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EVALUATION OF METABOLIC LOSSES IN WHOLE BODY SWEAT FROM MEASUREMENTS OF SMALL SKIN AREAS

by

W. VAN BEAUMONT

for
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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March, 1971

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EVALUATION OF METABOLIC LOSSES IN WHOLE BODY SWEAT FROM MEASUREMENTS OF SMALL SKIN AREAS

SECTION I INTRODUCTION

In order to make up an accurate metabolic balance for the active human organism it has become apparent that dermal losses of nutrients have to be included in the calculations. A survey of the general literature shows that with the inclusion of the Apollo 14 flight no useful information concerning losses of metabolic constituents in human sweat during actual space flights is available. One reason for this gap in our knowledge is the fact that no practical method for sweat sampling had been designed during space flight conditions. Lutwak et al (1) analyzed the chemical composition of the 14-day inflight underwear from the crew of Gemini 7, but this type of collection is hardly satisfactory. Both Johnson and Sargent (2) and the G. E. Missile and Space Division (3) suggested the use of plastic armbags for collection of human sweat. However it is common experience that in order to collect any sweat with this method high environmental temperatures, in combination with physical exertion, are required. This type of situation is not commonly encountered during space flight conditions and the unavailability of one hand for the long collection time makes this collection procedure impractical.

Obviously, if dermal losses have to be determined another collection technique has to be employed. The present study deals with the problem of sweat collection from small skin areas and the predictability of whole body sweat constituent losses from the subsequent analysis.

SECTION II RESEARCH AIMS

The selected method of collection was the unventilated capsule filter paper absorption method. (See Section III, A1) This method has several advantages:

1. It is technically very simple.
2. Does not require high sweating rates.
3. Does not interfere with other activites.
4. Can be used for every skin area.

In order to determine the usefulness of this technique the following questions had to be answered:

1. How accurate and reliable is the filter paper collection method compared to other sweat collection techniques?
2. Can whole body sweat volume losses be extrapolated from the regional measurements?

   If question 2 could be answered affirmatively then the feasibility of chemical analysis with this technique had to be determined. It was decided that for spaceflights the most important ionic sweat constituents were Na^+, Cl^- and Ca^{++}.

3. Can sweat calcium be determined with the filter paper collection technique?

   While the filter paper technique had been employed for sweat sodium and chloride evaluations, it was unknown whether this technique was useful for sweat calcium determinations.

4. Is it possible to predict whole body sweat ion losses from regional analyses?

   During later stages of the project it appeared desirable to know whether pharmacologically induced local sweating could be used in the case of no actual thermal sweating:

5. Is pharmacologically induced local sweating similar or different from thermal sweating in the same region?

SECTION III METHODS

A. Sweat Rate Measurements

1. Filter Paper Collection Method

Aluminum capsules as described by Schwartz et al (4), with a surface area of 12.56 cm^2 were anchored by rubber straps to different areas of the skin. Three discs of filter paper were weighed in small airtight bottles and then placed in the unventilated sweat collection chambers. After an accurately timed short period of sweating (5 - 15 minutes) the filter paper discs were removed from the sweat capsule and placed in the airtight jar for reweighing. The rate of sweating was determined from the difference in weight and expressed in $mg/cm^2/min$.

2. Electrohygrometry

Small ventilated skin capsules (5.3 cm^2) were placed in close proximity to the unventilated capsules with similar rates of sweating as established with hygrometry techniques. The high air flow of 1500 cc/min through the small capsules ensured complete evaporation of the secreted sweat. The moist effluent air from the skin capsules was guided over lithium chloride coated humidity sensors (Hygrodynamics, Silver Springs, Md.). The rates of sweating were continuously recorded on a Honeywell 1912 Visicorder (Figure 1). The simultaneous calibration of the multichannel hygrometry system was performed with a technique described previously (5). The results of this calibration technique were compared with two gravimetric procedures.

First a known amount of water was evaporated and the graphically recorded values compared with the measured weight changes of three serially arranged drierite tubes.

Secondly, a small moistened disc of foam rubber was placed under one capsule for a timed period. In both cases the integrated graphic recordings gave identical values as the gravimetric procedures.

The actual sweat measurements were made during resting and exercise situations. During the resting experiment, the subject sat in a specially constructed lounge chair, which permitted complete evaporation from the body surface. The chair was placed on a Potter bed balance, which recorded continuously and graphically on the Visicorder the whole body sweat loss. The environmental conditions during the resting experiments varies between 37°C and 43°C DB, 30% RH.

The exercise experiments were carried out on a Monark bicycle ergometer, in environmental conditions varying from 25-50°C DB and 30-40% RH.

For pharmacological activation of sweat glands the method of pilocarpine iontophoresis (1-4 ma) was employed (6).

B. Chemical Analyses of Sweat

1. Regional Measurements

The sweat collected on the filter paper was diluted out in the airtight sample bottle after completion of the weighing procedure. Mostly 4 cc of deionized water was used as dilutant. The solution was analyzed for chloride with a Cotlove chloridometer, sodium with a P and I flame photometer and calcium with a Jarrell-Ash atomic absorption spectrophotometer.

2. Whole Body Sweat Analysis

Each subject was rinsed off with 4 L distilled water, which was subsequently analyzed for chloride, sodium and calcium content. Clothes worn by the subjects where also rinsed in this water. Details of this procedure are described elsewhere (7). The concentrations were calculated from whole body weight losses, as measured by the Potter balance which is accurate to ± 3 grams.

A total of 11 male subjects participated in the various parts of the experiments. All were healthy; none were obese or exceptionally tall and all but one were between 22 and 30 years old. One subject was 39 years old.

SECTION IV RESULTS

1. Regional Sweat Rate Measurements

The results of the various procedures by which the ventilated capsule electrohygrometry technique was calibrated were all in close agreement with the calibration values obtained with the technique normally employed in our laboratory (5). Compared to the sweating rates by this technique the filter paper absorption method gave continuously lower yields. During resting experiments and low rates of sweating the measurements on the forearm and lower leg were 51% and 41% (See Table 1a) respectively below electrohygrometry determinations. Since this lower yield could be due to hidromeiosis, that is the local inhibition by high water vapor pressure, a ventilated capsule was temporarily replaced with a unventilated skin capsule with filter paper. It can be seen from figure 1a that while the filter paper absorption method indicated a lower value than the initial hygrometry measurement, upon removal of the unventilated capsule the rate of sweating actually had not changed according to electrohygrometry.

During exercise the absolute difference of results with the 2 methods actually remained constant, however on the back this variation was quantitatively less (Table 16). Attempts to ensure that no leaking from adjacent sites affected the results did not have any noticeable effect. During steady state levels of sweating there was a constant difference between ventilated and unventilated sweat rate measurements; during short transient periods varying differences could be found. An example is presented in Figure 2, where the maximal rate of sweating was three times as high as that which could be measured with the filter paper technique.

2. Assessment of Whole Body Sweat Losses from Regional Measurements

The extrapolation of whole body sweat losses from measurements of a very small area proved quite feasible. Over a large range of sweating rates, evolved by several combinations of rest and exercise, there appeared to be a direct relationship between total and regional sweat loss. Inter-individual variations were quite large, especially in the relative contributions of different areas. While the filter paper method does not necessarily give the absolute true value for regional sweating rates, the deviation appears to be numerically constant, for any one skin region. Because of this, the slopes of the lines in Figure 3a, 3b, 3c are identical when compared to hygrometrically calculated relationships.

During measurements on resting man it was noticed that certain body positions affected the relative distribution of sweating rates over the body surface. An example of this is presented in a recording from a thermally sweating man who was passively moved from a supine to a sitting position with elevated knees (Figure 4). The recording demonstrates that the chest, thigh and arm sweat rates changed approximately 20% in different directions. No noticeable differences in internal or cutaneous temperatures can account for this reactions. Under these conditions the sweating rates from the legs were much less influenced by the changes in body position. In exercising man these influences of posture were not noticeable.

3. Sweat Calcium Determinations from Regional Samples and Whole Body

The primary problem was to measure low concentrations of calcium with sufficient accuracy. Much time was spent on selecting an absorbent with sufficiently constant and low background content of Ca. It appeared that Whatman No. 541 filter paper met the required standards, and was thus used for the ensuing sweat calcium determinations. The data from the final recovery experiment are presented in Table Ic.

The chemical analysis from regional sweat samples indicated that the calcium content was relatively constant after a period of 15 minutes sweating. The differences which were recorded were always related inversely to the rate of sweat secretion. Regional measurements from 3 subjects are presented in Tables 2, 3, 4 and Figures 5 (a-e), 6 (a-d), 7 (a-c). It can be seen that the initial sweat samples always contained greater amounts of calcium than subsequent samples. These later samples contained mostly between 0.5 and 1.5 meq Ca/L. In some of the regional measurements (Figure 5 a, b, d) and in whole body sweat calcium determinations (Figure 8 a, b, c), it appeared that in warmer environments the sweat calcium content was higher at comparable rates of sweating.

Since apparently some calcium remains in the skin or the sweat glands, a few experiments were carried out to determine the rate of calcium deposition in the skin (Table 3d, 4c). When a sweating man in a warm environment was moved to a cool room for 1 hour and then returned to the hot room, the initial sweat sample again contained a higher concentration of calcium.

When whole body sweat calcium losses were compared with regional measurements it became obvious that the region with a comparable rate of sweating to that of the whole man, would show similar concentration curves. Analysis of figures 5 ad, 6 d, 7 d shows that the sweat rate - sweat [Ca] curves for the forearm and the whole body are quite similar. The curves for other areas are in general more to the right, because of the higher sweat secretion rates.

4. Sweat Chloride and Sodium Determinations from Regional Samples and Whole Body

The results of the sweat analyses from various body regions under different conditions are presented in Tables 6, 7, 8 and Figures 9 (a-h), 10 (a-j) and 11 (a-h).

While these data demonstrate the wide variations in regional rates of sweating, they also showed the differences in chemical composition of sweat in different regions with similar rates of sweating. Whole body measurements were very similar to those of the forearm or forehead, at least at sweat rates smaller than 1.0 $mg/cm^2/min$. In nearly every experiment the sweat sodium concentration was higher than that of sweat chloride, but not always to the same extent.

The highest salt concentrations were found on the forehead or back, especially in warm environments. Values of 80 meq/L for chloride were found on numerous occasions, but for whole body sweat the chloride content seldom rose above 50 meq/L.

The slopes of the sweat rate-sweat [Cl] curves changed with the temperature of the environment and the skin temperatures.

In a few experiments special attention was paid to the effect of decreasing sweat rates on sweat composition after profuse sweating. As can be seen from Figures 15 a - f, the sweat composition curve relates to different values for decreasing sweat rates. Especially after physical exertion the rate of sweating can fall by 50% in one or two minutes, but the salt concentration remains high. In the experiments in warmer environments it was noticed that after 1/2 hour the earlier relationship had not been reestablished.

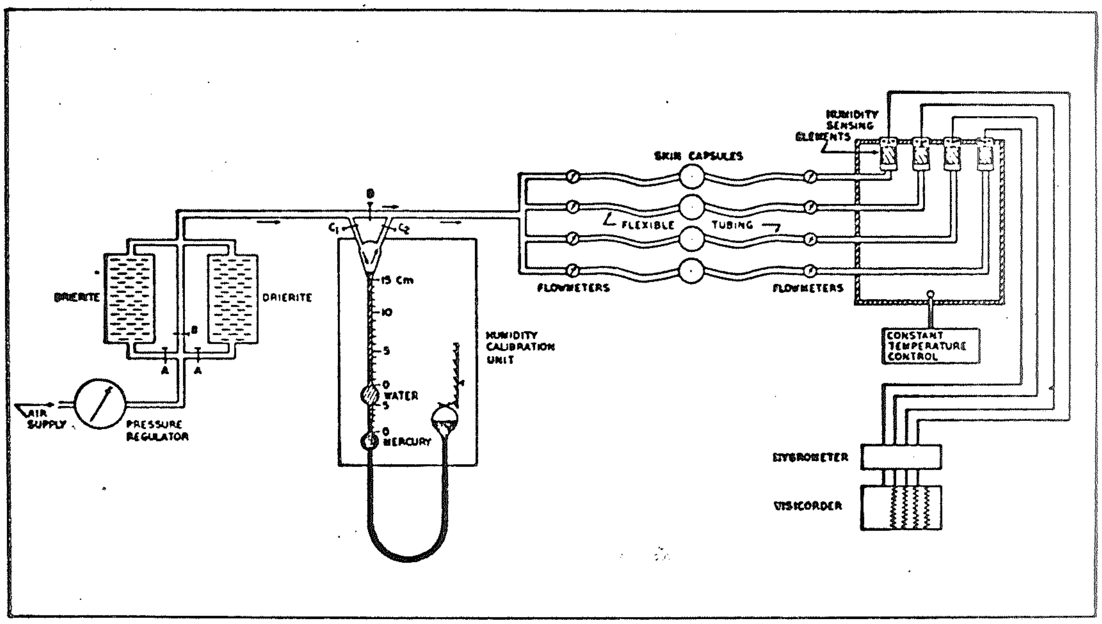
5. Comparison of Thermal and Pharmacologically Induced Sweating

In a nonthermally sweating man the sweat glands activated locally by pilocarpine iontophoresis respond differently then when stimulated by heat.

Their activity pattern during pharmacological stimulation, when recorded by electrohygrometry produced a noncyclic tracing (Figure 12). During thermal sweating a pulsatile pattern of secretary activity is always noticeable (Figure 13). During thermal sweating the reflex response to cooling is quite distinct, while pharmacologically activated sweat glands fail to respond (Figure 14). Similarly, on initiation of exertion thermal sweating can be increased instantaneously, while drug activated glands remain unresponsive.

In addition, the relationship between sweating rate and sweat chloride concentration is noticeably different between the 2 modes of stimulation. Especially at lower rates of sweating, drug sweat is more concentrated. However at higher secretion rates the chloride concentration of thermal sweat becomes higher than drug sweat.

FIG. 1



ELECTROHYGROMETRY SYSTEM

FIG: 1A

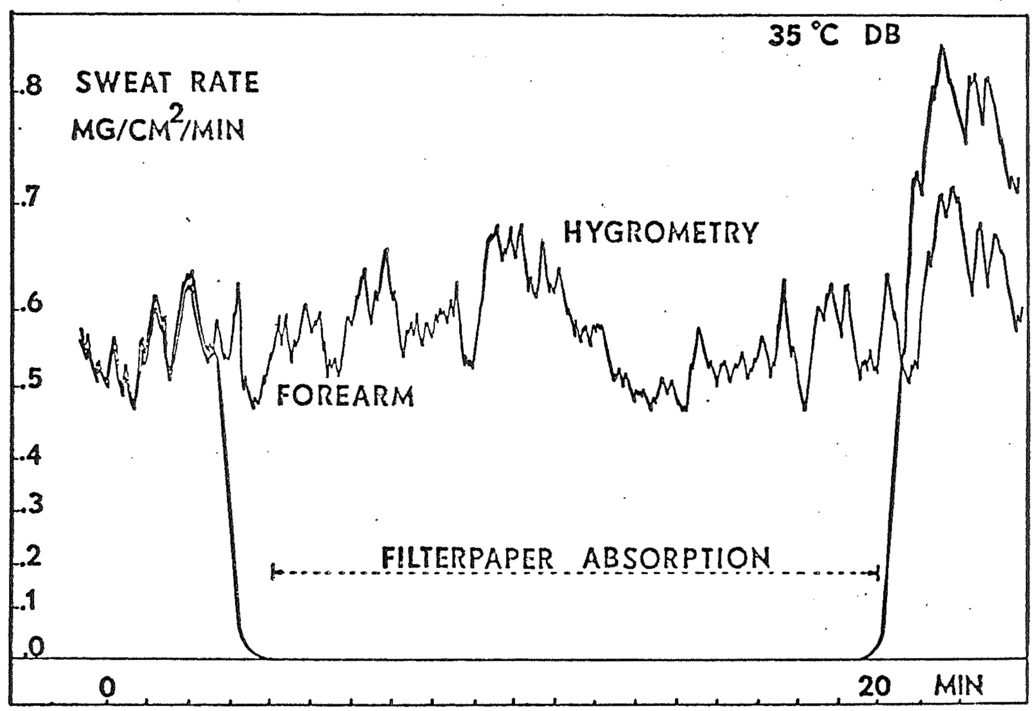
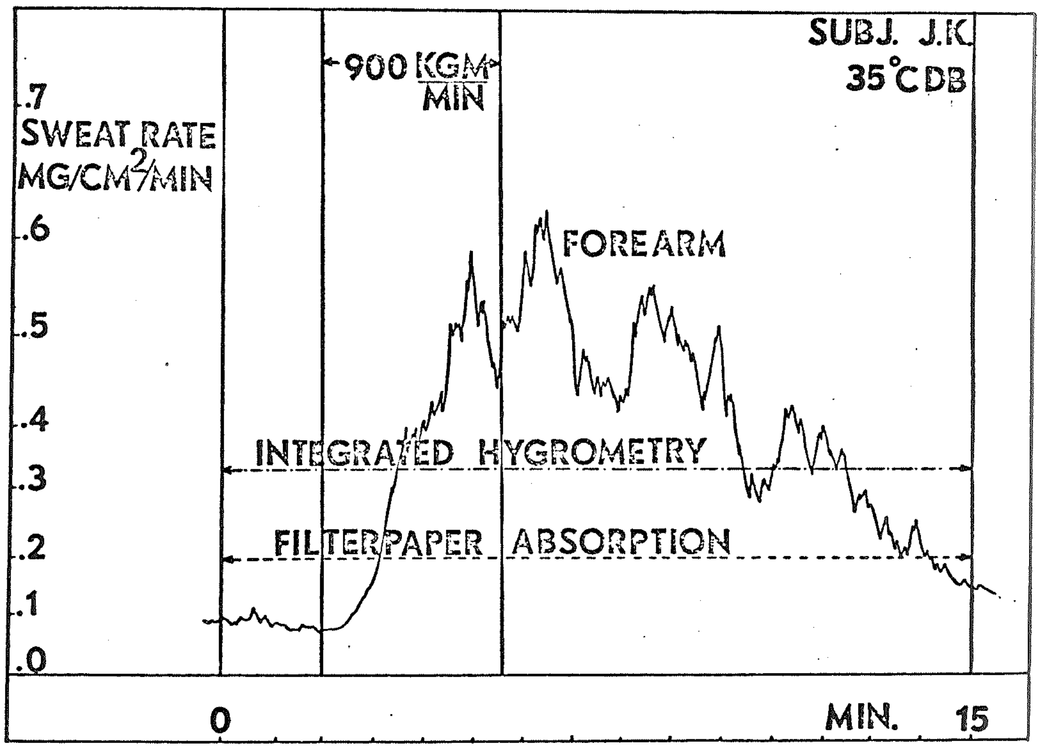
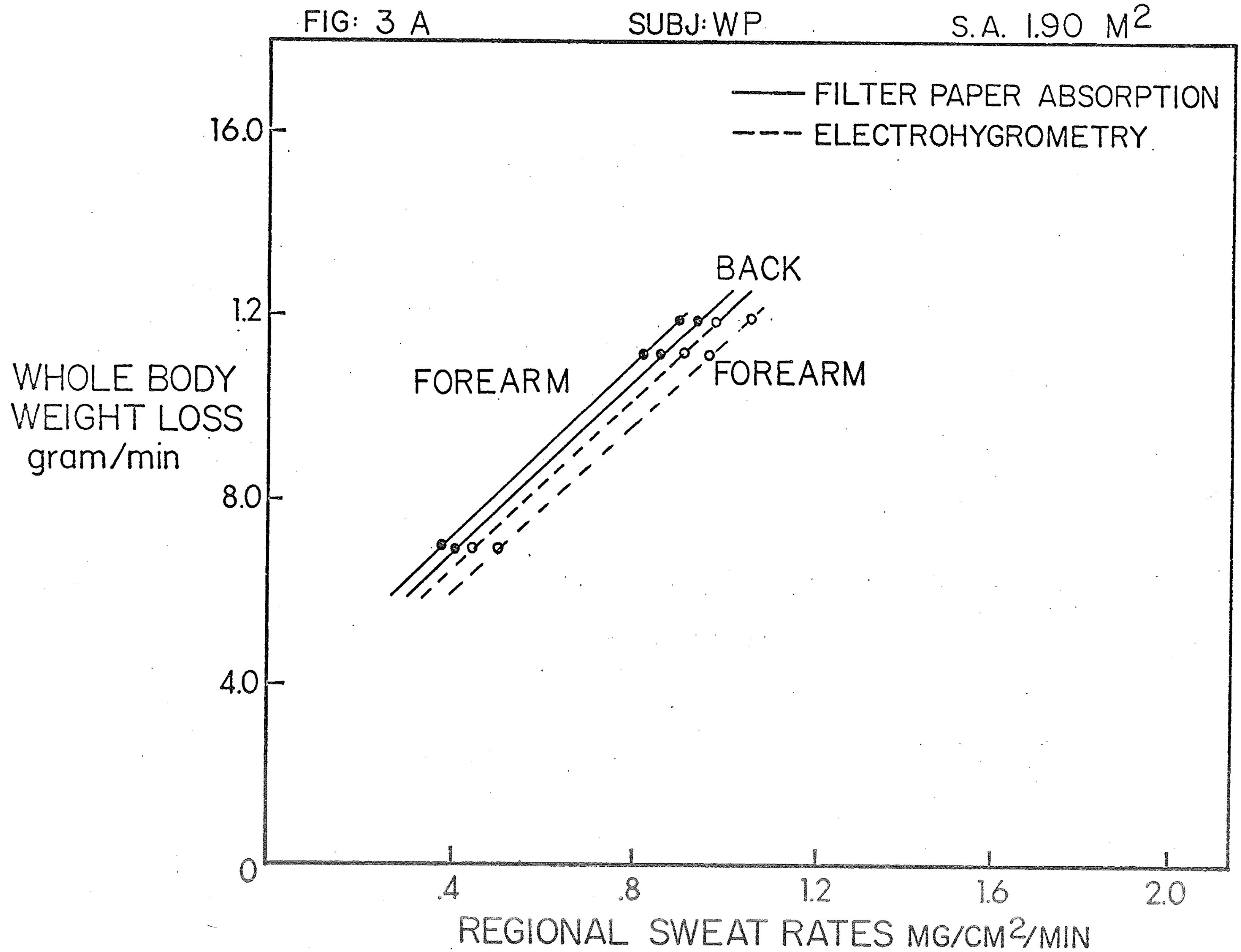

35 °C DB
SWEAT RATE
MG/CM^2/MIN
.8
.7
.6
.5
.4
.3
.2
.1
.0
HYGROMETRY
FOREARM
FILTERPAPER ABSORPTION
0
20 MIN

FIG : 2



900 KGM/MIN
SUBJ. J.K.
35°C DB
.7
SWEAT RATE
MG/CM²/MIN
.6
.5
.4
.3
.2
.1
.0
FOREARM
INTEGRATED HYGROMETRY
FILTERPAPER ABSORPTION
0
MIN.
15

FIG: 3 A


SUBJ: WP
S.A. 1.90 M2
FILTER PAPER ABSORPTION
ELECTROHYGROMETRY
BACK
FOREARM
FOREARM
WHOLE BODY
WEIGHT LOSS
gram/min
16.0
1.2
8.0
4.0
0
.4
.8
1.2
1.6
2.0
REGIONAL SWEAT RATES MG/CM2/MIN

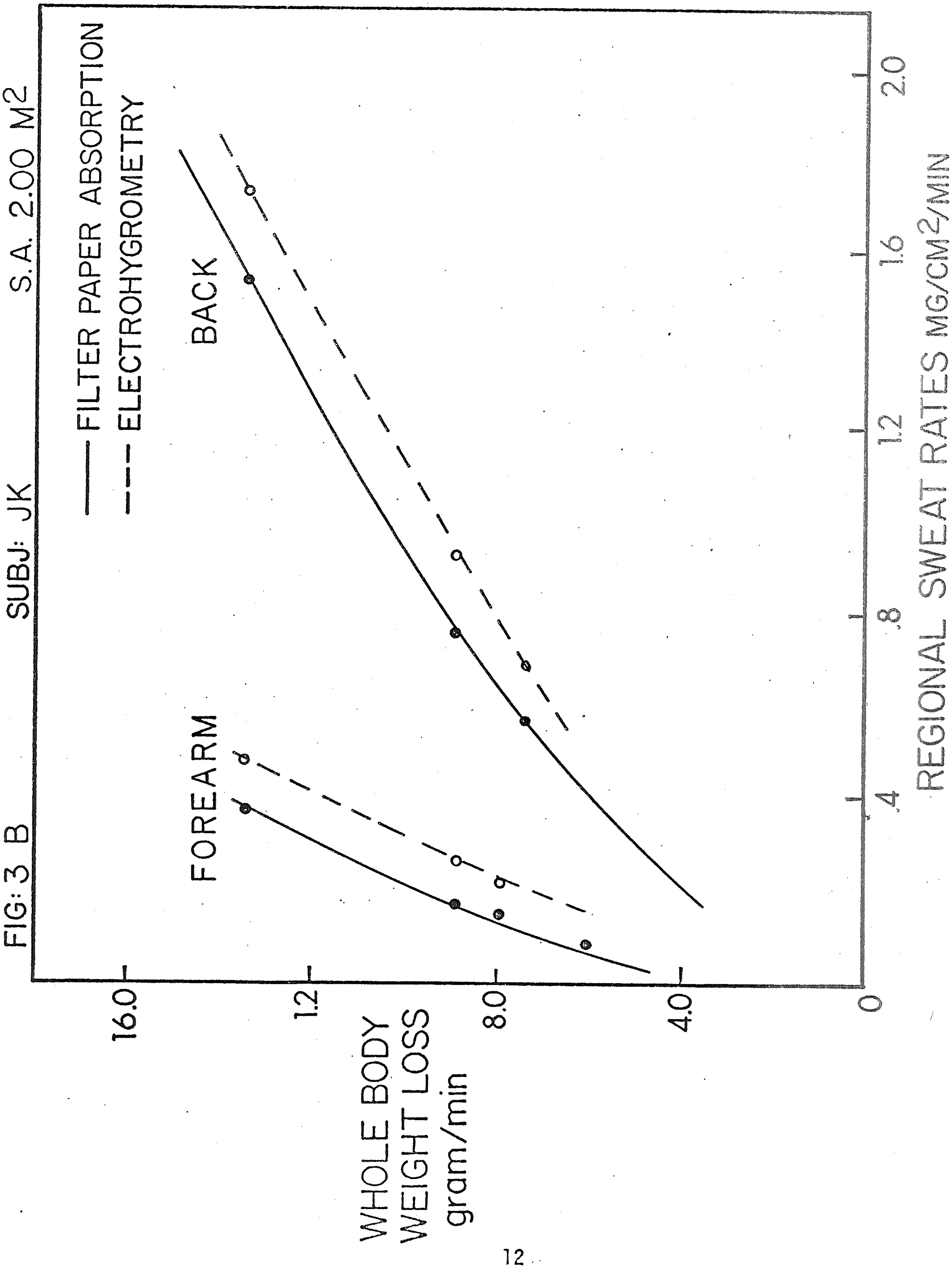

SUBJ: JK
S.A. 2.00 M2
FILTER PAPER ABSORPTION
ELECTROHYGROMETRY
BACK
FOREARM
WHOLE BODY
WEIGHT LOSS
gram/min
16.0
1.2
8.0
4.0
0
.4
.8
1.2
1.6
2.0
REGIONAL SWEAT RATES MG/CM2/MIN

