values were reflected in higher $\bar{T}_b$ values for the individuals wearing the Army Arctic gear (Figure 3). Rates of heat loss were similar in both the Army and the Navy cold-weather clothing during rest at -40°F (Figure 4); during work, however, heat storage occurred at a more rapid rate while the Army Arctic gear was worn (mean rate of heat storage = 69.5 $\pm$ 4.2 W/m^2 compared with 43.5 $\pm$ 3.7 W/m^2 for the Navy A1 ensemble).

A2 (Buoyant, Intermediate-Cold-Weather) Jacket

Figure 5 presents the final hourly mean ($\pm$ S.E.) values of T_{re} for all eight test subjects during testing in the four environments for evaluation of the intermediate-cold-weather jacket. During the first hour of sitting, T_{re} declined by 0.2 to 0.3°C, which is comparable to the decline of 0.3°C during quiet sitting at 70°F. During the work periods in the test environments, rectal temperature did not increase as much as it did during the control, but the difference (0.1°C) was insignificant. During the second hour of rest, the T_{re} declined by $\sim$0.6°C in all environments, including the control at 70°F. Final T_{re} averaged $\sim$37.2 in the four test environments compared with 37.3° in the 70°F climate ($p>0.05$).

Following the first hour of rest in the test environment, mean skin temperature was lower by $\sim$3.4°C (Figure 6). (Note: $\bar{T}_{sk}$ was lower in the 39°F environment than in the 20°F, but this was most likely the result of the wearing of the A2 pants along with the jacket in environments $\leq$20°F.) During work, $\bar{T}_{sk}$ was found to rise to $\sim$31°C in the 39°, 20°, and 0°F environments. At -10°F, however, after 1 hour of exercise, $\bar{T}_{sk}$ rose to only 28.8°F. Following the second hour of rest, $\bar{T}_{sk}$ declined to values similar to those observed after rest 1, with the lowest $\bar{T}_{sk}$ found at -10°F.

Table I. Rate of metabolic heat production (mean ± S. E.) for test subjects (n = 8) wearing A1 (Extreme-Cold-Weather) clothing while sitting (rest) or working (walk) in various environmental temperatures.

Ambient Temperature	Rest (50')		Walk (110')		Rest (170')	
	ml/kg/min	W/m^2	ml/kg/min	W/m^2	ml/kg/min	W/m^2
* 70°F (21.1°C)	3.94 ± 0.31	56 ± 4	16.50 ± 0.50	236 ± 7	4.14 ± 0.31	59 ± 4
5°F (-15°C)	5.96 ± 1.05	85 ± 15	20.72 ± 0.97	296 ± 14	5.85 ± 0.47	84 ± 7
-10°F (-23.3°C)	6.01 ± 0.43	86 ± 6	20.78 ± 0.36	297 ± 5	7.15 ± 0.30	102 ± 4
-30°F (-34.4°C)	6.54 ± 0.57	93 ± 8	21.95 ± 0.93	314 ± 13	6.76 ± 0.58	97 ± 8
-40°F (-40°C)	6.38 ± 0.47	91 ± 7	20.91 ± 0.83	299 ± 12	6.54 ± 0.71	93 ± 10

* Tests were conducted while individuals wore utility clothing.

As seen in Figure 7, mean body temperature followed the same pattern as the $\bar{T}_{sk}$ values. Following rest 1, $\bar{T}_b$ was lower in the test environments than in the 70°F control. (Again, the 39°F value appears low because no overpants were worn in this environment.) During work, $\bar{T}_b$ increased in all environments, with no significant difference from the control at 39°, 20°, and 0°F. $\bar{T}_b$ at -10°F, however, was lower than that observed at 70°F. After the final hour of rest at -10°F, $\bar{T}_b$ was similar to those values seen after rest 1.

Similar to the testing with the A1 ensemble, no differences in HR were observed between the control condition and any of the four experimental tests at 60, 120 or 180 minutes of exposure. While HR's during rest were similar to those found in the A1 tests, the HR values were slightly lower (∿115 beats/min) during the 1-hour work period when the A2 ensemble was worn.

As evident from Figure 8, during the first rest period, the rate of heat loss increased as the environmental temperature decreased. There was no difference in rate of heat loss during rest between 39° and 20°F, but these two values were significantly lower than the heat loss observed at 0° and -10°F. Walking on the treadmill elicited a positive heat storage under all conditions. The rate was higher, however, during exercise at 39° and 20°F than at 0° and -10°F. Rates of heat loss after the second hour of rest were similar to those observed during the first hour of rest. Unlike the rates of heat loss for the first rest period, however, there was no difference in heat loss between the 39° and 20°F environments and the 0° and -10°F environments.

During the first and second hours of rest, the $\dot{V}O_2$ values were similar for the three tests conducted between 0°F and 39°F and did not differ from the control at 70°F (Table II). Values at -10°F were significantly higher than the control for both rest periods. During work, $\dot{V}O_2$ values ranged from 20 to 25% higher in the test environments than in the control.

Table II. Rate of metabolic heat production (mean ± S. E.) for test subjects ($n = 8$) wearing A2 (Intermediate-Cold-Weather) clothing while sitting (rest) or working (walk) in various environmental temperatures.

Ambient Temperature	Rest (50')		Walk (110')		Rest (170')	
	ml/kg/min	W/m^2	ml/kg/min	W/m^2	ml/kg/min	W/m^2
* 70°F (21.1°C)	3.94 ± 0.31	56 ± 4	16.50 ± 0.50	236 ± 7	4.14 ± 0.31	59 ± 4
39°F (3.9°C)	4.49 ± 0.36	64 ± 5	20.26 ± 0.66	290 ± 9	5.00 ± 0.48	71 ± 7
20°F (-6.7°C)	5.04 ± 0.23	72 ± 3	21.14 ± 0.78	302 ± 11	4.35 ± 0.21	62 ± 3
0°F (-17.8°C)	5.10 ± 0.22	73 ± 3	19.95 ± 0.30	285 ± 4	4.91 ± 0.46	70 ± 7
-10°F (-23.3°C)	6.38 ± 0.47	91 ± 7	20.75 ± 0.48	297 ± 7	6.48 ± 0.68	93 ± 10

* Tests were conducted while individuals wore utility clothing.

