ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

AMRL Project No. T13
SGO Project No. 611
SPMEA 727.3

4 December 1945

1. PROJECT AMRL No. T13, SGO No. 611 - Survey of Foot Measurements and the Proper Fit of Army Shoes;
Second Partial Report - Study of Sweating of the Feet of Marching Troops.

a. Authority: First Indorsement SPMDO 421.3 - ASF-SGO, Washington, D. C., dated 24 September 1945

b. Purpose: To obtain factual information pertaining to foot sweating with regard to:

1. The rate and volume of sweat secretion;
2. The relationship of sweating to foot symptoms;
3. The water retentive characteristics of service shoes and of various types of socks.

2. DISCUSSION:

None.

3. CONCLUSIONS:

In a temperate zone, summer environment:

a. Neither burning of the feet nor the development of blisters appears to result from the accumulation of excessive moisture within the sock.

b. Service shoes, reversed upper, composition sole, whether dubbed or not, permit dissipation of only a relatively small amount of foot moisture to the exterior atmosphere.

c. The sweat adsorbed by shoes is predominantly into the shoe-upper, despite the fact that the weight of the leather in the sole is greater than that in the upper. Socks, wool, light, are not capable of retaining the amount of sweat excreted by some men during a warm summer day.

4. RECOMMENDATIONS:

None.

Submitted by:

Arthur Freedman, Captain, MC
Charles M. Kirkpatrick, Tec 3

APPROVED William B. Bean
WILLIAM B. BEAN
Major, Medical Corps
Commanding

Incl.-Appendix

APPENDIX

1. INTRODUCTION:

The accumulation of sweat inside shoes has been blamed for many of the foot disabilities which marching troops suffer. In warm environments, in particular, blisters and the sensation of burning of the soles of the feet have been attributed to excessive sweating. Furthermore, the presence of moisture leads to tissue maceration and provides a favorable environment for interdigital fungus growth. It has been asserted also that the application of dubbing to shoes increases the retention of sweat, and this practice has therefore come to be regarded somewhat unfavorably by troops. In the course of other studies on the relationship of shoes to the development of foot casualties among marching troops, the opportunity was available to subject these beliefs to test.

2. CONDITIONS:

Troops were marched over a 13.7 mile course, for which the actual marching time was 4 hours and 20 minutes, at a rate of 119 paces per minute. New service shoes, reversed upper, composition sole were issued at intervals during the test and were worn continuously for an average of 6½ hours daily. Two short breaks and a longer one for lunch were allowed. The observation procedures before and after each march occupied approximately 30 minutes each. The use of powder was not permitted. The marching course lay over rolling country, one-third on concrete road, one-third on improved dirt and gravel road, and one-third on unimproved dirt road. Water and salt were allowed ad libitum and were provided in abundant quantity. The troops began marching over the established course ten days before any observations on sweating were made, and observations were continued throughout 32 days of testing. The men, all of whom had been in the Army for a minimum of 8 months prior to their arrival at the Laboratory for study, were at least partially conditioned before data were collected. Typical Kentucky mid-summer environmental conditions were encountered during the test days. The weather data shown in the respective tables are for shade conditions and, therefore, are lower than temperatures in the sun. The test group used for these studies was chosen at random.

3. RESULTS:

a. Amount and Effect of Sweating:

(1) Moisture was trapped in the sock by inserting a thin boot of rubber dam between the sock and the shoe of one foot. By weighing the enclosed sock before and after a march, the total amount of accumulated sweat was readily determined. The results of one series of observations, shown in Table 1, indicate that the sweating rates for one foot for different men may vary at least from 2.0 to 8.5 grams per hour, at the temperatures encountered.

(2) Each subject was interrogated concerning any difference in sensation between the foot wearing the rubber boot and the one without it. In only one instance did the foot wearing the rubber boot seem warmer than the other, and in no instance was the sensation of burning of the soles of the feet associated with the presence of the rubber boot. Blisters did not develop in connection with the increased accumulation of moisture.

