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# THERMAL BALANCE OF MEN UNDER ATROPINE THERAPY WEARING CHEMICAL PROTECTIVE CLOTHING

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Edgewood Arsenal
Aberdeen Proving Ground, Maryland

October 1973

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In warm environments the use of atropine in the treatment of casualties from anticholinesterase agents presents a possible hazard because the inhibition of sweating by atropine may lead to a dangerous rise in body temperature. Recently it was shown that after a 2-mg dose of atropine sulfate the effects of a deficit in sweating could be avoided by artificial wetting the clothing. One objective was to test this concept when the dose was increased to 6 mg. At this dose and an indoor temperature of 41°C, an initial wetting of the clothing with a liter of water was sufficient to prevent an undue rise in body temperature for 3 hours whereas when the clothing was

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initially dry the body temperature rose at an unsafe rate. A second objective was to evaluate the efficiency of evaporative cooling from wet clothing as a fraction of the evaporative cooling required to balance the heat equation. The conclusions were as follows: The elevation of body temperature in men wearing the two-layer chemical protective assembly in consequence of the inhibition of sweating by atropine given for treatment of the effects of anticholinesterase agents can be prevented by artificial wetting of the clothing. The efficiency of evaporative cooling of clothed men decreases as the water content of the clothing increases. For clothing containing water amounting to 50 percent of the dry weight of the clothing, the efficiency is reduced by about one-half. However from the physiological standpoint, wetting the clothing does increase the effective cooling of the body and there is a corresponding decrease in heat storage.

## SUMMARY

In warm environments the use of atropine in the treatment of casualties from anticholinesterase agents presents a possible hazard because the inhibition of sweating by atropine may lead to a dangerous rise in body temperature. Recently it was shown that after a 2-mg dose of atropine sulfate the effects of a deficit in sweating could be avoided by artificial wetting of the clothing. One object was to test this concept when the dose was increased to 6 mg. At this dose and an indoor temperature of 41°C, an initial wetting of the clothing with a liter of water was sufficient to prevent an undue rise in body temperature for 3 hours whereas when the clothing was initially dry the body temperature rose at an unsafe rate. A second object was to evaluate the efficiency of evaporative cooling from wet clothing as a fraction of the evaporative cooling required to balance the heat equation. The conclusions were as follows:

The elevation of body temperature in men wearing the two-layer chemical protective assembly in consequence of the inhibition of sweating by atropine given for treatment of the effects of anticholinesterase agents can be prevented by artificial wetting of the clothing.

The efficiency of evaporative cooling of clothed men decreases as the water content of the clothing increases. For clothing containing water amounting to 50 percent of the dry weight of the clothing, the efficiency is reduced by about one-half. However from the physiological standpoint, wetting the clothing does increase the effective cooling of the body and there is a corresponding decrease in heat storage.

## PREFACE

The work described in this report was authorized under Project No. 1W662710AD2501, Medical Defense Against Chemical Agents, Biomedical Evaluation of Protective Materiel. The data were collected in September 1971 and in May, June, November, and December 1972 and in January of 1973.

The volunteers in these tests are enlisted US Army personnel. These tests are governed by the principles, policies, and rules for medical volunteers as established in AR 70-25 and the declaration of Helsinki.



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# THERMAL BALANCE OF MEN UNDER ATROPINE THERAPY WEARING CHEMICAL PROTECTIVE CLOTHING

## I. INTRODUCTION.

In the treatment of anticholinesterase poisoning by means of atropine the amount of atropine injected should vary with the severity of the poisoning. An excess of atropine will produce its typical effects including, if the environment is warm, the inhibition of thermal sweating with its attendant rise in body temperature. If CBR protective clothing is being worn, the insulation of the clothing will also favor a rise in body temperature. The combined effects of an injection of 2 mg of atropine and the wearing of protective clothing, on normal volunteers exposed to several warm environments, have recently been described.[1] In an environment dry enough to prevent accumulation of sweat in the clothing, the deficit in evaporative heat loss associated with the atropine was matched by the increment in storage of heat in the body. However, when the clothing was wetted, either artificially or by the accumulation of sweat in a more humid environment, the increment in heat storage associated with the inhibition of sweating by atropine was less. That is, water from the wet clothing compensated in part for the deficit in sweat. In combat a soldier could receive as much as 6 mg of atropine without having been exposed to any anticholinesterase before medical help arrived if signs or symptoms were misinterpreted. In order to examine this situation the experiments were resumed. Doses of 2 and 6 mg were employed.

In addition an effort was made to evaluate the efficiency of evaporative cooling from wet clothing. Theoretical considerations suggest that the thermal insulation of the clothing would reduce the impact of the evaporative cooling on the heat balance of the man. It would be expected that the cooling effect of the evaporation of a given quantity of water would be less if the evaporation took place in the outer layer of the wet clothing rather than directly on the skin under dry clothing. Although wetting the clothing could increase the amount of water evaporated and also the effective cooling of the body, the increase in effective cooling would be less than the increase in total evaporation. In order to evaluate these terms, it is necessary to calculate the requirement for evaporative cooling from other terms in the heat equation and to relate this to the observed evaporation. Also the wetness of the clothing must be defined.

## II. CALCULATIONS.

The heat balance may be written

$$E = M - W + R + C - S,$$

where

M = heat produced in metabolism

W = heat lost in external work (treadmill tilted upward)

R = heat gained from the environment by radiation

C = heat gained from the environment by convection

S = heat stored in the body

E = heat lost from the body by evaporation. This is distinguished from E′, the heat of evaporation of water from the clothed body.

Thus the efficiency of evaporative cooling is defined as the fraction E/E′.

The quantities in the heat balance equation were evaluated as follows in watts (watts = 1.163 X Calories per hour) per square meter of body surface area, A, estimated from the height and weight.

M = $mt\,[2.7 + 3.2\,(V-0.7)^{1.65} + G\,(0.23 + 0.29\,(V-0.7))]/A$, in watts per man. This is equation (4) of Givoni and Goldman[2] where mt is the total mass in kg of the clothed man plus any load carried, V is the speed of walking in m/sec and G is the treadmill grade in percent.

W = $0.098\, mt \times V \times G/A$, in watts per man. This is equation (2) of Givoni and Goldman.[2]

R + C = $(11.6/Clo)\,(Ta - Ts)/1.8$, in watts/$m^2$. This is equation (5) of Givoni and Goldman[2] where Clo is the thermal insulation, Ta is ambient temperature and Ts is mean skin temperature.

We have used the observed skin temperature averaged over time during the exposure instead of the standard figure of 36 used by Givoni and Goldman. Also the equation was developed for the quartermaster's standard man with surface area of 1.8 sq m so that this divisor is used instead of the surface area of the individual employed above to reduce M and W to the terms of our heat balance equation.

Clo is calculated from equations of Givoni and Goldman[2]:

Clo = $1.50\ Veff^{-0.20}$, for assembly I

Clo = $0.99\ Veff^{-0.25}$, for assemblies II and III

Clo = $0.57\ Veff^{-0.30}$, for assembly IV where

Veff = Vair + 0.004 (M-105) in m/sec. This is equation (8) of Givoni and Goldman[2] where Vair is the windspeed, and M is in watts per man.

$$S = \frac{\Delta Tb \times m \times 0.83 \times 1.163}{t \times A}, \text{ watts/m}^2,$$ where $\Delta Tb$ is the change in mean body temperature (1/3 change in unweighted mean skin temperature + 2/3 change in rectal temperature), m is the nude weight, t is the time in hours, and 0.83 is the specific heat of the body.

$$E' = \frac{\Delta\, mt \times 0.58 \times 1.163}{t \times A}, \text{ watts/m}^2$$ where $\Delta$ mt is the loss in clothed weight during the exposure period and 0.58 is the heat of evaporation of a gram of water.

From $\Delta$mt is subtracted the change in clothes weight in the blank assembly (5 minutes rest only) and the difference in weight between the oxygen inhaled and the carbon dioxide exhaled during the walk. The latter is 0.3 gm per liter of oxygen per hour at a respiratory exchange ratio of 0.88. The number of liters of oxygen is M in watts per man divided by 5.7, where 5.7 = 1.163 X 4.9, the number of calories per liter of oxygen at an R of 0.88.[3] A further subtraction is made for water evaporated from the lungs by assuming the expired air to be 88% saturated at 33°C[4] and containing 0.031 grams per liter, and the ambient (inspired) air to contain 0.020 grams per liter at 41°C and 0.011 at 29°C. The ventilation rate is assumed to be 23 liters of air per liter of oxygen consumed[5] as estimated above.

The wetness of the clothing is evaluated in terms of the average weight of the four pieces of fatigues and underwear during the exposure divided by the initial dry weight. The initial wet weight is corrected for the change in weight of the four pieces during the blank rest period. The average wet weight thus is the corrected initial weight plus the final weight divided by 2.

## III. METHODS.

The subjects were enlisted men from the group of medical volunteers and two civilian experimenters (table I). The clothing assemblies are identified in table II. The various items of clothing were components of the standard protective assembly but the impregnation was omitted. The clothing was laundered in an automatic washing machine the day before each experiment and spun in the dryer at 64 ± 5°C for 75 minutes to maintain a uniform initial state of dryness. In one test the standard dry weight after heating to constant weight in an oven at 105°C (the standard condition for textile testing[6]) was 1109 gm for the fatigues and 662 gm for the long underwear. This was 16 gm less than the weights of the clothing after removal from the dryer of the washing machine. Thus the four-piece suit as generally used had a regain of 1.4 percent for the outer layer and 2.4 percent for the inner layer. The fatigues and underwear were weighed in the environmental chamber, and placed in plastic bags overnight to permit distribution of water when added. The men were weighed nude, and again wearing only the electrode and thermocouple harness. The fatigues and underwear were then removed from the plastic bags, weighed and put on with the remaining components of the assembly. The men were weighed clothed before and after the exposure period. The men then undressed. The fatigues and underwear were weighed; the men were weighed again wearing only the harness, and finally nude. A Buffalo platform beam scale was used to weigh to the nearest gram with an accuracy estimated at ± 10 gm. The man sat on a low-backed stool fastened to the platform to help minimize changes in body position. The four pieces of the suit were weighed on a Toledo scale indicating from 1 to 500 gm to the nearest gram.

Table I. Subjects

| Initial | Volunteer number | Age | Height | Weight | Surface area |
|---|---|---|---|---|---|
| Al | 6450 | 33 | 175 | 74 | 1.88 |
| Tu | 6427 | 20 | 183 | 94 | 2.18 |
| Bl | 6460 | 18 | 183 | 105 | 2.30 |
| Ed | 6441 | 27 | 180 | 54 | 1.68 |
| An | 6448 | 25 | 183 | 76 | 1.98 |
| Ge | 6458 | 19 | 167 | 71 | 1.80 |
| Gi | 6443 | 31 | 173 | 91 | 2.06 |
| La | 6445 | 21 | 166 | 65 | 1.72 |
| Da | 6457 | 27 | 187 | 79 | 2.05 |
| Fy | 6242 | 22 | 186 | 93 | 2.18 |
| Ni | 6266 | 19 | 173 | 77 | 1.90 |
| Ca | 6267 | 22 | 188 | 74 | 1.99 |
| No | 6239 | 19 | 177 | 74 | 1.89 |
| Cr | DAC | 61 | 172 | 57 | 1.66 |
| Mo | DAC | 46 | 166 | 85 | 1.92 |

Table II. Clothing Assemblies

| Item | Approximate weight | Assembly I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|---|
| | gm | | | | | | | | |
| Boots | 1700 | X | X | X | X | X | X | X | X |
| Socks | 75 | X | X | X | X | X | X | X | X |
| Undershirt* | 430 | X | | | | | | | |
| Underdrawers* | 450 | X | | | | | | | |
| Jacket, sateen cotton | 650 | X | X | X | | | | | X |
| Trousers, sateen cotton | 640 | X | X | X | | | | | X |
| T-shirt, cotton | 120 | | X | X | | | | | |
| Shorts, cotton | 90 | | X | X | X | X | | | |
| Gloves, cotton | 100 | X | X | X | | | | | X |
| Mask and hood | 1060 | X | X | | | X | | X | X |
| Harness | 2165 | X | X | X | X | X | X | X | X |

* 1/2 cotton, 1/2 wool

The three electrodes on the front of the chest made possible the recording of the electrocardiogram (ECG) and the counting of the heart rate. Elastic straps supported thermocouples on the front and back of the chest, the hip and the thigh for recording skin temperature. Rectal temperature was recorded from a thermocouple at a depth of 7.5 cm. The thermocouples were recorded once a minute by a Leeds and Northrup Speedomax.