DISCUSSION

There are several approaches to determining whether a clothing ensemble affords adequate protection against cold. These approaches are based either upon objective analysis of physiological data, including body temperature, heart rate, and metabolic measurements, or upon empirically derived estimates determined from the physical properties of the clothing. In theory, these two approaches should not be considered separate entities, but rather, should complement each other in the determination of appropriateness of protective clothing.

Thermal comfort in a cold environment appears to depend upon the $\bar{T}_{sk}$ value (1). When $\bar{T}_{sk}$ is between 33 and 34°C, the individual is deemed comfortable in a "pleasant" environment. As $\bar{T}_{sk}$ decreases to 31°C, however, the environment is perceived as being one of "unpleasant coldness,"and thermogenic shivering will begin as $\bar{T}_{sk}$ declines to 30°C. Environments invoking $\bar{T}_{sk}$ values <29°C are are considered to be "extremely cold." Based on these thermal sensations, individuals tested with the A1 ensemble would have been considered extremely cold while sitting in all the cold environments. During work, the cold-weather clothing appeared adequate to keep an individual within thermal comfort during exposures at 5° and -10°F only. At -30° and -40°F, $\bar{T}_{sk}$ fell to <30°C and the individual would have perceived this environment as one of unpleasant coldness. Although the Army Arctic clothing tended to keep $\bar{T}_{sk}$ higher than the A1 ensemble during exposure at -40°F, $\bar{T}_{sk}$ values still fell within the "extremely cold" range while the subjects were seated. With the A2 ensemble, it was similarly evident that the individual could not maintain $\bar{T}_{sk}$ at a comfortable level during all seated experimental sessions. During exercise, $\bar{T}_{sk}$ was maintained at ∿31°C in all except the coldest (i.e., -10°F) environments.

A further means of determining the protective qualities of a clothing system is to look at the time it takes for $\bar{T}_{sk}$ to reach the level at which thermogenic shivering begins. It has been demonstrated that, if $\bar{T}_{sk}$ should decrease to 30°C in less than 1 hour in a cold environment, the clothing ensemble is considered inadequate cold protection (1). Based on this criterion, it is evident from the $\bar{T}_{sk}$ data after 60 minutes of exposure that none of the clothing tested (A1, A2, Army Arctic gear) afforded sufficient protection in environmental temperatures between 39°F and -40°F.

The adequacy of protective clothing also can be ascertained by evaluating the changes in mean body temperature, as well as the resulting calculated rate of heat loss. It is estimated that a resting, awake "standard" man (i.e., 70 kg, 170cm, 1.8m^2) can lose a total of ∿160W or 90 W/m^2 of heat without undue discomfort (2). This heat loss would correspond to a change in mean body temperature of ∿2.5°C. A look at the $\bar{T}_b$ data during the cold exposures reveals no condition under which $\bar{T}_b$ decreased 2.5°C from the initial "warm" body value either during testing with the A1 or Army Arctic ensembles (Figure 3) or with

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(1) Tanaka, M. and T. Furuya. Experimental studies on human injury under hot and cold. Boei eisei (National Defense Medical Journal) 23: 115-125, 1976.

(2) Belding, H. S. Protection against dry cold. In: Physiology of Heat Regulation and the Science of Clothing. Edited by L. H. Newburgh, New York: Hafner Publishing Co., 1949, pp. 351-366.

the A2 ensembles (Figure 7). Since the change in $\bar{T}_b$ is reflected in the calculation of body heat loss, it is not surprising that the data show no instances in which the maximum levels of body heat loss are attained during any of the experimental trails (see Figures 4 and 8). However, if the individuals had continued the rest period for more than the allotted 1 hour, a critical decrease in body heat content probably would have occurred. For example, during the -40°F exposure with the A1 ensemble, the hourly heat loss for the first hour of rest averaged 45.7 W/m^2. If this rate of heat loss were to continue for 2 hours, the total body heat loss would be ∿90 W/m^2. As seen in the current protocol for testing the cold-weather clothing, this critical decrease in body heat can be postponed by having the test subjects perform moderate work in the cold environments to increase the metabolic heat load and thus prolong the total exposure time.

Tolerance time to cold environments can be predicted on the basis of measured $\bar{T}_{sk}$ values, clothing insulation (clo) and either predicted or measured metabolic rate. The clo values of the tested ensembles can be estimated based on the relationship that there is ∿0.35 clo per kg of clothing. Estimated clo values therefore are as follows: (a) total A1 ensemble = 3.03 clo; (b) Army Artic gear = 4.30 clo; (3) A2 ensemble at 39°F = 1.50 clo; (d) A2 ensemble at temperatures <39°F = 2.74 clo. If the maximum permissible heat loss is assumed to be 90 W/m^2, and if these estimated clo values, the measured $\bar{T}_{sk}$ values, the measured resting metabolic rate values, and the relationship for convective and radiative heat loss are used, the tolerance time can be calculated as follows:

$$\text{time} = \frac{90}{\dfrac{6.45\,(\bar{T}_{sk}-T_a)}{\text{clo}} - 0.75M} \qquad \underline{1}$$

where T_a = ambient temperature (°C)
M = resting metabolic rate in W/m^2. It is assumed that 75% of the resting metabolic heat will be dissipated through the clothing with the remaining 25% lost through the respiratory tract and insensible sweating.
6.45 = heat transfer coefficient in $W/m^2/°C$

Tolerance times for the experimental temperatures would thus be:

1. A1 ensemble

   a. -40°F (-40°C) = 1.3h
   b. -30°F (-34.4°C) = 1.6h
   c. -10°F (-23.3°C) = 2.2h
   d. + 5°F (-15°C) = 3.7h

2. A2 ensemble

   a. -10°F (-23.3°C) = 2.0h
   b. 0°F (-17.8°C) = 1.9h
   c. 20°F (- 6.7°C) = 3.7h
   d. 39°F (3.9°C) = 1.9h

3. Army Arctic

-40°F (-40°C) = 2.8h

4. Utility Uniform

70°F (21°C) = 13.2h

From these calculations, it is evident that, without some means of increasing the metabolic heat produced in the cold environments, the individual will rapidly begin to lose body heat after a relatively short period of time, will become hypothermic, and will terminate the exposure.