FIG: 3 B

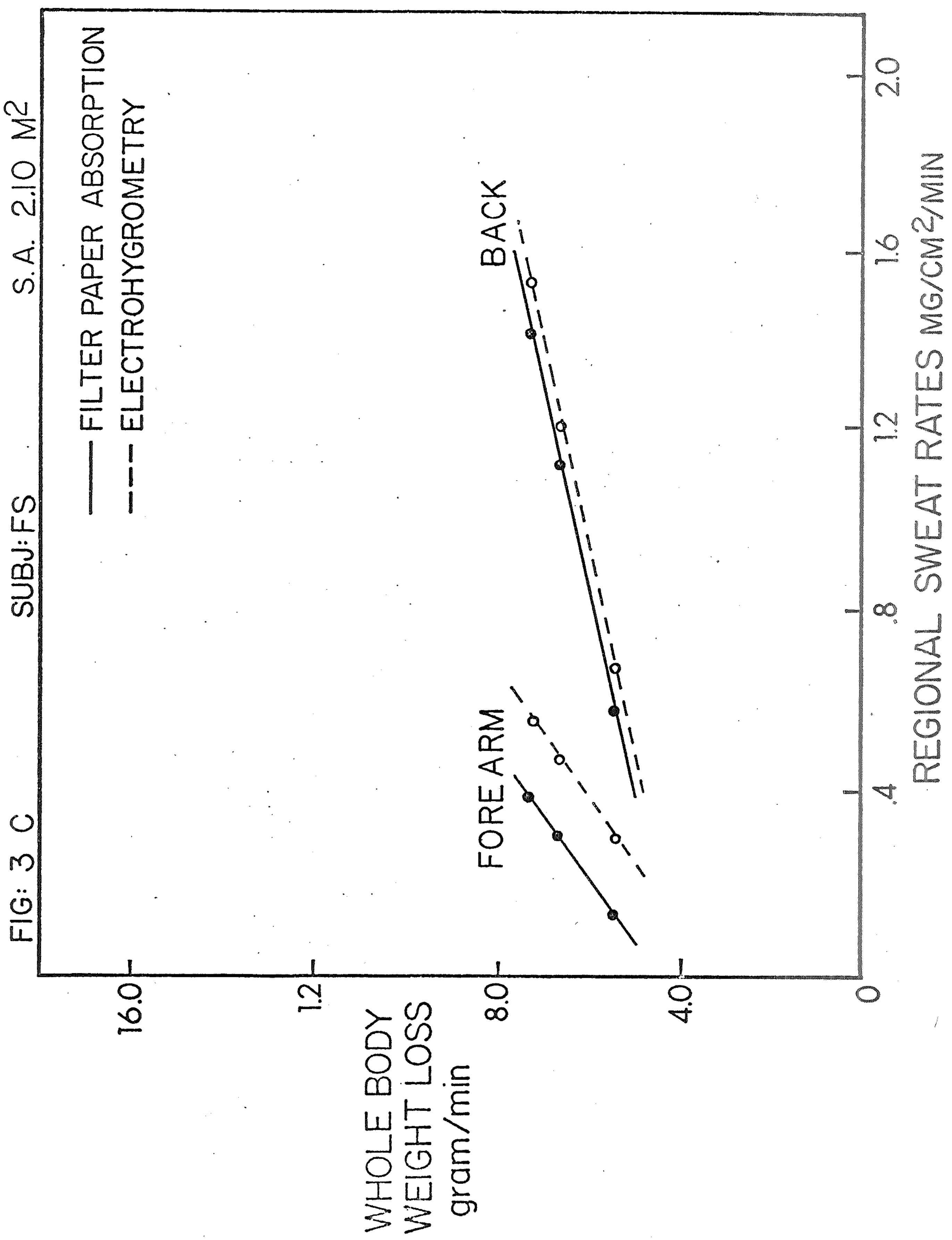


FIG: 3 C
SUBJ: FS
S.A. 2.10 M2
FILTER PAPER ABSORPTION
ELECTROHYGROMETRY
BACK
FORE ARM
WHOLE BODY
WEIGHT LOSS
gram/min
16.0
1.2
8.0
4.0
0
.4
.8
1.2
1.6
2.0
REGIONAL SWEAT RATES MG/CM2/MIN

FIG: 4

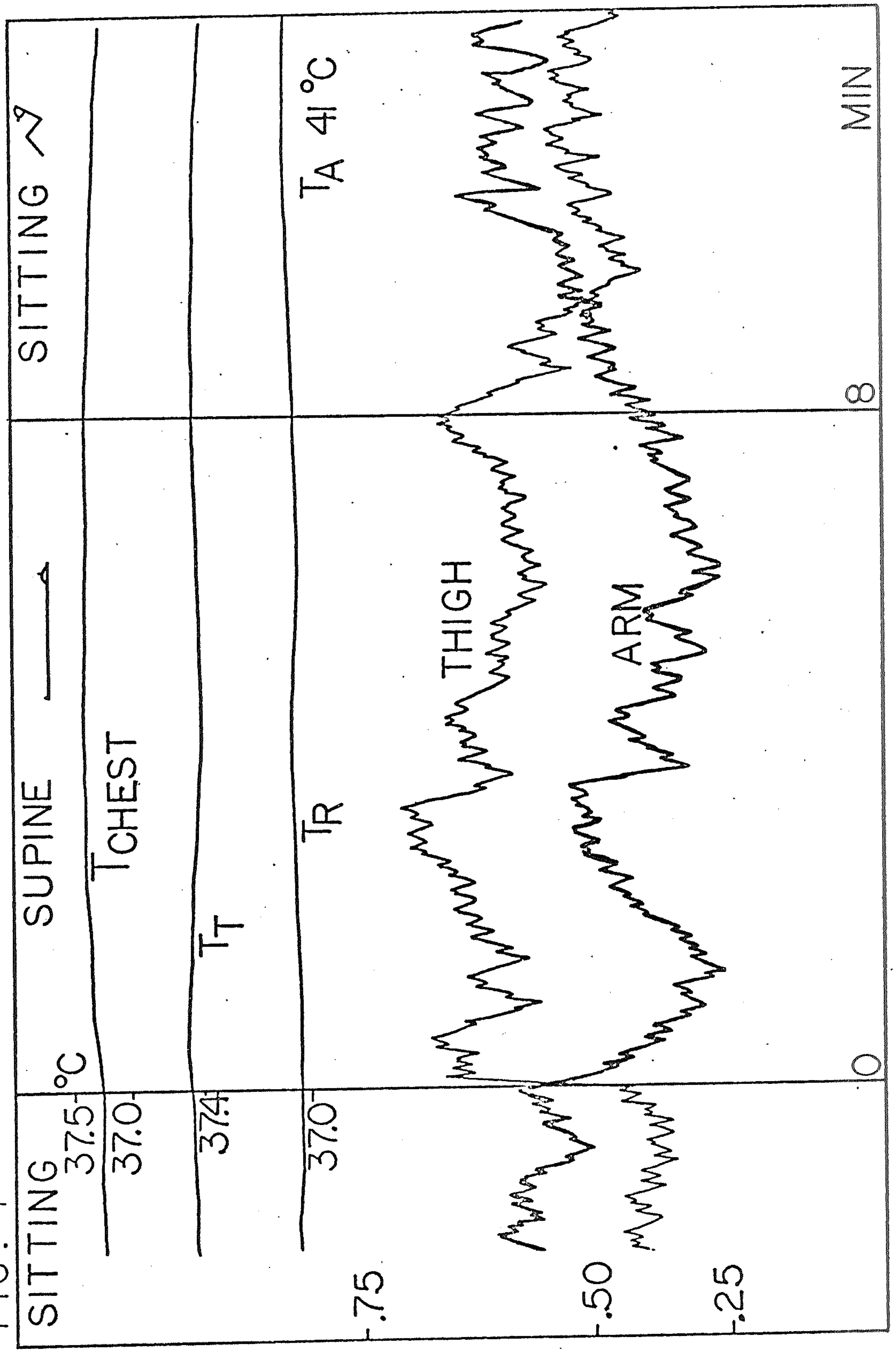

SITTING
SUPINE
SITTING
°C
37.5
37.0
37.4
37.0
T CHEST
T T
T R
T A 41 °C
THIGH
ARM
0
8
MIN
.75
.50
.25

FIG: 5 A SUBJ: W B SKIN AREA: L. LAT. BACK

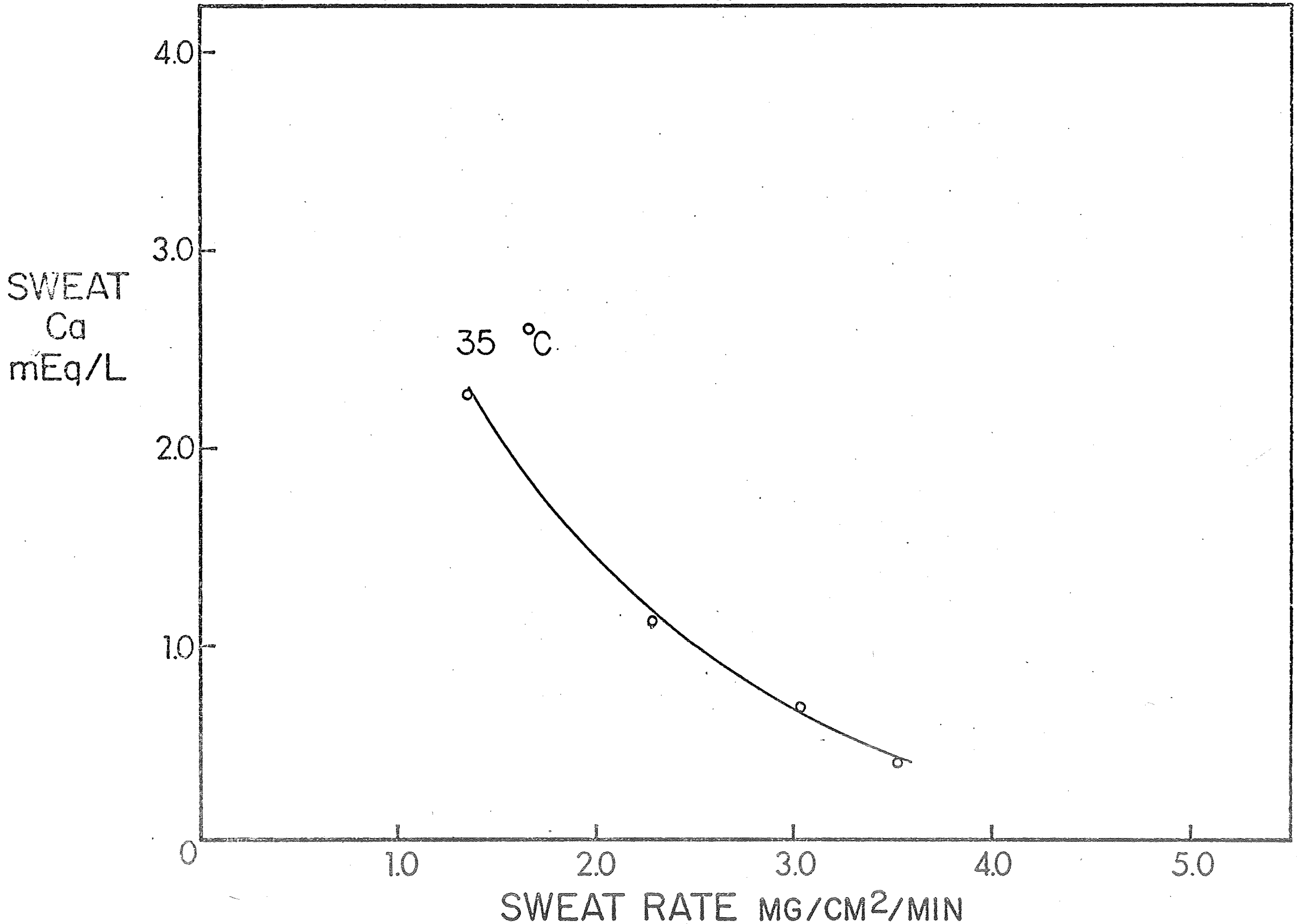


FIG: 5 B

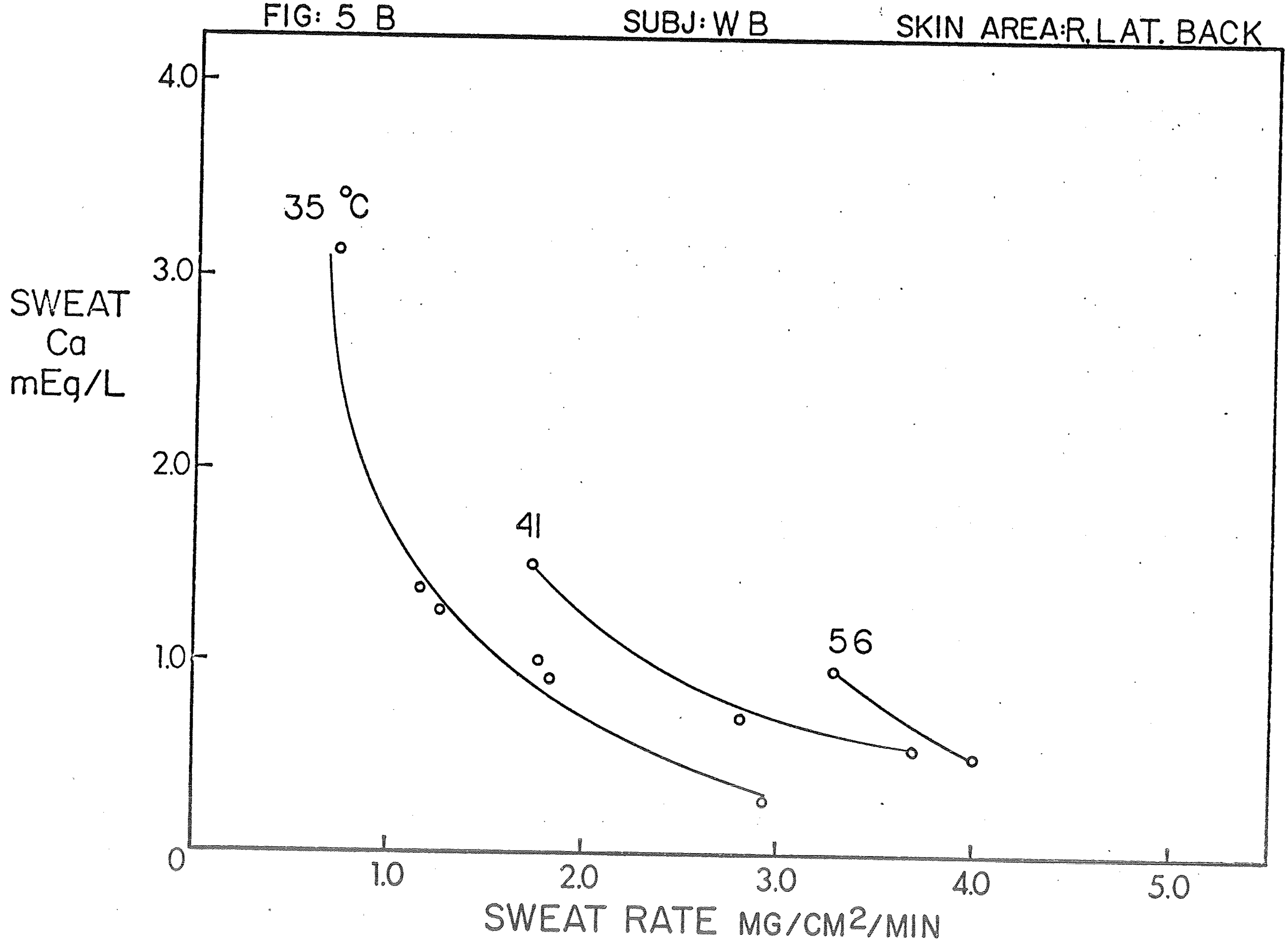

SUBJ: W B
SKIN AREA: R. LAT. BACK
SWEAT
Ca
mEq/L
4.0
3.0
2.0
1.0
0
35 °C
41
56
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN

FIG: 5 C SUBJ: WB SKIN AREA: LAT. CALF

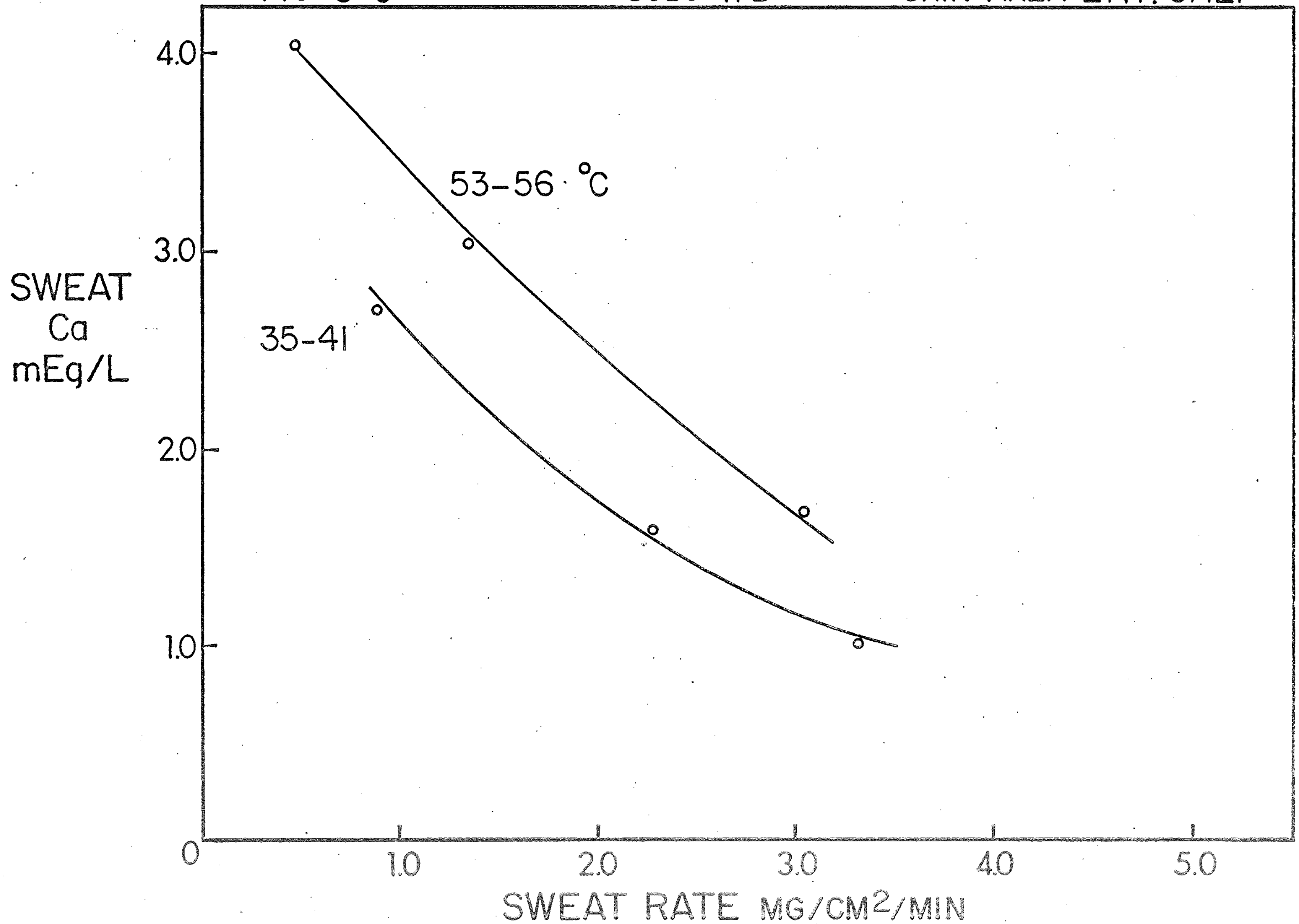


FIG: 5 D SUBJ: WB SKIN AREA: FH, FA, WB

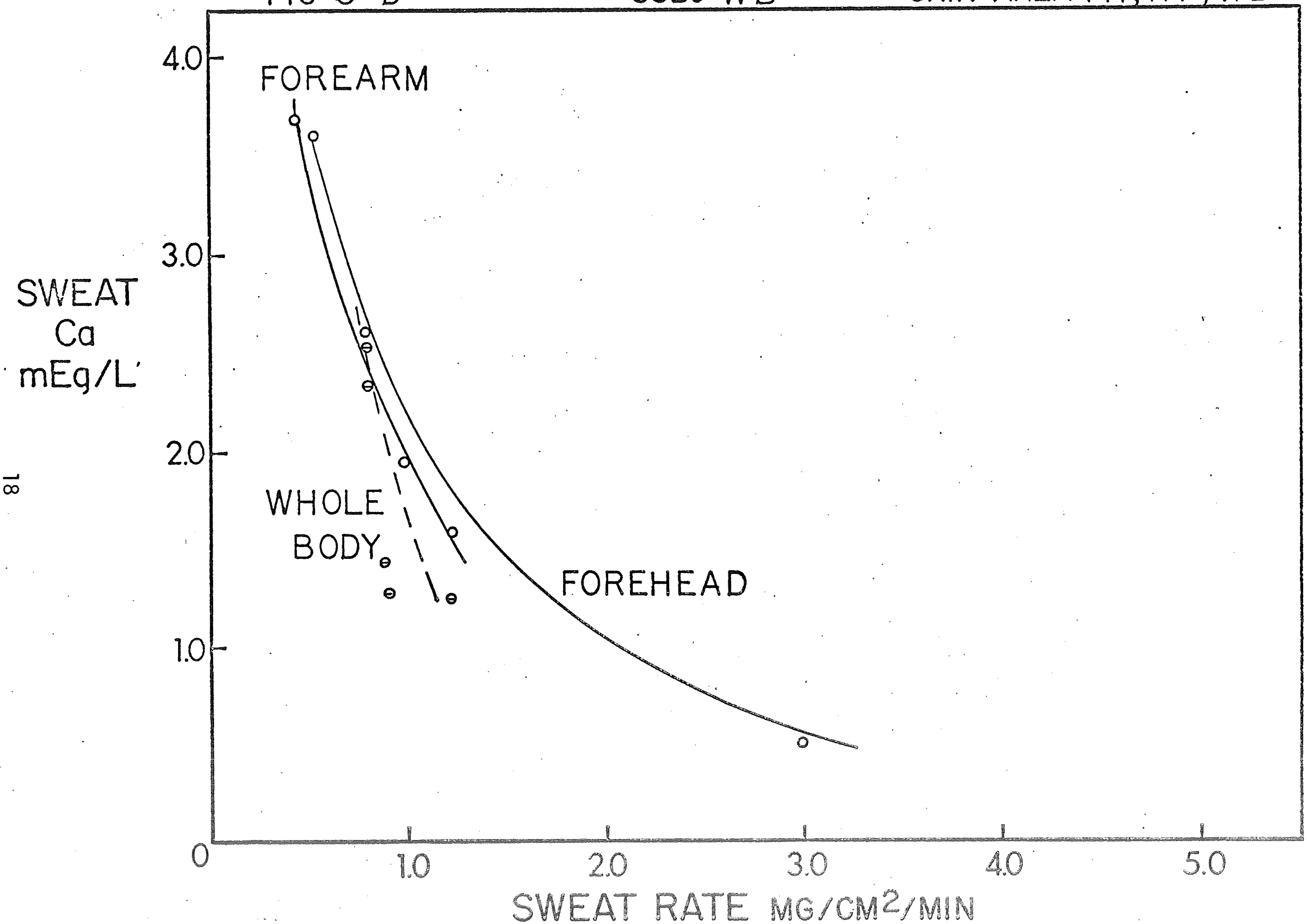


FIG: 6 A SUBJ: FB SKIN AREA: R. LAT. BACK.