There were three series of experiments.

In series A (table III) the room temperature was 41°C dry bulb (DB) and 24°C wet bulb (WB), the wind speed 0.05 m/sec, and the men wore assembly I. During the exposure period the men reclined in supine position on plastic webbing on a folding chair for 3 hours, interrupted by clothed weighings at hourly intervals. Doses of 2 and 6 mg of atropine sulfate were given intramuscularly. The 6-mg dose was given in three injections of 2 mg at 10-minute intervals. Experiments with dry clothing were conducted in September 1971. In May and June 1972 an additional group of men received the 6-mg dose and wore initially wet suits (1000 gm of water added).

In the experiments with dry suits in series A, a square capsule enclosed an area of 9 sq cm on the volar surface of the forearm. Dry gas (98.5% $O_2$ + 1.5% $N_2$) was passed into the capsule at rates of from 0.05 to 0.45 liters per minute. The relative humidity of the outflowing air was recorded by means of a series of lithium chloride sensors (hydrodynamics). The dryness of the compressed gas was tested by passing it over silica gel. Since the silica gel did not gain in weight, the water content was considered to be zero. The water content of the effluent gas thus

Table III. SERIES A
Clothing Assembly I, Rest, Wind Speed, 0.05 m/sec, DB 41°C, WB 24°C

| Man | Date | Dose | Time of * injection | Time in assembly | Mask off at | Weight of 4-Pc Suit Before Dry | Weight of 4-Pc Suit Before Wet | Weight of 4-Pc Suit After | Nude weight loss | Hour | Clothed weight loss | M | R+C | S | E | E' | E/E' |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mg | Min | Min | Min | Gm | Gm | Gm | Gm | | Gm | watts/sq m | | | | | |
| Ca | 9-14 | 0 | --- | 180 | 180 | 1923 | --- | 2260 | 1061 | 1st | 137 | 58 | 11 | 1 | 68 | 46 | 1.47 |
| | | | | | | | | | | 2nd | 286 | 58 | 10 | 10 | 58 | 97 | 0.60 |
| | | | | | | | | | | 3rd | 283 | 58 | 10 | 3 | 65 | 96 | 0.68 |
| Fy | 9-15 | 0 | --- | 180 | 95 | 2117 | --- | 2735 | 1616 | 1st | 230 | 58 | 10 | 2 | 66 | 72 | 0.92 |
| | | | | | | | | | | 2nd | 363 | 58 | 10 | 5 | 63 | 117 | 0.53 |
| | | | | | | | | | | 3rd | 390 | 58 | 11 | -2 | 71 | 121 | 0.59 |
| No | 9-16 | 0 | --- | 180 | 180 | 2066 | --- | 2325 | 1522 | 1st | 152 | 58 | 10 | 10 | 58 | 54 | 1.07 |
| | | | | | | | | | | 2nd | 306 | 58 | 10 | 1 | 67 | 109 | 0.62 |
| | | | | | | | | | | 3rd | 299 | 58 | 10 | 6 | 62 | 107 | 0.58 |
| Ni | 9-17 | 0 | --- | 180 | 180 | 1989 | --- | 2027 | 717 | 1st | 166 | 58 | 12 | 14 | 56 | 59 | 0.95 |
| | | | | | | | | | | 2nd | 188 | 58 | 11 | 4 | 65 | 67 | 0.97 |
| | | | | | | | | | | 3rd | 183 | 58 | 10 | 8 | 60 | 65 | 0.92 |
| Ca | 9-20 | 2 | 26 | 180 | 180 | 2017 | --- | 2144 | 955 | 1st | 191 | 58 | 12 | 24 | 46 | 65 | 0.71 |
| | | | | | | | | | | 2nd | 155 | 58 | 9 | 21 | 46 | 53 | 0.87 |
| | | | | | | | | | | 3rd | 226 | 58 | 9 | 10 | 57 | 77 | 0.74 |
| Fy | 9-21 | 2 | 27 | 180 | 180 | 2024 | --- | 2315 | 1115 | 1st | 226 | 58 | 10 | 8 | 60 | 70 | 0.86 |
| | | | | | | | | | | 2nd | 72 | 58 | 8 | 28 | 38 | 22 | 1.73 |
| | | | | | | | | | | 3rd | 304 | 58 | 7 | 2 | 63 | 95 | 0.66 |
| No | 9-22 | 2 | 25 | 78 | 68 | 1972 | --- | ---- | ---- | 1st | 132 | 58 | | | | | |
| Ni | 9-23 | 2 | 56 | 180 | 180 | 1980 | --- | 2053 | 604 | 1st | 174 | 58 | 12 | 5 | 65 | 62 | 1.05 |
| | | | | | | | | | | 2nd | 141 | 58 | 9 | 33 | 34 | 50 | 0.68 |
| | | | | | | | | | | 3rd | 155 | 58 | 8 | 17 | 49 | 55 | 0.89 |
| Fy | 9-28 | 6 | 25 + 45 | 150 | 110 | 2076 | --- | 2052 | 428 | 1st | 193 | 58 | 10 | 15 | 53 | 60 | 0.88 |
| | | | | | | | | | | 2nd | 214 | 58 | 8 | 47 | 19 | 66 | 0.29 |
| Ni | 9-30 | 6 | 28 + 48 | 160 | 89 | 2067 | --- | 2035 | 269 | 1st | 122 | 58 | 11 | 21 | 48 | 44 | 1.09 |
| | | | | | | | | | | 2nd | 84 | 58 | 8 | 42 | 24 | 30 | 0.80 |
| Tu | 5-23 | 6 | -40 -20 | 180 | 180 | 2161 | 3143 | 2447 | 294 | 1st | 330 | 58 | 9 | 15 | 52 | 102 | 0.51 |
| | | | | | | | | | | 2nd | 288 | 58 | 8 | 14 | 52 | 89 | 0.58 |
| | | | | | | | | | | 3rd | 199 | 58 | 7 | 15 | 50 | 62 | 0.81 |

*Time of a single injection or range of times within which 3 injections were given; intramuscular. Negative values refer to time before donning clothing.

Table III. (Contd)

| Man | Date | Dose | Time of * injection | Time in assembly | Mask off at | Weight of 4–Pc Suit Before Dry | Weight of 4–Pc Suit Before Wet | Weight of 4–Pc Suit After | Nude weight loss | Hour | Clothed weight loss | M | R+C | S | E | E' | E/E' |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mg | Min | Min | Min | Gm | Gm | Gm | Gm | | Gm | watts/sq m | | | | | |
| Ge | 6-5 | 6 | -40 -20 | 51 | 15 | 1996 | 2976 | 2609 | | | | | | | | | |
| Ed | 6-6 | 6 | -40 -20 | 120 | 109 | 1906 | 2894 | 2348 | 130 | 1st | 294 | 58 | 10 | 5 | 63 | 118 | 0.53 |
| | | | | | | | | | | 2nd | 268 | 58 | 10 | -5 | 73 | 108 | 0.68 |
| Da | 6-19 | 6 | -40 -20 | 180 | 180 | 2018 | 2999 | 2446 | 196 | 1st | 298 | 58 | 6 | 0 | 64 | 98 | 0.65 |
| | | | | | | | | | | 2nd | 222 | 58 | 6 | 9 | 55 | 73 | 0.75 |
| | | | | | | | | | | 3rd | 195 | 58 | 5 | 8 | 55 | 64 | 0.86 |
| La | 6-20 | 6 | -44 -24 | 180 | 180 | 1898 | 3384 | 2562 | 106 | 1st | 318 | 58 | 6 | 6 | 57 | 125 | 0.46 |
| | | | | | | | | | | 2nd | 288 | 58 | 6 | 5 | 58 | 114 | 0.52 |
| | | | | | | | | | | 3rd | 210 | 58 | 5 | 8 | 54 | 83 | 0.66 |
| Gi | 6-21 | 6 | -43 -21 | 180 | 180 | 2169 | 3156 | 2630 | 425 | 1st | 293 | 58 | 8 | 17 | 49 | 96 | 0.51 |
| | | | | | | | | | | 2nd | 258 | 58 | 7 | 9 | 56 | 84 | 0.67 |
| | | | | | | | | | | 3rd | 225 | 58 | 7 | 6 | 59 | 73 | 0.81 |
| Al | 5-22** | 6 | -46 -26 | 30 | 15 | 2027 | ---- | 2023 | 59 | | 117 | | | | | | |

*Time of a single injection or range of times within which 3 injections were given; intramuscular. Negative values refer to time before donning clothing.

**DB/WB 29/20°C, treadmill 3 mph and 10% grade, 3 mph wind. Walked intermittently about 21 min, could not maintain pace.

represents a net gain and the product of this and the air flow gives the sweat rate of the skin under the capsule. The temperature of the adjacent skin was measured with a thermocouple.

In series B (table IV) there were two environmental conditions: dry bulb 29°C, wet bulb 20°C, wind speed 1.34 m/sec; and dry bulb 41°C, wet bulb 24°C and wind speed 0.05 m/sec. The men wore assembly I and walked at 10% grade at 3 mph (1.34 m/sec) with or without a 28.5 $\mu$g/kg iv dose of atropine sulfate. These men were subsequently given the 6-mg dose when they took part in the experiments of series A. Initially zero, 400, and 1000 gm of water were added to the four-piece suits. In this series a man sat for 5 minutes to allow time for equilibration and for the atropine injections before beginning to walk. The man also dressed in a fresh suit and sat for 5 minutes and undressed without walking to provide a blank on the weight changes before and after the walk.

In series C (table V) the two civilians walked in repeated tests of assemblies I, II, and III to which initially zero, 400 and 1000 gm of water were added. The treadmill and wind speeds were 1.34 m/sec. The temperatures were 41°C dry bulb, 24°C wet bulb or 29°C dry bulb, 19°C wet bulb. One man performed two tests following an iv injection of 28.5 $\mu$g/kg in the 5-minute rest period before the walk, in order to minimize accumulation of sweat in the initially dry assembly. Blank weight changes, over a 5-minute rest period were determined with a fresh suit for each one tested during walking.

The level walks lasted 30 minutes. At 10% grade the time was shorter, as indicated in table V, because the subject became exhausted. Note that the M17A1 mask was worn in the shortest walk (7 November). On 8 November the subject wore an M17A1 mask with the voicemitter cut out to permit breathing unhampered by filters and valves. Since this seemed to favor endurance, the cut out mask was used for the remaining tests in this series.

## IV. RESULTS.

### A. Series A.

Individual experiments and results are listed in table III. Only Fy and Ni took part in all three experiments with initially dry clothing. With the 6-mg dose they did not complete the planned period of study in the hot room. The stay in the hot room was prolonged by removing the mask and hood at the times indicated in the table. Of the men wearing initially wet suits after the 6-mg dose of atropine sulfate, one man, Ge, felt sick and left early; another, Ed, did not tolerate the mask and left after two hours; the other four, Tu, Da, La, and Gi were able to remain completely clothed for the planned period of 3 hours.