It is possible to calculate the insulation required to maintain a comfortable $\bar{T}_{sk}$ of 90°F (32°C):

$$\text{Insulation required} = \frac{6.45\,(32 - T_a)}{0.75\,M} \tag{2}$$

For the -40°F experiments, resting $M = 88\ W/m^2$; therefore at -40°F, 7.04 clo of clothing insulation would be required to keep a person comfortable. Solving Equation 2 for T_a, it is calculated that the lowest temperature at which the A1 ensemble (estimated clo = 3.03) would keep $\bar{T}_{sk}$ at 32°C while the individual is seated would be 0.6°C (33.2°F). On the other hand, the Army Arctic gear (estimated clo = 4.30) could be worn down to -12.5°C (9.5°F). The A2 cold-weather system could be comfortable in temperatures as low as 6.8°C (44.3°F) when the individual is at rest.

Two important factors should be mentioned at this point. First, it should be stressed that <u>any</u> clothing system is only as good as its weakest link. Hence, if gloves and boots are not adequate to prevent hand and foot temperatures from declining below 4°C (39°F), which is considered the "safe" point for terminating cold exposures, the clothing ensembles could not be expected to provide sufficient protection against the cold environment. Another important point concerns the wearing of long underwear during these cold exposures. Since clo values are related to the weight of the clothing, the more bulk, the greater the insulation. If the A1 ensemble were worn without the long underwear, the total weight of the clothing system would be reduced by 0.55 kg. This would be sufficient to decrease the estimated clo value to 2.84, which is very similar to the value of 2.74 clo for the A2 ensemble. It is thus evident that the small differences between the protective capability of the A1 and A2 ensembles could be directly attributed to the wearing of long underwear with the A1 ensemble.

The values of $\dot{V}O_2$ (see Table I) indicate that some shivering may have been present as a means of increasing metabolic heat production during the quiet sitting periods, particularly in the colder environments in which the A1 ensemble was tested. As the ambient temperature declined, $\dot{V}O_2$ values were seen to increase during both rest periods. The lowering of $\bar{T}_{sk}$ in response to the cold environments was apparently beyond the threshold for induction of shivering (i.e., <30°C). During the work period, $\dot{V}O_2$ also was greater than those values found during the control trial at 70°F. This response may have had a dual cause: thermogenic shivering and the increased external load of the clothing weight (3). By use of a metabolic prediction equation (4), it could be expected that the 8.66 kg of weight added by the Al ensemble could account for a 9% increase in metabolic rate over that predicted for similar work in utility clothing. The remaining increase in metabolic rate could be attributed to the thermogenic shivering in the cold environments.

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(3) Teitlebaum, A. and R. F. Goldman. Increased energy cost with multiple clothing layers. Journal of Applied Physiology 32:743-744, 1972.

(4) Pandolf, K. B., B. Givoni, and R. F. Goldman. Predicting energy expenditure with loads while standing or walking very slowly. Journal of Applied Physiology 43: 577-581, 1977.

CONCLUSIONS

The results of this series of trials indicate that the tested ensembles (A1, A2, Army Arctic) would not keep an inactive person warm for a prolonged period of time. Low $\bar{T}_{sk}$ appears to be more of a problem than low core temperature, at least for the period of time investigated in this study. The low $\bar{T}_{sk}$ contributes to thermogenic shivering and extreme-cold discomfort of the exposed individuals. If exposure were prolonged, a decline in core temperature would rapidly follow, and the individual would become hypothermic, unless a means of increasing metabolic heat production were found. As seen in these exposures, moderate exercise for 1 hour can prolong the exposure time and keep body temperatures from declining. Other work/rest schedules, in which temperatures are not permitted to fall for as long a period of time, would prolong exposure further.

The Army Arctic gear appears superior to the Navy's A1 (Extreme-Cold-Weather) clothing in terms of estimated clothing insulation values and, hence, calculated tolerance times and observed $\bar{T}_{sk}$ values. The higher insulation of the Army gear keeps $\bar{T}_{sk}$ from decreasing to the low levels of the A1 clothing. Tolerance times for the inactive person in the Army gear would be expected to be more than twice as long as for individuals wearing the Navy clothing.

When the A1 and A2 jackets are compared, it is apparent that the primary difference between the two ensembles lies in the wearing of thermal underwear with the A1 system. More insulation is thus added, which would keep $\bar{T}_{sk}$ higher and therefore diminish the rate at which body heat is lost.

