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Oxygen consumption and body temperature during sleep in cold environments

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Kreider, M. B. and P. F. Iampietro. *Oxygen consumption and body temperature during sleep in cold environments.* J. Appl. Physiol. 14(5): 765–767. 1959.—Six young soldiers slept at the following ambient temperatures: 25.5° to 26°C (78°–80°F), 15° to 18.5°C (60°–65°F) and −32° to −34.5°C (−25°–−30°F). Rectal (T_r) and skin temperatures were recorded and mean weighted skin temperature (T_s) was calculated at ½-hour intervals every night; oxygen consumption ($\dot{V}O_2$) was measured at 6-minute intervals on occasional nights. During sleep at a 'comfortable' temperature (25.5°C) T_r, T_s and VO_2 decreased below the resting levels measured just before retiring. During sleep in cold environments, T_r and T_s dropped to still lower levels with the lowest values recorded at an early hour of the night. $\dot{V}O_2$ during sleep in the cold did not differ from values recorded during sleep at 25.5°C. Lowest values measured during sleep in the coldest environment were 35.5°C, 30.5°C and 78 Cal/m² for T_r, T_s and body heat debt, respectively. These values may represent the limits of body cooling compatible with substantially continuous sleep in the cold.

In a 'comfortable' environment, body temperature and metabolism exhibit a characteristic fall during sleep at night (1, 2) and reach the lowest point in the 24-hour diurnal cycle in the early morning hours (3). Although the effect of cold exposure on metabolism and body temperature during the daytime hours has been studied (4), little is known about the effect of cold on the heat exchanges of the body during the night. This paper reports skin and rectal temperatures and oxygen consumption of men during sleep in various cold environments and compares them with values measured at comfortable conditions.

METHODS

Six soldiers with ages ranging from 19 to 22 years, weight from 68 to 84 kg and body surface area from 1.77 to 2.1 m² slept at various ambient temperatures for a total of 105 man-nights. The ambient temperatures fell into three groups: 25.5° to 26°C (78°–80°F), 15° to 18.5°C (60°–65°F) and −32° to −34.5°C (−25°–−30°F). Not all men slept at each ambient temperature. Total exposure at any one temperature was less than 3 weeks. Rectal (T_r) and skin temperatures (10 points) were measured at ½-hour intervals throughout the night and mean weighted skin temperatures (T_s) and body heat content were calculated (2). Oxygen consumption ($\dot{V}O_2$) was measured at 6-minute intervals throughout the night by a continuous flow system (5). Simultaneous measurements of all variables were not made on all men.

Before each study the men rested for 1–2 hours in a comfortable environment (78°–80°F); they retired for the night at 2230–2300 hours and arose at 0600–0700 hours.

The protective sleeping gear was adjusted to the ambient temperatures in an attempt to provide progressively colder sleeping conditions as ambient temperature was lowered. The sleeping equipment used at the lowest temperatures consisted of woolen underwear, socks and a double sleeping bag with air mattress; at the higher temperatures, cotton shorts and a sheet and blanket were used. The ambient temperatures were constant throughout the night.

RESULTS

General. The subjects generally slept throughout the night; however, short periods of wakefulness (15 min. or less) were not uncommon and occurred most frequently during the early morning hours, at which time rectal and skin temperatures were lowest. The greatest frequency of awakening was encountered at the coldest ambient temperatures. In a few cases it was necessary to terminate the exposure prematurely because of discomfort and sleeplessness due to cold. From frequent observations of the position of the subject it appeared that gross body movements occurred more frequently in the latter part of the night. Of the three sleeping environments used, the greatest decrease in body temperature occurred at the coldest environmental temperatures.

Rectal temperature. At the comfortable temperature (25.5°C) T_r dropped steadily during the early hours of

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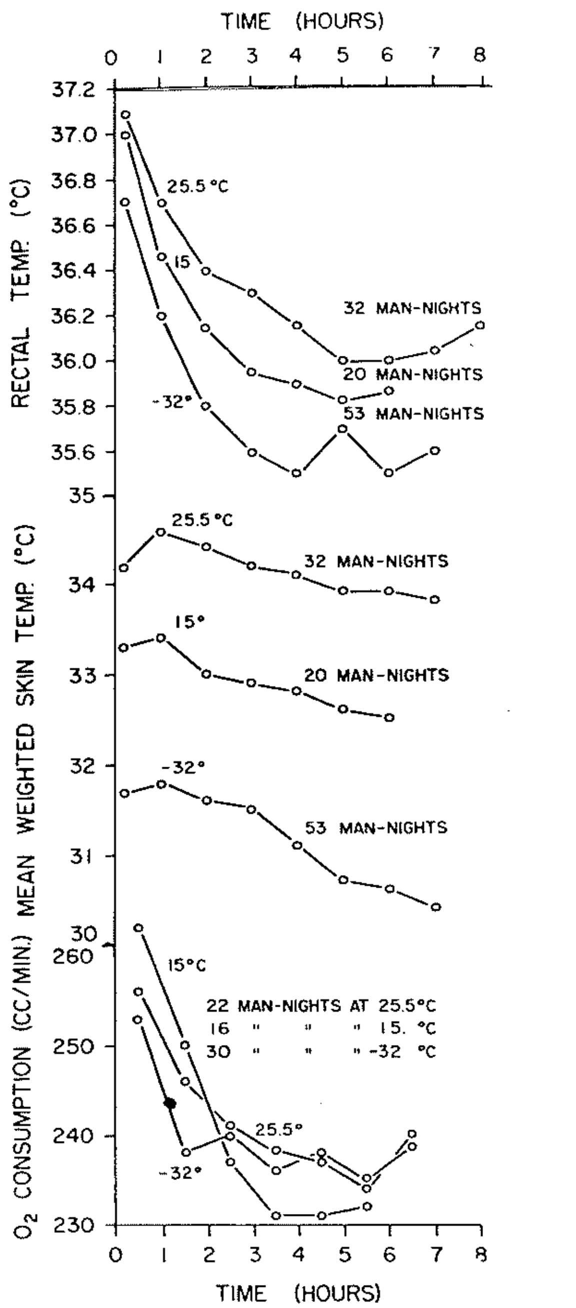