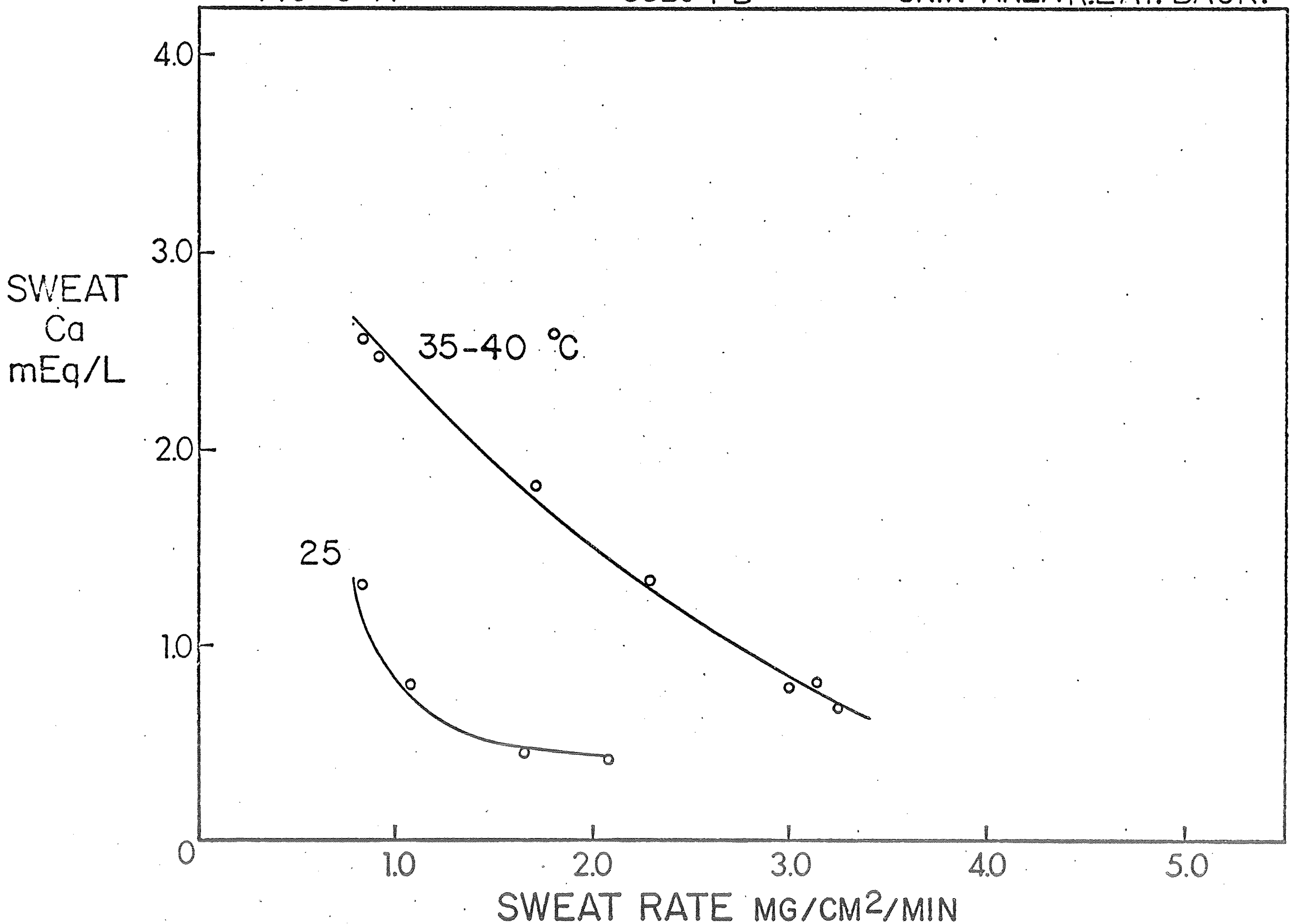


FIG: 6 B SUBJ: FB SKIN AREA: L.LAT. BACK

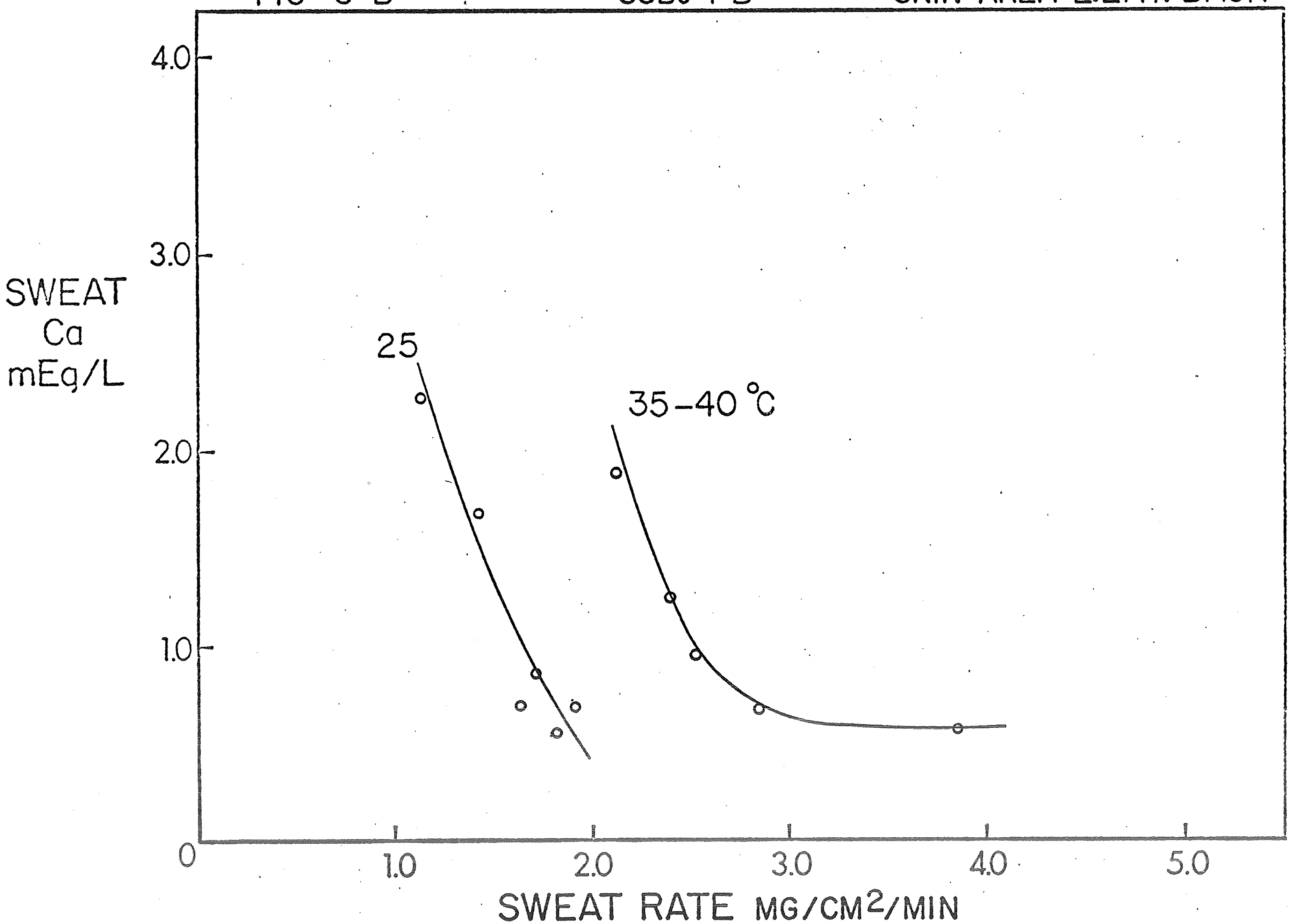
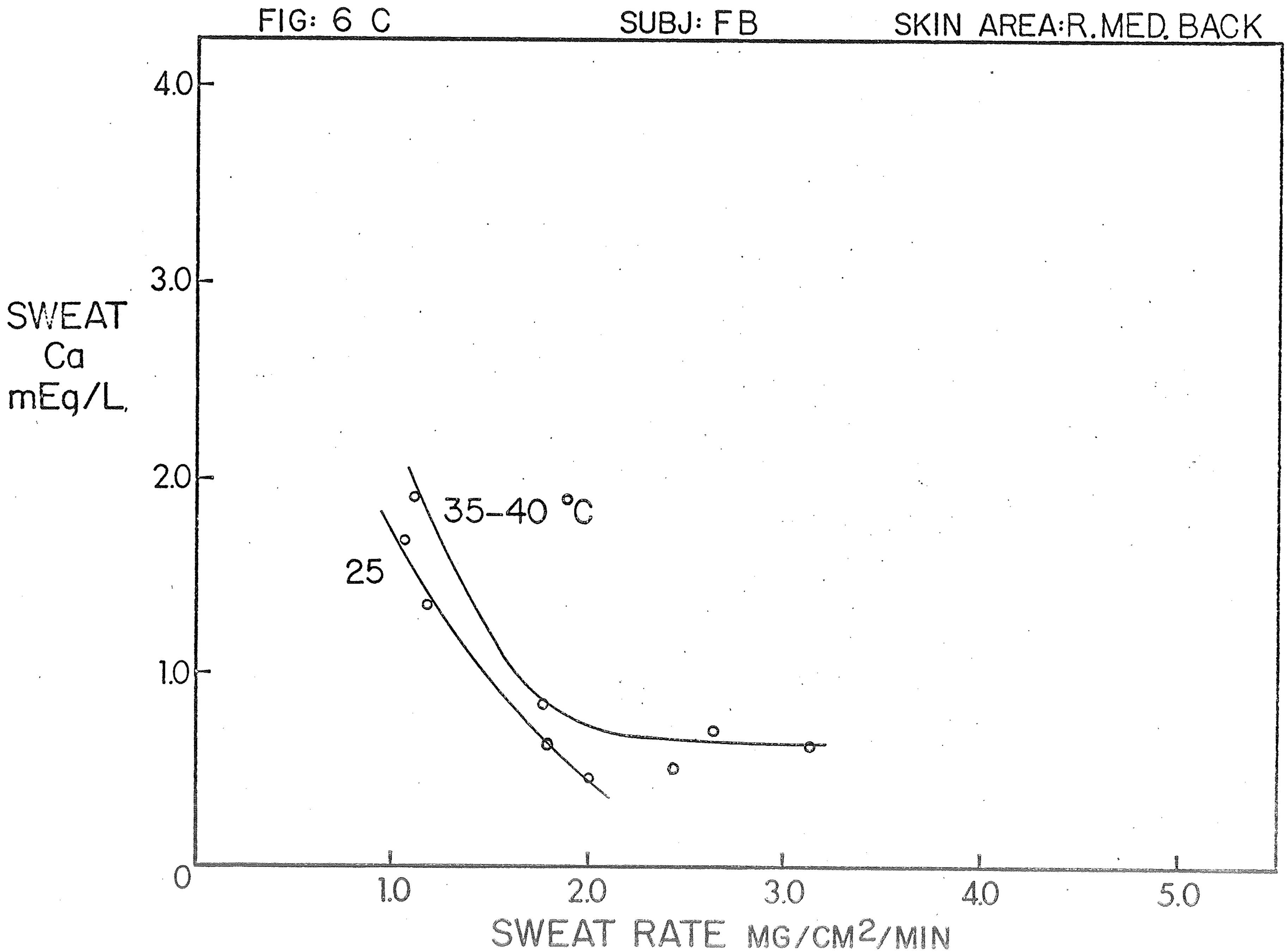


FIG: 6 C



SUBJ: FB
SKIN AREA: R. MED. BACK
SWEAT
Ca
mEq/L.
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
35-40 °C
25

FIG: 6 D

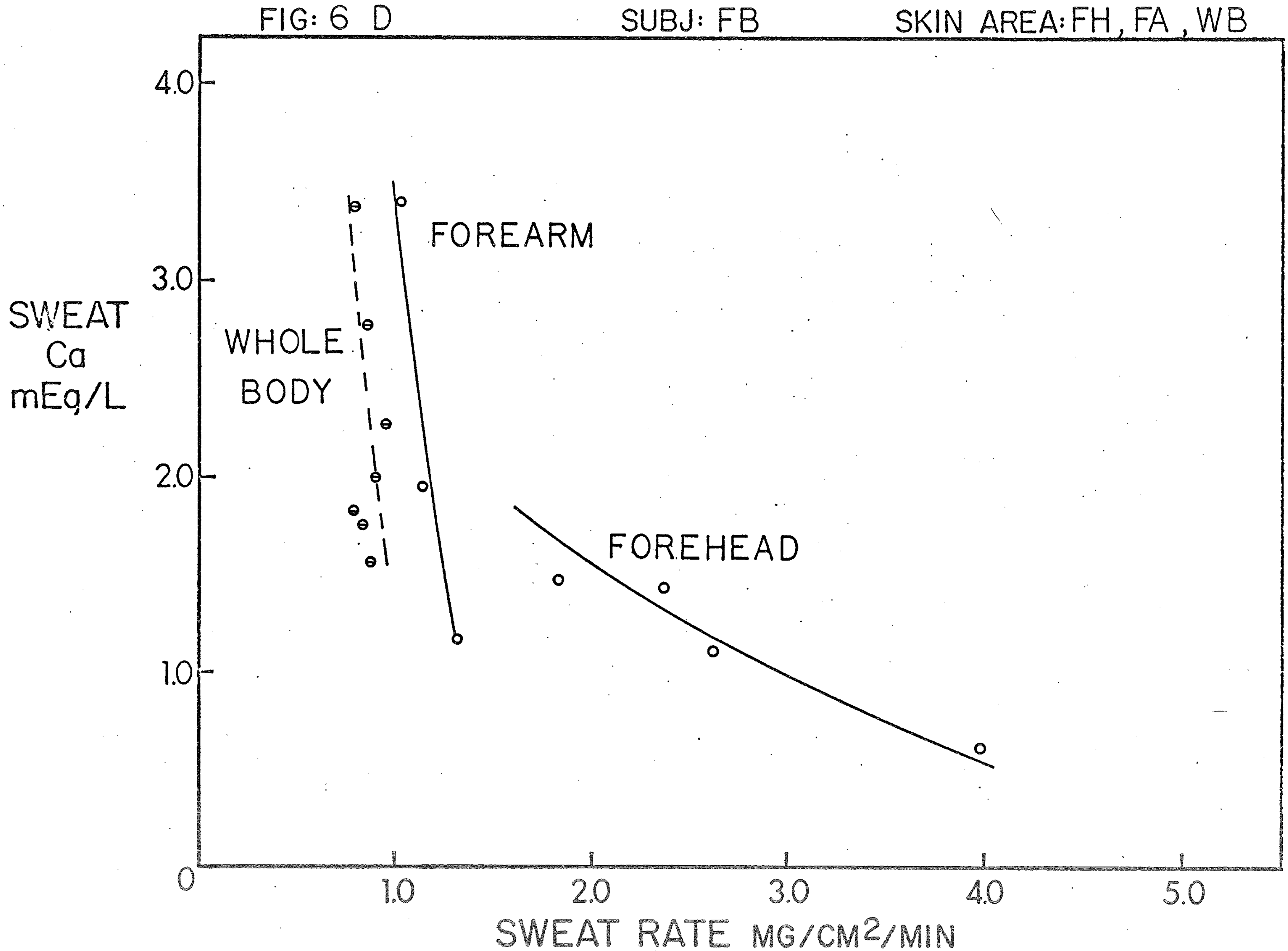
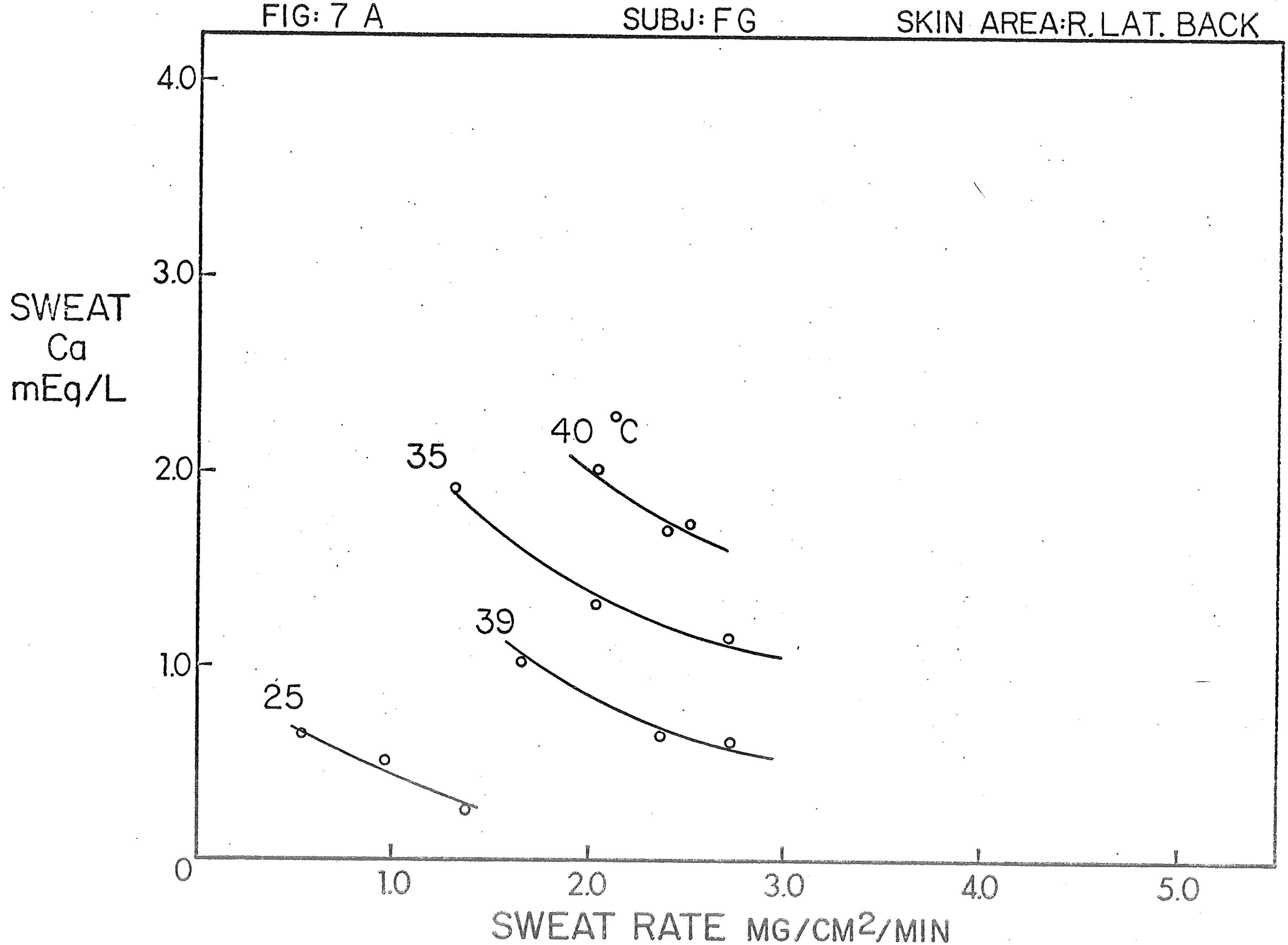

SUBJ: FB
SKIN AREA: FH, FA, WB
SWEAT Ca mEq/L
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
WHOLE BODY
FOREARM
FOREHEAD

FIG: 7 A


SUBJ: F G
SKIN AREA: R. LAT. BACK
SWEAT
Ca
mEq/L
4.0
3.0
2.0
1.0
0
40 °C
35
39
25
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN

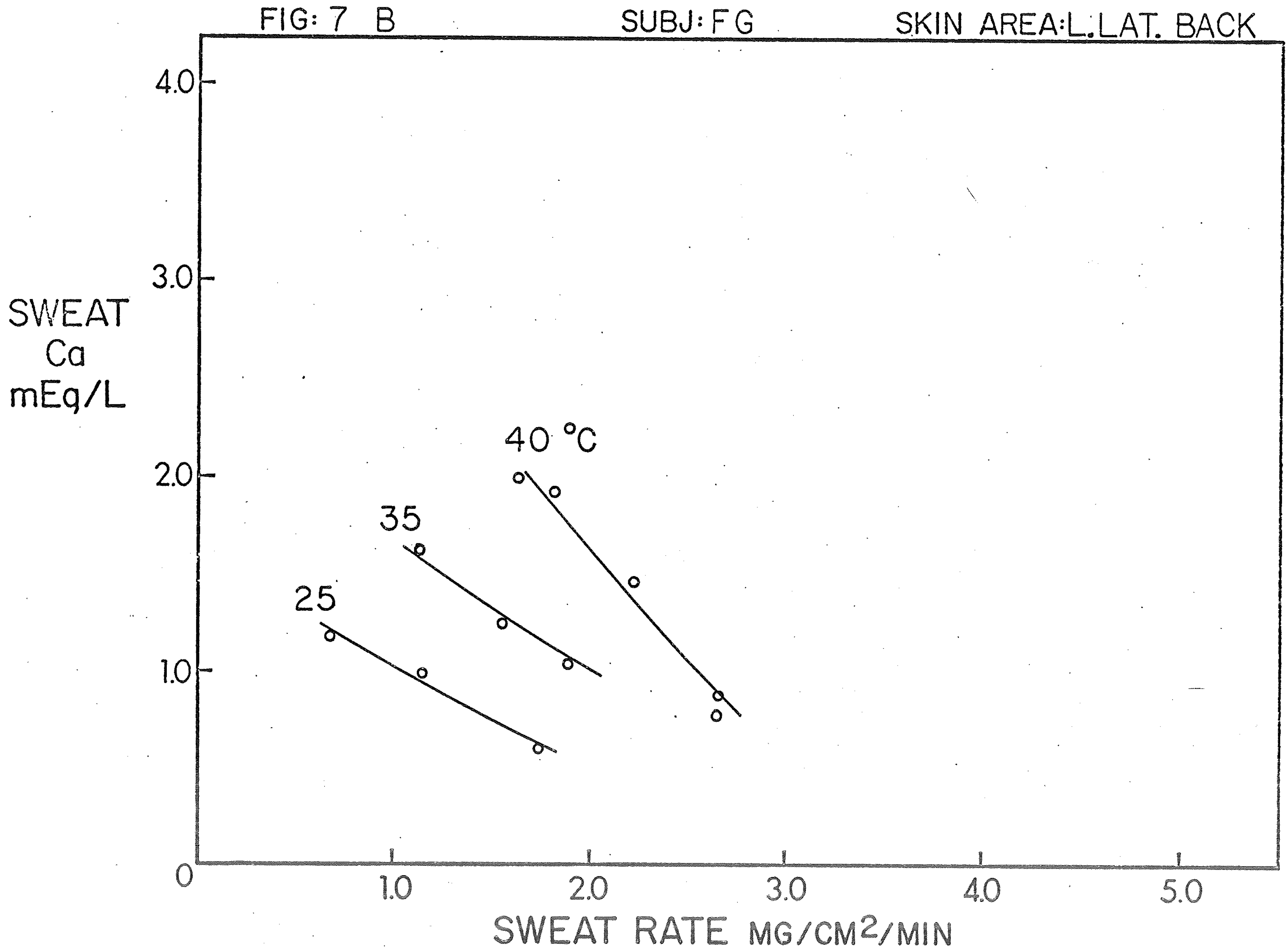


FIG: 7 B
SUBJ: F G
SKIN AREA: L. LAT. BACK
SWEAT
Ca
mEq/L
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
40 °C
35
25

FIG: 7 C SUBJ: F G SKIN AREA: R. MED. BACK

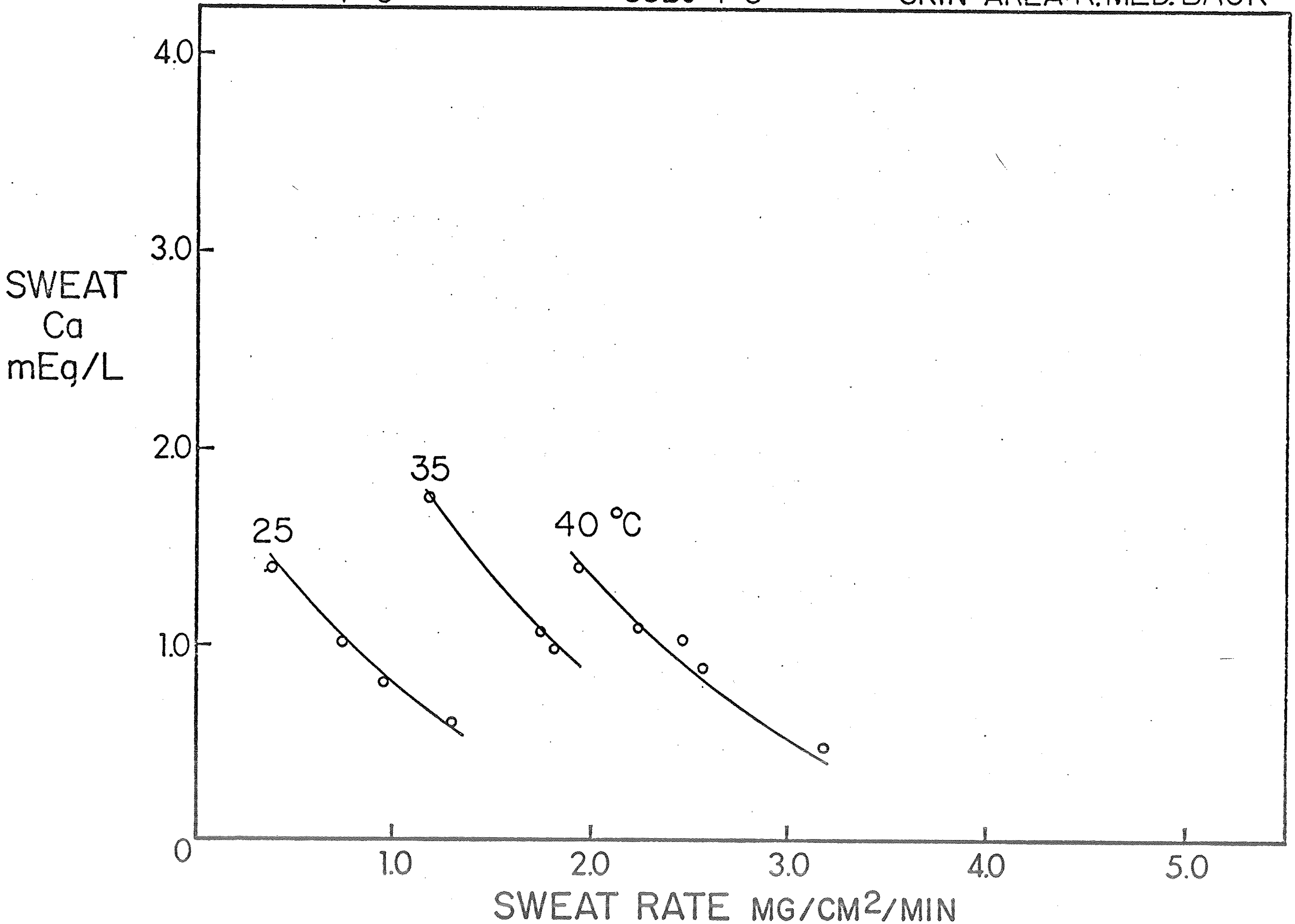


FIG: 7 D

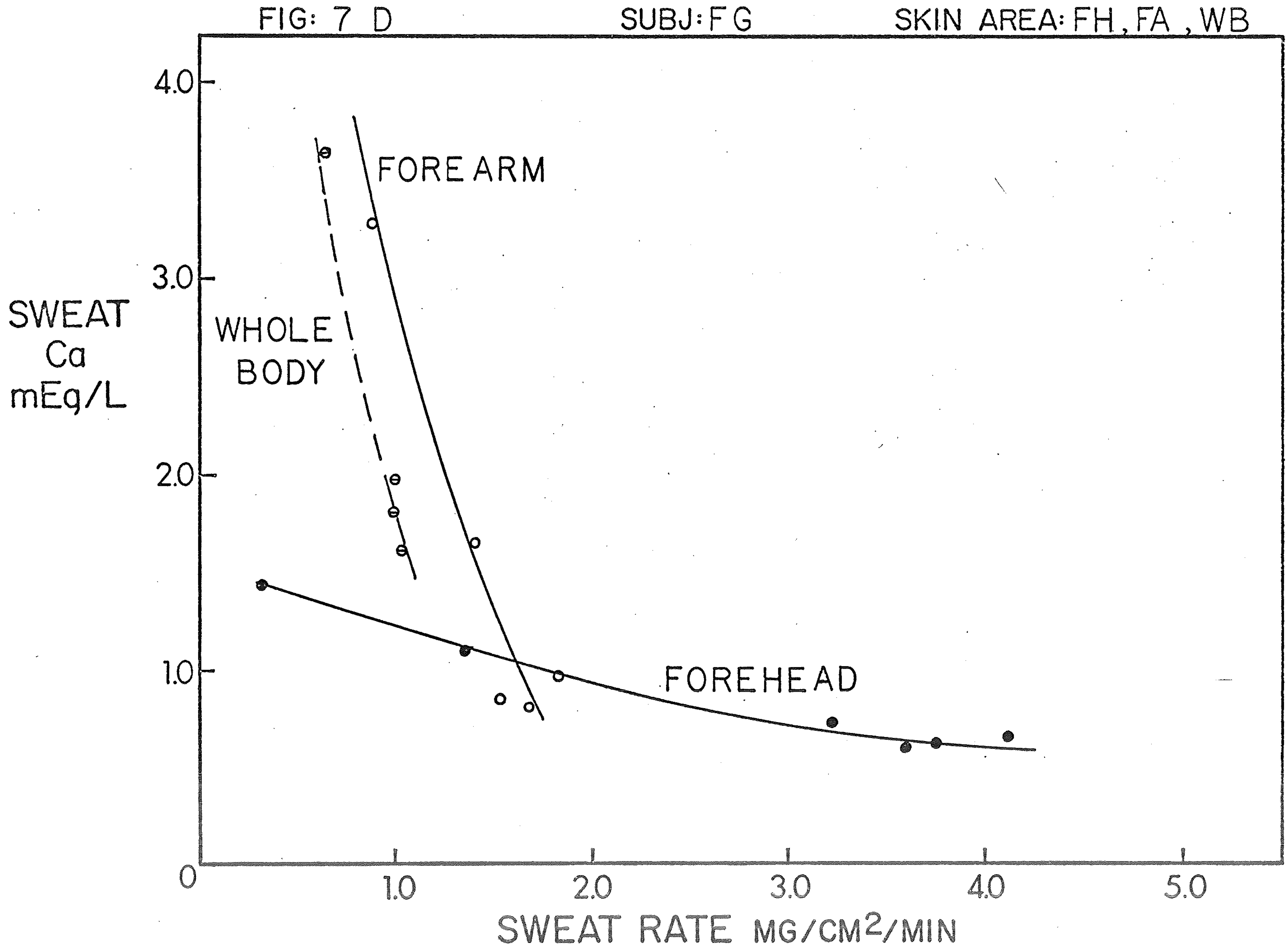

SUBJ: F G
SKIN AREA: FH, FA, WB
SWEAT
Ca
mEq/L
4.0
3.0
2.0
1.0
0
WHOLE
BODY
FOREARM
FOREHEAD
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN