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APPENDIX A. ILLUSTRATIONS

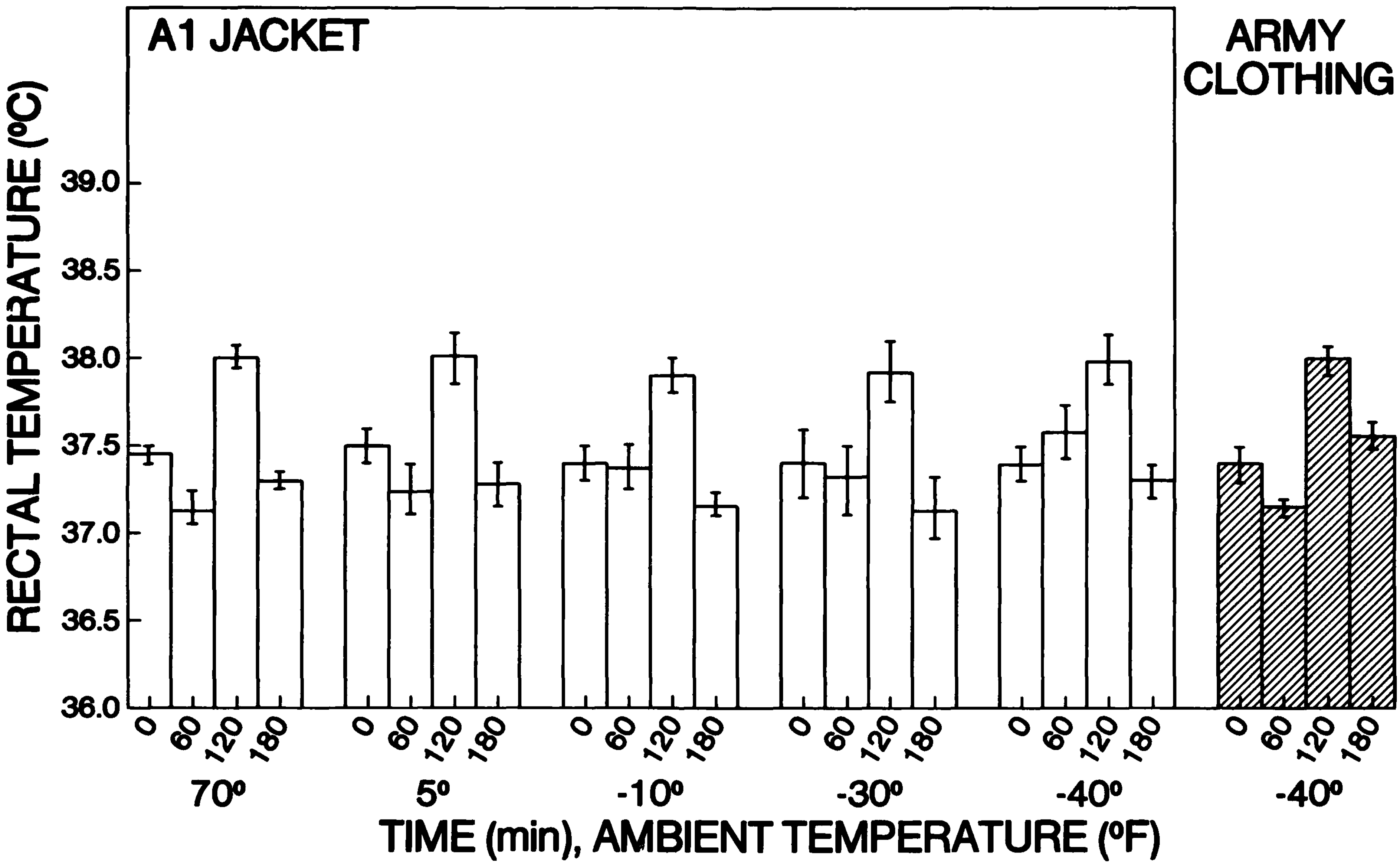

Figure 1. Final hourly values (mean $\pm$ S.E., n = 8) of rectal temperature (T_{re}) during exposures to various environmental temperatures while the A1 (Extreme-Cold-Weather) clothing was worn

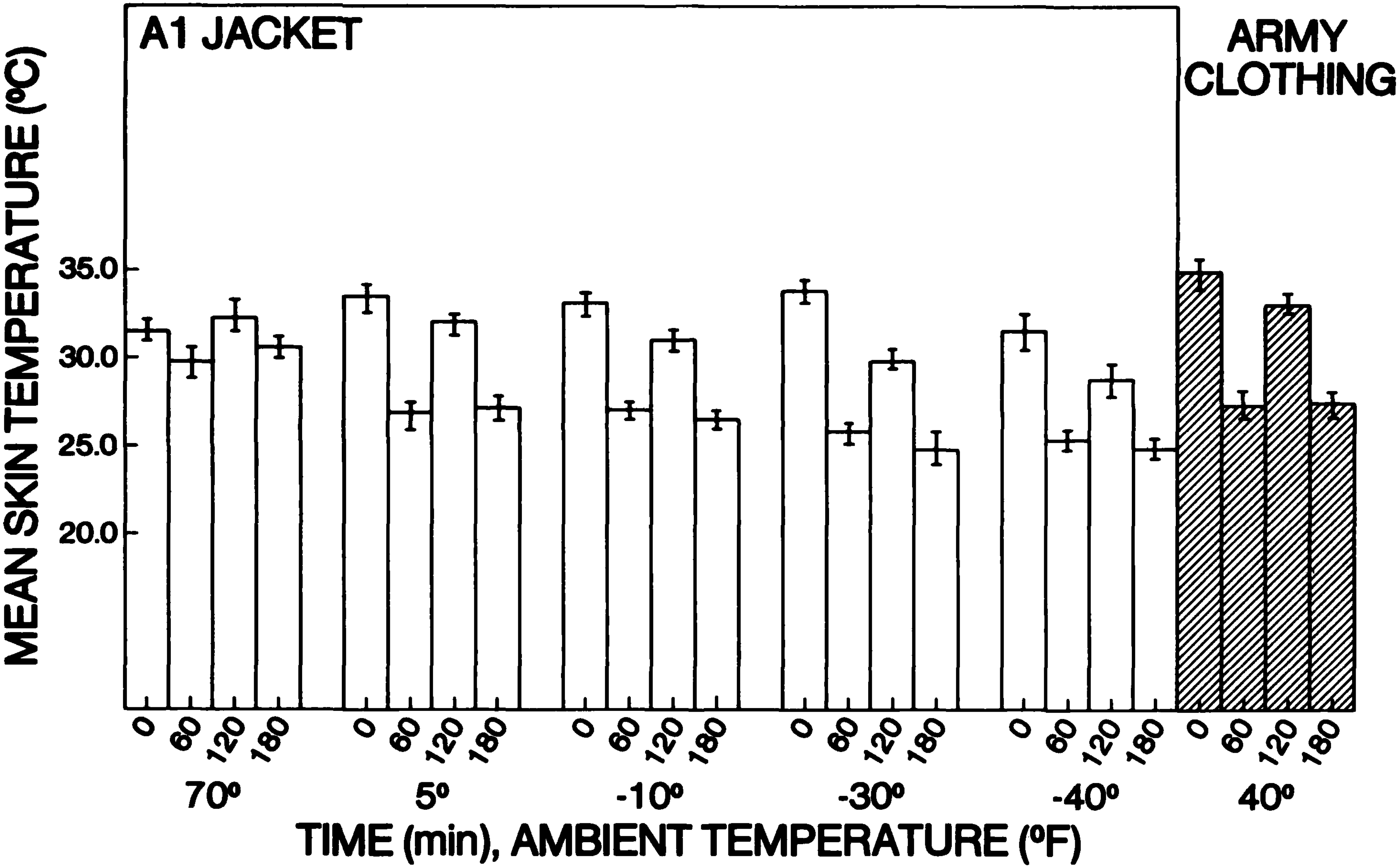

Figure 2. Final hourly values (mean ± S.E., n = 8) of mean skin temperature ($\bar{T}_{sk}$) during exposures while the A1 (Extreme-Cold-Weather) clothing was worn