The changes in body temperatures with time are plotted in figure 1. Without atropine the men were almost able to maintain temperature equilibrium in spite of the heat load of the protective assembly. When the four-piece suit was initially wet the increases in body temperature were small even after the 6-mg dose. When the suit was initially dry there were substantial increases in body temperatures with both the 2- and the 6-mg doses. After the 2-mg dose the skin temperature began to level off at 120 minutes. After the 6-mg dose the men left the hot room while their temperatures were still on the rise so that the full effect was

Table IV. SERIES B
Clothing Assembly I, Treadmill 1.34 m/sec, Grade 10%

| Man | Date | Condition | Time Rest | Time Walk | Weight loss Nude | Weight loss Clothed | Weight of 4-Pc Suit Before Dry | Weight of 4-Pc Suit Before Wet | Weight of 4-Pc Suit After | Wet* / Dry | M | W | R+C | S | E | E' | $E_r / E$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Min | Gm | Gm | Gm | Gm | Gm | | watts/sq m | | | | | | |
| | | | | | | | 29°C DB, 20°C WB, 1.34 m/sec Wind | | | | | | | | | | |
| Al | 5-15 | Blank | 5 | --- | 130 | 16 | 2174 | --- | 2191 | | | | | | | | |
| | 5-15 | Control | 5 | 30 | 681 | 227 | 2011 | --- | 2315 | 1.08 | 359 | 56 | -36 | 77 | 190 | 138 | 1.38 |
| | 5-15 | Atropine** | 5 | 30 | 235 | 142 | 2049 | --- | 2088 | 1.01 | 359 | 56 | -36 | 118 | 144 | 77 | 1.87 |
| Tu | 5-16 | Blank | 5 | --- | 5 | 5 | 2132 | --- | 2144 | | | | | | | | |
| | 5-16 | Control | 5 | 30 | 636 | 298 | 2153 | --- | 2346 | 1.05 | 390 | 61 | -41 | 99 | 189 | 168 | 1.12 |
| | 5-16 | Atropine** | 5 | 30 | 132 | 154 | 2121 | --- | 2141 | 1.01 | 390 | 61 | -32 | 274 | 23 | 85 | 0.27 |
| Bl | 5-17 | Blank | 5 | --- | 171 | 57 | 2232 | --- | 2294 | | | | | | | | |
| | 5-17 | Control | 5 | 30 | 1072 | 419 | 2250 | --- | 2738 | 1.12 | 412 | 64 | -35 | 94 | 219 | 198 | 1.11 |
| | 5-17 | Atropine** | 5 | 23 | 270 | 213 | 2221 | --- | 2247 | 1.02 | 412 | 64 | -37 | 234 | 77 | 105 | 0.73 |
| | | | | | | | 41°C DB, 24°C WB, 0.05 m/sec Wind | | | | | | | | | | |
| Ed | 6-1 | Blank | 5 | --- | 159 | 54 | 1895 | --- | 1925 | | | | | | | | |
| | 5-31 | Control | 5 | 18 | 447 | 129 | 1892 | --- | 2070 | 1.05 | 306 | 48 | 21 | 89 | 190 | 90 | 2.11 |
| | 5-30 | Atropine** | 5 | 18 | 141 | 92 | 1837 | --- | 1850 | 1.01 | 306 | 48 | 15 | 136 | 137 | 40 | 3.42 |
| Gi | 6-12 | Blank | 5 | --- | 141 | 42 | 2062 | --- | 2089 | | | | | | | | |
| | 6-13 | Control | 5 | 22 | 1026 | 401 | 2245 | --- | 2701 | 1.11 | 393 | 62 | 22 | 145 | 208 | 306 | 0.67 |
| | 6-14 | Atropine** | 5 | 25 | 512 | 278 | 2154 | --- | 2289 | 1.04 | 393 | 62 | 17 | 189 | 159 | 171 | 0.93 |
| An | 5-30 | Control | 5 | 30 | 769 | 418 | 2000 | 2389 | 2507 | 1.22 | 354 | 56 | 24 | 98 | 224 | 227 | 0.99 |
| La | 6-14 | Blank | 5 | --- | 30 | 80 | ---- | 2217 | 2104 | | | | | | | | |
| | 6-12 | Control | 5 | 30 | 491 | 424 | 1893 | 2280 | 2214 | 1.16 | 352 | 55 | 23 | 132 | 188 | 258 | 0.73 |
| | 6-13 | Atropine** | 5 | 30 | 143 | 330 | 1869 | 2259 | 1982 | 1.11 | 353 | 55 | 21 | 139 | 179 | 184 | 0.97 |
| Ge | 5-30 | Blank | 5 | --- | 28 | 76 | ---- | 3156 | 2995 | | | | | | | | |
| | 6-1 | Control | 5 | 18 | 449 | 408 | 2017 | 3004 | 2821 | 1.40 | 366 | 58 | 22 | 78 | 252 | 404 | 0.62 |
| | 5-31 | Atropine** | 5 | 18 | 142 | 391 | 2010 | 2999 | 2652 | 1.37 | 366 | 58 | 21 | 142 | 187 | 382 | 0.49 |
| Da | 6-13 | Blank | 5 | --- | 30 | 80 | ---- | 2968 | 2789 | | | | | | | | |
| | 6-14 | Control | 5 | 30 | 491 | 424 | 1944 | 2937 | 2795 | 1.40 | 357 | 56 | 30 | 111 | 220 | 310 | 0.71 |
| | 6-12 | Atropine** | 5 | 28 | 143 | 330 | 1974 | 2961 | 2419 | 1.32 | 357 | 56 | 28 | 138 | 191 | 256 | 0.75 |

*Mean weight of 4-piece suit during walk over initial dry weight.
**Atropine sulfate injected intravenously, 28.5 μg/kg during initial rest period.

Table V. SERIES C

Treadmill and Wind Speeds 1.34 m/sec

| Man | Date | Temp DB | Temp WB | Grade | Assembly | Condition | Time Rest | Time Walk | Weights in rest: Weight loss Nude | Weight loss Clothed | Suit 1 Before | Suit 1 After | Net weights in walk: Weight loss Nude | Weight loss Clothed | Suite 2 Before | Suite 2 After | Wet* / Dry | M | W | R+C | S | E | E' | E/E' |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °C | °C | % | | | Min | Min | Gm | Gm | Gm | Gm | Gm | Gm | Gm | Gm | | Watts/sq m | | | | | | |
| Cr | 11-7 | 41 | 24 | 10 | I | Dry | 5 | 18 | 166 | 43 | 1883 | 1907 | 486 | 169 | 1967 | 2160 | 1.06 | 322 | 50 | 27 | 87 | 212 | 229 | 0.92 |
| Cr | 11-8 | 41 | 24 | 10 | I | Dry | 5 | 24 | 199 | 40 | 1857 | 1953 | 714 | 230 | 1994 | 2256 | 1.12 | 316 | 49 | 24 | 118 | 173 | 234 | 0.74 |
| Cr | 11-9 | 41 | 24 | 10 | I | +400 | 5 | 28 | 55 | 75 | 2297 | 2171 | 808 | 302 | 2111 | 2402 | 1.22 | 318 | 50 | 31 | 121 | 178 | 263 | 0.68 |
| Cr | 11-10 | 41 | 24 | 10 | I | +1000 | 5 | 28 | 44 | 96 | 2859 | 2637 | 750 | 450 | 2619 | 2739 | 1.45 | 320 | 50 | 36 | 106 | 200 | 392 | 0.51 |
| Cr | 11-14 | 41 | 24 | 0 | I | Atropine | 5 | 30 | 211 | 30 | 1887 | 1967 | 156 | 134 | 1953 | 1932 | 1.04 | 160 | 0 | 22 | 81 | 101 | 106 | 0.95 |
| Cr | 11-13 | 41 | 24 | 0 | I | Dry | 5 | 30 | 159 | 22 | 1842 | 1916 | 702 | 226 | 1959 | 2260 | 1.12 | 160 | 0 | 25 | 43 | 142 | 178 | 0.80 |
| Cr | 11-16 | 41 | 24 | 0 | I | +400 | 5 | 30 | 52 | 56 | 2219 | 2092 | 683 | 255 | 2135 | 2349 | 1.20 | 160 | 0 | 31 | 50 | 141 | 200 | 0.71 |
| Cr | 11-17 | 41 | 24 | 0 | I | +1000 | 5 | 30 | 123 | 100 | 2801 | 2599 | 512 | 397 | 2636 | 2658 | 1.43 | 162 | 0 | 36 | 35 | 163 | 312 | 0.52 |
| Cr | 12-5 | 41 | 24 | 0 | III | Atropine | 5 | 30 | 116 | 25 | 1343 | 1363 | 225 | 161 | 1360 | 1384 | 1.02 | 159 | 0 | 37 | 82 | 114 | 126 | 0.90 |
| Cr | 12-4 | 41 | 24 | 0 | III | Dry | 5 | 30 | 106 | 25 | 1314 | 1341 | 451 | 260 | 1399 | 1535 | 1.07 | 158 | 0 | 44 | 29 | 173 | 213 | 0.81 |
| Cr | 11-28 | 41 | 24 | 0 | III | +400 | 5 | 30 | 55 | 63 | 1774 | 1624 | 383 | 357 | 1569 | 1524 | 1.17 | 160 | 0 | 52 | 20 | 192 | 291 | 0.66 |
| Cr | 12-1 | 41 | 24 | 0 | III | +1000 | 5 | 30 | 60 | 112 | 2377 | 2182 | 213 | 446 | 2163 | 1885 | 1.48 | 161 | 0 | 59 | 10 | 210 | 375 | 0.56 |
| Mo | 12-18 | 41 | 24 | 0 | II | Dry | 5 | 30 | 167 | 39 | 1423 | 1481 | 455 | 265 | 1461 | 1588 | 1.08 | 197 | 0 | 43 | 61 | 179 | 187 | 0.96 |
| Mo | 12-19 | 41 | 24 | 0 | II | +400 | 5 | 30 | 160 | 63 | 1797 | 1698 | 329 | 377 | 1701 | 1633 | 1.20 | 195 | 0 | 55 | 47 | 203 | 257 | 0.79 |
| Mo | 12-15 | 41 | 24 | 0 | II | +1000 | 5 | 30 | 100 | 95 | 2433 | 2291 | 361 | 585 | 2263 | 1998 | 1.51 | 198 | 0 | 58 | 24 | 232 | 396 | 0.59 |
| Mo | 12-11 | 41 | 24 | 0 | III | Dry | 5 | 30 | 114 | 34 | 1410 | 1445 | 474 | 279 | 1454 | 1543 | 1.06 | 196 | 0 | 42 | 44 | 194 | 190 | 1.02 |
| Mo | 12-12 | 41 | 24 | 0 | III | +400 | 5 | 30 | 119 | 67 | 1798 | 1733 | 368 | 418 | 1737 | 1667 | 1.21 | 197 | 0 | 58 | 41 | 214 | 284 | 0.75 |
| Mo | 12-8 | 41 | 24 | 0 | III | +1000 | 5 | 30 | 110 | 118 | 2454 | 2274 | 273 | 524 | 2240 | 1969 | 1.46 | 196 | 0 | 59 | 20 | 235 | 368 | 0.64 |
| Mo | 1-9 | 29 | 19 | 0 | III | Dry | 5 | 30 | 67 | - 2 | 1411 | 1447 | 293 | 152 | 1434 | 1475 | 1.04 | 196 | 0 | -31 | 56 | 109 | 106 | 1.03 |
| Mo | 1-10 | 29 | 19 | 0 | III | +400 | 5 | 30 | 49 | 41 | 1797 | 1689 | 200 | 279 | 1703 | 1589 | 1.17 | 196 | 0 | -18 | 39 | 139 | 196 | 0.71 |
| Mo | 12-21 | 29 | 19 | 0 | III | +1000 | 5 | 30 | 51 | 78 | 2405 | 2275 | 78 | 391 | 2291 | 1998 | 1.50 | 195 | 0 | - 8 | -14 | 201 | 275 | 0.73 |
| Mo | 12-20 | 29 | 19 | 10 | III | +1000 | 5 | 12 | 45 | 70 | 2394 | 2252 | 137 | 240 | 2255 | 2132 | 1.56 | 386 | 61 | -10 | -70 | 385 | 452 | 0.85 |
| Cr | 11-27 | 41 | 24 | 10 | IV ⨍ | Dry | 5 | 30 | 89 | 28 | | | 630 | 491 | | | | 307 | 48 | 106 | 17 | 348 | 370 | 0.94 |
| Cr | 11-21 | 41 | 24 | 0 | IV ⨍ | Dry | 5 | 30 | 66 | 21 | | | 419 | 353 | | | | 153 | 0 | 88 | 7 | 234 | 267 | 0.88 |
| Cr | 11-24 | 41 | 24 | 0 | V ⨍ | Dry | 5 | 30 | 136 | 10 | | | 450 | 370 | | | | 156 | 0 | 95 | 11 | 240 | 280 | 0.86 |
| Cr** | 11-20 | 41 | 24 | 0 | VI ⨍ | Dry | 5 | 30 | | | | | 443 | 358 | | | | 154 | 0 | 77 | 21 | 210 | 251 | 0.84 |
| Cr** | 11-20 | 41 | 24 | 0 | VII ⨍ | Dry | 5 | 30 | | | | | 548 | 399 | | | | 155 | 0 | 86 | 1 | 240 | 283 | 0.85 |
| Cr | 11-22 | 41 | 24 | 0 | VIII | Dry | 5 | 30 | 130 | 5 | 1150 | 1180 | 652 | 292 | 1199 | 1395 | 1.11 | 159 | 0 | 46 | 18 | 187 | 213 | 0.88 |