FIG: 8 A

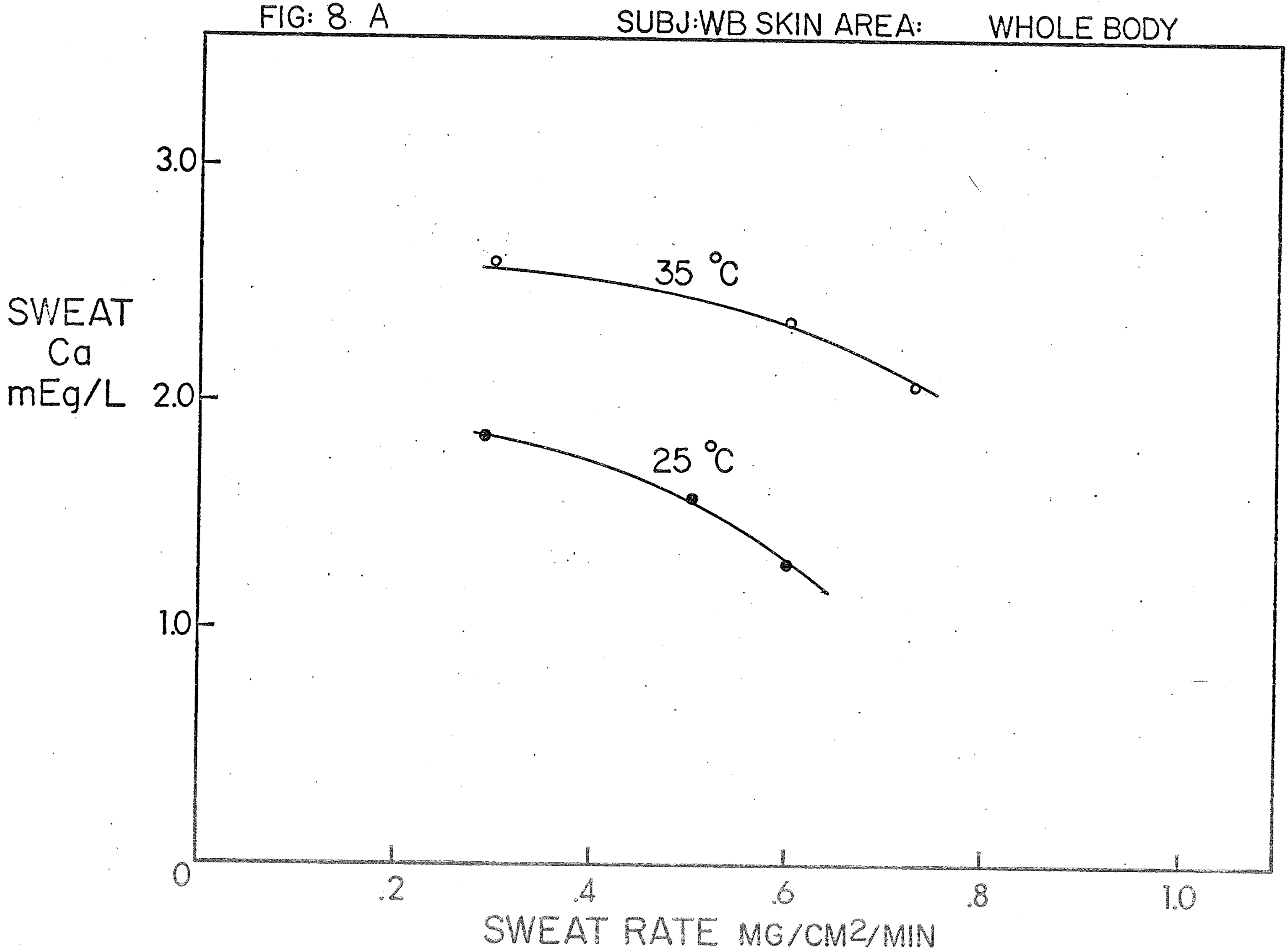

SUBJ:WB SKIN AREA: WHOLE BODY
SWEAT
Ca
mEg/L
3.0
2.0
1.0
0
.2
.4
.6
.8
1.0
35 °C
25 °C
SWEAT RATE MG/CM2/MIN

FIG: 8 B

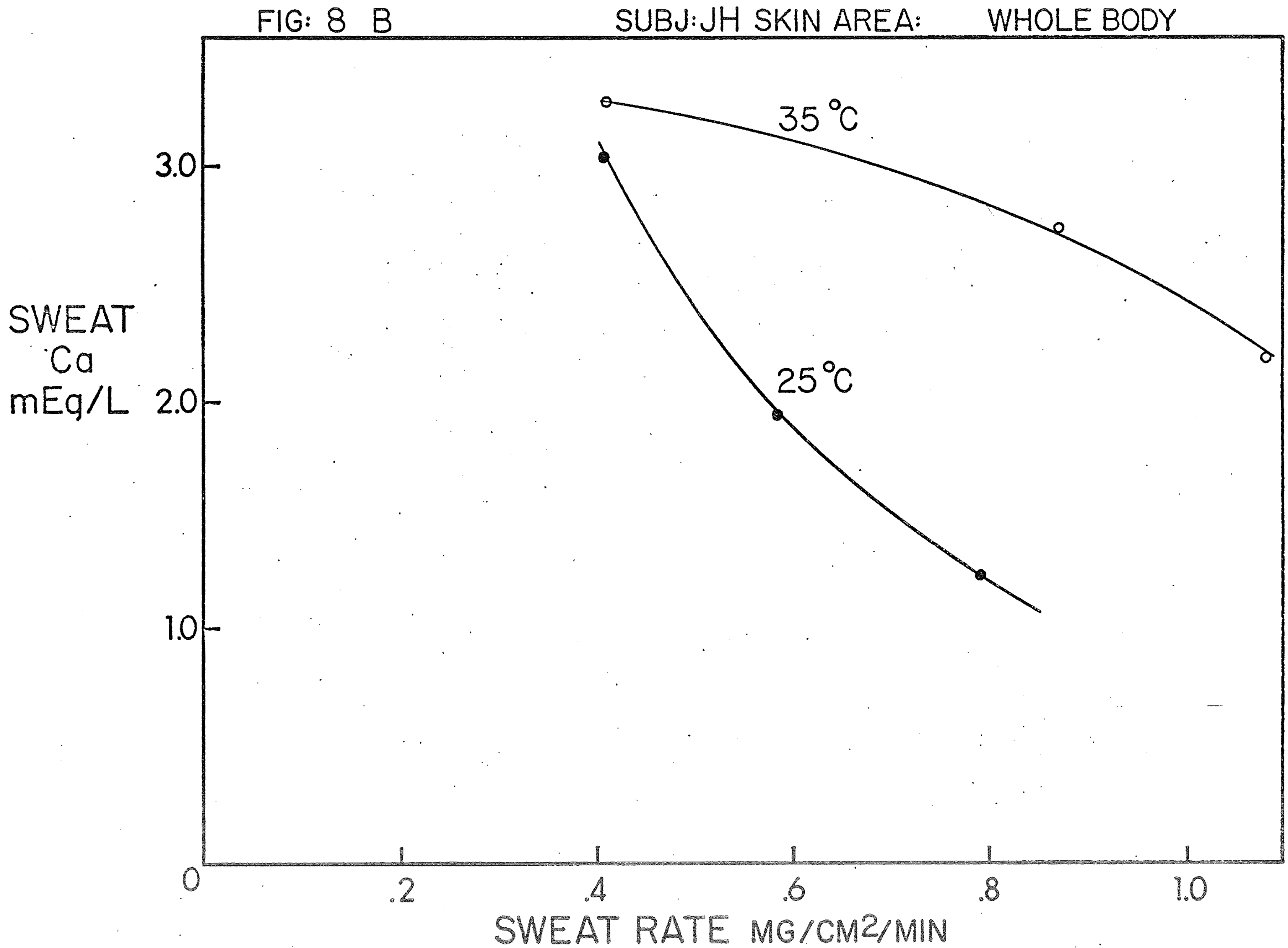

SUBJ: JH SKIN AREA: WHOLE BODY
35 °C
25 °C
SWEAT Ca mEq/L
3.0
2.0
1.0
0
.2
.4
.6
.8
1.0
SWEAT RATE MG/CM2/MIN

FIG: 8 C SUBJ:JP SKIN AREA: WHOLE BODY:

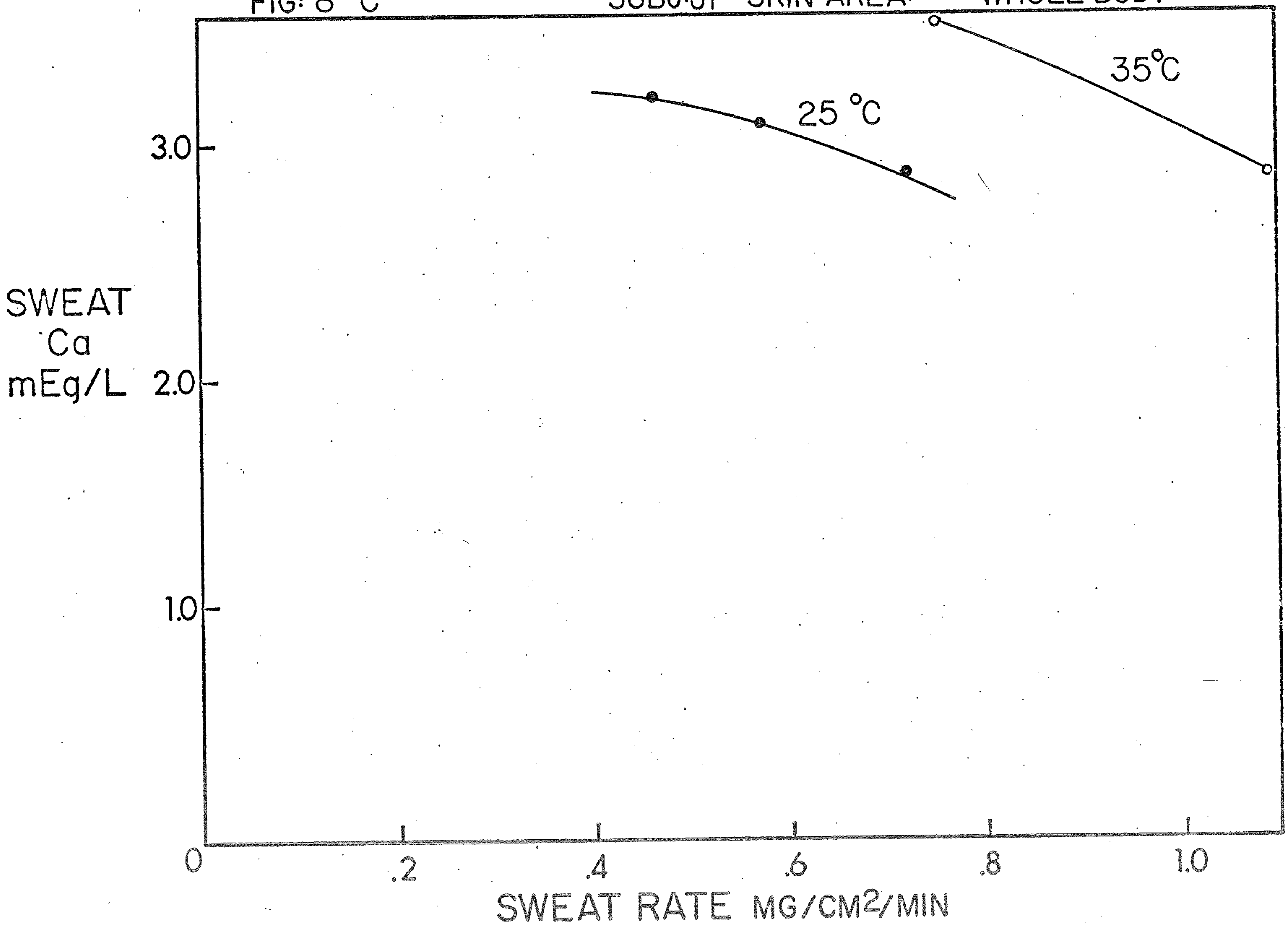


FIG: 9 A

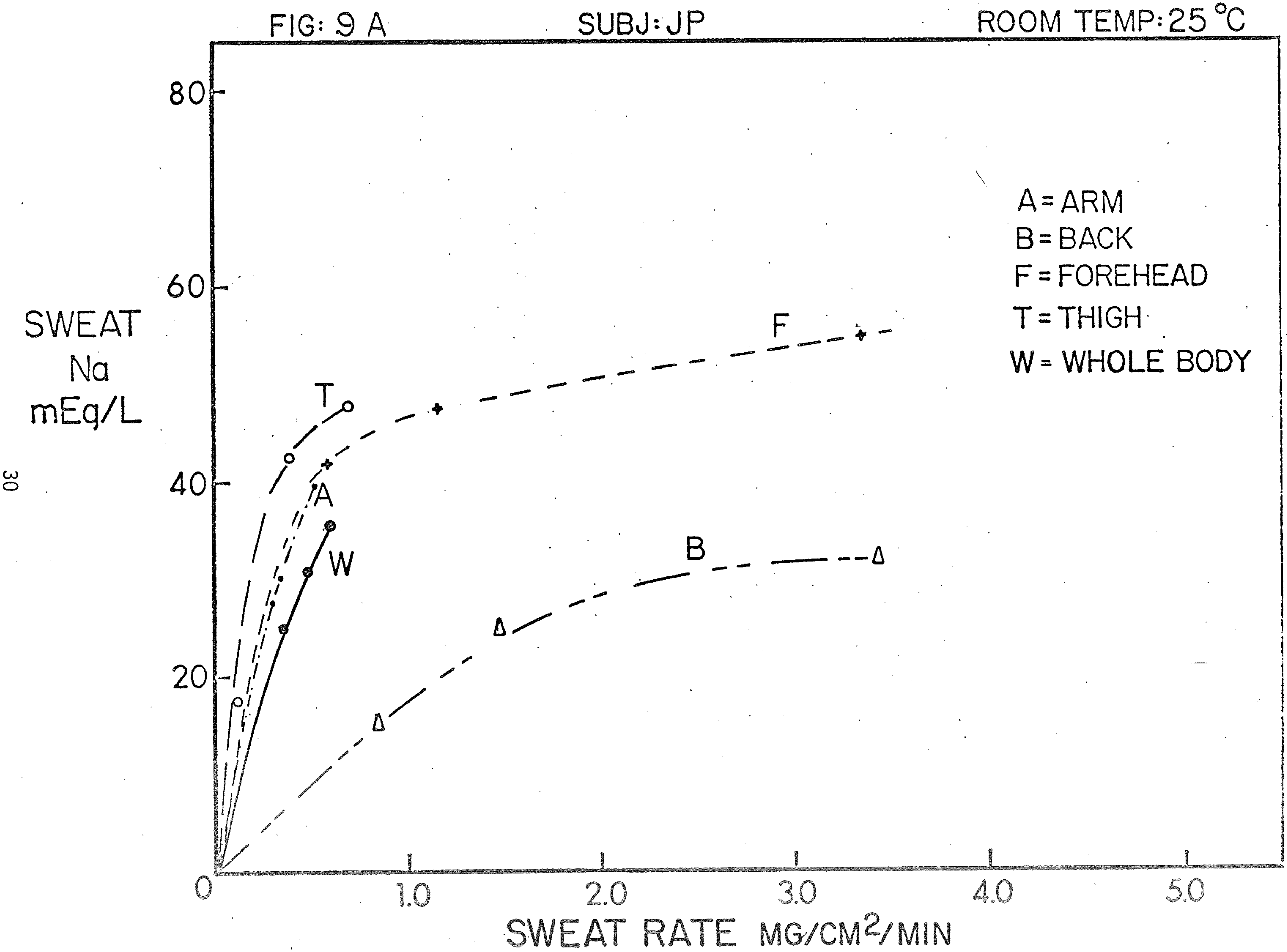

SUBJ: JP
ROOM TEMP: 25 °C
SWEAT Na mEq/L
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY
T
A
W
F
B

FIG: 9 B SUBJ: J P ROOM TEMP: 25 °C

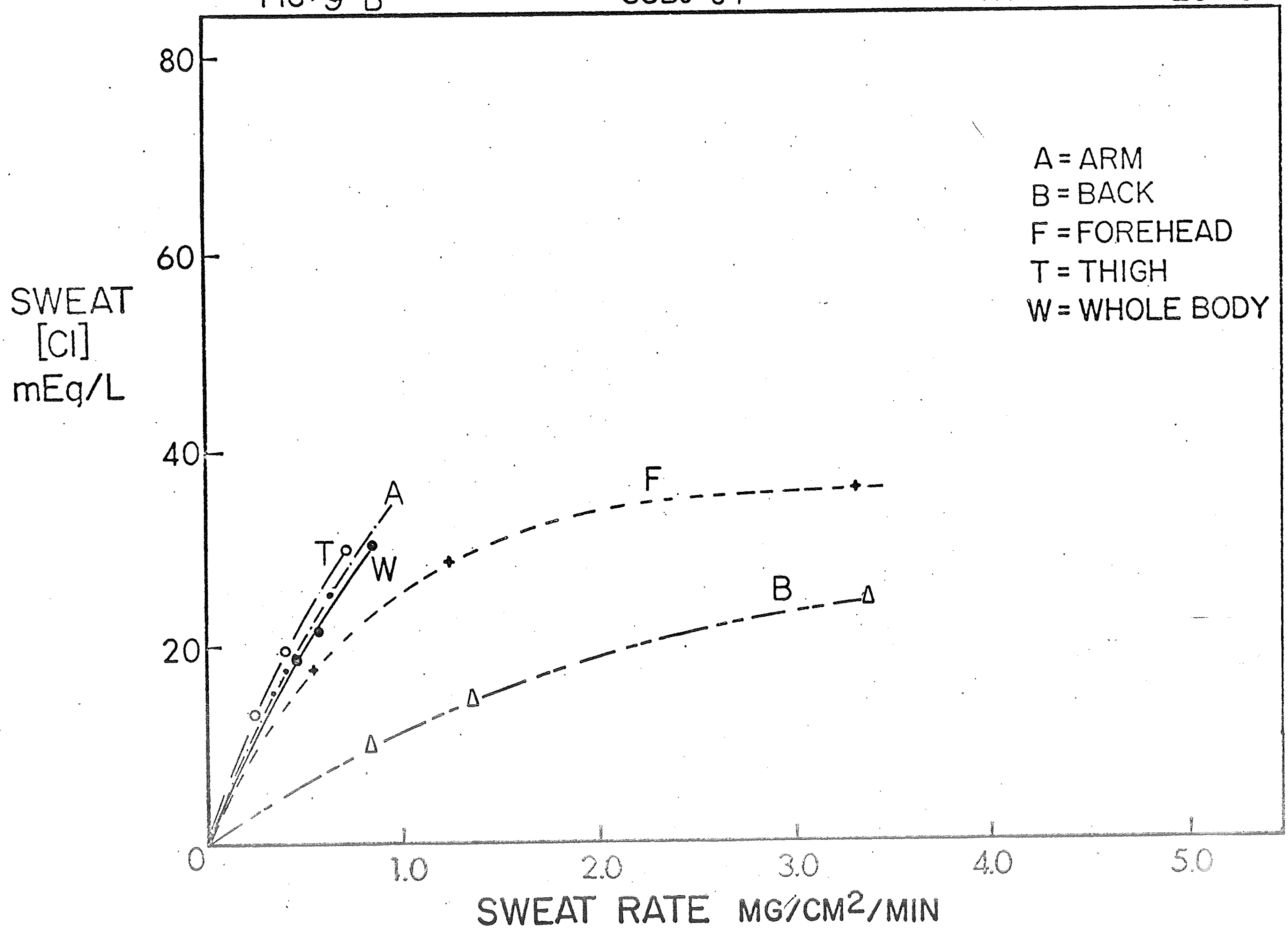


FIG: 9 C

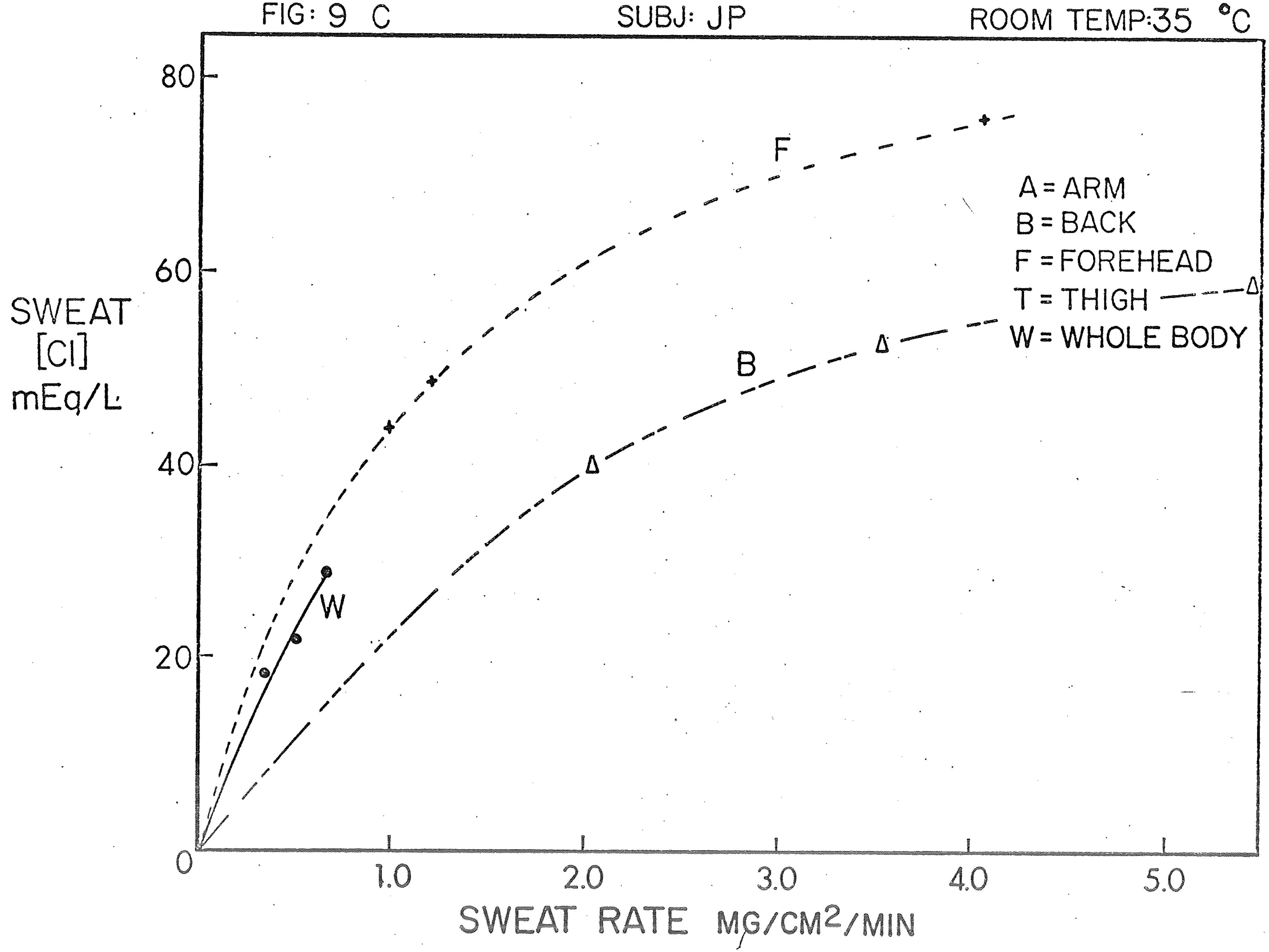

SUBJ: JP
ROOM TEMP:35 °C
SWEAT [Cl] mEq/L
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
F
B
W
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY

FIG: 9 D

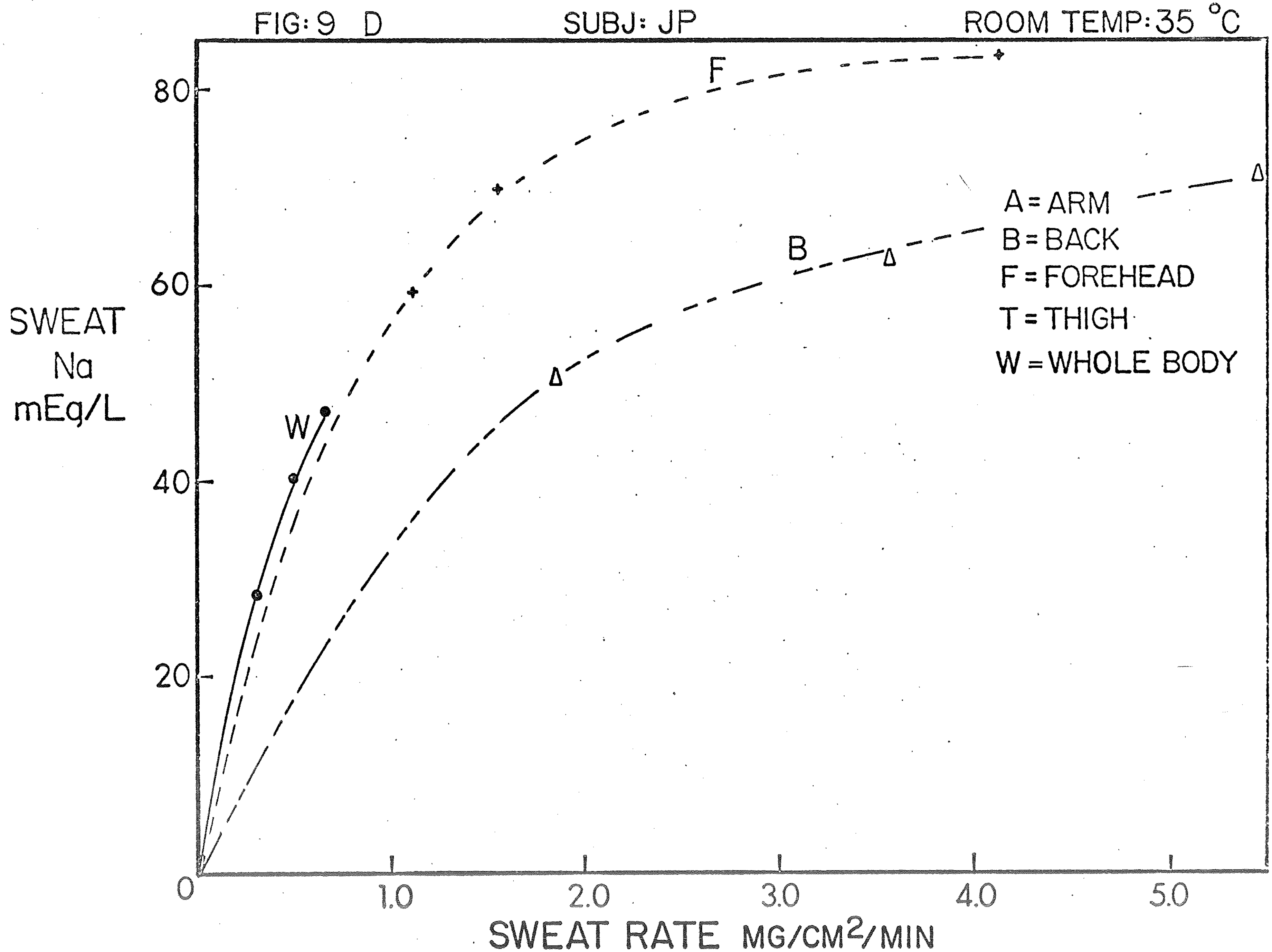

SUBJ: JP
ROOM TEMP: 35 °C
SWEAT
Na
mEq/L
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
F
B
W
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY