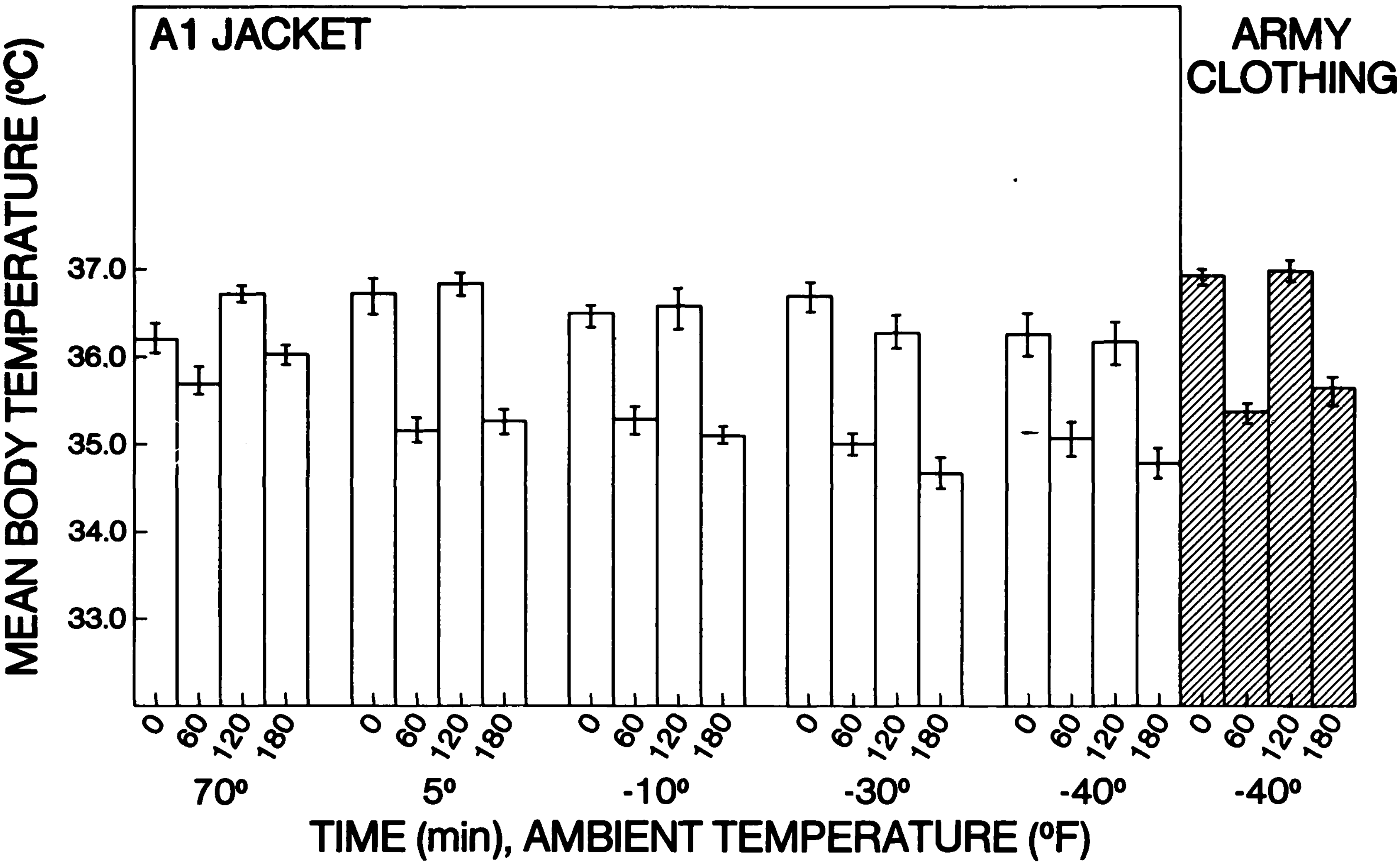

Figure 3. Final hourly values (mean ± S.E., n = 8) of mean body temperature ($\bar{T}_b$) during exposures while the A1 (Extreme-Cold-Weather) clothing was worn