*Mean weight of 4-piece suit during walk over initial dry weight

**No blank

⨍ Unmeasured drip

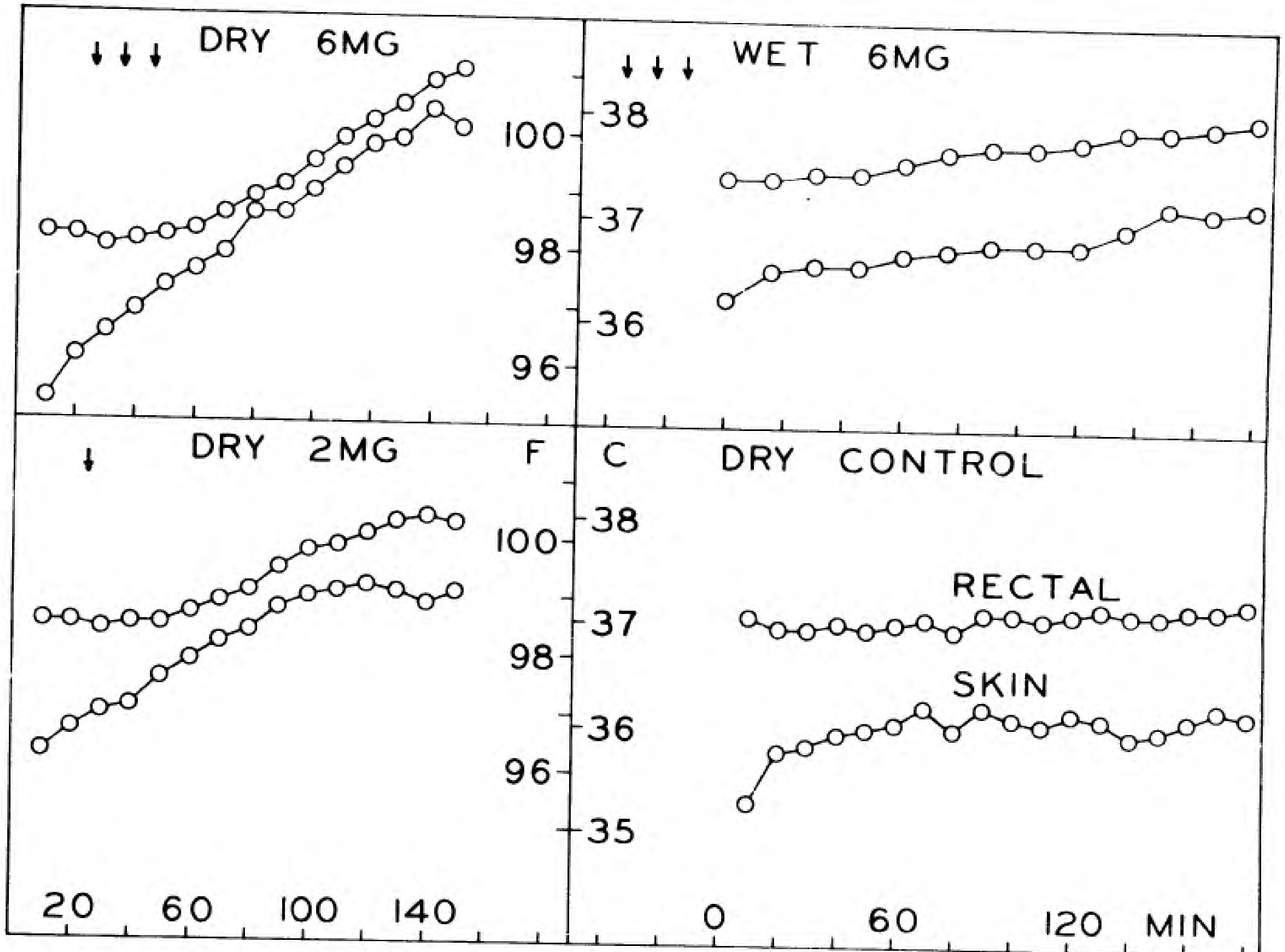


Figure 1. Series A. Rectal and Average Skin Temperature in Men at Rest Wearing Assembly I at 41°C

Vertical arrows indicate the intramuscular injection of 2 mg of atropine sulfate. Panels marked Dry Control, Dry 2 mg and Dry 6 mg refer to average data for Ev and Ni. The Wet 6 mg panel refers to average data for Tu, Da, Gi, and La.

undetermined. Reference to Appendix table I shows that the rates of heat storage in watts/sq m in the second hour for Fy and Ni were 5 and 4 without atropine, 28 and 33 with 2 mg, and 47 and 42 with 6 mg. Corresponding figures for the other five men with 6 mg and the initially wet suit were 14, -5, 9, 5, and 9.

The initially wet four-piece suits lost weight during the three hours in the hot room and there was a consistent progressive rise in the E/E' ratio.

The data for the continually recorded local sweating in Fy and Ni are summarized in table VI. Without atropine the sweat rate and skin temperature increased progressively with time in Ni but in Fy they reached peak values in the second hour and then declined. The effects of the 2-mg dose were typical in that the sweat rate was very low in the second hour and recovered in the third hour. In the third hour of the 6-mg tests there was some recovery of water output but not nearly to the extent seen with the 2-mg dose.

B. **Series B.**

The individual experiments and results are listed in table IV. From the blank experiments was learned what the weight changes in the four-piece suit were during dressing, undressing and a 5-minute rest period. The 2-mg atropine experiments served to screen out volunteers who might not be good candidates for the 6-mg dose and also provided somewhat drier suits than those in the controls because of the inhibition of sweating.

In the experiments at 29°, the man walked twice in one morning the first time without and the second time with atropine. The men were given a cold shower bath after the first walk to avoid starting the second walk in an overheated condition. In Tu and Bl, however, the showers resulted in extensive changes in skin temperature before and during the second walk. The resulting calculations of heat storage yielded such high values that inclusion with the other experiments did not seem justified. The body temperatures for Al, Tu, and Bl are shown in figure 2 together with average results for 4 men walking once a day from an earlier report.[1] otherwise under the same conditions.

In the experiments at 41°C, the men walked only once a day and the storage values were in the expected range. However, in this group, differences between men obscured the trends as may be seen by inspection of table IV. Atropine produced the expected increases in heat storage in Ed and Gi wearing initially dry suits. Large increases in storage were prevented by wetting the suits worn by La and Da but not in Ge who walked only 18 instead of 30 minutes.

C. **Series C.**

In this series an effort was made to relate the efficiency of evaporative cooling to the water content of the clothing. Repeated observations were made on only two men. Cr was unable to complete 30 minutes at the 10 percent grade and subsequent tests were made on the level. Also different clothing assemblies were compared under similar conditions of initial wetting. The conditions and results are summarized in table V. In figures 3 and 4 are shown the skin and rectal temperatures under four of the six man-condition combinations. Figure 3

Table VI. Arm Sweat, Series A

| Time | Volunteer Fy | | | | | Volunteer Ni | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Air flow | Relative humidity | Sweat rate | Temperature Rectal | Temperature Arm | Air flow | Relative humidity | Sweat rate | Temperature Rectal | Temperature Arm |
| Min | l/min | % | gm/min/sq m | °F | °F | l/min | % | gm/min/sq m | °F | °F |
| | | | 15 Sep 71 Control | | | | | 17 Sep 71 Control | | |
| 10 | 0.20 | 6.1 | 0.53 | 98.5 | 94.7 | 0.20 | 12.7 | 1.10 | 98.8 | 94.4 |
| 20 | 0.20 | 10.9 | 0.94 | 98.4 | 96.7 | 0.20 | 11.0 | 0.95 | 98.6 | 95.1 |
| 30 | 0.20 | 9.9 | 0.86 | 98.4 | 96.6 | 0.20 | 10.5 | 0.91 | 98.6 | 95.4 |
| 40 | 0.20 | 34.2 | 2.95 | 98.6 | 98.4 | 0.30 | 11.3 | 1.46 | 98.5 | 95.9 |
| 50 | 0.40 | 16.9 | 2.92 | 98.5 | 98.8 | 0.30 | 9.6 | 1.24 | 98.5 | 96.0 |
| 60 | 0.40 | 15.2 | 2.63 | 98.5 | 97.6 | 0.30 | 14.4 | 1.87 | 98.6 | 96.2 |
| 70 | 0.40 | 34.7 | 5.99 | 98.6 | 98.1 | 0.40 | 15.8 | 2.73 | 98.7 | 96.1 |
| 80 | 0.45 | 17.3 | 3.36 | 98.6 | 97.9 | 0.40 | 14.2 | 2.45 | 98.4 | 96.1 |
| 90 | 0.45 | 19.3 | 3.75 | 98.9 | 97.8 | 0.40 | 14.5 | 2.51 | 96.6 | 96.2 |
| 100 | 0.45 | 21.4 | 4.16 | 98.9 | 97.6 | 0.40 | 13.4 | 2.32 | 98.6 | 96.3 |
| 110 | 0.45 | 20.0 | 3.89 | 98.8 | 96.9 | 0.40 | 15.5 | 2.68 | 98.6 | 96.8 |
| 120 | 0.45 | 19.9 | 3.87 | 98.9 | 96.6 | 0.40 | 15.8 | 2.73 | 98.6 | 96.8 |
| 130 | 0.40 | 22.6 | 3.91 | 99.1 | 96.2 | 0.40 | 22.0 | 3.80 | 98.7 | 97.3 |
| 140 | 0.40 | 17.0 | 2.94 | 98.8 | 95.3 | 0.40 | 18.5 | 3.20 | 98.7 | 96.8 |
| 150 | 0.40 | 10.3 | 1.78 | 98.8 | 96.3 | 0.40 | 18.7 | 3.23 | 98.8 | 96.8 |
| 160 | 0.40 | 8.6 | 1.49 | 98.9 | 96.4 | 0.40 | 22.2 | 3.84 | 98.9 | 97.2 |
| 170 | 0.40 | 10.8 | 1.86 | 98.8 | 96.3 | 0.40 | 22.9 | 3.96 | 98.9 | 96.9 |
| 180 | 0.40 | 10.3 | 1.78 | 98.9 | 96.5 | 0.40 | 21.3 | 3.68 | 99.0 | 97.2 |
| | | | 21 Sep 71, 2 mg | | | | | 23 Sep 71, 2 mg | | |
| 10 | 0.20 | 9.4 | 0.81 | 99.0 | 94.7 | 0.20 | 19.8 | 1.70 | 98.5 | 94.4 |
| 20* | 0.20 | 13.4 | 1.16 | 98.8 | 95.2 | 0.20 | 12.9 | 1.11 | 98.2 | 94.8 |
| 30 | 0.20 | 16.6 | 1.43 | 98.8 | 95.2 | 0.20 | 13.1 | 1.13 | 98.1 | 95.5 |
| 40 | 0.20 | 7.6 | 0.66 | 98.8 | 95.5 | 0.20 | 13.8 | 1.19 | 98.0 | 95.0 |
| 50** | 0.20 | 5.2 | 0.45 | 98.8 | 97.1 | 0.20 | 18.8 | 1.62 | 98.1 | 95.9 |
| 60 | 0.10 | 6.5 | 0.28 | 98.9 | 98.0 | 0.20 | 17.8 | 1.54 | 98.0 | 95.7 |
| 70 | | | | 99.0 | 98.5 | 0.20 | 5.8 | 0.50 | 98.1 | 96.5 |
| 80 | | | | 99.4 | 98.6 | 0.05 | 4.9 | 0.11 | 98.2 | 97.4 |
| 90 | 0.20 | 15.6 | 1.35 | 99.7 | 98.7 | 0.05 | 7.9 | 0.17 | 98.4 | 97.7 |