FIG: 9 E SUBJ: JP ROOM TEMP: 43 °C

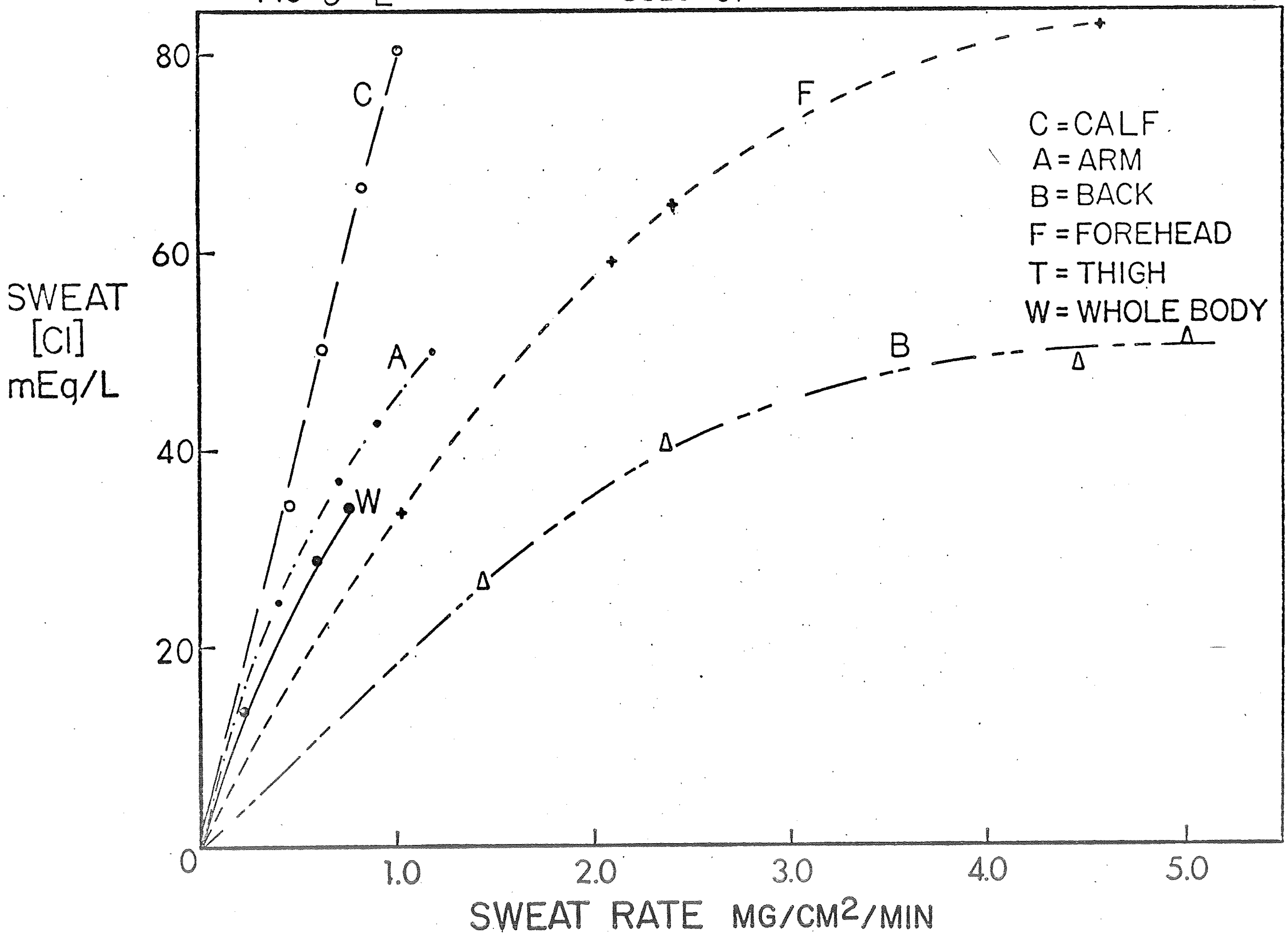


FIG: 9 F SUBJ: JP ROOM TEMP: 43 °C

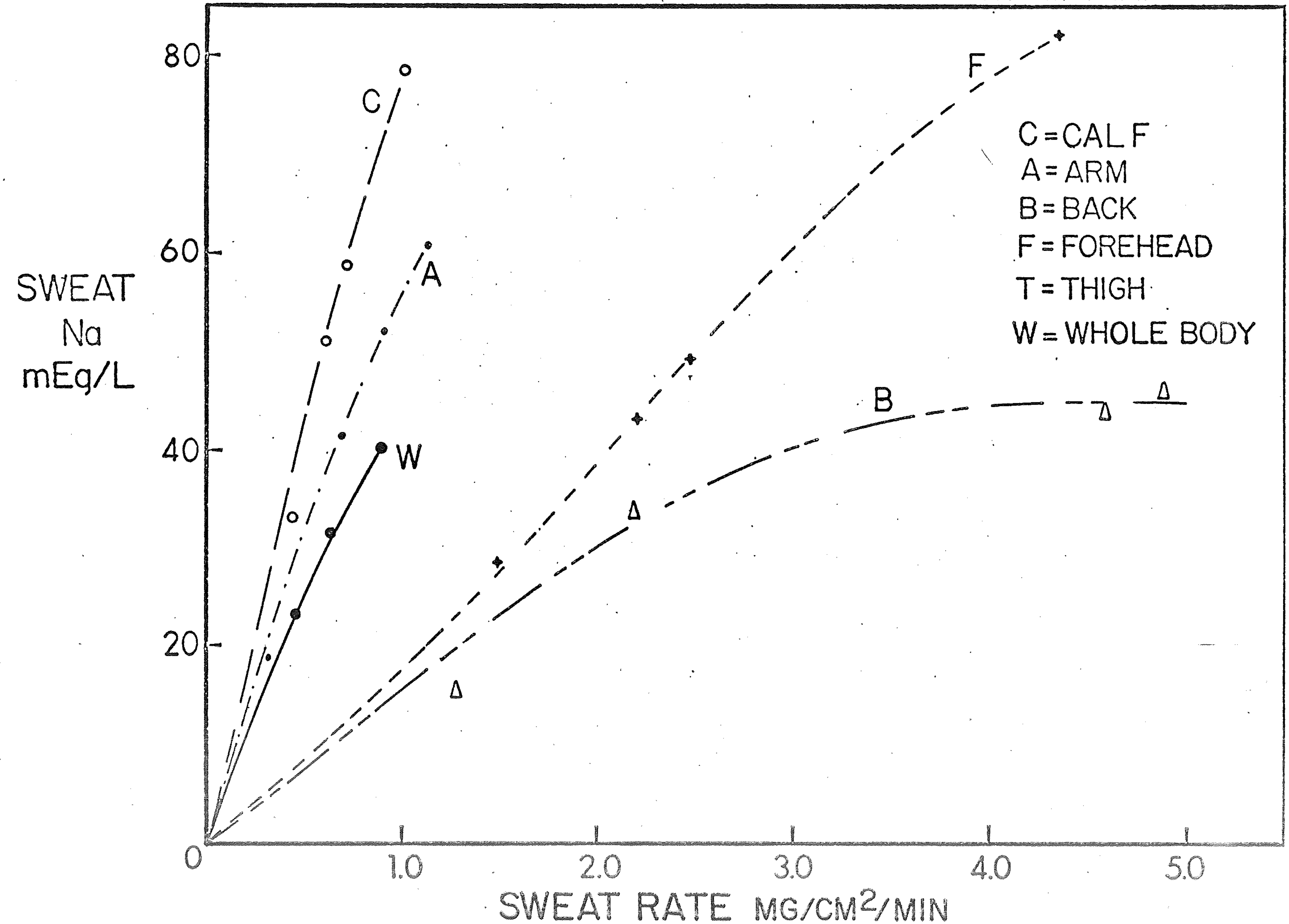
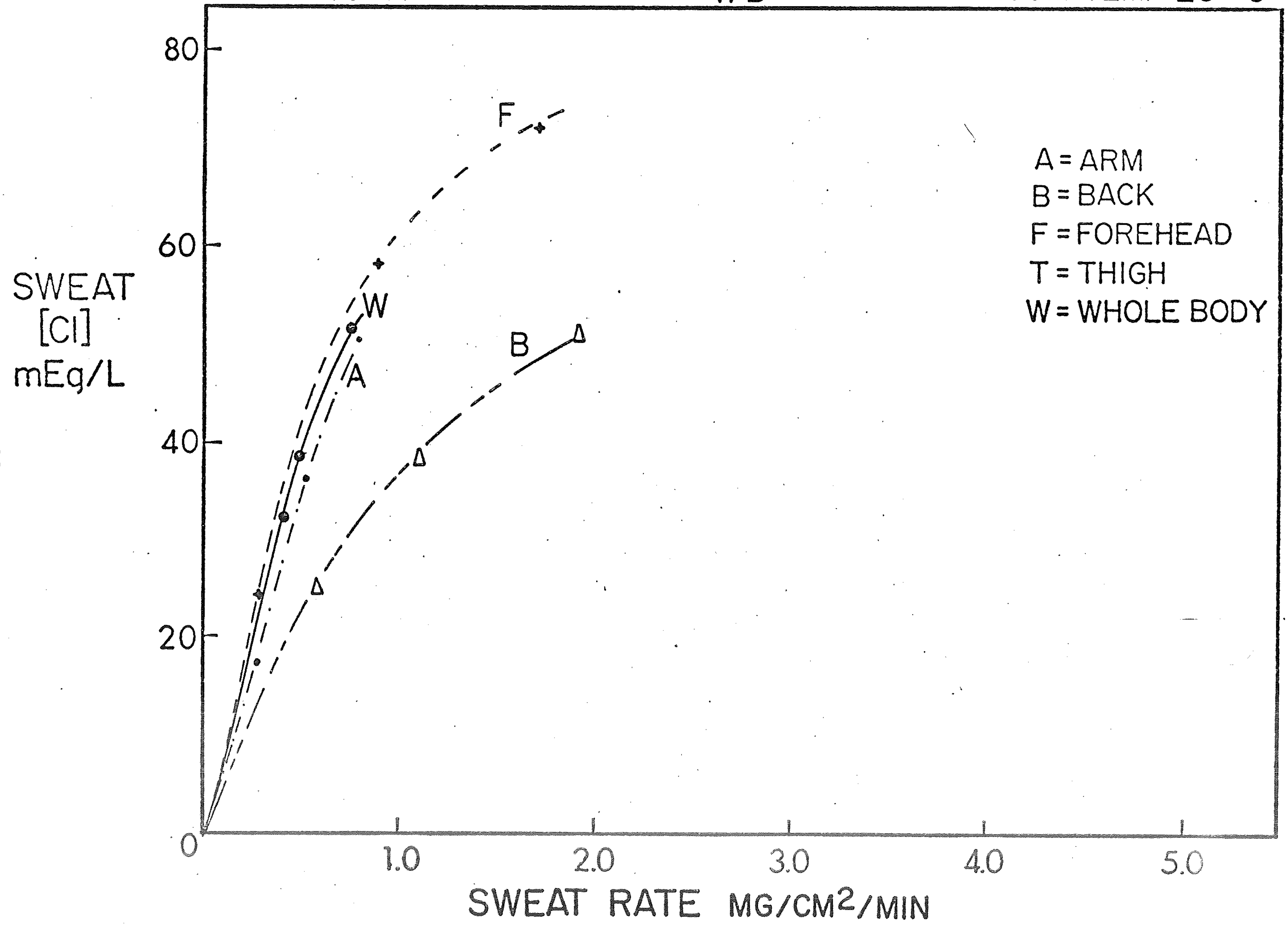


FIG: 10 A SUBJ: W B ROOM TEMP: 25 °C



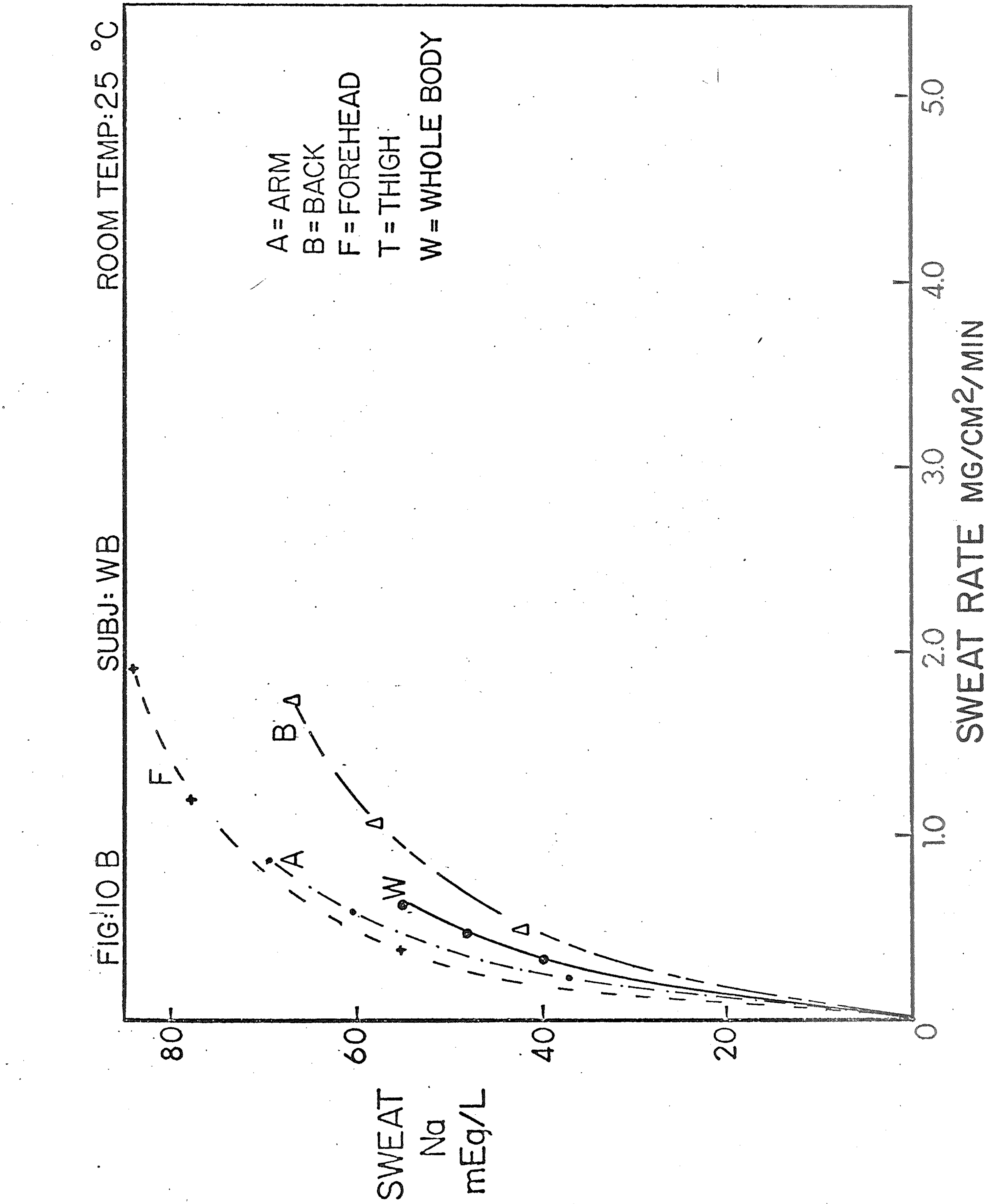


FIG: 10 B
SUBJ: WB
ROOM TEMP: 25 °C
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY
SWEAT Na mEq/L
SWEAT RATE MG/CM2/MIN
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
F
B
A
W

FIG: 10 C SUBJ: WB ROOM TEMP: 35 °C

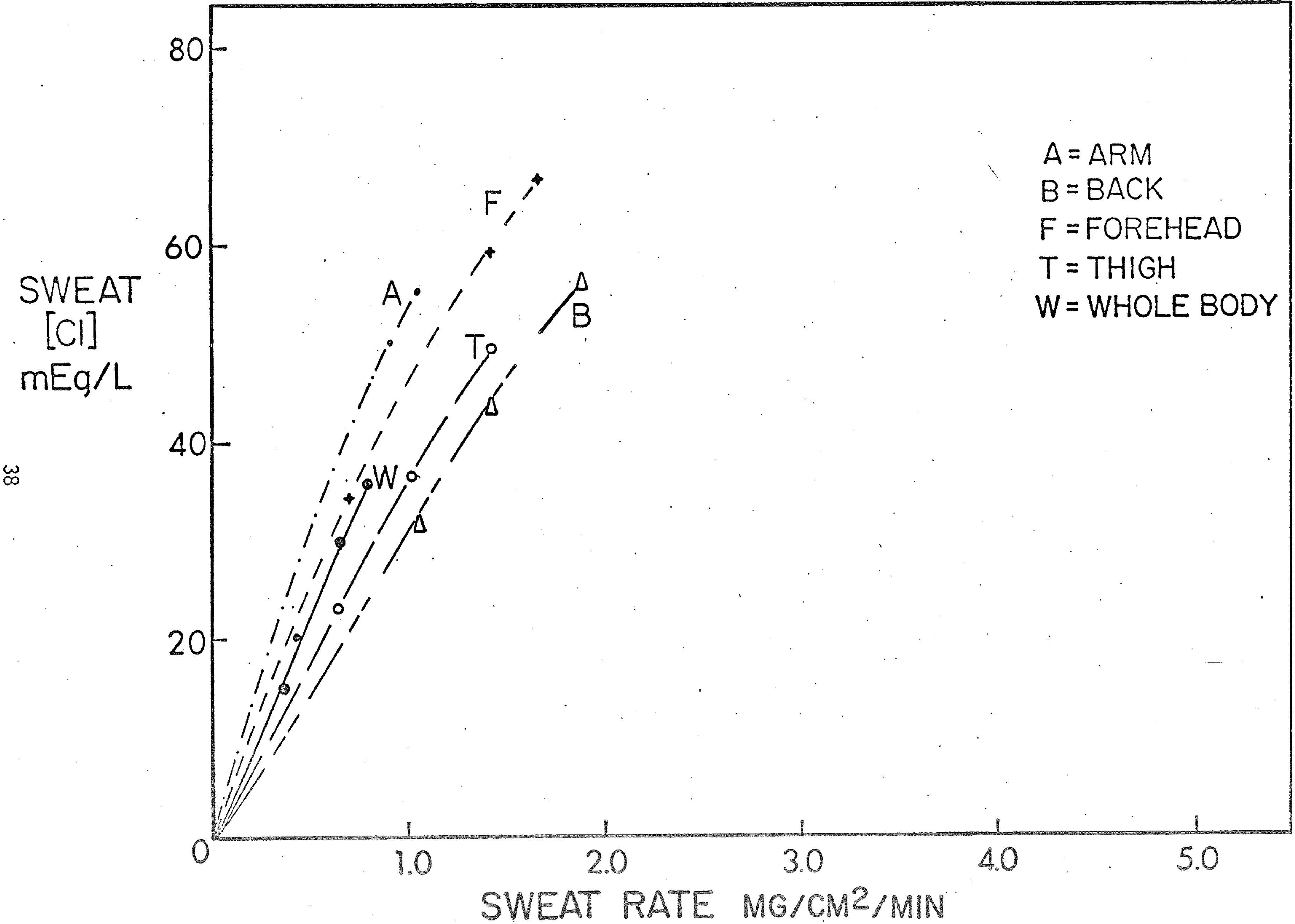
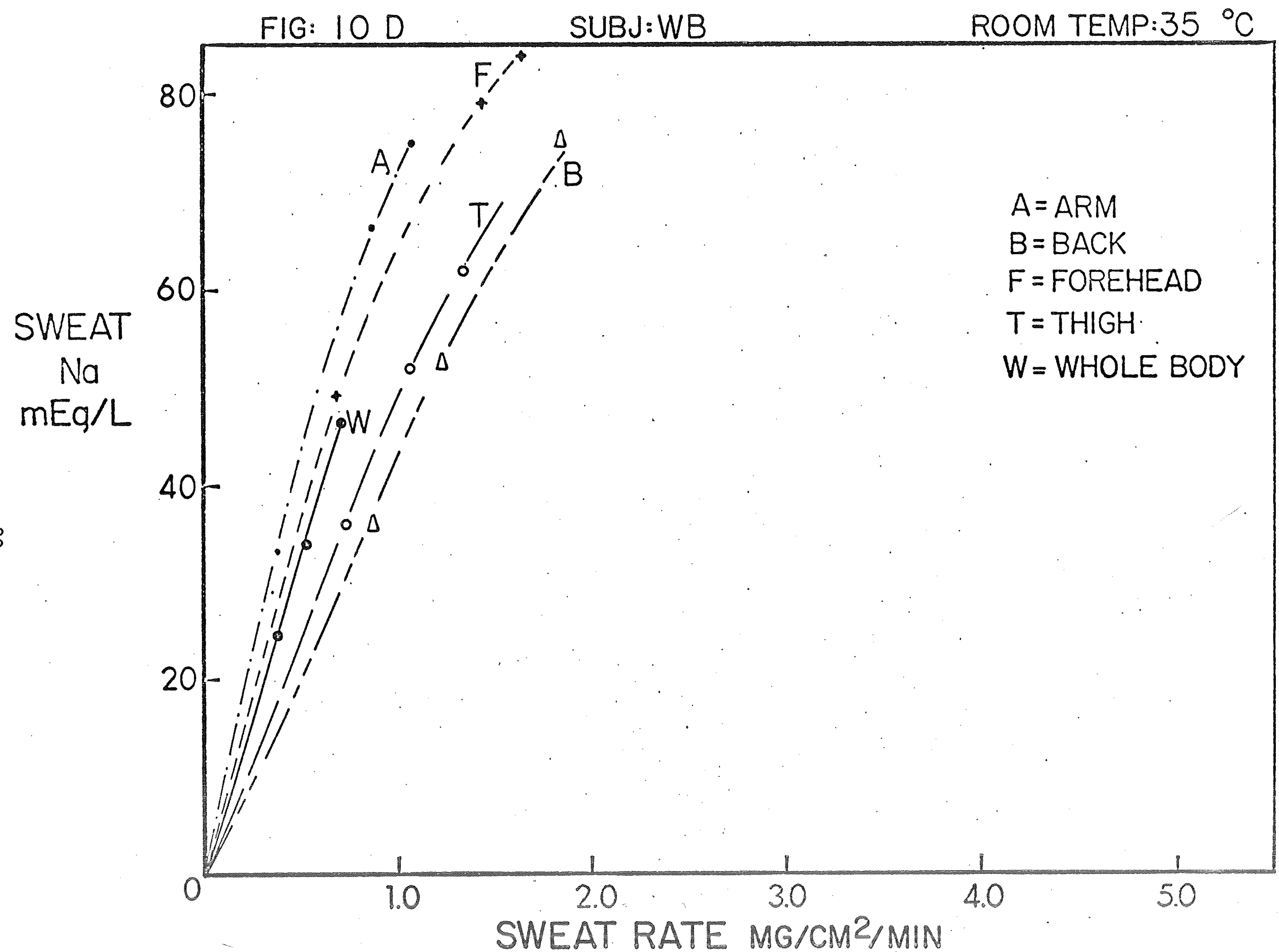


FIG: 10 D



SUBJ: WB
ROOM TEMP: 35 °C
SWEAT Na mEq/L
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
A
F
T
B
W
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY

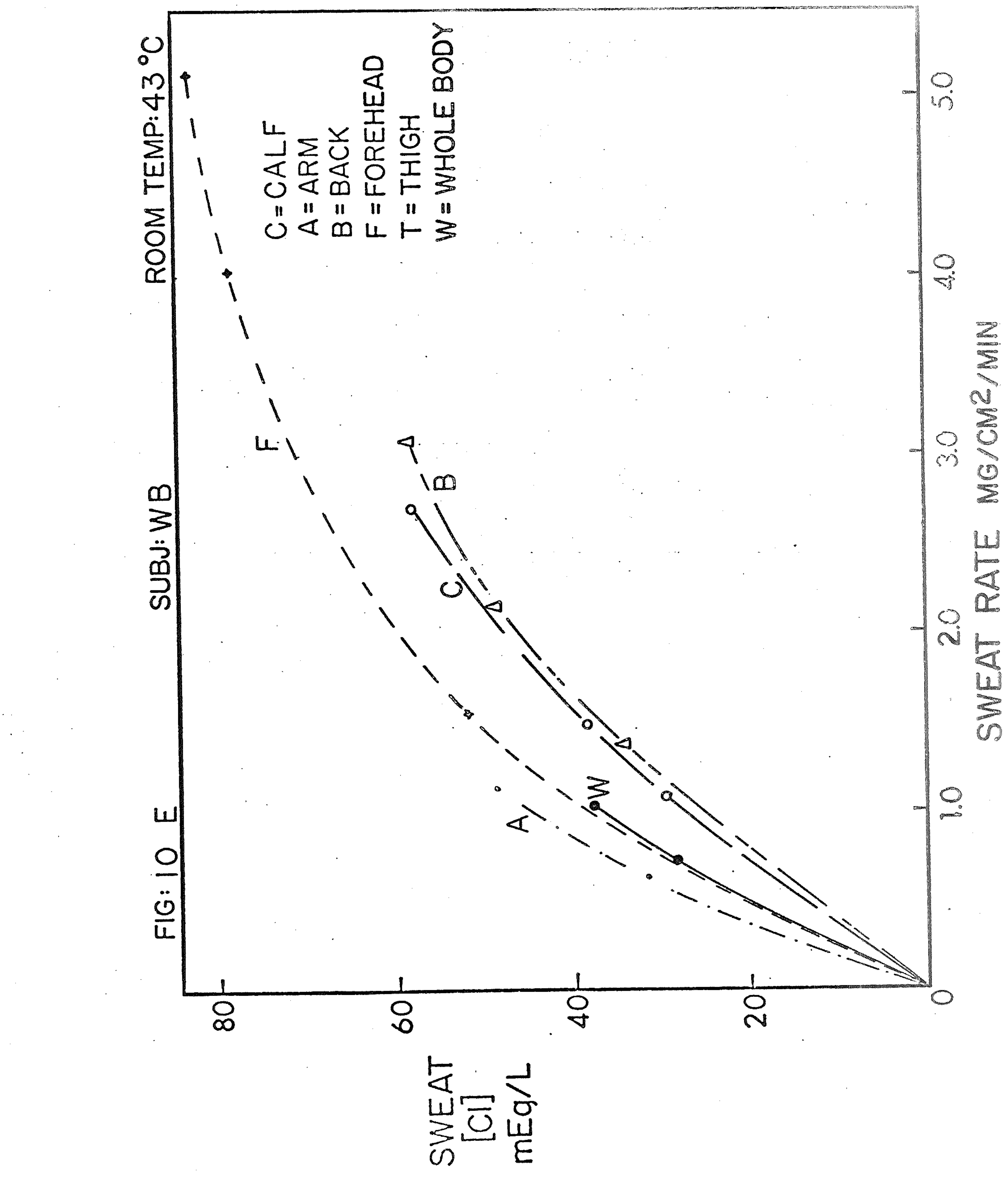


FIG: 10 E
SUBJ: WB
ROOM TEMP: 43 °C
C = CALF
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY
F
C
B
W
A
SWEAT [Cl] mEq/L
0
20
40
60
80
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN

