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TECHNICAL REPORT
67-82-CM

ELECTRICALLY HEATED HANDWEAR

by
Herman Madnick and Alice Park

March 1967

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Organic Materials Division
C&ED-46

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FOREWORD

A long-standing problem, protecting the hands against injury from extreme cold, is considered in depth in this report. The inadequacy of conventional handwear, the need for auxiliary heating, and specifically, the merits of electrically heated gloves are discussed. The report will be of interest to anyone who is concerned with the problems of operating and maintaining equipment under extreme low temperature conditions.

The problem of cold injury has long been troublesome. A satisfactory solution has been sought, in fact, ever since World War II when the problem became acute, not only in sub-arctic regions, but also in Europe. Electrically heated handwear was suggested a number of years ago as the ideal solution, but until recently technical problems have stood in the way of development. Simple, inexpensive wiring systems, rechargeable batteries, and new materials are now available, however, and electrically heated gloves, capable of greatly extending the time men can work on equipment under extreme cold, are within reach. Under some conditions of use, such electrical handgear could be plugged into the power units of vehicles, thus permitting unlimited and uninterrupted maintenance work in the cold.

Grateful acknowledgment is made to Dr. Ralph Goldman of the Army Research Institute of Environmental Medicine for his cooperation in supplying background information on his research and cold chamber tests on electrically heated gloves.

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CONTENTS

ABSTRACT

Electrically heated handwear is presented as a solution to the hand-protection problem for equipment operators and other military personnel who must use their hands in extremely cold conditions for prolonged periods. The problem of hand cold injury, the inadequacy of conventional solutions and existing handwear, and various experimental approaches are discussed. The U.S. Army Natick Laboratories has assembled an auxiliary electrical handwear system and is continuing research efforts to improve electrically heated handwear. It is concluded that because of the demonstrated need for such handwear and the current feasibility of manufacturing it, electrically heated handwear should be supplied to the appropriate personnel.

ELECTRICALLY HEATED HANDWEAR

1. INTRODUCTION

Man's greatest physical assets -- his hands -- become his most frustrating liability under the numbing powers of cold weather. With his dexterous hands and nimble fingers, man has translated his mental superiority into technological triumph over his environment. Ingeniously he has engineered comfortable micro-environments to shelter himself in -100°F polar weather. The U.S. Armed Forces have designed insulated Arctic cold-dry clothing to protect its soldiers when they must leave these heated shelters and be exposed to extreme cold for prolonged periods.

Man has overcome the cold problem -- for all but 5 percent to 10 percent of his body. His hands and feet may become vulnerable to cold injury even when his torso is warm in generally adequate Arctic clothing. While the development of insulated rubber boots during the Korean War has mitigated the foot-protection problem, the soldier's hands still defy clothing experts' attempts to keep them warm under extreme cold conditions.

The soldier who is often relatively inactive, and who must use his fingers to manipulate equipment in extremely cold temperatures for long periods, finds the warmest Arctic mittens that can be developed are clumsy and inadequate. Research has shown it is physically impossible to design handwear with enough insulation to protect a soldier's hands under many special conditions. In the classic illustration (Figure 1), any mitten bulky enough to protect a soldier while he is inactive for eight hours at -20°F, although dressed in Arctic clothing, would be larger than his body.

The U.S. Army Natick Laboratories have turned to development of electrically heated auxiliary handwear to overleap the limitations of conventional clothing. This report presents a review of research and experimental attempts to restore man's hands to maximal efficiency even in Arctic cold.

2. THE PROBLEM OF HAND COLD INJURY

One of the most baffling aspects of keeping hands warm in a cold climate has been protecting a man's fingers when he is relatively inactive or operating complex equipment in extremely cold temperatures.

This problem drew attention early in World War II in connection with cold injuries suffered by pilots flying at high altitudes in unheated cockpits. The nature of the problem and its etiology were discussed in the article, "High Altitude Frostbite," Surgery, Gynecology and Obstetrics, December 1943, from which Figure 2 is taken.

Casualties from cold injuries were higher than from wounds received in enemy action among airborne personnel of the Eighth Air Force during the 14 months ending December 1943 (1). A third of all frostbite casualties required hospitalization and many of these were unable to return to action for months, if ever.

An obvious cause of frostbite was the extreme cold, ranging from -22°F down to -60°F at altitudes averaging 25,000 feet above sea level. Injuries from wind blast entering through openings for the gun moun were frequent, particularly among waist gunners seated in the most exposed positions.