Table VI. (Contd)

| Time | Volunteer Fy | | | | | Volunteer Ni | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Air flow | Relative humidity | Sweat rate | Temperature | | Air flow | Relative humidity | Sweat rate | Temperature | |
| | | | | Rectal | Arm | | | | Rectal | Arm |
| Min | 1/min | % | gm/min/sq m | °F | °F | 1/min | % | gm/min/sq m | °F | °F |
| 100 | 0.20 | 16.9 | 1.46 | 100.0 | 99.1 | 0.05 | 9.9 | 0.19 | 98.7 | 98.3 |
| 110 | 0.20 | 19.0 | 1.64 | 100.0 | 98.9 | 0.05 | 10.5 | 0.23 | 98.8 | 98.5 |
| 120 | 0.20 | 23.8 | 2.06 | 100.3 | 99.1 | 0.05 | 13.7 | 0.30 | 99.2 | 98.6 |
| 130 | 0.20 | 35.1 | 2.03 | 100.4 | 99.0 | 0.05 | 21.9 | 0.47 | 99.5 | 98.7 |
| 140 | 0.20 | 36.6 | 3.16 | 100.4 | 98.7 | 0.20 | 36.4 | 3.14 | 99.8 | 98.7 |
| 150 | 0.20 | 34.1 | 2.94 | 100.4 | 98.5 | 0.20 | 26.6 | 2.30 | 100.1 | 98.9 |
| 160 | 0.30 | 40.0 | 5.18 | 100.6 | 99.0 | 0.20 | 26.7 | 2.31 | 100.2 | 99.0 |
| 170 | 0.40 | 35.1 | 6.06 | 100.5 | 98.7 | 0.20 | 31.1 | 3.69 | 100.3 | 98.9 |
| 180 | 0.40 | 33.6 | 5.80 | 100.4 | 98.5 | 0.20 | 32.1 | 2.77 | 100.2 | 98.5 |
| | 28 Sep 71, 6 mg | | | | | 30 Sep 71, 6 mg | | | | |
| 10 | 0.20 | 9.9 | 0.86 | 98.5 | 93.5 | | | | 97.9 | 94.1 |
| 20* | 0.20 | 8.9 | 0.77 | 98.4 | 94.7 | 0.20 | 5.3 | 0.46 | 97.9 | 95.7 |
| 30* | 0.20 | 15.0 | 1.30 | 98.2 | 96.4 | 0.05 | 10.5 | 0.23 | 97.8 | 95.8 |
| 40* | | | | 98.3 | 95.5 | 0.05 | 8.8 | 0.19 | 97.9 | 96.7 |
| 50 | 0.05 | 5.6 | 0.12 | 98.3 | 96.5 | 0.05 | 10.4 | 0.22 | 98.1 | 97.0 |
| 60 | 0.05 | 5.5 | 0.12 | 98.5 | 97.5 | 0.05 | 9.4 | 0.20 | 98.1 | 97.6 |
| 70 | 0.20 | 10.8 | 0.93 | 98.6 | 98.0 | 0.05 | 9.8 | 0.21 | 98.5 | 98.0 |
| 80 | 0.20 | 6.9 | 0.60 | 99.0 | 98.5 | 0.05 | 10.1 | 0.22 | 98.8 | 98.7 |
| 90 | 0.20 | 5.3 | 0.48 | 99.2 | 98.9 | 0.05 | 10.3 | 0.22 | 99.0 | 98.8 |
| 100 | 0.20 | 5.1 | 0.44 | 99.6 | 99.3 | 0.05 | 10.3 | 0.22 | 99.4 | 99.5 |
| 110 | | | | 100.0 | 99.6 | 0.10 | 10.3 | 0.44 | 99.7 | 99.6 |
| 120 | 0.05 | 5.1 | 0.14 | 100.4 | 100.0 | 0.10 | 9.1 | 0.39 | 100.0 | 99.8 |
| 130 | | | | 100.6 | 100.1 | 0.10 | 10.7 | 0.46 | 100.4 | 99.9 |
| 140 | 0.20 | 6.1 | 0.53 | 100.8 | 100.5 | 0.10 | 12.5 | 0.54 | 100.9 | 100.0 |
| 150 | 0.20 | 7.0 | 0.60 | 101.1 | 100.1 | 0.10 | 13.4 | 0.58 | 101.0 | 99.4 |
| 160 | | | | | | 0.10 | 16.7 | 0.72 | 101.4 | 99.8 |

*Injection of 2 mg at 26, 36, 46 min for volunteer Fy

*Injection of 2 mg at 28, 38 and 48 min for volunteer Ni

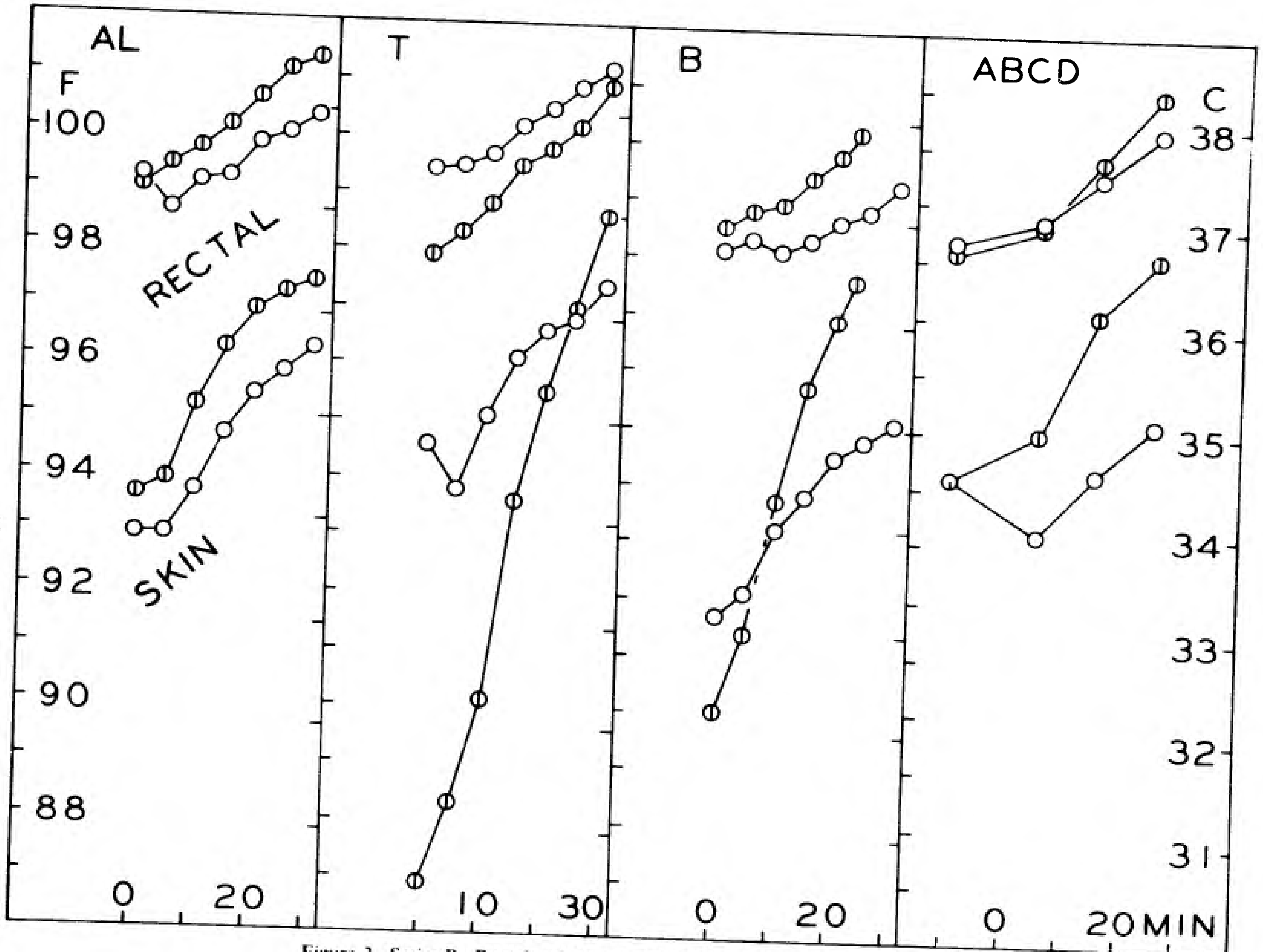


Figure 2. Series B. Rectal and Average Skin Temperatures During Walking at 10-Percent Grade and 20°C in Assembly I

Individual data for Al, Tu, and Bl compared with average data for ABCD in the previous report.[1] Open circles without atropine, vertical bars with atropine. Al, Tu, and Bl walked with atropine after cold shower baths after the walk without atropine. In ABCD the walks were initial walks on separate days.