FIG: 11 A SUBJ: JH ROOM TEMP: 25 °C

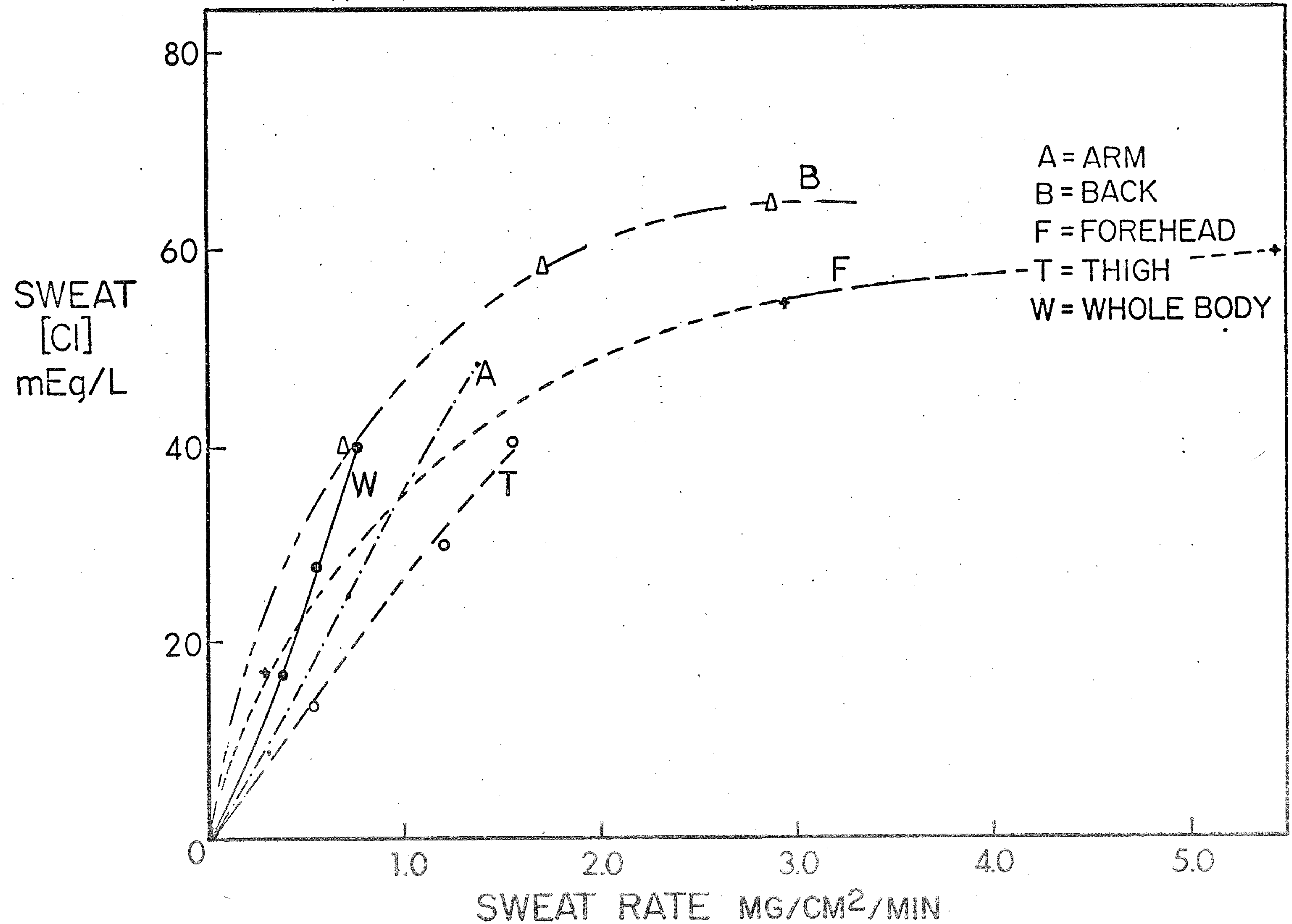


FIG: 11 B SUBJ: JH ROOM TEMP: 25 °C

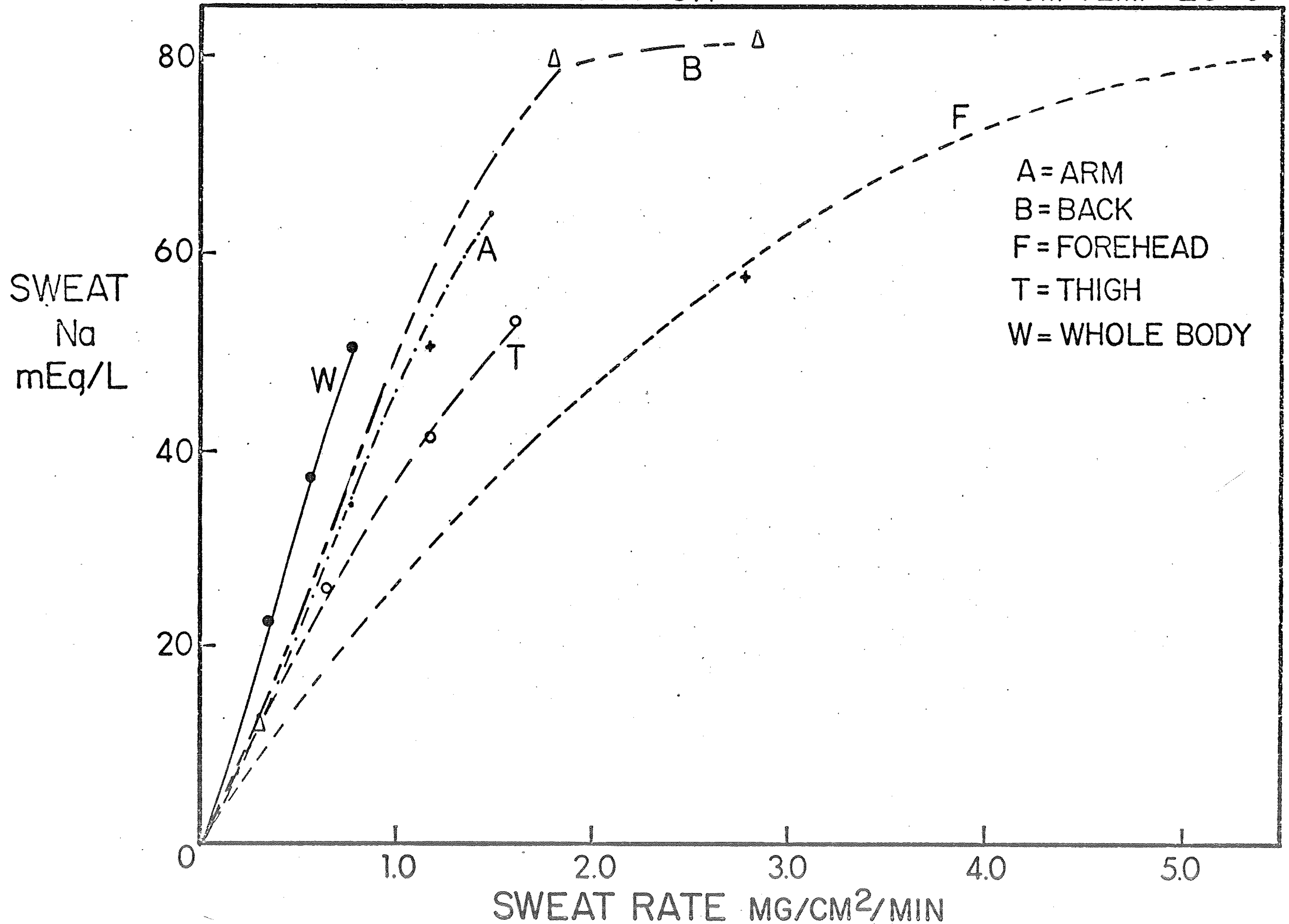


FIG: 11 C SUBJ: JH ROOM TEMP: 35 °C

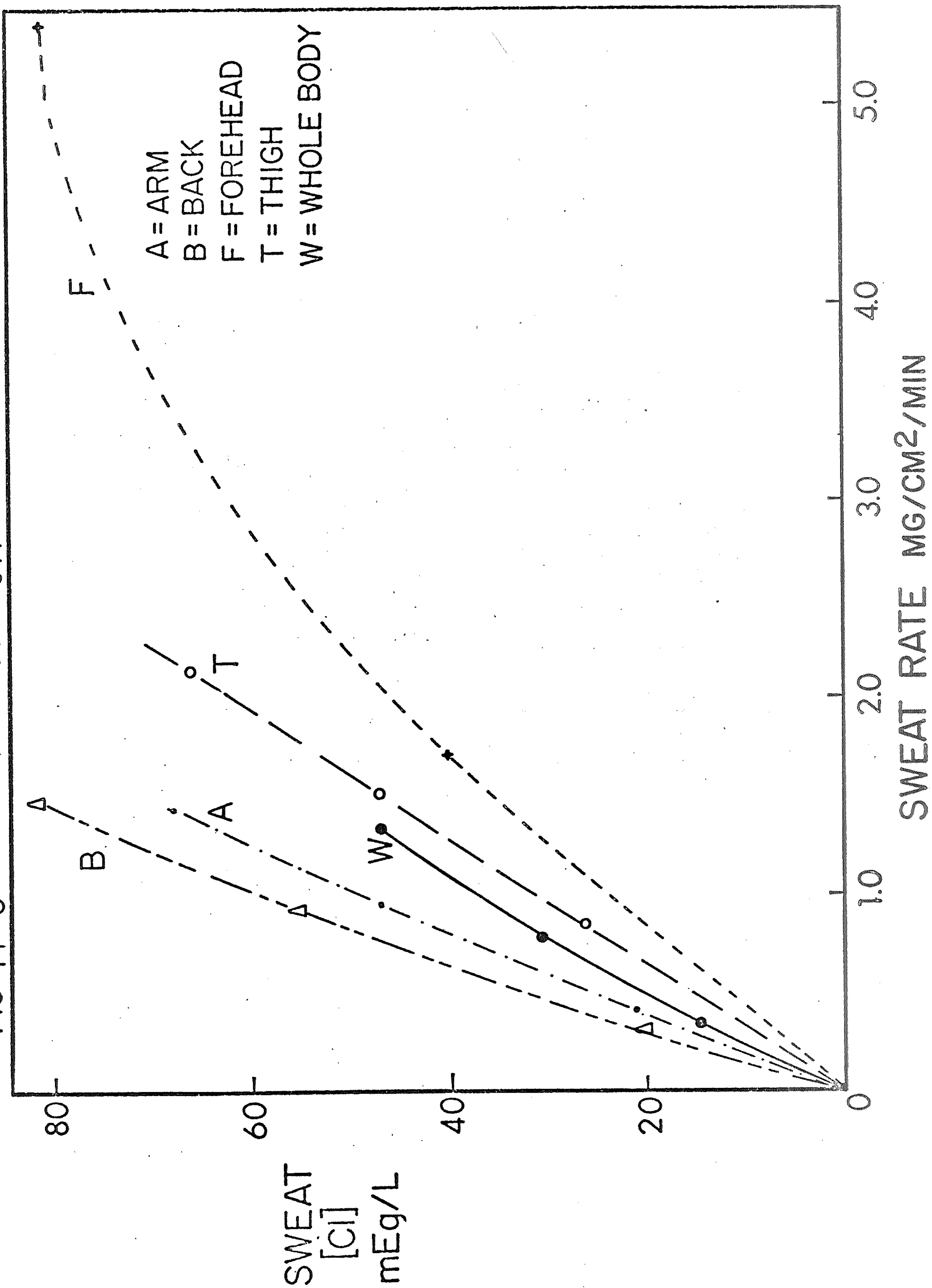


FIG: 11 D

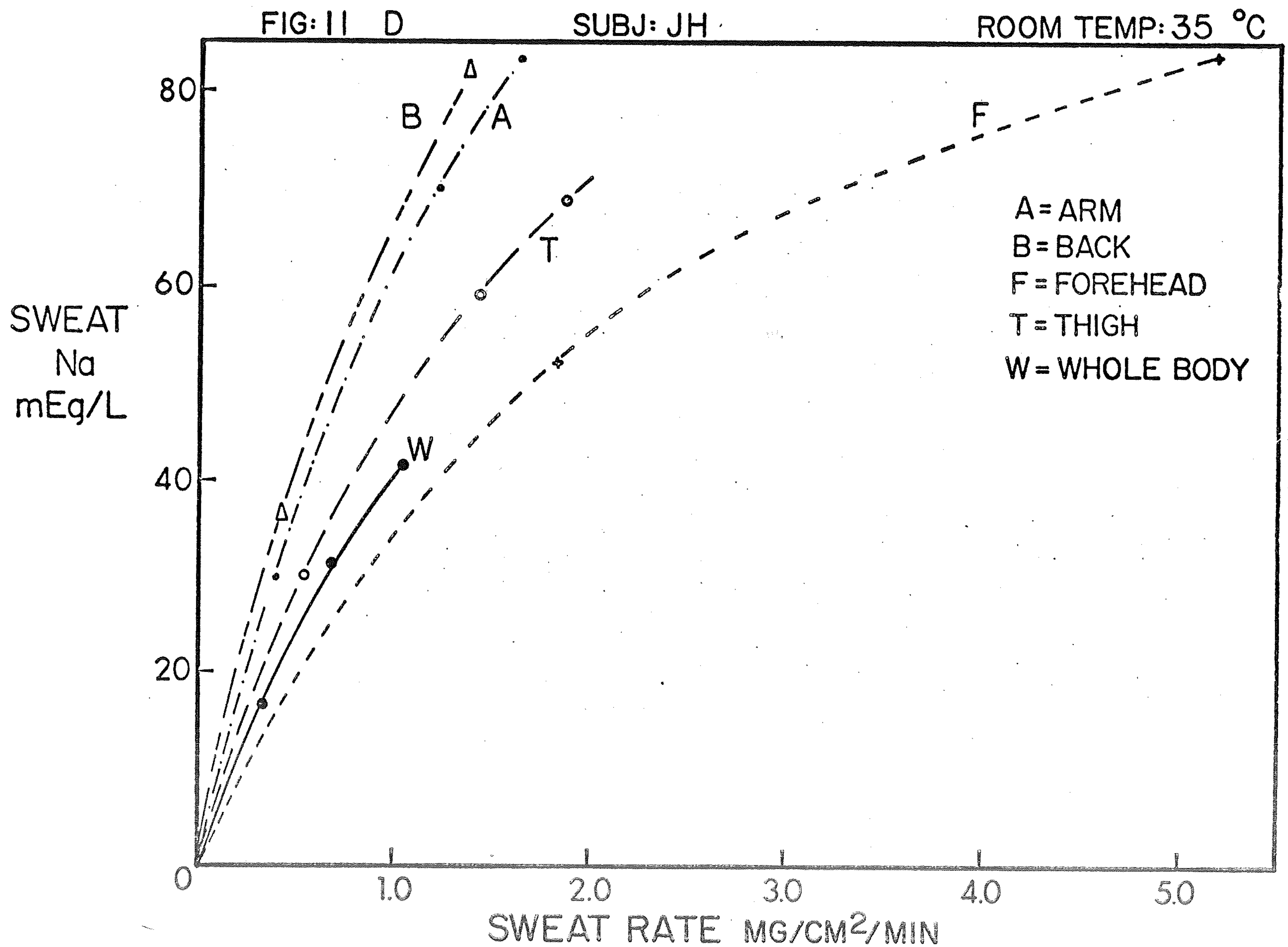
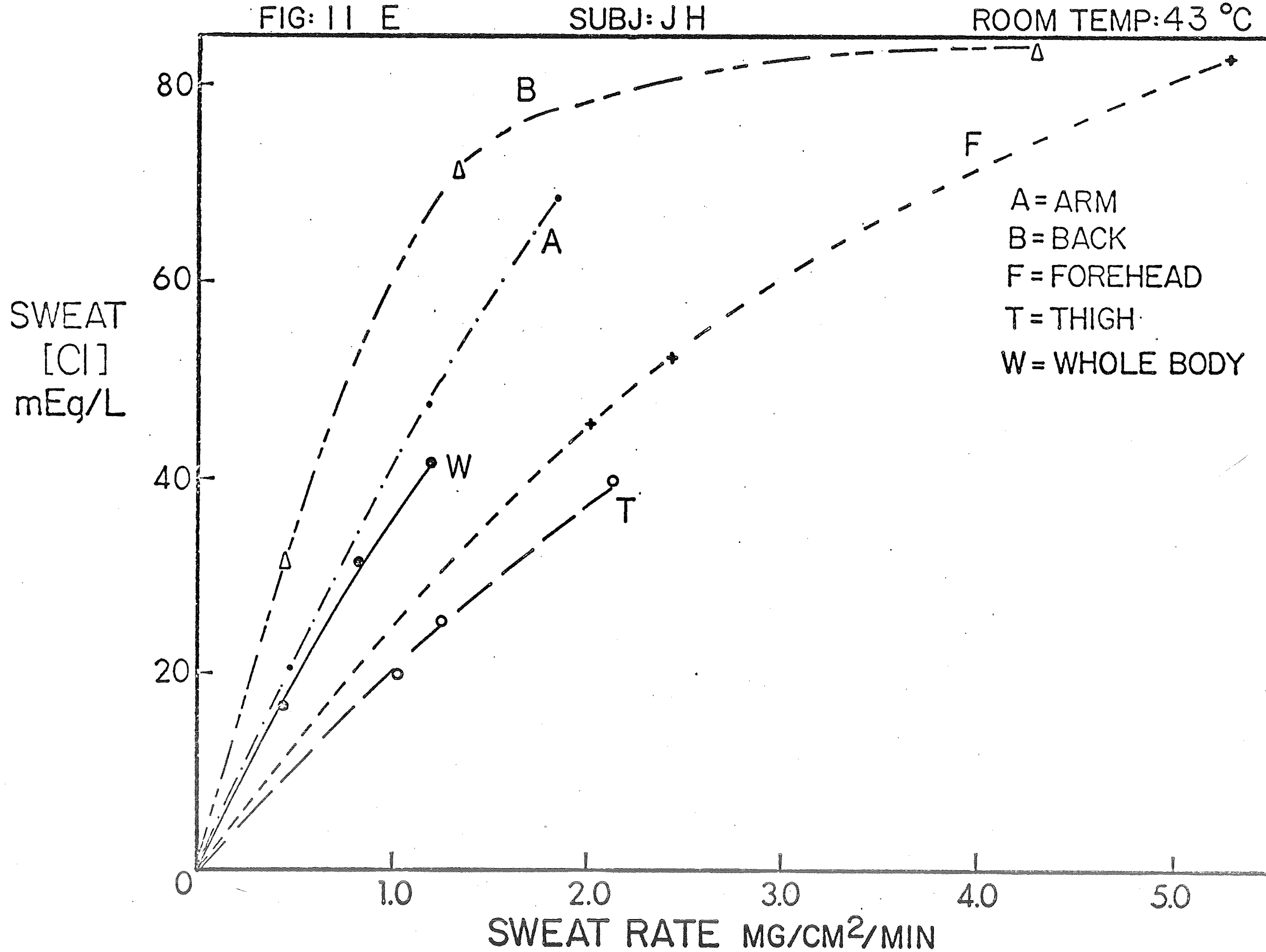

SUBJ: JH
ROOM TEMP: 35 °C
SWEAT
Na
mEq/L
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
B
A
T
W
F
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY

FIG: 11 E



SUBJ: J H
ROOM TEMP: 43 °C
SWEAT [Cl] mEq/L
80
60
40
20
0
1.0
2.0
3.0
4.0
5.0
SWEAT RATE MG/CM2/MIN
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY
B
A
F
W
T

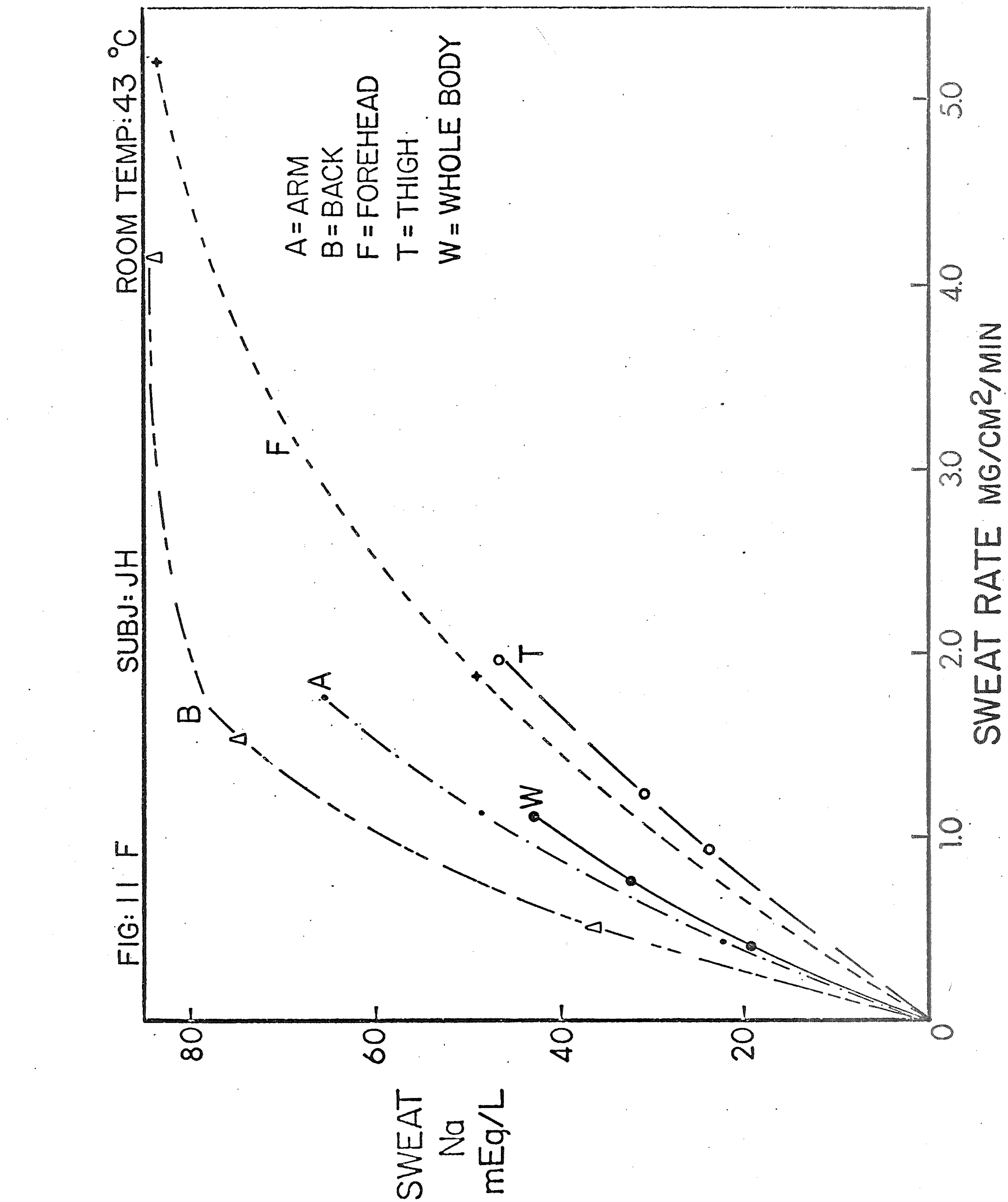
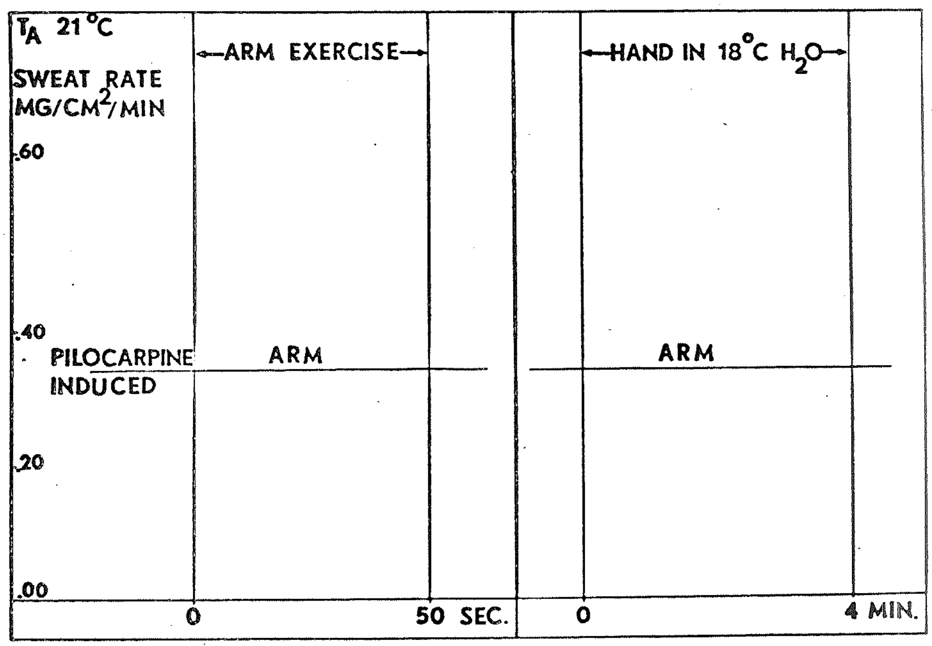


FIG: 11 F
SUBJ: JH
ROOM TEMP: 43 °C
A = ARM
B = BACK
F = FOREHEAD
T = THIGH
W = WHOLE BODY
SWEAT Na mEq/L
SWEAT RATE MG/CM2/MIN
0
1.0
2.0
3.0
4.0
5.0
20
40
60
80
A
B
F
T
W

FIG: 12



T_A 21 °C
SWEAT RATE
MG/CM^2/MIN
.60
.40
.20
.00
PILOCARPINE
INDUCED
←ARM EXERCISE→
ARM
0
50 SEC.
←HAND IN 18°C H_2O→
ARM
0
4 MIN.

FIG : 13

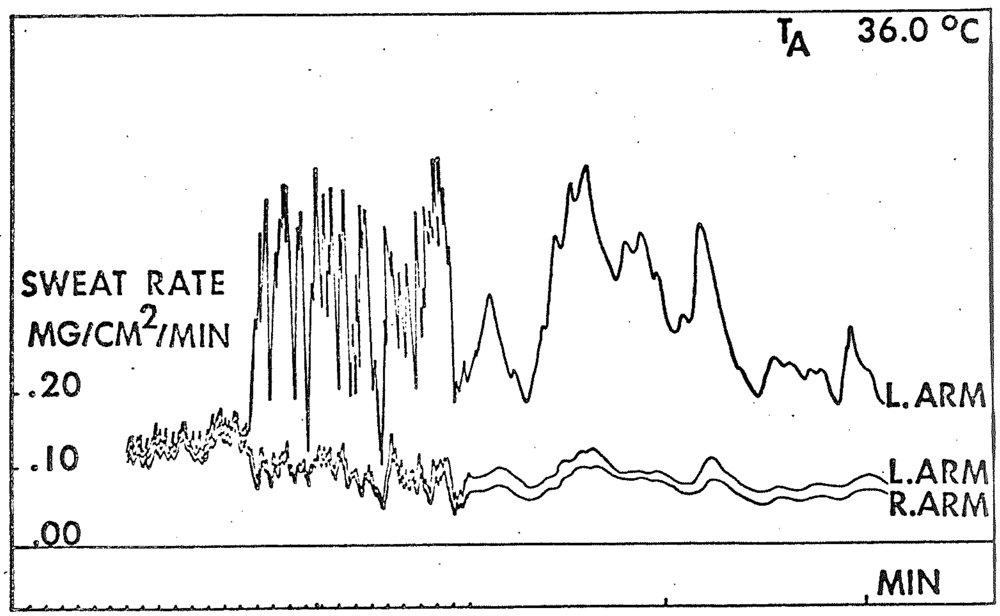
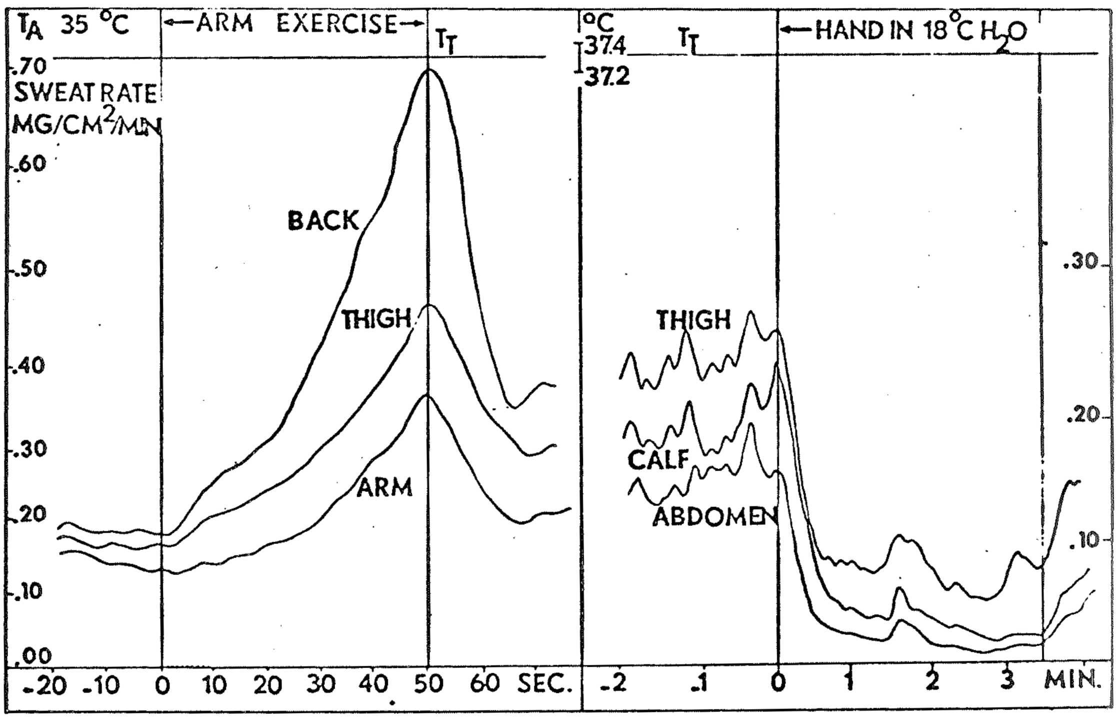


FIG : 14



T_A 35 °C
←ARM EXERCISE→
T_T
.70
SWEAT RATE
MG/CM²/MIN
.60
.50
.40
.30
.20
.10
.00
BACK
THIGH
ARM
-20 -10 0 10 20 30 40 50 60 SEC.
°C
37.4
37.2
T_T
←HAND IN 18°C H_2O
THIGH
CALF
ABDOMEN
.30
.20
.10
-2 -1 0 1 2 3 MIN.