FIG. 1. Rectal temperature (*upper*), mean weighted skin temperature (*middle*) and O_2 consumption (*lower*) of men sleeping at night at various ambient temperatures.

the night and increased slightly at the end of the night. During sleep in the cold environments this characteristic decrease was exaggerated (fig. 1). Colder ambient temperatures produced lower T_r's. T_r dropped to 36.0°, 35.8° and 35.5°C at ambient temperatures of 25.5°, 15° and −32°C, respectively.

Although not apparent in figure 1, the time required to reach the low T_r (average of time for each individual to reach his lowest T_r) during the night decreased with the decreasing ambient temperatures as follows: 5.3 hours at 25.5°C, 4.4 hours at 15°C and 3.5 hours at −32°C.

Skin temperature. At 25.5°C, T_s rose during the first hour and gradually decreased for the remainder of the night. This is consistent with the pattern previously reported (2). There appeared to be a progressive depression of this early increase with progressively lower ambient temperatures (fig. 1). Even though T_s fell to lower values in the cold, the total drop was not always greater because T_s at the time of the first measurement was lower. These lower starting temperatures were due to the cold exposure during the time of getting into the sleeping bag in the cold environment. The time required to reach the low T_s (average of time for each individual to reach his lowest T_s) during the night was 6.3 hours at 25.5°C, 6.4 hours at 15°C and 5.2 hours at −32°C.

Body heat content. Body heat content was calculated from T_r, T_s and body weight. During sleep at 25.5°C a gradual decrease in body heat content occurred during the early hours of the night and a slight increase occurred during the last few hours. During cold exposure, body heat content dropped still lower and reached the lowest point by the end of the night. The drop was generally most rapid in the first few hours with only slight changes during the last 2 hours. The heat debt at −32°C was 3½ times the heat debt at comfortable conditions. Body heat debt at the end of the night was 42, 88 and 145 Cal. at ambient temperatures of 25.5°, 15° and −32°C, respectively. Expressed on a body weight basis, the body heat content at the end of the night at ambient temperatures of 25.5°, 15° and −32°C was 28.7, 27.9 and 27.2 Cal/kg body weight, respectively.

Oxygen consumption. $\dot{V}O_2$ decreased sharply during the first 2–3 hours at the comfortable temperature and changed only slightly during the last hours (fig. 1). During sleep at the colder temperatures (15° and −32°C) the average $\dot{V}O_2$ for the night was not significantly different (fig. 1) from values at 25.5°C. These data reflect measurements made only during sleep and do not include any measurements made during prolonged periods of wakefulness. However, if values during wakefulness were included, $\dot{V}O_2$ during the latter part of the night would be higher in the cold than in the warm.

DISCUSSION

In general, our results show a parallel between ambient temperature and body temperatures, i.e. sleeping in increasingly colder environments produces progressively lower skin and rectal temperature. On the other hand, $\dot{V}O_2$ was similar for all conditions studied.

It is interesting to note that despite a progressive decrease in ambient temperature $\dot{V}O_2$ did not increase above levels characteristic of sleep in more comfortable environments. This is contrary to responses during wakefulness (4, 6). It is probable that the similar heat productions found at all three ambient temperatures were a manifestation of the absence of shivering during sleep (7, 8) in the colder environments. In the early morning hours, during sleep in the coldest environment, there were periods of wakefulness when increased body movement and possibly shivering occurred (9). The values for $\dot{V}O_2$ during these periods were not included in the data and are not reflected in the curves in figure 1. Scholander *et al.* (8, 10) have reported that Caucasian subjects have an increased $\dot{V}O_2$ during 'sleep' in the cold. However, they state that with their subjects there were considerable periods of wakefulness, movement and shivering throughout the night. The differences between their results and those of the present study probably are attributable to the fact that they included data collected during such periods of wakefulness and we did not.

It is logical to expect that there are limits of body cooling compatible with substantially continuous sleep in the cold. Under the conditions of our study it appears that these limits were reached during sleep in the coldest environment (−32°C). Body heat debt at the end of the night was 78 Cal/m^2 (3½ times the debt incurred during sleep at 25.5°C) and T_r and T_s were 35.5°C and 30.5°C, respectively.

Although these values may represent the limits of body cooling which could be tolerated under the conditions of our study before sleep was terminated, there are many factors which may influence these limits and which should be investigated. Examples of these factors are: rate of cooling, the differential temperatures of various parts of the body, fatigue and preheating or cooling.

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