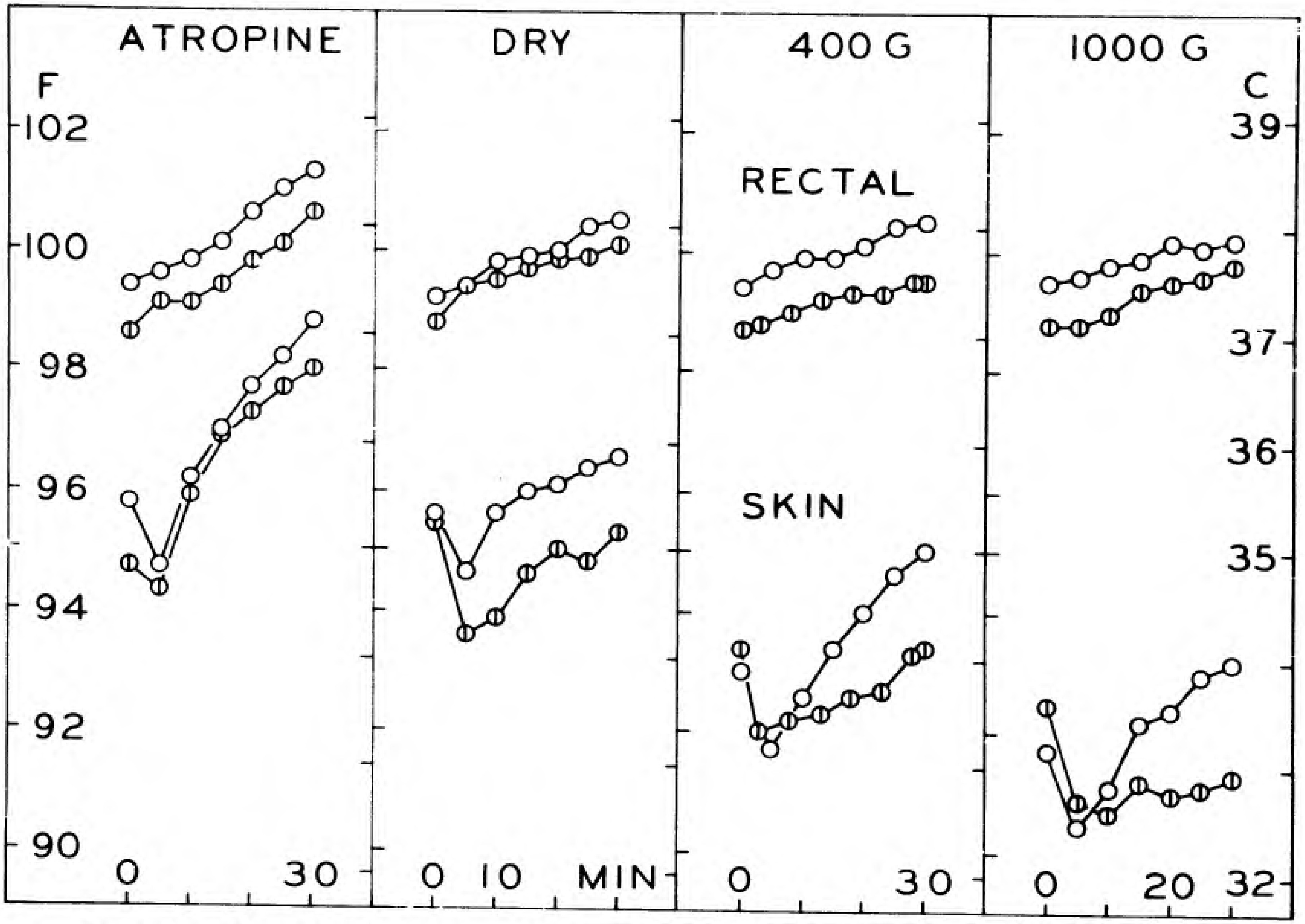


Figure 3. Series C. Rectal and Mean Skin Temperatures of Cr Walking on Level Treadmill at 41°C for Indicated Suit Conditions

Open circles for assembly I, barred circles for assembly III.

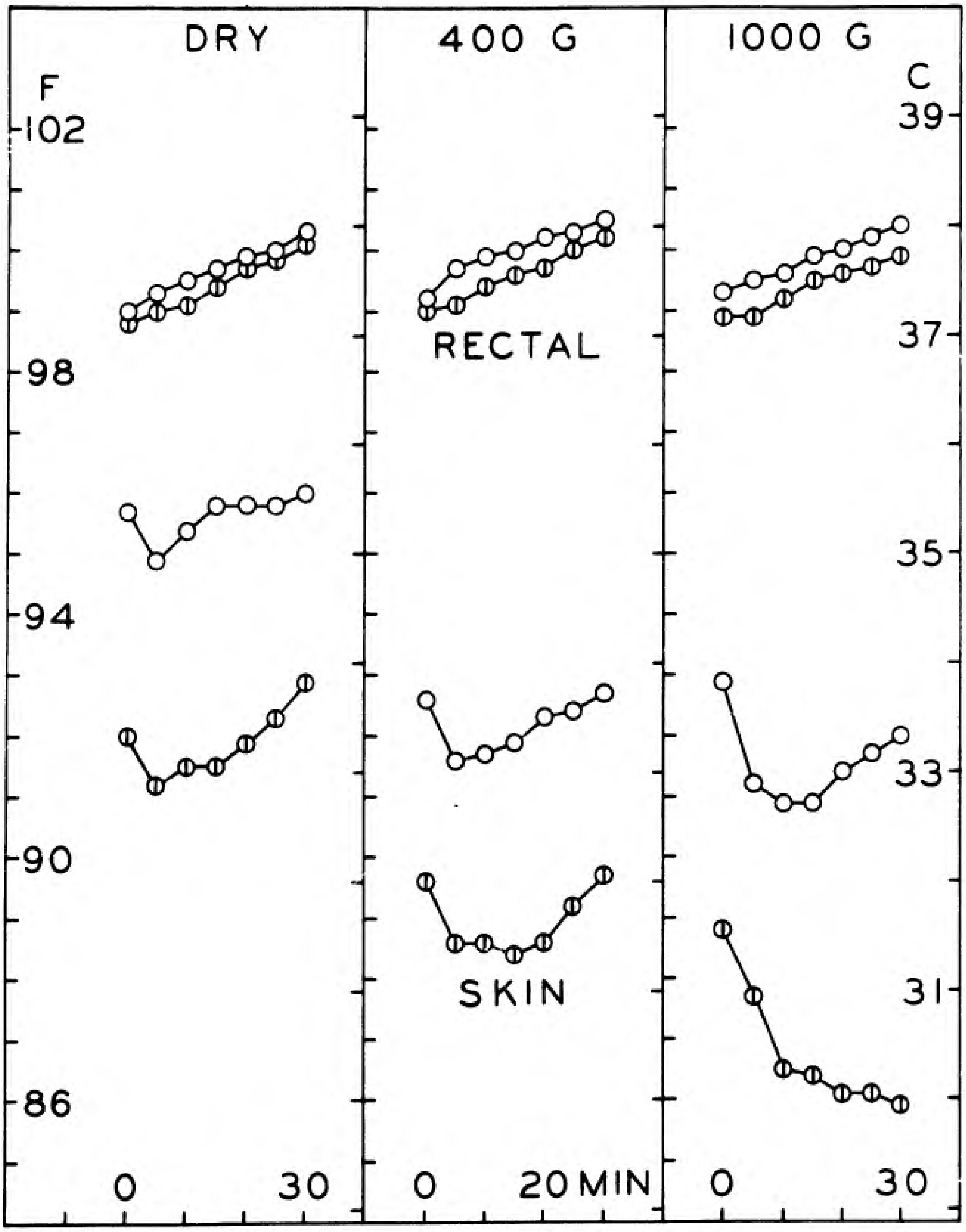


Figure 4. Series C. Rectal and Mean Skin Temperatures of Mo Walking on Level Treadmill in Assembly III at the Indicated Suit Conditions

Open circles for 41°C, barred circles for 29°C.

illustrates the difference between assemblies I and III and figure 4 illustrates the difference between 41 and 29°C environmental temperatures. The various changes in conditions had a greater effect on skin than on rectal temperature. Figures 5 and 6 for Cr and figures 7 and 8 for Mo give the individual data on energy exchange and weight changes in relation to suit wettedness. M and R+C were little affected by wettedness so that changes in S were reflected in changes in the opposite direction in E. In most conditions the gain in weight of the suit during the walk arising from the accumulation of sweat changed to a loss when the suit was initially wet and this was associated with a decrease in sweating (nude loss) and an increase in evaporation (clothed loss). However in the grade walks by Cr, the rate of sweating was large enough to maintain a positive gain in the suit weight.

When the efficiency of evaporative cooling was plotted against wettedness in figure 9 there was a uniform downward trend from the origin diminishing in slope as wettedness increased. Also the points for Mo were above those of Cr with one exception.

## V. DISCUSSION.

The results in series A are sufficient to demonstrate that wetting the clothing will provide enough evaporative cooling to make up the deficit in sweating resulting from an excess of atropine. Although this may be a documentation of the self-evident, some statement to this effect should be added to technical manuals dealing with the treatment of chemical casualties.

The results for water output under the capsule are in general agreement at the 2-mg dose with those reported earlier.[1] The new data at the 6-mg dose can be compared with those of Webb, *et al.*[7] for the whole man at doses of from 5 to 9 mg. They reported a residual weight loss which they considered to represent insensible perspiration (that is, diffusion of sweat-free water). Their figures increased with skin temperature: the largest, 0.55 gm/min, came at 36.6°C. This is somewhat more than the minimum values for the capsule at higher skin temperatures. The difference can be attributed to differences in technique to a certain extent; also the skin resistance data of Beuttner[8] suggests that the output is probably less from the forearm than from other locations.

In series B some of the results are unexplained. The large changes in skin temperature in volunteers Tu and Bl during the walk following the cold shower point to a failure of the usual formula for estimating mean body temperature. The effect of cold showers does not appear to have been investigated before. Stolwijk and Hardy[9] weight the skin and internal temperature in the ratio of 1:9 in contrast to the 1:2 ratio used here. If the 1:9 ratio is used, the values of S for control and atropine respectively become 88 and 180 for Tu and 69 and 145 for Bl. These are more in agreement with the average values of 70 and 137 for this condition reported before (series 1[10]). Another difficulty with series B is the occurrence of E/E′ ratios greater than one. This points to an overestimate of M by the formula or an error in S or E′, or both. Volunteer Ed is the most conspicuous example. Here E′ is off by 100, although the decrease in E′ from 90 to 40 as a result of atropine counter-balances almost exactly the increase in S from 89 to 136.