FIG: 15 A SUBJ: JP ROOM TEMP: 35 °C

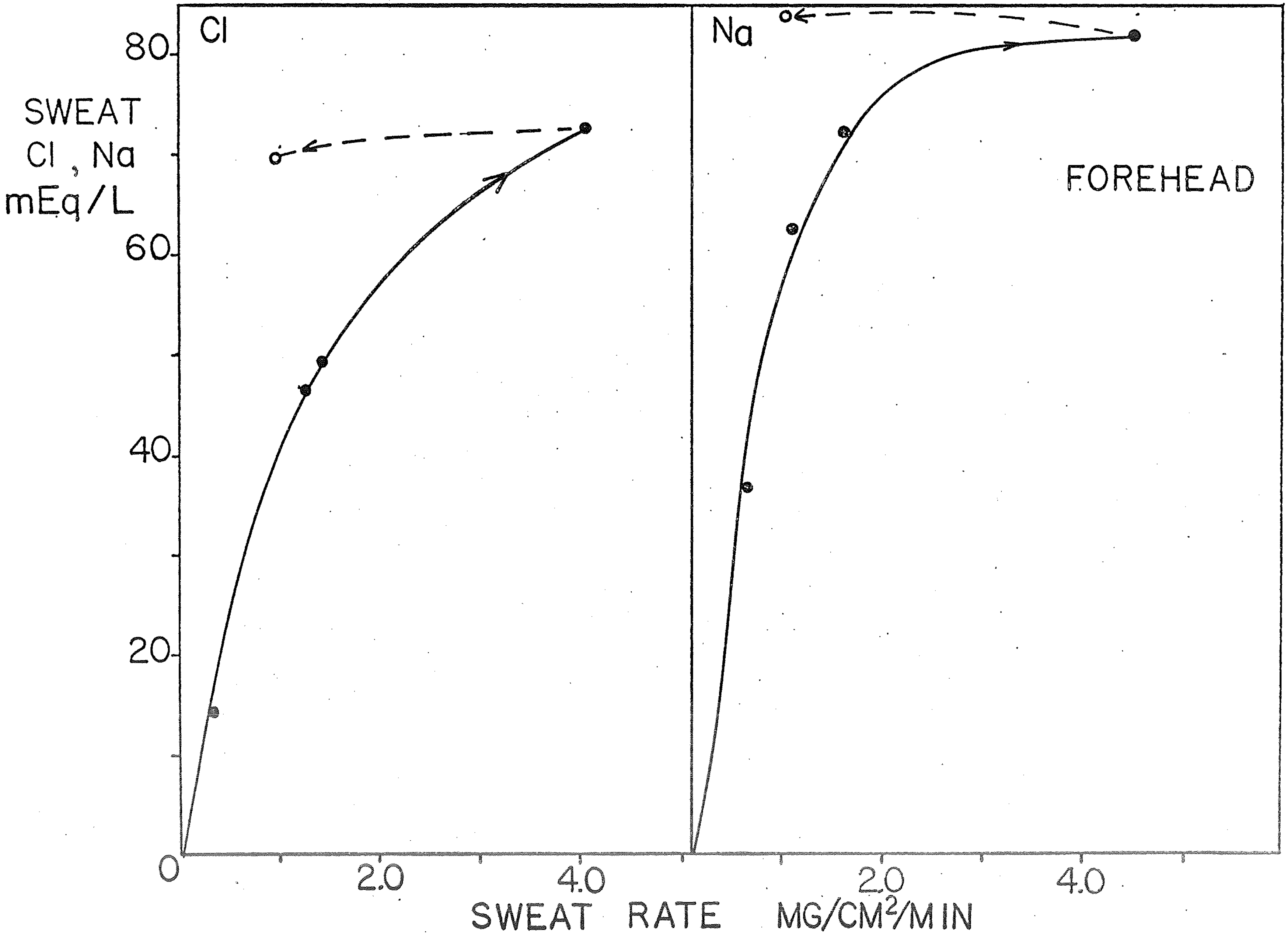


FIG: 15 B SUBJ: WB ROOM TEMP: 35 °C

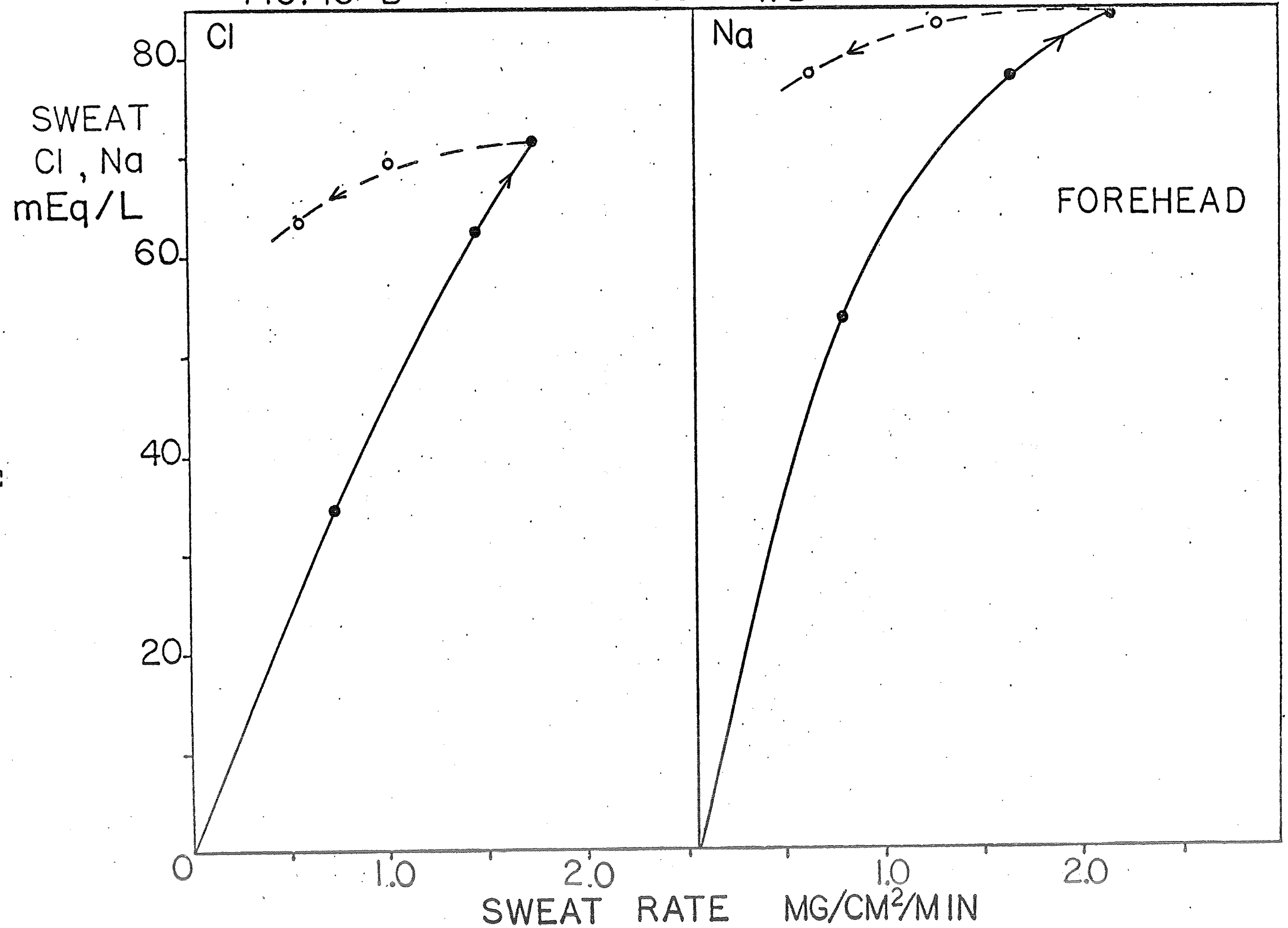
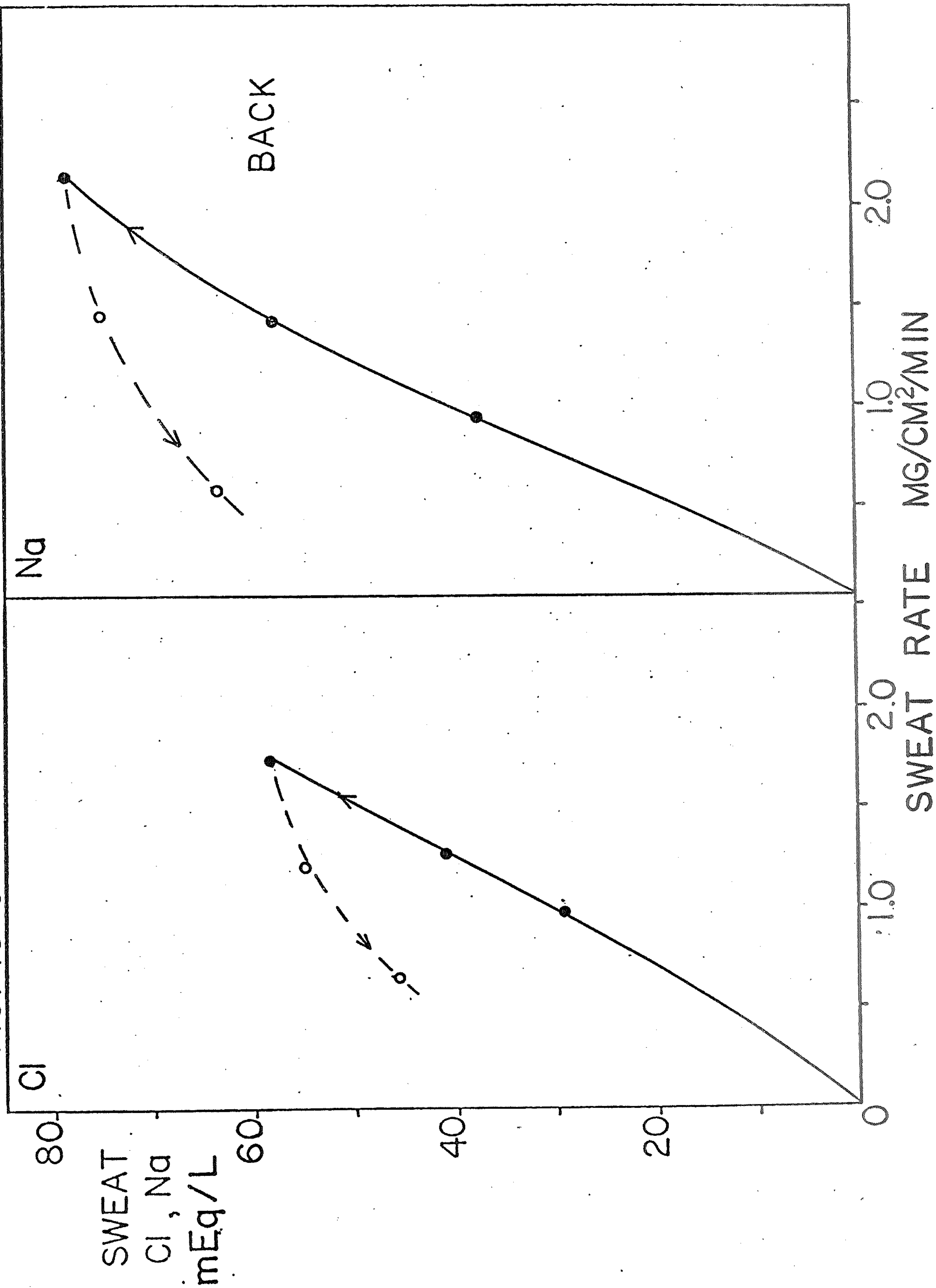


FIG: 15 C SUBJ: W.B ROOM TEMP: 35 °C



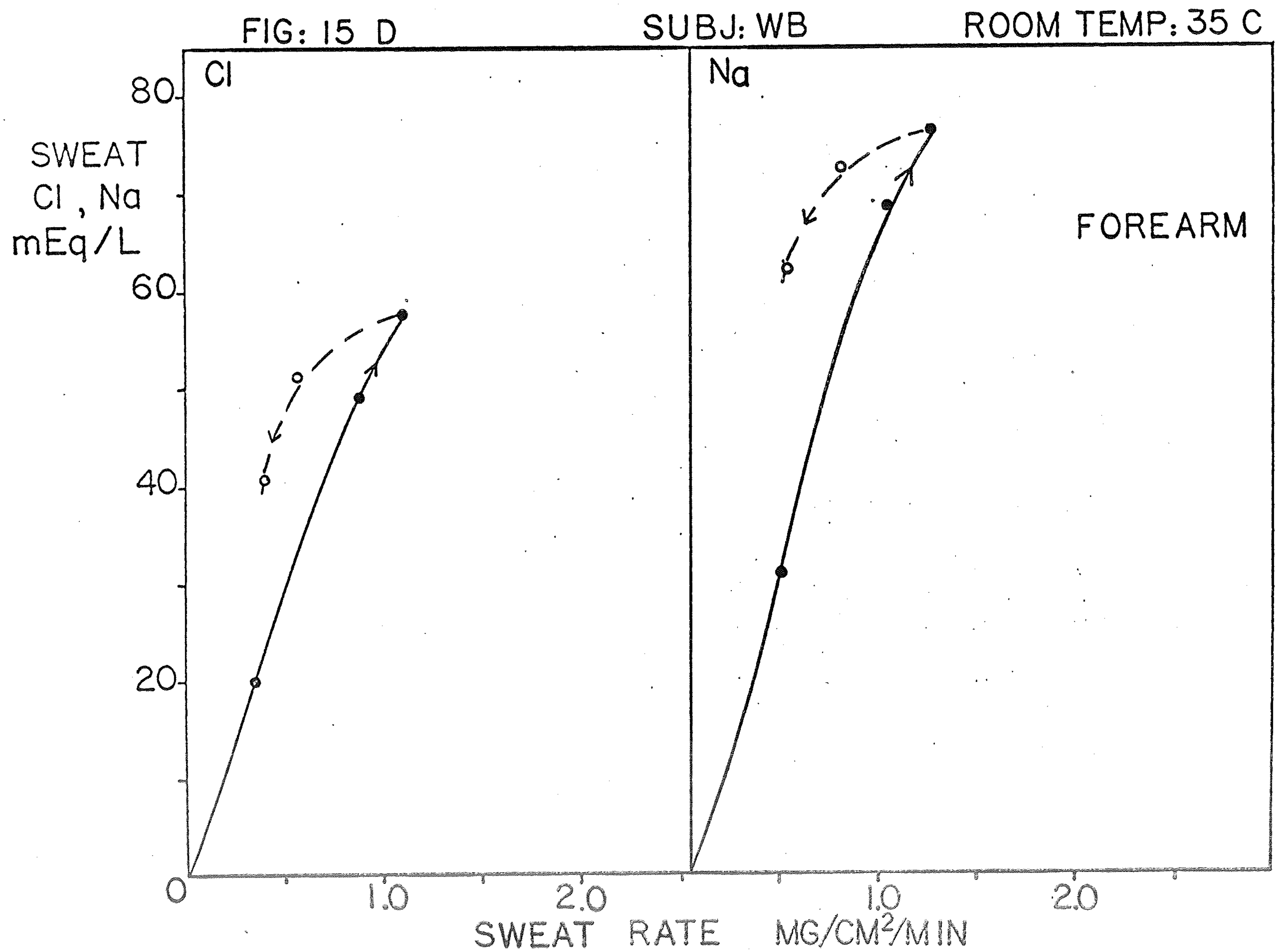


FIG: 15 D
SUBJ: WB
ROOM TEMP: 35 C
Cl
Na
FOREARM
SWEAT
Cl , Na
mEq/L
80
60
40
20
0
1.0
2.0
1.0
2.0
SWEAT RATE MG/CM2/MIN

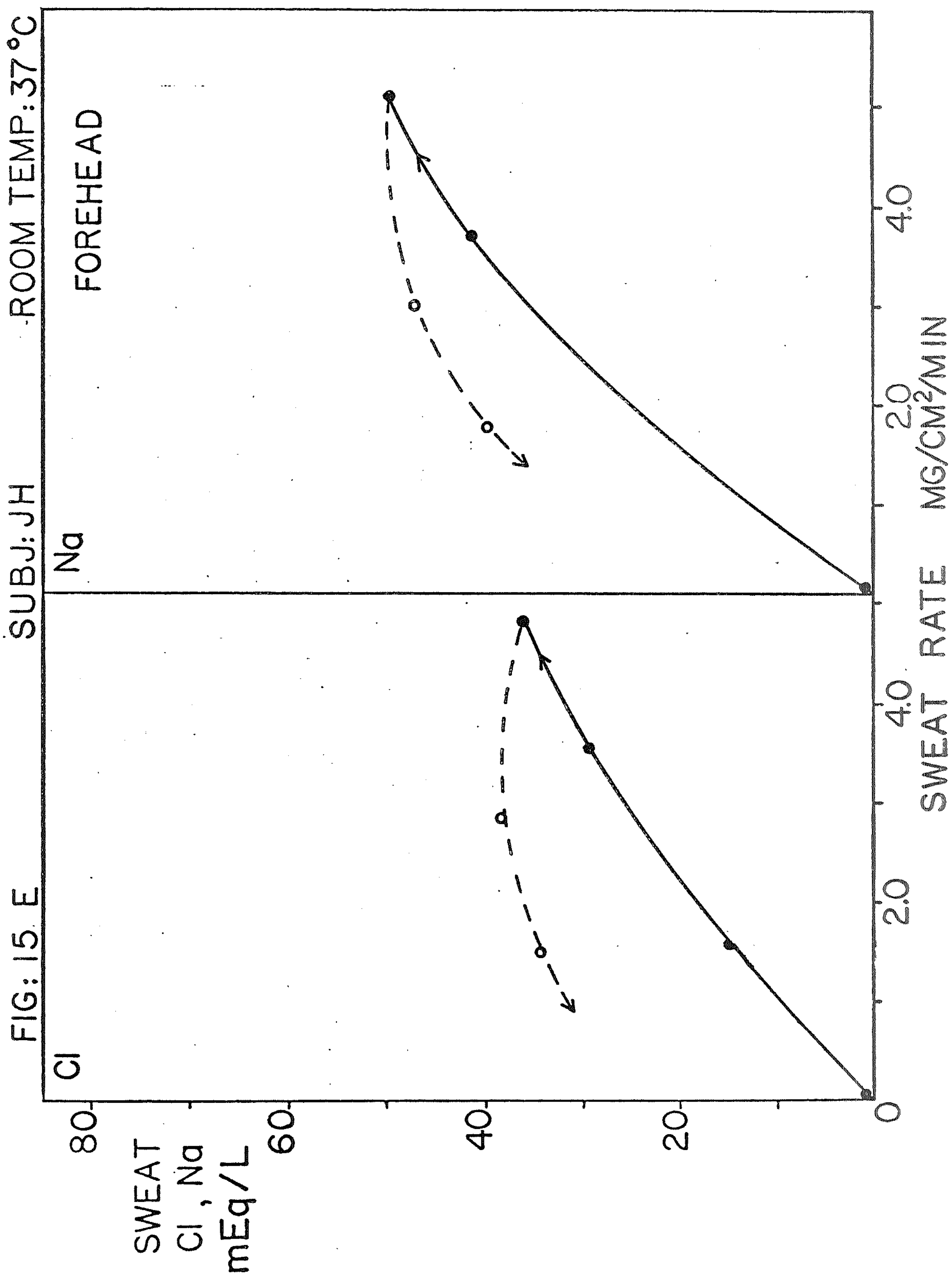


FIG: 15 E
SUBJ: JH
ROOM TEMP: 37 °C
FOREHEAD
Cl
Na
SWEAT Cl, Na mEq/L
80
60
40
20
0
2.0
4.0
SWEAT RATE MG/CM²/MIN

FIG: 15 F SUBJ: JH ROOM TEMP: 37 °C

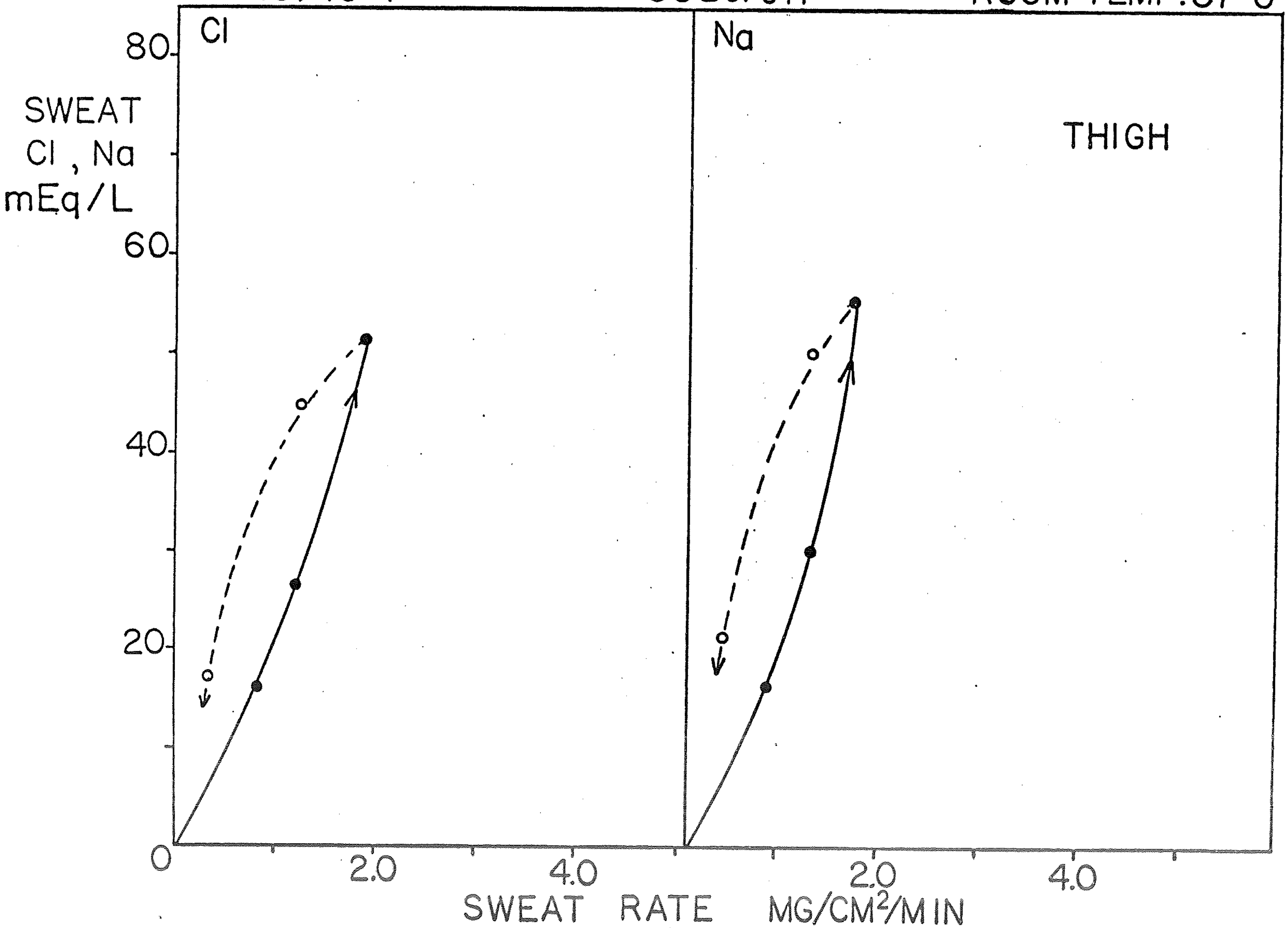


TABLE 1a

COMPARISON OF SWEAT RATE MEASUREMENTS BY UNVENTILATED AND VENTILATED CAPSULE DURING REST

SUBJECT	SKIN AREA	FILTERPAPER (F)	HYGROMETER (H)	UNITS	F/H x 100
J.K.	Lateral Calf	0.39	0.62	$mg.cm^{-2}min^{-1}$	
	"	0.41	0.72	"	
	"	0.32	0.46	"	
	"	0.32	0.62	"	
	$\bar{X}$	0.36	0.60	"	60%
W.P.	Lateral Calf	0.37	0.45	"	
	"	0.23	0.52	"	
	"	0.29	0.54	"	
	"	0.32	0.63	"	
	$\bar{X}$	0.30	0.53	"	56%
F.S.	Lateral Calf	0.13	0.35	"	
	"	0.18	0.45	"	
	"	0.41	0.48	"	
	"	0.44	0.64	"	
	$\bar{X}$	0.29	0.48	"	60%
J.K.	Volar Forearm	0.07	0.22	"	
	"	0.05	0.13	"	
	"	0.08	0.10	"	
	"	0.09	0.14	"	
	$\bar{X}$	0.07	0.15	"	46%
W.P.	Volar Forearm	0.12	0.27	"	
	"	0.27	0.54	"	
	"	0.21	0.43	"	
	"	0.10	0.26	"	
	$\bar{X}$	0.17	0.37	"	46%
F.S.	Volar Forearm	0.14	0.31	"	
	"	0.18	0.39	"	
	"	0.24	0.44	"	
	"	0.40	0.64	"	
	$\bar{X}$	0.24	0.44	"	54%
	Mean	0.24	0.43	"	55%

TABLE 1B

REGIONAL SWEATING RATES DURING MUSCULAR EXERCISE
(.225 kgm/min)

SUBJECT	SKIN AREA	FILTERPAPER (F)	HYGROMETER (H)	UNITS	F/H x 100
J.K.	R. Forearm	0.13	0.24	$mg.cm^{-2}min^{-1}$	
	"	0.14	0.28	"	
	"	0.09	0.23	"	
	$\bar{X}$	0.12	0.25	"	48%
	L. Forearm	0.19	0.26	"	
	"	0.15	0.30	"	
	"	0.09 (1)	0.23	"	
	$\bar{X}$	0.14	0.25	"	56%
	Back	0.85	1.10	"	
	"	1.12	1.15	"	
	"	0.43 (1)	0.53	"	
	$\bar{X}$	0.80	0.92	"	87%
W.P.	R. Foreman	0.39	0.64	"	
	"	0.40	0.58	"	
	"	0.20 (2)	0.34	"	
	$\bar{X}$	0.33	0.52	"	63%
	Back	0.58	0.67	"	
	"	0.61	0.70	"	
	"	0.21 (2)	0.25	"	
	$\bar{X}$	0.46	0.57	"	80%

1. Included 3 minutes of moderate exercise (900 kgm/min) and ensuing recovery. with maximal sweat rates of 0.50 $mg/cm^2/min$ on the forearm and 1.20 $mg/cm^2/min$ on the back.