Because of their limited activity, most of the crew members did not generate enough heat to maintain body warmth. Hands were frostbitten when gunners or radio operators removed protective gloves to manipulate controls or change ammunition belts and touched the cold-soaked metal (2).

The etiology of cold injury to pilots and crew members was basically the same as that encountered by ground troops in Europe and elsewhere during World War II, as the Surgeon General's report, Cold Injury, Ground Type (1958), notes. The report points out that many of the 91,000 cases of cold injury suffered by American Armed Forces over the war period could have been avoided if the lessons in proper hygiene and methods for rewarming cold extremities learned by the U.S. Army Air Corps in 1942-43 had been applied to prevent frostbite among ground troops.

3. INADEQUACY OF CONVENTIONAL HANDWEAR

a. Standard Solution: Arctic Mittens

For ground troops, the approach up to the present has been to provide hand protection through a layered system consisting of a working glove which the soldier thrusts into an overmitten or handwarmer between manual tasks. In this way, body heat transmitted to the hands is conserved to help maintain hand warmth. Figure 3 shows the standard military Arctic cold-dry mitten.

b. Special Problems

This layered system is satisfactory for moderately cold temperatures, particularly when the hand wear can be kept dry and men can generate enough heat through exercise to keep warm.

However, in many situations this method of keeping the hands warm is inadequate. At times, men are forced to function with minimal handwear for prolonged periods at temperatures of -20°F and colder, while operating equipment requiring manual dexterity impossible to achieve with bulky Arctic mittens. Cold burn from contact with cold-soaked equipment of highly conductive materials adds to the possibility of cold injury through local loss of body heat when the men remove their handwear.

The limited activity of equipment operators increases the problem of keeping their extremities warm. Even the superior insulation of the standard cold weather uniform, rated at 4.3 clo overall, cannot compensate for physical inactivity since the soldier is losing body heat faster than he is generating it. This is particularly so for the hands.

Vasoconstriction, which occurs whenever a man in Arctic clothing is <u>at rest</u> in temperatures below +30°F, cancels the possibility of any handwear maintaining a hand skin temperature of 60°F, necessary for dexterity (3); yet no mittens are needed during heavy exercise (vasodilatation) at even -20°F.

c. Limitations of Insulation

In addition to warmth, the soldier working with his hands in extreme cold requires gloves which will not interfere with finger dexterity and tactility. Such gloves cannot be designed under presently known insulation principles, or when a minimal number of sizes are used to fit all military personnel.

Army Quartermaster stress physiologists developed equations working out the protective value of insulation to the fingers, fingertips, and dorsal and palmar hand surfaces when considered as cylinders, spheres and plane surfaces, respectively (3). Van Dilla, Day and Siple concluded that no glove giving more than 1 to 1.25 clo protection could be constructed.

To provide the 4 clo of insulation to the fingers required by Arctic cold, a glove would have to be constructed of a 3.3-inch fabric, obviously impractical for field use. A fabric 1/4-inch thick, considered to be the upper limit for reasonable dexterity, would give fingers only .89 clo protection. Figure 1 shows the relative size of mittens needed for different exposure times and activity levels at -20°F.

Arctic mittens are ineffective for rewarming purposes under severe conditions. Comparing methods for rewarming hands, Bradford exposed subjects dressed in a modified cold-dry uniform and fuel handler's gloves to -25°F temperatures until any hand point chilled to 45°F, usually within 11 minutes (4). Subjects then attempted to rewarm their hands by inserting them into (1) Arctic cold-dry mittens, (2) experimental electrically heated muff, and (3) same muff disconnected and unheated.

Although the subjects were able to avoid frostbite, their hands never rewarmed enough in the mittens or unheated muff to perform manual tasks efficiently. Cooled hands inserted into the electrically heated muffs rewarmed to 70°F within 18 minutes.

But even with the latter handwear, the fuel handler would be limited to 10 minutes of work before he would be forced to stop for a re-warming period of 18 minutes. Work interruptions increased in subsequent exposures of the hands: the periods of use became consecutively shorter and the periods for rewarming consecutively longer.