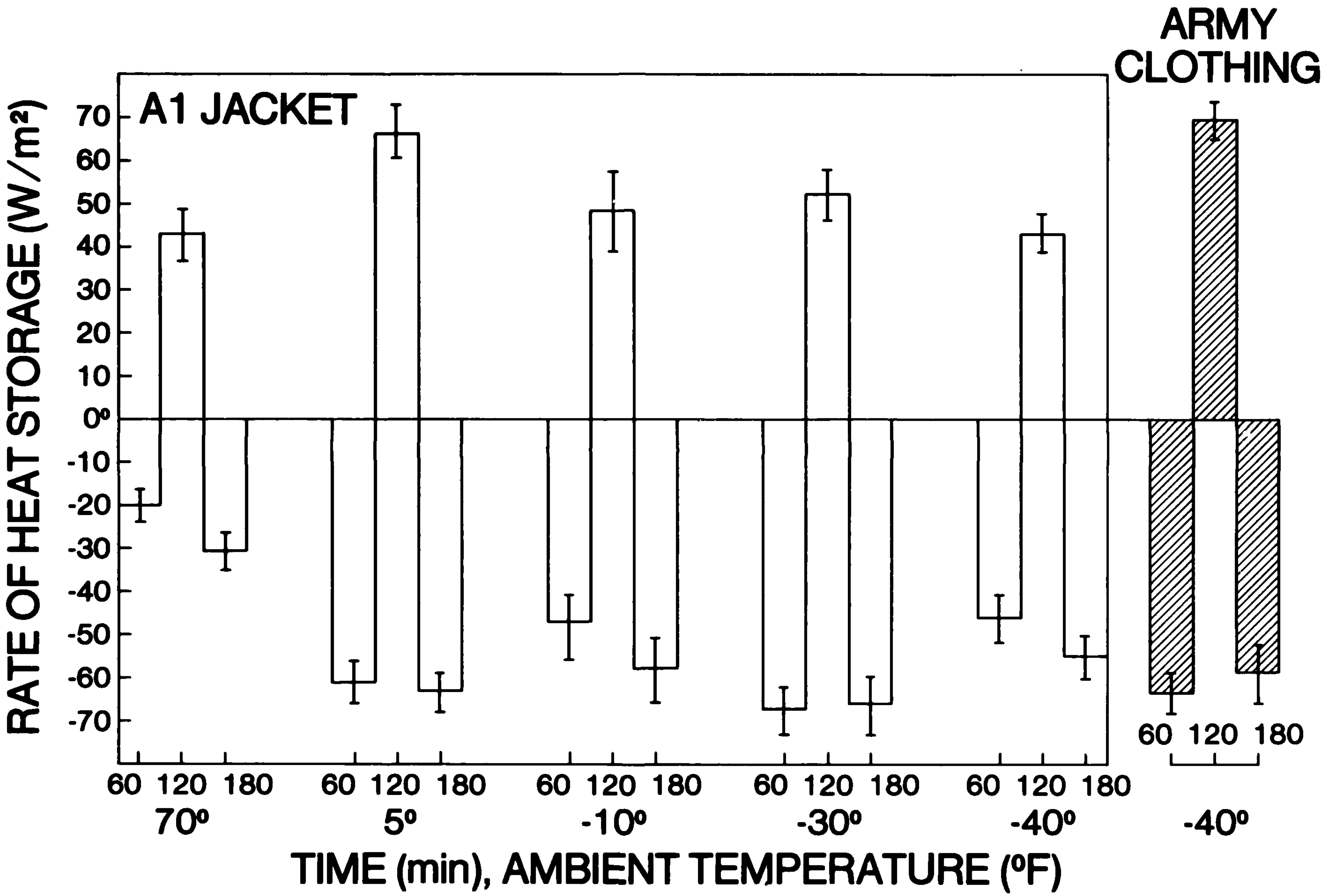

Figure 4. Final hourly values (mean $\pm$ S.E., n = 8) of rates of heat storage during exposures while the A1 (Extreme-Cold-Weather) clothing was worn

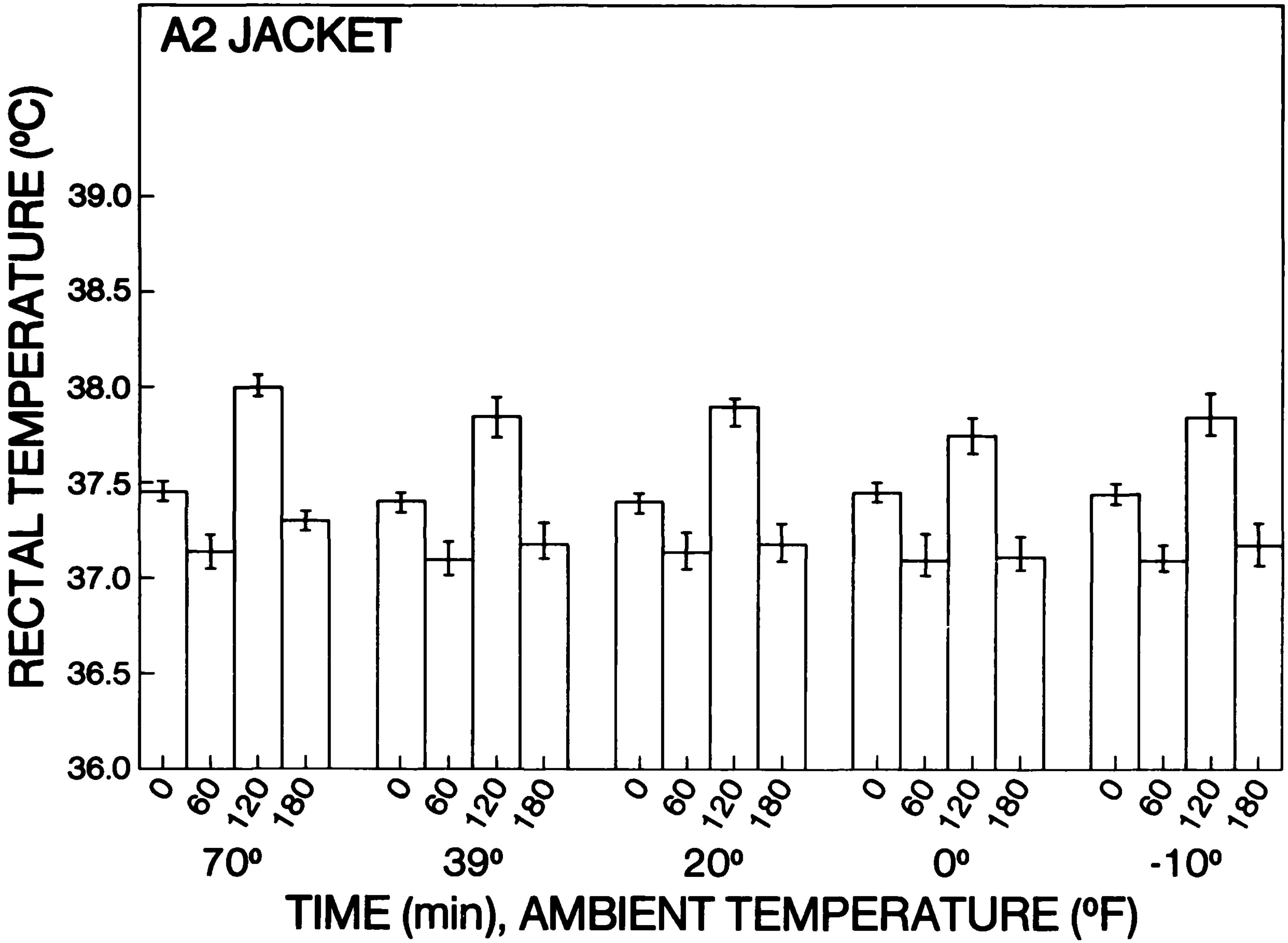

Figure 5. Final hourly values (mean ± S.E., n = 8) of rectal temperature (T_{re}) during exposures while the A2 (Buoyant, Intermediate-Cold-Weather) clothing was worn