(3) Some subjects who did report burning of the soles of the feet asserted that the burning was not associated with the wearing of the rubber boot, but was noted instead during rest periods rather than during actual marching. This suggested that burning may be a manifestation not of sweat accumulation, but of the presence of an excess of intercullular fluid in the dermis or epidermis appearing as a circulatory phenomenon, in the lower extremities of men resting after exercise. Since the volume of such fluid would be too little to detect by volume displacement, an attempt was made to test for its presence by injecting 0.1 cc of saline intradermally into the soles of subjects who noted burning and into the soles of others who did not, in the expectation that absorption of the fluid introduced might occur more rapidly in one group than in the other. Unfortunately, this proved unsuccessful since it was not possible to produce blebs on the soles of the feet in a standard manner, and the thickness of the epidermis interfered with accurate assessment of their rate of disappearance.

TABLE 1

AMOUNT AND RATE OF FOOT SWEATING OF TROOPS MARCHING IN A WARM ENVIRONMENT*

DAY OF TEST	24th	25th	
MEAN SHADE TEMPERATURES	D.B. 83°F R.H. 55%	D.B. 84°F R.H. 59%	
NAME	SWEAT ACCUMULATION (GRAMS/6½ Hrs.)	SWEAT ACCUMULATION (GRAMS/6½ Hrs.)	MEAN SWEATING RATE FOR ONE FOOT (GRAMS/Hr)
Woo	12.2	14.5	2.0
Fir	15.0	25.0	3.1
Wea	20.7	33.8	4.2
Voz	24.5	29.5	4.2
Buf	29.0	32.6	4.7
Phi	35.5	41.8	5.9
Woh	36.9	43.2	6.2
Sin	37.1	29.5	5.1
Cru	54.5	55.0	8.5

Incl.

* Sweat was measured as the increase in the sock weight when an impermeable boot of thin rubber dam was worn between the sock and shoe on one foot. The sweat which adhered to the rubber was fairly constant at 2.0 grams and is not included in the above figures.

b. Retention of Sweat by Footgear:

(1) The transmission of sweat by shoes was estimated in a manner similar to that described above. Each subject wore the rubber boot between his sock and shoe on one foot and omitted it on the other. Both the sock and shoe were weighed before and after marching, the shoe being brushed vigorously before weighing to remove any dust picked up on the road. The results presented in Table 2 show that the shoe on the foot wearing the rubber boot consistently lost weight during the march, while the other shoe gained weight, the mean weight loss in the one case being 9.6 grams, and the mean weight gain in the other being 9.1 grams. The loss of weight of the shoe containing the rubber boot may be attributed to the fact that no moisture was picked up from the foot, while some of the intrinsic moisture within the shoe evaporated and some of the composition sole wore away. (The total moisture content of a shoe is approximately 26 grams. This was determined by drying a new shoe in an oven at 75°C for 12 hours to nearly constant weight).

TABLE 2

DISPOSAL OF SWEAT BY FOOTGEAR

Comparison Between Changes in Sock and Shoe Weights When Sweat is Trapped in Sock and When it is not Trapped

(Data are in grams)

DAY OF TEST	MEAN SHADE TEMPERATURES D.B. °F.	R.H.%	SUBJECT	CHANGE IN SOCK WEIGHT RUBBER BOOT WORN	CHANGE IN SOCK WEIGHT RUBBER BOOT OMITTED	CHANGE IN SHOE WEIGHT RUBBER BOOT WORN	CHANGE IN SHOE WEIGHT RUBBER BOOT OMITTED
10	85	60	Woh	+ 28.2	+ 12.8	- 8.5	+ 5.7
			Bel	+ 30.6	+ 6.8	- 12.7	+ 5.9
11	86	67	Woh	+ 31.7	+ 13.3	- 7.6	+ 19.8
			Bel	+ 26.3	+ 6.9	- 10.9	+ 5.9
12	88	64	Woo	+ 16.7	+ 18.7	- 9.6	- 1.6
			Vos	+ 46.9	+ 20.7	- 12.1	+ 14.7
13	86	62	Woo	+ 12.7	+ 13.8	- 7.2	+ 4.5
			Vos	+ 50.9	+ 21.7	- 8.5	+ 17.5
	MEAN			+ 30.5	+ 14.3	- 9.6	+ 9.1

Incl.