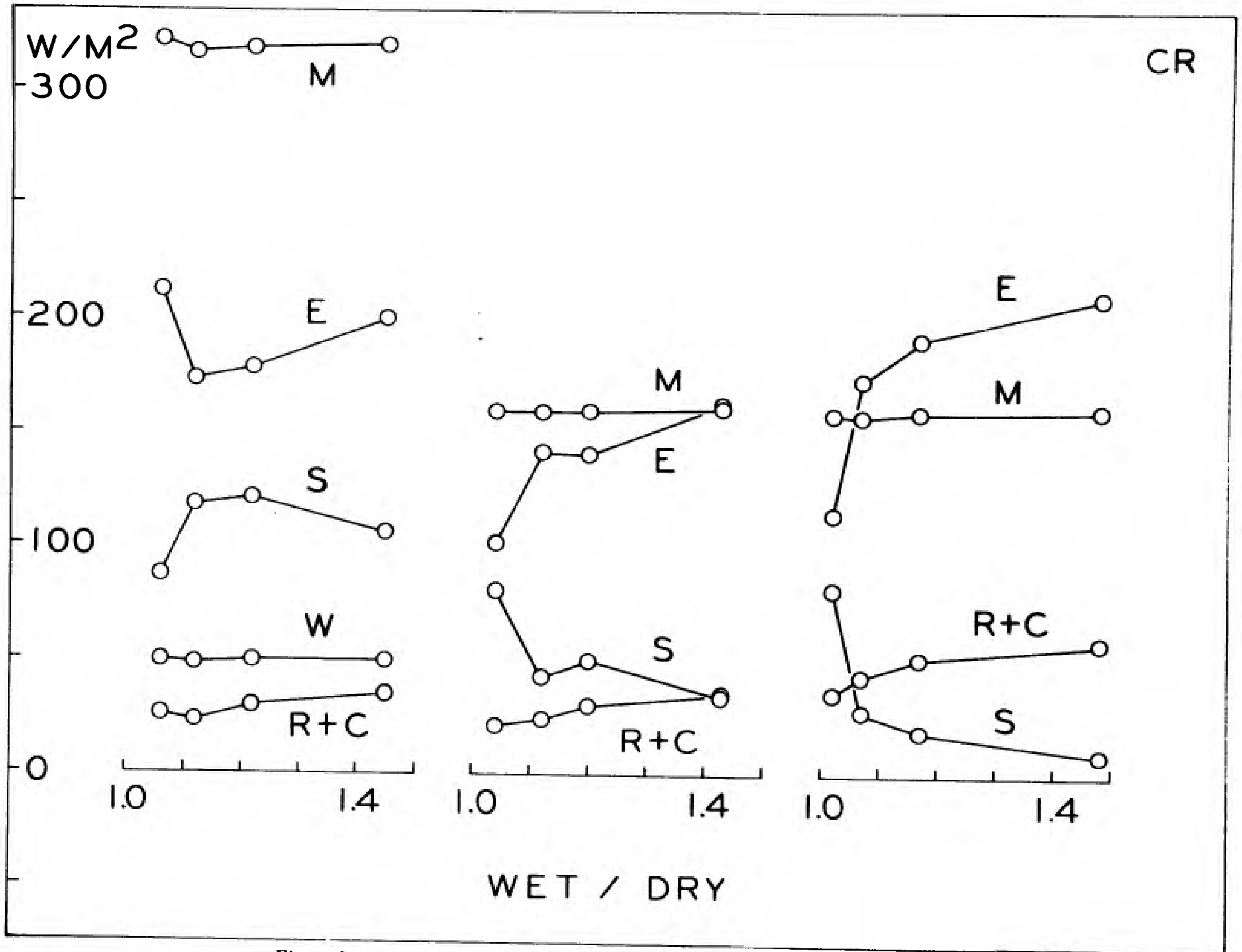


Figure 5. Series C. Energy Exchange in Watts/Sq M of Cr for Various Ratios of the Average Wet Weight to the Dry Weight of the Four-Piece Suit

Left group, treadmill at 10 percent grade, assembly I.
Center group, level treadmill, assembly I.
Right group, level treadmill, assembly III. All at 41°C.

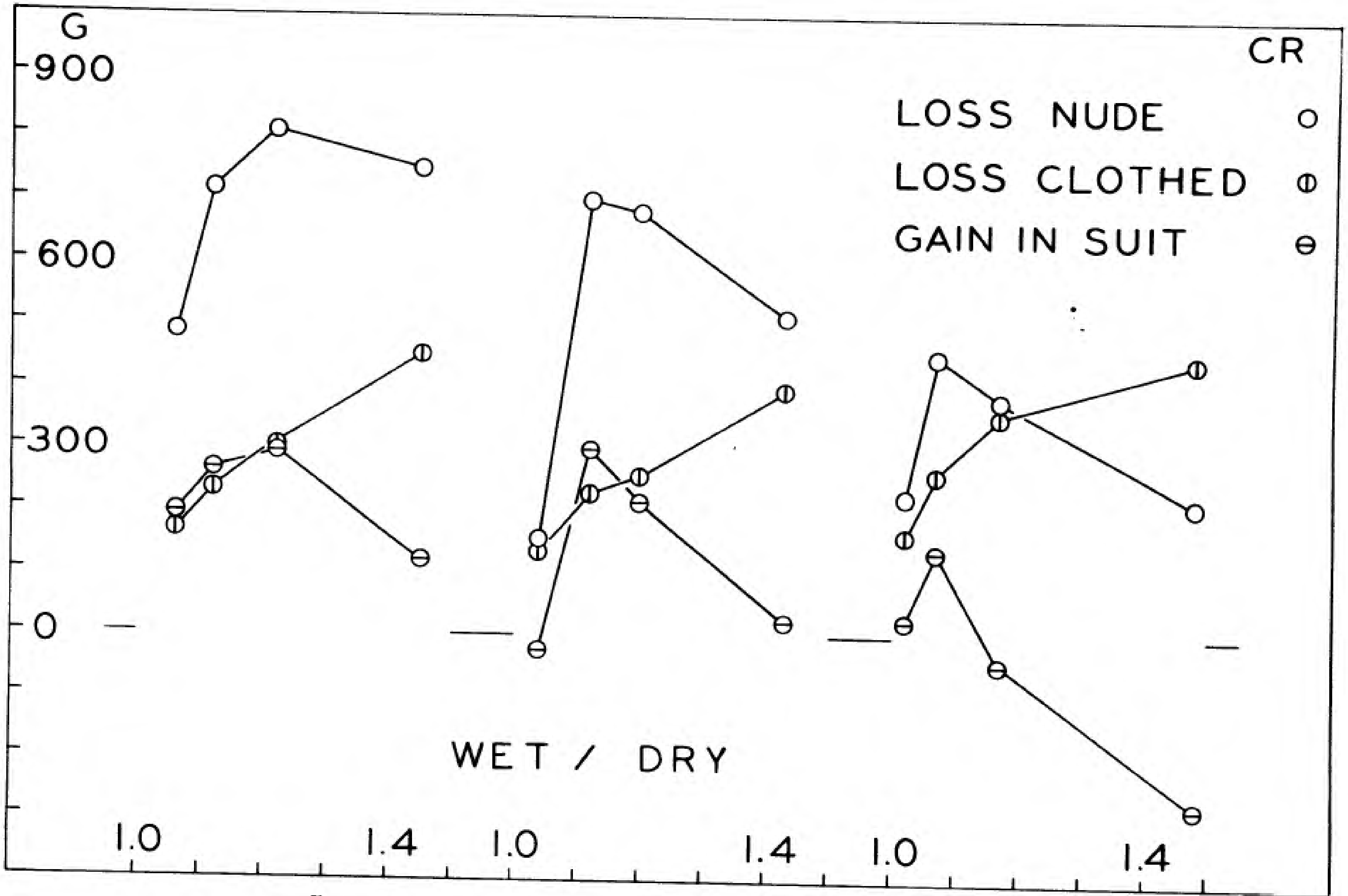


Figure 6. Series C. Weight Changes in Grams in Cr for Various Ratios of the Average Wet Weight to the Dry Weight of the Four-Piece Suit

Groups as in figure 5.

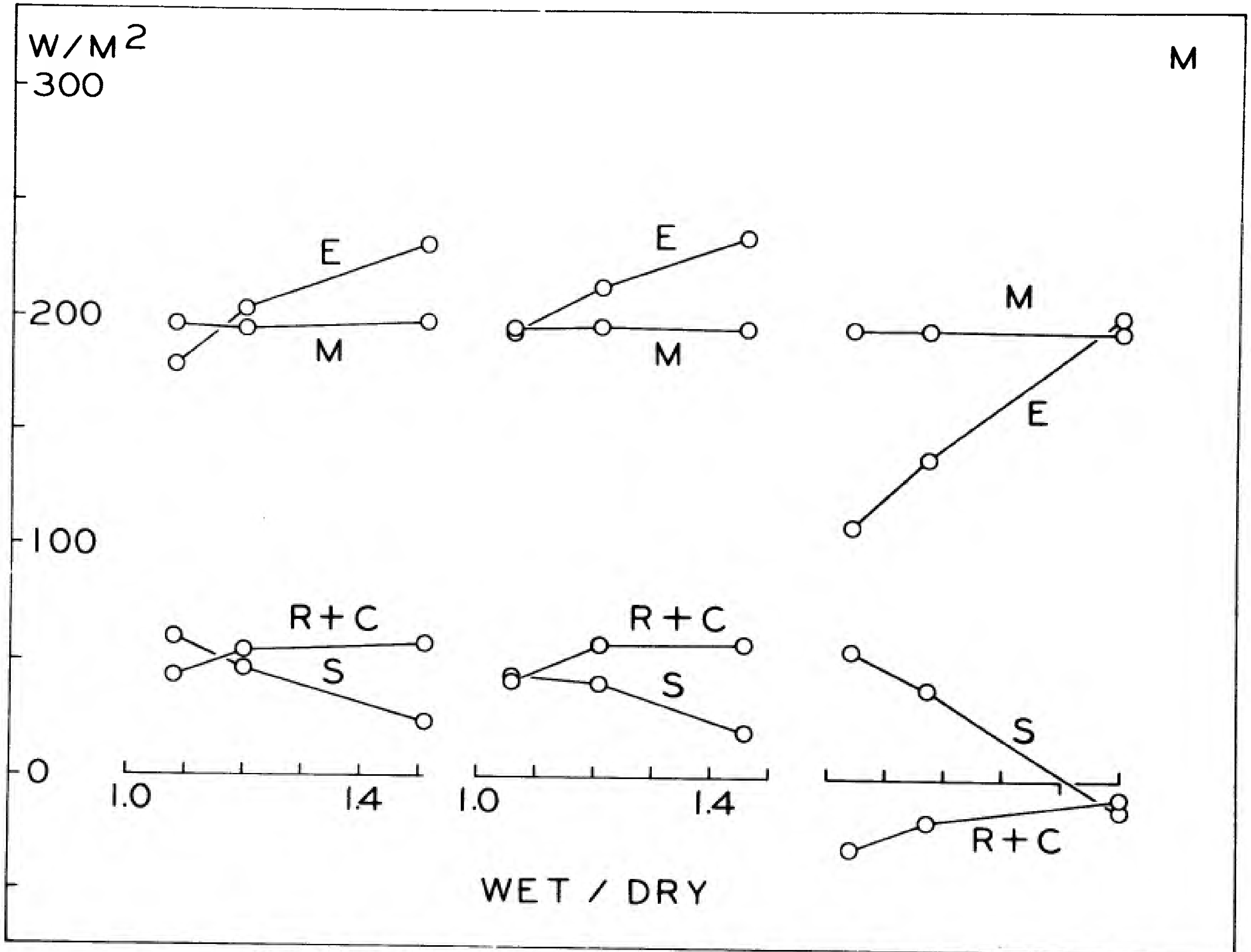


Figure 7. Series C. Energy Exchange in Watts/Sq M of Mo for Various Ratios of the Average Wet Weight to the Dry Weight of the Four-Piece Suit

Left group, assembly II at 41°C.
Center group, assembly III at 41°C.
Right group, assembly III at 29°C. All with level treadmill.