The soldier's hands and feet remain the limiting factor in his ability to surmount the hazards of extreme cold and to work efficiently in Arctic climates. Like radiators, the extremities are the first point to become cold when the central heater, or body, closes the radiator valves (vasoconstricts) and the last to become warm when normal heat flow resumes. Military requirements for Arctic clothing specify protection for an inactive soldier for 8 hours at -40°F in 3 mph winds. Man has been able to meet this standard for all but 5 percent to 10 percent of the body - the extremities.

4. HISTORY OF AUXILIARY HEATING FOR THE HANDS

a. Heated Clothing for Aviators

As researchers realized they had nearly exhausted the protection capabilities of clothing, they turned to the possibility of utilizing auxiliary heat to overcome the special problems of inactivity and extreme cold. Various heating methods, from catalytic and electrical handwarmers to centrally heated ensembles, were investigated.

Among the first to develop electrically heated handwear and clothing was the U.S. Army Air Corps in its attempts to prevent high altitude frostbite among aviators during World War II. Electrically heated handwear was considered the best solution since the required power could be obtained from the airplane. Heat was distributed over the backs of the hands, leaving palmar surfaces free for functional purposes.

The very real value of heated handwear to pilots and airplane crews was proven in March 1943, when a sharp increase in the number of frostbite casualties during the preceding month was investigated by the Army Air Corps. One of the principal causes of the increase was found to be shortages of the electrically heated gloves and boots (2).

For aviators, the matter of heating the extremities quickly enlarged into a concept of an entirely electrically heated suit to replace bulky, cold weather clothing. This reduced the amount of space required in the cockpit and increased the pilot's freedom of movement. When it became apparent that protection was needed against ground conditions when the planes were down in cold areas, Arctic clothing was provided in survival kits.

With the problems of power supply and emergency needs solved, electrically heated clothing came into wide use in military aviation. Accordingly, the concept of electrically heated handwear and footwear, as distinct from heated body clothing, receded into the background and received little attention.

b. Handwarmers for the Ground Soldier

The Army Quartermaster Corps, faced with the need to provide the field soldier with an adequate independent means of protection for the hands against the cold, explored the possibilities of handwarmers.

In 1945, the Army Quartermaster Climatic Research Laboratory suggested local heat should be applied to the whole hand and wrist area, rather than just the palm. Experiments showed that while hand-held devices warmed the palms, skin temperatures on the back of the hands were consistently lower (5).

Handwarmers had other drawbacks besides spotty, nonuniform heat. Tests of the type of so-called "hand heaters" sold generally to fishermen and hunters, which depend on low temperature combustion of hydrocarbons, indicated some of the combustion by-products (particularly carbon monoxide) could be hazardous under some uses.

Catalytic handwarmers also proved difficult to ignite properly, awkward to refuel, and almost impossible to regulate in respect to heat output (6). The heaters did not provide enough heat to maintain ha. warmth or to rewarm the cold hands of men during the performance of sedentary tasks, as on outpost duty.

Heated handwarmers were compared to parka pockets for rewarming cold hands exposed to 12°F temperatures in a 3 mph wind (7). Tests indicated the handwarmers, at the maximal heat output for hand-held comfort, were only 10 per cent more efficient than the pockets alone. With better insulation, pockets might prove just as efficient in rewarming hands while also disposing of the hand heaters.

The Army's Engineer Research and Development Laboratory concluded after testing the catalytic heaters that, although the devices were unsatisfactory as designed, "the principle of handwarming is sound and that handwarmers are necessary for Arctic operations."(6)

Later, studies conducted by the University of Pittsburgh found existing methods of rewarming individuals ineffecient. It was recommended that attention be focused on preventing the man from becoming cold in the first place (8).

c. Electrically Heated Clothing

The U.S. Air Force met the problem of cold protection for their aircraft mechanics and ground crews, as well as air crews, by providing them with electrically heated suits, gloves and boots. The Army Quartermaster Climatic Research Laboratory tried the Air Force heated clothing at Ft. Churchill and confirmed that comfort and heat balance could be maintained, but at the expense of restricted mobility. Subjects had to remain within the range allowed by a cord connected to a power supply.

The development of electrically heat . clothing as auxiliary heating for operators of the Skysweeper, an antiaircraft weapon developed in 1955, was considered and discarded because of the difficulty of supplying the necessary power. No lightweight, rechargeable batteries were available then.

During the late 1950's, the U.S. Army Natick Laboratories explored the possibility of providing electrically heated handwear and footwear to armored vehicle crews. Studies of circuiting and location of thermostats were conducted and items were developed experimentally. An impasse was reached, however, when vehicle designers were unwilling to provide a source of power, particularly when the vehicles were inactive.