(2) It is possible to derive from these data the percentage of moisture retained by the shoe. To do this one must assume that the foot sweats at the same rate on two successive days and that the presence of the rubber dam does not alter the sweating rate. Table 1 does suggest that the sweating volume is reasonably constant on successive days but it was not possible to verify the latter assumption. Table 3, which is derived from Table 2, compares the sock weight increase when the rubber boot is worn with the combined sock and shoe weight when the rubber boot is not worn, both for the same foot on successive days and for the opposite foot on the same day.

TABLE 3

RETENTION OF SWEAT BY SHOE AND SOCK

SUBJECT	AMOUNT OF FOOT SWEATING* (Grams)	INCREASE IN TOTAL SHOE AND SOCK WEIGHT** (Grams)	PROPORTION OF SWEAT RETAINED BY SHOE AND SOCK
Woh	28.2	18.5	65.6%
Bel	30.6	12.7	41.5%
Woh	31.7	33.1	104.5%
Bel	26.3	12.8	48.5%
Woo	16.7	17.1	102.5%
Voz	46.9	35.4	75.5%
Woo	12.7	18.3	144.0%
Voz	50.9	39.5	77.5%
M E A N	30.5	23.4	

RATIO OF THE MEANS - 76.5%

*Determined when rubber boot worn as the increase in sock weight,
**Determined when rubber boot not worn.

(3) The data, which are only approximations, indicate that a large part of the moisture from sweating of the foot actually remains in the shoe and the sock and does not get to the outside. In those instances in which the shoe and sock actually weighed more than the amount of sweat measured when the rubber boot was worn, it is likely that the sweating rates of the feet differed during the two tests and that some of the road dirt picked up by the shoes was not brushed off.

(4) Dubbed shoes are compared with undubbed shoes both with regard to their own capacity to adsorb moisture and with regard to their influence on the accumulation of moisture within the sock. The dubbing was applied generously and worked in well. It is apparent from Table 4 that there is not a great difference between the weight increase of the sock or the shoe whether or not dubbing is used. Dubbing, therefore, does not appear to affect significantly either the permeability of the shoes or their capacity to adsorb moisture from the foot surface.

TABLE 4

EFFECT OF DUBBING ON THE RETENTION OF SWEAT BY FOOTGEAR

Comparison of Increase in Sock and Shoe Weight Due to Sweat Accumulation when Dubbed and New Undubbed Shoes are Worn.

(Mean of 4 Subjects)*

DAY OF TEST	MEAN SHADE TEMPERATURES D.B. °F	R.H. %		INCREASE IN WEIGHT SOCK (GRAMS)	SHOE (GRAMS)
28	71	77	Dubbed	10.0	9.8
29	77	56	"	7.7	6.2
30	77	46	"	7.8	6.0
31	83	53	Undubbed	9.0**	9.8
32	86	47	"	8.8	9.2

*Troops marched 13.7 miles and wore their shoes 6½ hours.
**Mean of 3 subjects only.

Incl.

(5) The relative increase in weight of the sole and upper of the shoe, due to moisture accumulation, was estimated by weighing a shoe before and after a march, then severing the upper from the sole, weighing again to obtain the component values and finally weighing the shoe halves twelve hours later to determine the weight loss of each half as a consequence of equilibration with the atmosphere. Table 5 shows the results of such weighings on two different shoes.