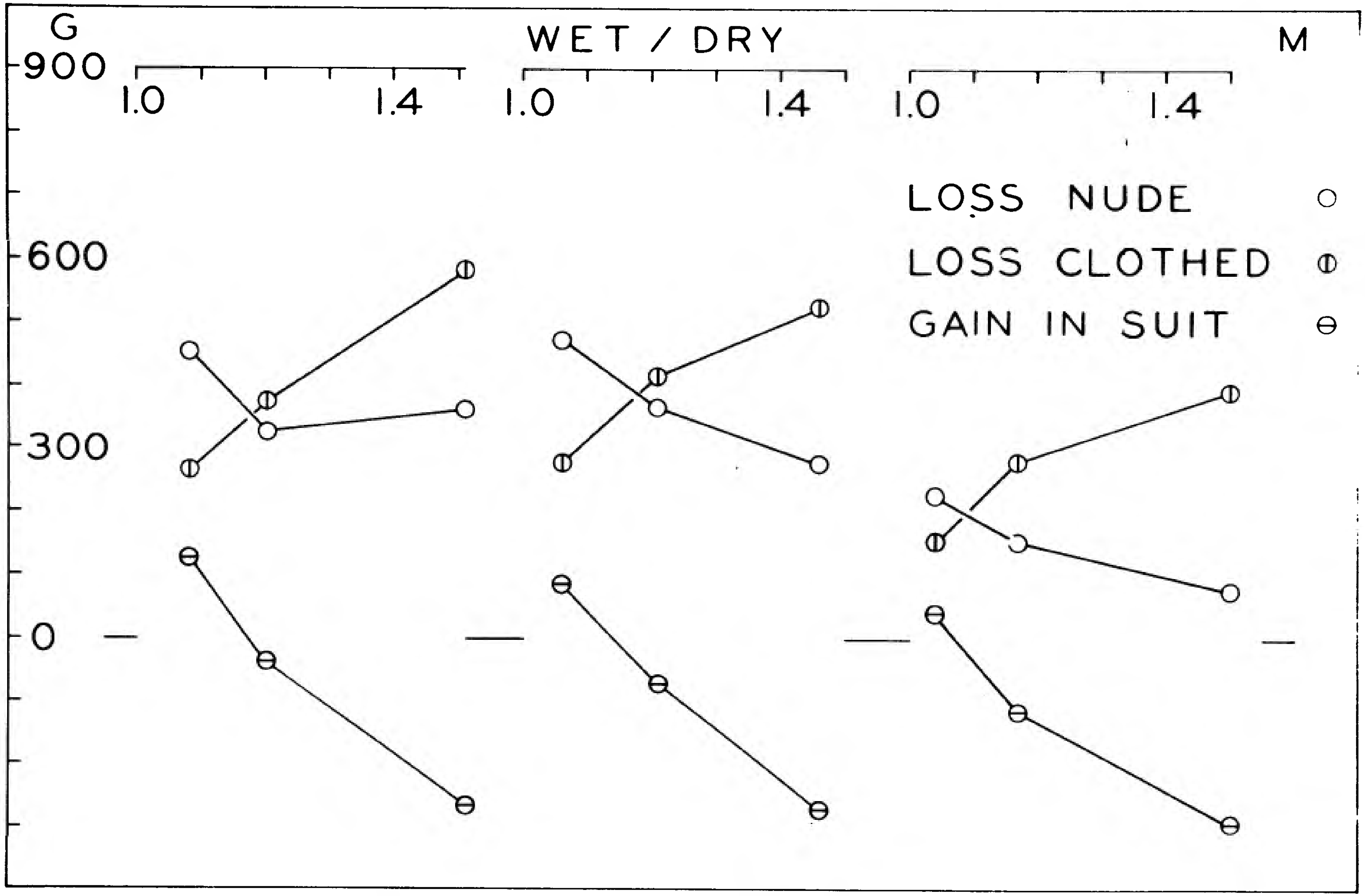


Figure 8. Series C. Weight Changes in Grams in Mo for Various Ratios of the Average Wet Weight to the Dry Weight of the Four-Piece Suit

Groups as in figure 7.

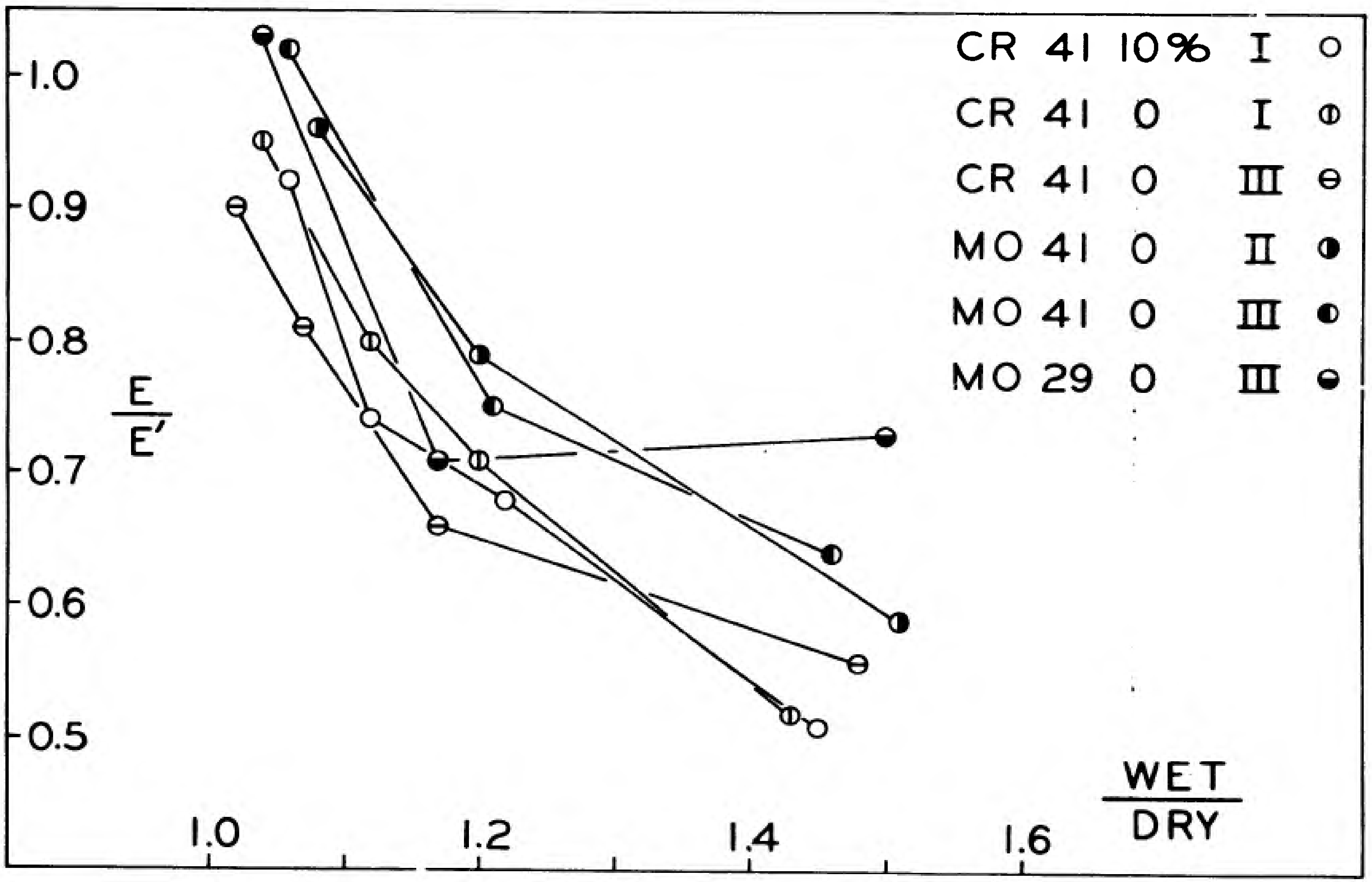


Figure 9. Series C. Evaporative Cooling Calculated from the Energy Exchange for the Man as a Fraction of the Total Heat of Evaporation of Water Calculated from the Clothed Weight Loss for Various Ratios of the Average Wet Weight to the Dry Weight of the Four-Piece Suit

In series C the ratios of E/E′ for the dry suit were near enough to unity to validate the estimates of the various quantities in the heat balance equation. These are difficult to measure accurately even under steady state conditions. Under the present circumstances it is enough to assume that M and R+C are not strongly influenced by the water in the suit so that the changes in E reflect mainly the changes in S. The estimate of R+C depends on Clo values developed for assemblies not identical with but only somewhat similar to the ones used here, and also the same Clo value was used for assemblies II and III, which differ by the presence or absence of the mask and hood. Removing the mask and hood from subject M in the dry suit reduced the heat storage from 61 to 44 without changing the skin temperature averaged over the duration of the walk (as indicated in R+C), but the inaccuracy in Clo evidently was small in comparison to the changes in E′. The differences between assemblies I and III (removal of the mask and hood and substitution of short for long underwear) appeared to be taken care of by the change in Clo, as indicated by the similarity of the curves in figure 9.

Belding *et al.*[11] reported experiments on heat transfer from a heated copper foot through 3 layers of woolen socks; the addition of water to the socks increased the conductivity. In our calculations the same Clo was used for differently wetted suits. If Clo had been decreasing with increasing wettedness, R+C would have increased. The increase in R+C would subtract from E thus further lowering the E/E′ ratio. Our calculation of R+C reflected only the changes arising from the observed temperature gradient between skin and ambient air.

The results for assemblies IV, V, VI, and VII were not too satisfactory because an unmeasured quantity of sweat dripped off, making E′ too large. It had been hoped that eliminating the clothing would improve the estimate of the heat balance.

The data in figure 9 document what has long been thought. In the words of Herrington,[6] "When liquid sweat is absorbed in the clothing on exposure to heat or during muscular work, this sweat will evaporate at some distance from the skin, drawing its heat of vaporization from the clothing and surrounding air. The body does not derive the full benefit of this evaporative cooling but only that part which results from increased temperature gradients between the skin and clothing surfaces on which evaporation takes place. - - There is no way of estimating accurately body heat lost by evaporation on exposure to intense heat or cold or during muscular exertion. The weight loss from the clothed human body (corrected for the inequality of $CO_2$ eliminated and $O_2$ consumed) always overestimates the effective evaporation loss under such conditions." Also, Fourt and Harris[12] state, "When the clothing absorbs liquid water, its thermal conductivity and thermal capacity greatly increase, and it tends to collapse onto and cling to the skin, reducing the insulative effect of air layers to a minimum. In addition, when the clothing is wet, the point of evaporation is shifted from the skin level into the clothing. This lessens the efficiency of cooling, in that a larger amount of the heat taken up in evaporating a given amount of water is drawn from the environment, and a smaller amount from the body, but it increases the effectiveness of evaporative cooling by eliminating the clothing as a resistance to evaporation." Also Burton and Edholm[13] state, "If the moisture that is evaporated at the skin condenses in the clothing at a certain level, 'wicks' to the surface of the clothing and reevaporates there, we cannot consider that all of the heat of vaporization of the water that has been evaporated has come from the body." These authors proceed to define the efficiency of evaporation in terms of the ratio of the dry insulation to the total insulation. Belding et al.[11]

working with a four-layer Arctic clothing assembly in a cold room have employed this concept to evaluate the efficiency for body warming of the heat of condensation of water that evaporates at the skin and condenses in the outer layers of clothing. They discuss the efficiency for skin cooling of the sweat that condenses in the clothing but appear not to consider the efficiency of the remainder that escapes from the clothing into the ambient air. It has been difficult to apply the Burton concept to the present assembly for the unevaporated sweat is distributed among the two layers so that one does not see distinct wet and dry layers as one might in a multilayered assembly in the cold. Also there was no way of estimating the effect of moisture on the thermal insulation of the suit. Thus the present results can be considered only as a first approximation. They (the present results) have resemblance to those obtained by Fourt and Harris (figure 57 in reference 12) witn their artificially sweating man which enabled them to distinguish the evaporation from the skin from the total evaporation including that from wet clothing. As the clothing dried the fraction of evaporation from the skin increased from about 40 percent to 100 percent. In what appears to be the only recent treatment of this problem Nishi and Gagge[14] discuss a model in which the sweat evaporates from a level halfway through clothing with a Clo value of 0.6 at rest at 32°C. Here the thermal insulation of the wetted half-layer decreases to 1/3, but the R+C and E change little from the figures for a model in which all the sweat vaporizes at the skin surface and permeates through dry clothing.

Although from the physical standpoint wetting the clothing reduces the cooling efficiency of the evaporated sweat, the well-known physiological benefits remain, namely, the reduction in sweat production and heat storage.

## VI. CONCLUSIONS.

The elevation of body temperature in men wearing the two-layer chemical protective assembly in consequence of the inhibition of sweating by atropine given for treatment of the effects of anticholinesterase agents can be prevented by artificial wetting of the clothing.

The efficiency of evaporative cooling of clothed men decreases as the water content of the clothing increases. For clothing containing water amounting to 50 percent of the dry weight of the clothing, the efficiency is reduced by about one-half. However from the physiological standpoint, wetting the clothing does increase the effective cooling of the body and there is a corresponding decrease in heat storage.

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