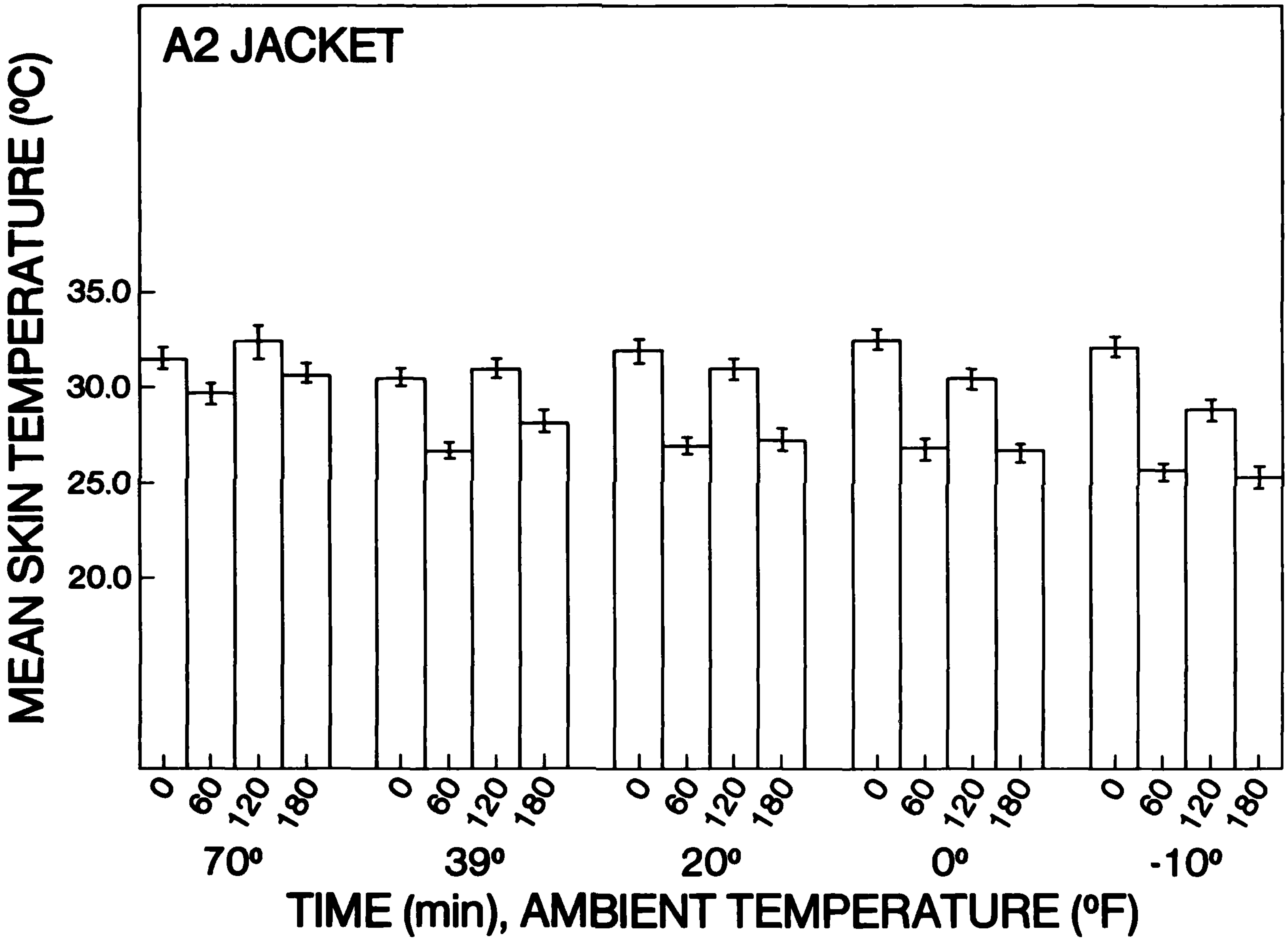

Figure 6. Final hourly values (mean $\pm$ S.E., n = 8) of mean skin temperature ($\bar{T}_{sk}$) during exposures while the A2 (Buoyant, Intermediate-Cold-Weather) clothing was worn