TABLE 5

DISTRIBUTION BETWEEN SOLE AND UPPER OF MOISTURE ADSORBED BY SHOES DURING MARCHING

(Data are in Grams)

	SHOE NO.1		SHOE NO.2	
Weight gain of shoe during march		18.0		16.0
Weight loss of upper after 12 hours at room temperature	8.9		6.9	
Weight loss of sole after 12 hours at room temperature	5.5		4.8	
Total weight loss due to evaporation of accumulated shoe moisture		14.4		11.7
Weight gain not accounted for		3.6		4.3

(6) These figures are interesting inasmuch as the weight of the leather upper of the shoe is only 23% of the total weight of the shoe while the weight of the leather components of the sole is approximately 36%, as shown in Table 6. It would appear, therefore, that the upper leather adsorbs a proportionately greater part of the sweat of the foot than the sole. To what extent this relates to the proportionate sweat production of the various foot surfaces cannot be stated precisely. Under certain influences the plantar surface of the foot sweats more abundantly than the dorsal but under other influences the reverse is true (1).

(1) Kuno,Y. - The Physiology of Human Perspiration, J&A Churchill, LTD, London,1934.

TABLE 6

WEIGHT OF COMPONENT PARTS OF SHOE

(Grams)

NON-LEATHER PORTION OF SOLE:			
Composition outsole	188.5		
Composition heel	124.5		
Metal shank	12.5		
		325.5	41%
PREDOMINANTLY LEATHER PORTION OF SOLE:			
Midsole and filler	131.5		
Insole, welt, filler and canvas	147.5		
		279.0	36%
LEATHER UPPER:		167.1	23%
Total Weight Exclusive of Nails		791.6	100%

(7) The moisture retentive capacities of various standard types of socks were also determined as a matter of record. Table 7 shows the results when 6 types of socks were dried in an oven to determine the amount of moisture absorbed from the atmosphere.

TABLE 7

MOISTURE CONTENT OF SOCKS AT EQUILIBRIUM WITH ATMOSPHERE
(D.B. 76°F, R.H. 50% Approx.)

TYPE OF SOCK	WEIGHT BEFORE DRYING	WEIGHT AFTER DRYING IN OVEN FOR 24 HOURS AT 50°C	MOISTURE CONTENT — PERCENT OF INITIAL WEIGHT
Wool, light, woven, O.D.	33.8 Gms.	31.1 Gms.	7.9%
Wool, light, knit, O.D.	42.8 "	38.0 "	11.2%
Cushion sole, 73-531824	42.7 "	38.9 "	8.8%
Cushion sole, 73-531828	43.3 "	37.7 "	10.8%
Wool, heavy, white, 73-532238	58.4 "	53.2 "	9.7%
Wool, ski, 73-534403	77.3 "	70.2 "	9.1%

(8). The mates to these socks were then soaked in water to determine their maximum adsorptive capacity. After soaking, the socks were allowed to hang for 3 hours at room temperature to permit all surface water to drip off. Some evaporation undoubtedly occurred during this period since the room conditions were approximately 76°F, D.B., 50% R.H. The amount of water uptake after soaking is shown in Table 8. It is of interest that neither of the socks, wool, light, would be capable of retaining the amount of sweat accumulated within the rubber boot in only 6½ hours in the case of CRU (Table 1).

Incl.

TABLE 8

WATER UPTAKE OF SOCKS AFTER THOROUGH SOAKING

TYPE OF SOCK	WEIGHT BEFORE DRYING	WEIGHT AFTER WETTING	WATER CONTENT PERCENT OF INITIAL WEIGHT
Wool, light, woven, O.D.	31.5 Gms.	71.5 Gms.	126.9%
Wool, light, knit, O.D.	41.9 "	86.0 "	105.2%
Cushion sole - 73-531824	37.8 "	97.7 "	158.4%
Cushion sole - 73-531828	41.9 "	110.6 "	163.9%
Wool, heavy, white - 73-532238	60.6 "	139.9 "	130.8%
Wool, ski, 73-534403	75.3 "	170.5 "	126.4%