In 1958, the problem reappeared in connection with the protection of acid and fuel handlers serving guided missiles who were required to make adjustments to the missiles prior to launching under possible conditions of extreme cold. These Laboratories tested a simple, low-pressure, air-distribution device to be worn beneath the fuel handler's clothing (9). In this system, hot air flowed to the extremities from four flexible hoses connected to a common mid-thoracic outlet.

After cold chamber tests of the hot-air principle, it was concluded heat must reach the extremities directly to keep them warm while the body itself is in thermal balance. However, the experimental hot-air device did not meet functional requirements for such a unit. One of the shortcomings was poor heat distribution: too much heat was given off to the body before the air reached the extremities. Test subjects could become nauseous and dizzy after a short period of exposure to the warmed air.

d. Electrically Heated Handwear as a Unit

In 1959, the Committee on Hand Functioning and Handwear of the National Research Council, Advisory Board on Quartermaster Research and Development recommended attention be focused on developing auxiliary heating units for the extremities rather than a general intra-clothing system. Army Quartermaster studies had shown the standard Arctic Cold-Dry clothing adequately protected the body torso and little or no auxiliary heat was needed in this area.

Yet the extremities, the vulnerable areas, could be adequately protected only by heat applied to them directly. It was found also that if the hands were warm, cooling of the overall mean body temperature had no effect on manual dexterity (10). While hands are most comfortable at a skin temperature of 80°F, only a level of 60°F needs to be maintained since manual dexterity and efficiency are not seriously impaired until hands cool below 60°F, when performance drops sharply.

5. CURRENT STATUS OF ELECTRICALLY HEATED GLOVES

a. Development of a 7-Pound Auxiliary Unit

The availability of new lightweight rechargeable batteries, such as silver cadmium cells, encouraged the U.S. Army Natick Laboratories to consider the possibility of a portable, electrically heated handwear unit. Cold chamber studies were conducted to measure the electrical power required to keep hands warm for 8 hours at -40°F in 3 mph winds, the Army military requirements for Arctic clothing (9).

A hand skin temperature of 60°F was aimed for since an 80°F level would require greater power and was warmer than necessary. It was determined that 5 watts per hand and foot would maintain the extremities at a minimum of 60°F under temperatures of -40°F with a 3 mph wind when the Arctic mitten was worn.

A total power pack of 120 watt-hours capacity would provide the required 8 hours of protection. This power capacity would supply each of the extremities with 6 hours of protection (5 watts per extremity per hour). The Arctic mitten alone would adequately protect the hand for one to two hours before auxiliary heat was required, and a margin of safety would be provided by short periods of activity, normal during any 8-hour period (11).

A complete auxiliary heating kit weighing about 7 pounds was assembled. This kit would allow the soldier dressed in standard Arctic clothing to remain effective, even while inactive, in extreme cold for up to 8 hours.

The kit included gloves knitted with wool and wire, and thermostatically controlled; heated insulated cold-dry boots, thermostatically controlled; a vest providing 11 silver cadmium 1.1 volt, 10 ampere rechargeable cells for 120 watt-hours capacity. A special recharging unit for the battery vest was available.

Since battery cells accounted for 90 per cent of this system's weight and cost, a decrease in these factors may be expected as power supplies with greater watt density are developed commercially.

Research to improve distribution of heat within the auxiliary glove continues. The ideal glove would distribute heat over the entire hand in such a way as to compensate for the differing cooling rates of various areas. The thermostat economizes on the power demand by keeping the hand at the minimal warmth necessary to prevent frostbite.

In the glove now supplied with this system, the thermostat is located at the dorsal web of the thumb, out of the way of the fingers. The original thermostat set point selected was 68°F but the 5th finger, in the most exposed position of all the digits, cooled to 40°F before the web cooled to 68°F, thus, the thermostat needed to be set higher than 68°F to maintain the little finger at the 60°F safety level.

Electrical resistance wires integrated into this auxiliary knitted glove distribute heat evenly and eliminate hot or cold spots. However, the knitted construction allows a great loss of heat when the auxiliary heated glove is removed from an outer mitten for work. A satisfactory way of windproofing the knit fabric still needs to be found.

b. Uses of the Auxiliary Heated Handwear Unit

For immediate purposes, the low-voltage system just described offers a simple low-cost solution to handwarmth problems where a power source is available. The system, compatible with a 12 or 24-volt AC or DC power source, can be plugged into vehicles, missiles, radio and radar equipment which have available power. Conceivably, the electrically heated handwear could replace large expensive heating systems in vehicle cabins or duty outposts where only one or two men require heat.