2. See 1. Maximal sweating rates attained 0.60 $mg/cm^2/min$ on the forearm and 0.45 $mg/cm^2/min$ on the back.

TABLE 1c

Calcium Recovery from Filterpaper (Dilution 4 ml)

Ca Standard meg/L	ML. Standard in 541 Filter-paper	Calculated Concentration meg/L	Observed Blank	Blank meg/L	$\frac{OBS}{CALC}$ x 100 =
.5	.5	.05	.08	.03	160%
.5	1.0	.10	.11	"	110
.5	4.0	.25	.33	"	132
1.0	.5	.11	.09	"	81
1.0	1.0	.20	.18	"	90
1.0	4.0	.50	.68	"	136
3.0	.5	.31	.40	"	129
3.0	1.0	.60	.70	"	116
3.0	4.0	1.50	2.16	"	144
.5	.5	.05	.04	.04	80
.5	1.0	.10	.09	"	90
.5	4.0	.25	.34	"	136
1.0	.5	.11	.08	"	72
1.0	1.0	.20	.17	"	85
1.0	4.0	.50	.74	"	148
3.0	.5	.31	.34	"	109
3.0	1.0	.60	.56	"	93
3.0	4.0	1.50	1.96	"	130
				Mean	113% Recovered

TABLE 2a

CALCIUM CONCENTRATION IN SWEAT

Subject WvB

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L
35	1.75	5-15	R. Lat. Back	1.78	1.12		
"	"	"	L. " "	2.19	1.14	.64	2.26
"	"	"	R. Med. Back	1.44	1.08		
35	"	5-10	R. Lat. Back	2.31	0.78		
"	"	"	L. " "	2.58	1.03		
"	"	"	R. Med. Back	2.30	1.16		
"	"	15-20	R. Lat. Back	3.03	0.19		
"	"	"	L. " "	3.36	0.33		
"	"	"	R. Med. Back	4.75	0.67		
"	.75	25-35	R. Lat. Back	1.85	0.95		
"	.75	"	L. " "	2.92	0.56	.77	1.41
"	.75	"	R. Med. Back	1.44	0.53		

TABLE 2a (Cont'd)

CALCIUM CONCENTRATION IN SWEAT

Subject WvB

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L
35°	1.5	5-17	Forehead	.72	2.60		
"	"	30-38	Forehead	1.11	1.44		
"	"	45-53	"	1.47	1.45		
"	"	5-14	L. Med. Back	1.37	2.20		
"	"	30-39	"	1.43	1.74		
"	"	45-51	"	1.66	1.54		
"	"	5-14	R. Lat. Back	.96	3.15		
"	"	30-39	"	1.22	1.60		
"	"	45-51	"	1.17	1.82		
"	"	5-26	Med. Forearm	.49	3.74		
"	"	30-42	"	.73	2.18		
"	"	45-57	"	.84	2.04		
"	"	5-26	Lat. Thigh	.70	2.36	.73	1.18
"	"	30-42	"	.73	2.18		
"	"	45-57	"	.96	1.46		

TABLE 2b

CALCIUM CONCENTRATION IN SWEAT

Subject WvB

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA (12 cm^2)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca meg/L
41.5	1.5	5-15	Forehead	0.71	1.52		
"	"	"	Med. Forearm	0.57	2.84		
"	"	"	R. Med. Back	1.76	1.44	.70	5.41
"	"	"	Lat. Calf	1.04	2.76		
"	1.5	5-15	Forehead	1.82	0.58		
"	"	"	Med. Forearm	1.20	1.32		
"	"	"	R. Med. Back	2.84	0.72		
"	"	"	Lat. Calf	2.26	1.41		
"	"	20-30	Forehead	2.17	0.29		
"	"	"	Med. Forearm	1.22	0.63		
"	"	"	R. Med. Back	3.58	0.57		
"	"	"	Lat. Calf	3.22	0.96	1.19	1.26
"	0	35-40	Forehead	.74	0.14		
"	0	"	Med. Forearm	0.79	0.96		
"	0	"	R. Med. Back	1.99	0.59		
"	0	"	Lat. Calf	1.63	1.29		

TABLE 2c

CALCIUM CONCENTRATION IN SWEAT

Subject WvB

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca meg/L
53°	0	5-20	Forehead	.48	3.66		
"	"	"	Med. Forearm	.31	4.99		
"	"	"	R. Med. Back	1.06	2.54		
"	"	"	Lat. Calf	.47	4.00		
56	1.5	3-13	Forehead	3.04	0.50		
"	"	"	Med. Forearm	1.23	3.01		
"	"	"	R. Med. Back	3.18	1.02		
"	"	"	Lat. Calf	1.50	3.28		
"	2.5	15-20	Forehead	5.83	0.19		
"	"	"	Med. Forearm	1.92	1.92	.89	2.76
"	"	"	R. Med. Back	4.09	0.46		
"	"	"	Lat. Calf	3.00	1.68		

TABLE 3a

CALCIUM CONCENTRATION IN SWEAT

Subject F. B.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA (12 cm^2)	SWEAT RATE $mg/cm^2/min.$	SWEAT Ca meg/L	SWEAT RATE $mg/cm^2/min.$	SWEAT Ca meg/L
25	1.5	5-15	R. Lat. Back	.91	1.27		
"	"	20-30	"	1.08	0.77		
"	"	35-45	"	1.55	0.49		
"	"	5-15	L. Lat. Back	1.36	1.71		
"	"	20-30	"	1.82	0.64		
"	"	35-45	"	1.60	0.85		
"	"	5-15	R. Med. Back	1.21	1.64	.58	1.84
"	"	20-30	"	1.57	0.42	(0-45 min)	
"	"	35-45	"	1.83	0.54		
25	1.5	5-15	R. Lat. Back	1.30	1.53		
"	"	20-30	"	2.06	0.48		
"	"	35-45	"	2.23	0.46		
"	"	5-15	L. Lat. Back	1.15	2.26		
"	"	20-30	"	1.33	0.62	.63	2.12
"	"	35-45	"	1.56	0.40	(0-45 min)	
		5-15	R. Med. Back	1.15	1.73		
		20-30	"	1.28	1.29		
		35-45	"	1.92	0.40		

TABLE 3b

CALCIUM CONCENTRATION IN SWEAT

Subject F.B.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA (12 cm^2)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca++ meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca++ meg/L
35	1	5-15	R. Lat. Back	.89	2.49		
"	"	20-30	"	.97	2.41		
"	"	35-45	"	1.04	2.28		
"	"	5-15	L. Lat. Back	1.27	1.73		
"	"	20-30	"	.85	.78		
"	"	35-45	"	.85	.91	.94 (0-45 min)	2.25
"	"	5-15	R. Med. Back	.75	1.86		
"	"	20-30	"	1.10	1.11		
"	"	35-45	"	1.15	.97		
37	1.5	5-15	R. Lat. Back	1.61	1.86		
"	"	20-30	"	2.90	0.58		
"	"	35-45	"	3.00	0.76		
"	"	5-15	L. Lat. Back	1.96	1.74		
"	"	20-30	"	3.83	0.58		
"	"	35-45	"	3.70	0.54	.92 (0-45 min)	2.76
"	"	5-15	R. Med. Back	1.22	1.83		
"	"	20-30	"	1.81	0.66		
		35-45	"	2.14	0.37		

TABLE 3c

CALCIUM CONCENTRATION IN SWEAT

Subject F.B.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA (12 cm^2)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L
39	1.5	5-15	R. Lat. Back	1.55	1.50		
"	"	"	L. Lat. Back	1.44	1.04	.82	3.28
"	"	"	R. Med. Back	1.32	1.50		
"	1.25	5-15	R. Lat. Back	1.83	0.73		
"	"	"	L. Lat. Back	1.38	0.84		
"	"	"	R. Med. Back	1.67	0.69	.84	2.00
"	"	20-30	R. Lat. Back	2.72	0.64		
"	"	"	L. Lat. Back	1.81	0.55		
"	"	"	R. Med. Back	1.94	0.48		
40	1.33	5-15	R. Lat. Back	1.94	1.75		
"	"	"	L. Lat. Back	2.45	0.79	.84	3.63
"	"	"	R. Med. Back	1.37	1.58		
"	"	5-15	R. Lat. Back	2.20	1.18		
"	"	"	L. Lat. Back	2.32	1.18		
"	"	"	R. Med. Back	2.31	1.00		
"	"	20-30	R. Lat. Back	3.08	0.57		
"	"	"	L. Lat. Back	2.63	0.57	.84	1.52
"	"	"	R. Med. Back	3.17	0.66		

TABLE 3d

CALCIUM CONCENTRATION IN SWEAT

Subject F.B.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L
43	1.5	5-15	Forehead	2.20	1.45		
"	"	"	Forearm	1.00	3.21		
"	"	"	R. Med. Back	1.00	2.14		
"	"	20-30	Forehead	2.36	0.93		
"	"	"	Forehead	1.33	1.30	.75	1.84
"	"	"	R. Med. Back	1.50	1.36		
"	REST	35-45	Forehead	2.80	0.48		
"	"	"	Forearm	1.15	1.94		
"	"	"	R. Med. Back	1.58	1.37		
		1	HOUR	REST IN	25°C		
"	1.5	5-15	Forehead	1.67	1.34		
"	"	"	Forearm	.76	2.72		
"	"	"	R. Med. Back	1.07	1.87		
"	2	20-30	Forehead	3.42	0.68	.79	1.78
"	"	"	Forearm	1.27	1.78		
"	"	"	R. Med. Back	1.51	1.58		

TABLE 4a

CALCIUM CONCENTRATION IN SWEAT

Subject F.G.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L
25	1.5	5-15	R. Lat. Back	0.57	0.75		
"	"	20-30	"	1.08	0.58		
"	"	35-35	"	1.30	0.26		
"	"	5-15	L. Lat. Back	0.75	1.36		
"	"	20-30	L. Lat. Back	1.08	1.05		
"	"	35-45	L. Lat. Back	1.79	0.45	.67	1.82
"	"	5-15	R. Med. Back	0.91	0.85	(0-45 min)	
"	"	20-30	R. Med. Back	.88	0.68		
"	"	35-45	"	1.22	0.49		
35	1.5	5-15	R. Lat. Back	1.34	1.99		
"	"	20-30	"	2.04	1.25		
"	"	35-45	"	2.52	1.12		
"	"	5-15	L. Lat. Back	1.25	1.54		
"	"	20-30	L. Lat. Back	1.54	1.02		
"	"	35-45	"	1.73	0.95	.75	2.44
"	"	5-15	R. Med. Back	1.25	1.78	(0-45 min)	
"	"	20-30	"	1.71	0.93		
"	"	35-45	"	1.69	1.07		

TABLE 4a

CALCIUM CONCENTRATION IN SWEAT

Subject F.G.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca^{++} meg/L
25	1.75	5-15	Forehead	1.14	2.29		
"	"	"	Forearm	.68	2.93		
"	"	"	R. Med. Back	.46	1.71	.54	3.45
"	"	"	Calf	.71	1.91	(0-15 min)	
"	"	5-15	Forehead	.47	1.47		
"	"	"	Forearm	.46	.86		
"	"	"	R. Med. Back	.38	1.30		
"	"	"	Calf	.51	.90		
"	"	20-30	Forehead	1.44	1.02		
"	"	"	Forearm	.80	1.13	.56	1.26
"	"	"	R. Med. Back	.60	0.94	(0-30 min)	
"	"	"	Calf	.77	0.73		

TABLE 4b

CALCIUM CONCENTRATION IN SWEAT

Subject F.B.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L
39	1.25	5-15	R. Lat. Back	1.60	1.04		
"	"	20-30	"	2.57	0.47		
"	"	35-45	"	2.17	0.46		
"	"	5-15	L. Lat. Back	1.61	1.96		
"	"	20-30	"	2.49	0.58	.93	1.55
"	"	35-45	"	2.38	0.28	(0-45 min)	
"	"	5-15	R. Med. Back	1.98	1.22		
"	"	20-30	"	3.11	0.39		
"	"	35-45	"	2.70	0.33		
40	1.25	5-15	R. Lat Back	2.00	2.04		
"	"	"	L. Lat. Back	2.16	1.52	1.11	3.30
		"	R. Med. Back	2.52	1.61	(0-15 min)	
"	"	5-15	L. Lat. Back	2.16	1.44		
"	"	"	L. Lat. Back	1.68	1.88		
"	"	"	R. Med. Back	2.23	1.34		
"	"	20-30	R. Lat. Back	2.50	0.93		
"	"	"	L. Lat. Back	2.60	0.76	.95	2.04
"	"	"	R. Med. Back	3.29	0.91	(0-30 min)	

TABLE 4c

CALCIUM CONCENTRATION IN SWEAT

Subject F.G.

REGIONAL						WHOLE BODY	
ROOM TEMP. °C	WORKLOAD Kp	TIME min.	SKIN AREA ($12\ cm^2$)	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L	SWEAT RATE $mg/cm^2/min$	SWEAT Ca ++ meg/L
40	1	5-15	Forehead	4.08	.66		
"	"	"	Forearm	1.23	1.49		
"	"	"	R. Med. Back	1.72	1.60		
"	"	20-30	Forehead	3.84	0.64		
"	"	"	Forearm	1.82	0.70		
"	"	"	R. Med. Back	2.10	0.99	0.9	1.74
"	REST	35-45	Forehead	3.65	.64	(0-45 min)	
"	"	"	Forearm	1.65	.75		
"	"	"	R. Med. Back	1.12	1.31		
		1	Hour Rest in	25° C			
"	1	5-15	Forehead	3.22	.96		
"	"	"	Forearm	1.61	2.09		
"	"	"	R. Med. Back	1.27	1.49		
"	1.75	20-30	Forehead	5.23	0.24		
"	"	"	Forearm	2.02	1.02	0.9	1.89
"	"	"	R. Med. Back	1.67	.76		

TABLE 5

SERIAL WHOLE BODY SWEAT CALCIUM DETERMINATIONS

SUBJECT	ROOM TEMP °C	WORKLOAD Kp	DURATION min	SWEAT RATE $mg/cm^2/L$	SWEAT Ca meg/L
W.V.B.	25	1	40	.31	1.78
"	"	2	25	.55	1.48
"	"	3	18	.61	1.10
J.C.P.	"	1	40	.45	3.24
"	"	2	30	.57	3.01
"	"	3	24	.74	2.94
J.H.	25	1	45	.40	3.00
"	"	2	34	.53	1.83
"	"	3	22	.80	1.27
W.V.B.	35	1	45	.35	2.48
"	"	1.5	30	.59	2.31
"	"	2.5	25	.70	2.08
J.C.P.	"	1	40	.59	4.36
"	"	2	23	.84	3.38
"	"	3	20	1.11	2.45
J.H.	"	1	35	.42	3.22
"	"	2	25	.89	2.70
"	"	3	18	1.18	2.16

TABLE 6a

SWEAT SODIUM AND CHLORIDE CONCENTRATIONS

Subject J.C.P.

DATE	SKIN AREA	SWEAT RATE mg/cm^2/min	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
4-28-70	Forehead	.51	22.0	43.8	1	25°C
	"	1.19	28.9	47.1	2	"
	"	3.40	33.4	55.0	3	"
	Back (Right)	.70	8.5	13.0	1	"
		1.21	14.8	27.2	2	"
		3.38	23.5	31.6	3	"
	Forearm	.21	13.6	30.8	1	"
		.34	16.9	36.0	2	"
		.55	25.0	39.6	3	"
	Thigh	.17	14.2	16.3	1	"
		.46	17.5	42.0	2	"
		.78	28.0	45.5	3	"
	Whole Body	.45	19.3	25.2	1	"
		.57	21.8	28.4	2	"
		.74	28.0	32.1	3	"

TABLE 6B

SWEAT Na AND Cl   Subject J.C.P.

DATE	SKIN AREA	SWEAT RATE $mg/cm^2/min$	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
12-11-69	Forehead	.50	14.2	37.7	3/4	35°C
	"	1.05	45.7	60.8	1 1/4	"
	"	1.30	46.8	70.2	1 3/4	"
	"	4.12	74.8	86.6	2 3/4	"
	"	.82	71.9	98.4	REST	"
	Back (High)	1.33	21.8	46.8	3/4	"
	"	1.90	39.6	48.5	1 1/4	"
	"	3.50	49.8	59.9	1 3/4	"
	"	6.14	60.5	72.5	2 3/4	"
	"	2.15	49.6	59.4	REST	"
	Back (Low)	.84	24.7	33.2	3/4	"
	"	1.25	37.7	47.4	1 1/4	"
	"	1.54	48.8	52.2	1 3/4	"
	"	1.96	55.0	68.5	2 3/4	"
	"	.77	39.6	49.7	REST	"
	Whole Body	.35	10.1	29.1	3/4	"
		.59	20.8	41.8	1	"
		.75	25.3	46.0	1	"
12-17-69	Forehead	1.05	36.6	30.0	3/4	43.0°C
	"	2.31	60.0	41.2	3/4	"
	"	2.47	62.4	44.1	1	"
	"	4.47	84.0	81.5	1	"
	"	2.24	65.3	48.2	REST	"

TABLE 6b (Cont'd)

SWEAT Na AND Cl

Subject J.C.P.

DATE	SKIN AREA	SWEAT RATE $mg/cm^2/min$	[Cl] meq/L	[Na] meq/L	WORK (Kp)	T_A
12-17-69	Chest	1.18	38.8	17.8	3/4	43.0°C
	"	2.10	53.6	30.1	3/4	"
	"	2.48	62.6	40.1	1	"
	"	5.33	64.3	49.8	1	"
	"	3.33	53.1	53.0	REST	

TABLE 6c

SWEAT Na AND Cl

Subject J.C.P.

DATE	SKIN AREA	SWEAT RATE $mg/cm^2/min$	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
12-17-69	Forearm	.48	23.0	17.4	3/4	43.0°C
	"	.86	38.5	42.9	3/4	"
	"	1.00	42.4	54.8	1	"
	"	1.18	48.4	60.2	1	"
	"	.73	41.0	45.8	REST	"
	Back (High)	1.52	23.0	14.6	3/4	"
	"	2.19	41.3	32.1	3/4	"
	"	4.65	47.0	41.1	1	"
	"	4.80	51.6	44.4	1	"
	"	2.57	46.7	33.7	REST	"
	Back (Low)	.91	26.7	35.3	3/4	"
	"	1.36	36.4	45.9	3/4	"
	"	1.89	44.0	44.2	1	"
	"	2.73	52.9	44.7	1	"
	"	1.34	37.2	37.6	REST	"
	Calf	.55	31.4	33.1	3/4	"
	"	.65	50.1	48.2	3/4	"
	"	.72	64.2	56.1	1	"
	"	.99	80.2	77.9	1	"
	"	.38	13.7	20.2	REST	"
	Whole Body	.44	19.9	23.3		
	"	.65	26.0	30.0		
	"	.80	31.2	39.0		

TABLE 7

SWEAT [Na] and [Cl] Subject W.V.B.

DATE	SKIN AREA	SWEAT RATE	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
4-27-70	Forehead	.28	23.5	55.0	1	25
		.90	58.9	81.8	2	"
		1.60	66.2	87.8	3	"
	Back	.44	23.2	42.6	1	"
		1.16	36.2	54.5	2	"
		1.98	47.4	66.0	3	"
	Forearm	.23	18.4	37.9	1	"
		.50	36.4	60.0	2	"
		.79	53.1	70.5	3	"
	Whole Body	.37	34.4	40.9	1	"
		.55	38.8	45.3	2	"
		.72	50.3	52.6	3	"

TABLE 7a

SWEAT SODIUM AND CHLORIDE CONCENTRATIONS Subject W.v.B.

DATE	SKIN AREA	SWEAT RATE	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
5-25-70	Forehead	.70	36.2	52.5	1	35°C
	"	1.45	61.8	79.0	2	"
	"	1.69	71.2	87.8	3	"
	"	.89	70.2	86.7	Recovery	"
		.42	64.3	80.3	Recovery	"
	Back	1.05	28.1	36.1	1	"
	"	1.32	41.6	56.5	2	"
	"	1.84	58.8	78.1	3	"
	"	1.22	56.1	75.4	Recovery	"
	"	.57	44.9	61.2	Recovery	"
	Arm	.50	20.2	31.6	1	"
	"	.80	49.3	70.3	2	"
	"	1.02	57.6	75.3	3	"
	"	.54	51.9	73.0	Recovery	"
	"	.51	41.6	58.5	Recovery	"
	Thigh	.73	21.2	35.0	1	"
	"	1.15	37.4	48.6	2	"
	"	1.40	49.8	61.6	3	"
	"	.77	55.4	70.3	Recovery	"
	"	.42	49.2	63.5	Recovery	"
	Whole Body	.35	15.8	22.3	1	"
	"	.59	29.2	31.2	2	"
	"	.70	37.1	44.3	3	"

TABLE 7b

SWEAT SODIUM AND CHLORIDE CONCENTRATIONS Subject W.V.B

DATE	SKIN AREA	SWEAT RATE $mg/cm^2/min$	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
9-19-69	Forehead	1.57	53.6	-	"	"
	"	4.02	78.2	-	"	"
	"	5.15	89.2	-	"	"
	Forearm	.74	31.8	-	"	"
	"	1.19	48.0	-	"	"
	"	1.51	63.5	-	"	"
	Back	1.55	29.2	-	"	"
	"	2.16	43.6	-	"	"
	"	3.30	58.1	-	"	"
	Calf	1.24	25.3	-	"	"
	"	1.76	35.0	-	"	"
	"	2.59	54.8	-	"	"
	Whole Body	.60 1.03	24.2 34.8	-	"	"

TABLE 8a

SWEAT SODIUM AND CHLORIDE CONCENTRATIONS Subject J. Hinchen

DATE	SKIN AREA	SWEAT RATE $mg/cm^2/min$	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
5-16-70	Forehead	.95	40.0	50.5	1	25°C
	"	3.00	49.5	54.5	2	"
	"	5.90	61.0	82.0	3	"
	Back	.29	7.6	10.5	1	"
	"	1.63	59.0	79.4	2	"
	"	2.99	61.9	82.9	3	"
	Arm	.15	11.4	29.1	1	"
	"	.58	21.6	37.2	2	"
	"	1.63	44.2	64.3	3	"
	Thigh	.54	14.9	27.9	1	"
	"	1.17	27.6	40.3	2	"
	"	1.64	39.8	55.1	3	"
	Whole Body	.40	16.9	22.0	1	"
	"	.53	27.0	33.9	2	"
	"	.90	41.4	52.7	3	"

TABLE 8b

Subject: J. Hinchen

DATE	SKIN AREA	SWEAT RATE	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
5-10-70	Forehead	1.65	38.6	49.7	1	35°C
	"	5.71	87.7	100.0	2	"
	"	7.63	95.1	107.1	3	"
	Back	.52	23.5	38.5	1	"
	"	1.10	60.7	85.2	2	"
	"	1.58	84.3	103.2	3	"
	Arm	.31	19.0	33.8	1	"
	"	1.30	44.4	66.0	2	"
	"	1.46	64.3	85.6	3	"
	Thigh	.70	16.3	28.4	1	"
	"	1.50	43.1	58.3	2	"
	"	1.94	64.3	70.0	3	"
	Whole Body	.41	15.0	18.1	1	"
	"	.75	30.0	30.8	2	"
	"	1.18	44.0	38.5	3	"

TABLE 8c

Subject: J. Hinchen

DATE	SKIN AREA	SWEAT RATE	[Cl] meg/L	[Na] meg/L	WORK (Kp)	T_A
5-29-70	Forehead	1.95	46.1	47.0	1	43°C
	"	5.11	84.1	85.1	2	"
	"	6.0	89.7	90.1	2.5	"
	Back	.50	31.3	38.1	1	"
	"	1.71	75.4	76.1	2	"
	"	4.02	83.1	85.5	2.5	"
	Arm	.49	19.8	22.1	1	"
	"	1.20	44.9	46.1	2	"
	"	1.79	66.0	65.2	2.5	"
	Thigh	.96	21.7	23.4	1	"
	"	1.15	25.2	27.0	2	"
	"	1.99	40.4	43.0	2.5	"
	Whole Body	.49	17.5	19.9	1	"
	"	.85	29.8	31.2	2	"
	"	1.24	39.9	42.0	3	"

SECTION V DISCUSSION

The problem of relating sweat volumes and sweat composition from small skin areas to whole body sweating has been investigated during several decades. Kuno (8) had already stated that general conclusions with regard to the pattern of whole body sweating can be drawn from measurements of sweating from small skin areas. Other investigators confirmed these observations, without making actual use of this phenomenon with regard for predicting whole body sweat rates. Custance (9) was the first to use a ventilated capsule technique to predict whole body sweating by recording from a 14 cm^2 skin area. This data are in complete agreement with our measurements, with the additional comment that the relationship is quite variable with different skin areas (Figure 3 a-c). There is also a large individual variability: subj. W. P. (Figure 3 c) who was a distinct ectomorph sweated much more uniformly over the whole skin areas then the other two mesomorphic subjects.

In most subjects we found a good correlation between whole body sweating and regional sweating rates in forearm when measured with the unventilated capsule, primarily because the apparent range is very similar between these two measurements. However, because the filter paper technique under estimates the rate of sweating in the forearm, the true maximal rate of sweating in the forearm is probably greater and thus also larger than that of the whole body. The difficulty of obtaining a true value for forearm sweat rates is apparently also affected by intra-individual variability. Johnson et al (2) using an impermeable glove in hot environments found also that forearm sweating rates and whole body sweating corresponded reasonably well. However in their study the ratio of sweat collected from the forearm to that of the whole body was smaller in the subject with the greater percentage of surface area on the forearm. The possibility that water vapor pressure effects the rate of sweating in a variable manner in different skin areas and subjects has to be considered.

While it is true that the rate of whole body sweating can be predicted from any small surface, the fact that sweat rate affects sweat composition resulted in highly similar sweat rate - sweat concentration curves for forearm and whole body. Curves for other skin areas differed in varying manner with each other, often because of much higher maximal sweating rates (forehead, back) or other unknown reasons. Whether the relationship between sweating rate and concentration is inversely or positively related (Na, Cl) is apparently inconsequential. What mechanisms and factors lay behind the regional variability in sweat chemistry is unknown. Obviously it is not the rate of sweat secretion alone, because even at similar sweating rates differences were noticeable.

The regional differences in sweat calcium content are difficult to evaluate because of the methodological variability in measuring very low calcium contents. In general though the lowest calcium concentrations were found on the cutaneous regions with the highest rates of sweating. Skin temperature had a definite effect, independent of sweating rate. Higher skin temperature resulted in higher calcium concentrations.

Our data show that the extremely high values for sweat calcium (10-15 meq/L) found by Paupe (10) and Consolazio (11) in a few cases, are not representative and probably erroneous. We did find initial sweat samples with approximately 5 meq/L occasionally, but during continued sweating most values fell in the 0.5 to 2.5 meq/L range. The reason for the initial high sweat calcium levels is not clear. Even after intensive pre-washing with deionized water, high initial sweat calcium concentrations were found. The decline of sweat calcium is very rapid indeed. In 10 or 15 minutes the concentration may drop to half its original value. After cessation of sweating, the calcium concentration will rise slowly and after 1 hour a measurable increase was noticed in 2 experiments. Compared with the ranges and variations reported in the literature, the filter paper collection technique can be used for estimating sweat calcium losses. We did not find the consistent very low calcium levels in sweat reported by Vellar and Astavold (11). However their collection technique and environmental conditions were different from those employed in our studies. The obtained results of sweat calcium analysis in this study fall in the range most often found by other investigators as quoted by Vellar et al (11).

The regional and whole body sweat analysis for chloride and sodium revealed that again the arm sweat rate - sweat concentration curves are quite similar to those of the whole body when the unventilated capsule technique is employed. At low sweat rates the curve for forehead salt concentration is often also quite similar to that of the whole body. The studies revealed that even at similar rates of sweating regional salt losses are different between different skin areas. Possibly the difference in duct length as reported by Takagi (12) could play a role, since the duct has reabsorptive capacity (13).

Apparently the sweat glands cannot adjust the chemical composition of sweat very quickly when the sweat rates fall suddenly. Very little is known about this phenomenon. Weiner et al (14) observed similar changes in sweat rate without a decrease in sweat chloride for the whole body. Our data from small skin areas are in agreement with Weiner's observation and suggest that sweat rate is not the only factor which influences sweat salt composition in a short experiment.

The fact that the sweat salt content remains high for such a prolonged period argues against a delayed "wash out" of concentrated sweat in the glands. The changes are also too sudden to suggest variation in hormonal (aldosterone) effects on the sweat gland duct. Possibly the rise in skin temperature during diminshed sweating in warm environments could increase the sweat salt concentration (14). However the increments in skin temperature are often small after profuse sweating during work in the heat, and may not account for the continued high sweat salt content during diminished sweat rates. It is also not likely that the precursor solution in the sweat gland coil is more concentrated, since it is normally already isotonic with the plasma. Perhaps the greater blood flow around the sweat glands over a prolonged time has altered the enzymatic activity of the high salt producing cells (15) and the slow reduction of these enzyme actions could produce the prolonged high sweat salt content at low sweat rates.

The studies on local drug-induced sweating showed that there is a fundamental difference between thermal sweat and sweat from pharmacologically activated sweat glands. Our data on sweat chloride and those recently by Sato et al (16) on potassium and sodium are essentially in agreement on this point. That different types of cells may have been activated, or that the duct cells played a variable role according to the type and rate of sweating remains a possibility. This is underlined by the observation that mechanically the sweat is expelled in a different manner. More detailed experiments are required to elucidate this point. The unpredictable relationship between sweat rate and sweat constitution makes the use of drug-induced sweating undesirable for the prediction of whole body sweat losses.

SECTION VI CONCLUSIONS AND SUMMARY

From the results of the present study the following conclusions can be made:

1. Measurements of sweat rates by ventilated capsule techniques (hygrometry) are more accurate than measurements with unventilated capsules, especially at low rates of sweating.

2. The difference of sweat rate measurements with the two techniques is constant.

3. Whole body sweat volume losses can be predicted from measurements on small skin areas by the filter paper absorption technique.

4. Total calcium losses in human sweat can be extrapolated from analyses of sweat samples from small skin areas.

5. The calcium content of human sweat is initially often very high and not representative for prolonged sweating.

6. Sweat from skin areas with similar sweat rates per unit skin area as the whole man, contains nearly the same amount of calcium as whole body sweat, when measured with the filter paper technique.

7. In each individual there are skin areas with sweat rates and sweat chloride (sodium) concentrations similar to that of the whole man.

8. Sweat induced locally by pharmacological activation is different from thermal sweat at similar sweat rates.

It proved not feasible to perform meaningful statistical analyses on the collect data. While many data were collected, every experiment on each individual subject had to be considered separately. The subjects showed some variations in body sweat chemistry, even in the same environment under presumable similar conditions (except perhaps for diet, which could not be controlled). Comparison of regional sweat analyses with whole body sweat measurements were therefore only justified during one experimental period.

The complexity of the experiment and the imposed physical stresses on the subjects enabled only the collection of a limited number of measurements. The experimental results of this study demonstrate individual and regional variability and suggest that good correlations between selected regional and whole body sweat losses should exist. However the definite proof of this has to be demonstrated in more extensive studies on larger population samples with dietary control and repeated experiments and similar environmental conditions. The results from this study point to the feasibility of the measuring technique and to the practical applicability of the method. However it is quite obvious that the prediction of dermal losses of nutrients from measurements of small skin areas is only possible when the relationship between whole body sweat and regional samples is known. Since there is suggestive evidence that this relationship changes with acclimatization to heat and with physical training additional information is imperative to ensure accurate extrapolations from regional measurements.

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