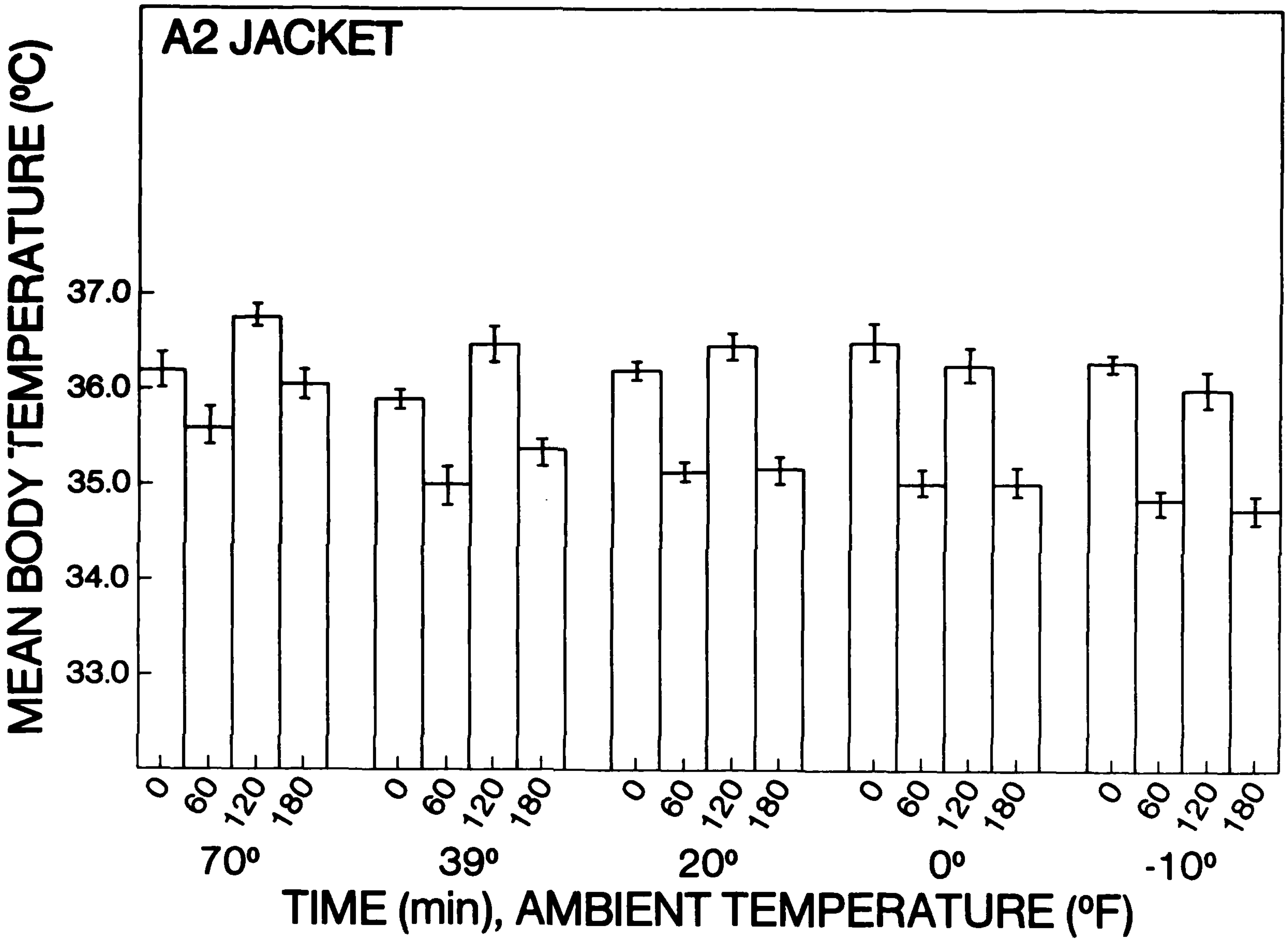

Figure 7. Final hourly values (mean ± S.E., n = 8) of mean body temperature ($\bar{T}_b$) during exposures while the A2 (Buoyant, Intermediate-Cold-Weather) clothing was worn

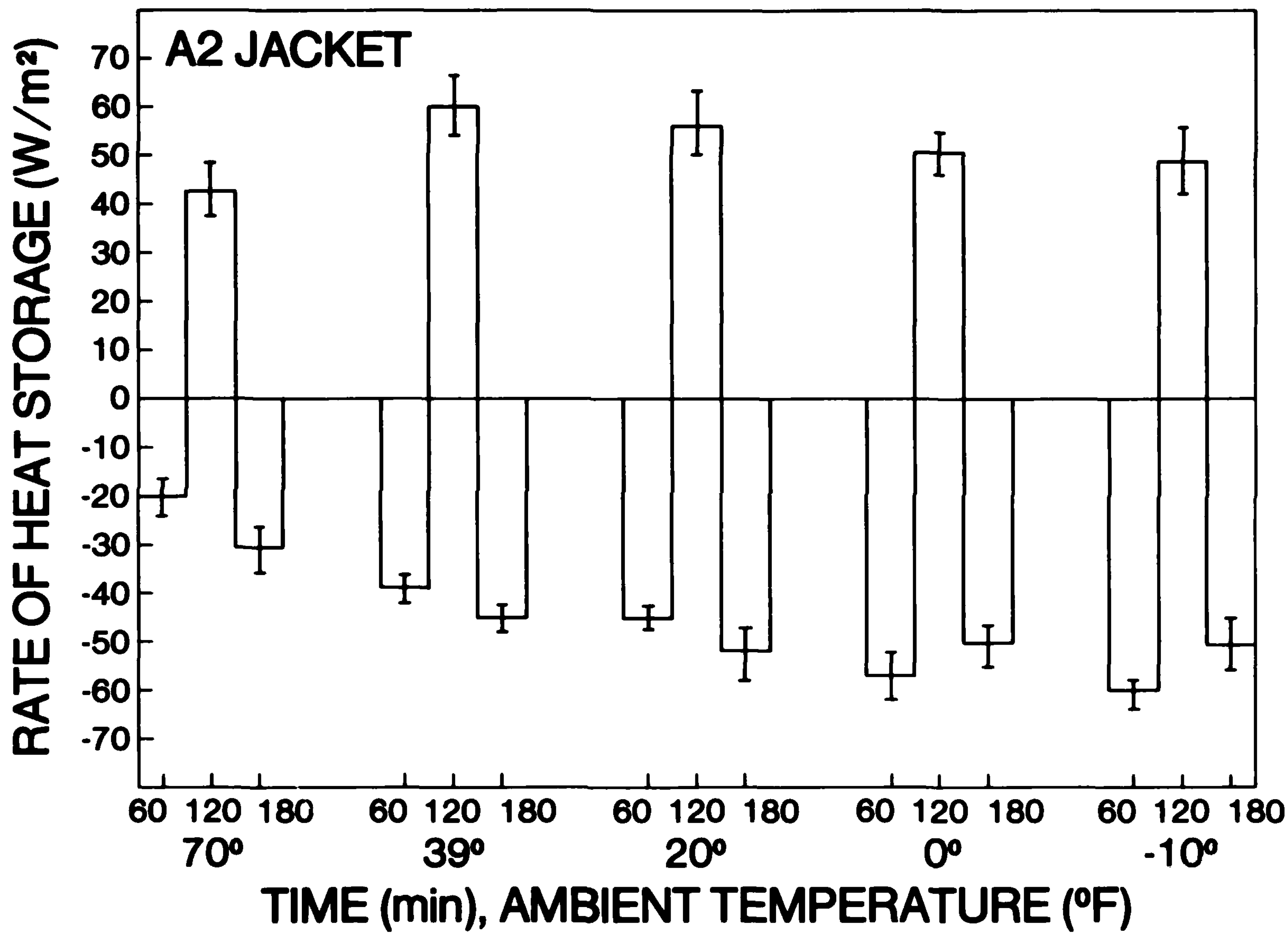

Figure 8. Final hourly values (mean ± S.E., n = 8) of rates of heat storage during exposures while the A2 (Buoyant, Intermediate-Cold-Weather) clothing was worn