For example, helicopters fall within this category when used in cold climates. While the cold injury problem of World War II military aviation does not require attention in situations such as Vietnam, where the major problem is dealing with excessive heat, this is not true in cold climates and the need for supplementary heat in open and low-flying aircraft still must be met.

Auxiliary handwear such as an electrically heated glove might feasibly replace expensive cabin heating systems in cold climates, or at least, as an emergency heat source, eliminate the waste of helicopters grounded because of malfunctioning cockpit heaters.

A pair of electrically heated gloves also could solve the hand protection problem of workers repairing helicopters and other equipment in extreme cold climates. Presently, Arctic workers haul faulty equipment back to heated shelters for repair work, a procedure that would be impossible under some conditions.

It is interesting to note that the Soviet Union developed electrically heated clothing items for use by their exploration base personnel in the Antarctic [12]. Russian personnel were reported to have worn (with the standard Russian Arctic Clothing) a 40-watt electrical heating system for the hands, chest and feet that enabled them to work in $-103^{\circ}F$ temperatures for short periods of time.

An electrically heated protective face mask, designated as ZMM-1, has also been developed by Soviet scientists at the Arctic and Antarctic Science Research Institute. The mask heats inhaled air and reportedly protects individuals even in $-103^{\circ}F$ cold.

c. Continuing Research and Development

The U.S. Army Natick Laboratories auxiliary heating system for the hands has not been intended for universal military use, but has been designed to meet the special needs of precision equipment operators, missile crews and other men required to perform exacting manual tasks in extreme cold for long periods.

While this program has been dropped due to a lack of a formal requirement, limited study has continued, following new developments in industry which might provide a breakthrough that would make possible a simpler, less expensive system. It has been made clear that a need exists for such auxiliary heated handwear and this need will increase as more complex equipment is designed for use in cold climates.

In the missile field, particularly, requirements for manual dexterity are critical for maintainence personnel and operators. The Natick Laboratories are carrying out clothing-equipment compatibility studies in conjunction with cold chamber tests of new missile systems. At the request of missile system directors, scientists of these Laboratories have checked the adequacy of standard and experimental clothing worn by personnel during early tests of new missile systems under simulated Arctic conditions.

The advantages of electrically heated handwear for a limited number of personnel have been demonstrated on many occasions. For example, during early tests of the Sergeant Missile System in 1959, it was found that certain tasks, particularly the operation of the theodolite and accessory equipment, required manual precision impossible to achieve while wearing Arctic mittens (13).

In 1965, tests of the same system, the azimuth orientation operator and the reference theodolite operators were supplied with either battery-powered or "plug-in" electrically heated glove liners (inserts) (14). These heating aids greatly improved the operators' ability to perform tasks requiring high manual dexterity for long periods in extreme cold.

On various occasions, the Natick Laboratories have supplied electrically heated gloves as research items to other missile systems. During 1966, these Laboratories were asked to provide special handwear for two different groups. One request was to outfit immediately members of an expedition to the Antarctic Plateau, sponsored by the National Science Foundation. The second need was for electrically heated items to protect the face and hands of workers testing U.S. Army experimental equipment at the Army Arctic Test Center, Ft. Wainwright, Alaska.

The Antarctic expedition anticipated conditions more severe than standard Arctic clothing is designed to meet. Men would be exposed to temperatures of -120°F with high winds while working at a weather station and climbing a 100-foot tower. Because of the immediacy of the request, the Natick Laboratories modified available items to meet the special requirements.

The expedition was supplied with one battery recharger, three battery vests (one spare), and two pairs of specially designed, electrically heated gloves. This handwear, as shown in Figure 4, differed from the 7-pound system mentioned previously in three ways: (1) the gloves were not equipped with thermostats to control the heat flow to resistance elements; (2) two electric circuits fed to each glove, rather than a single circuit, to increase the heating surface and double the heat provided; and (3) an insulated vest, which could be donned like a shirt, was designed to carry the cells, an improvement for comfort and battery-cell protection over the earlier vest, which hung around the neck like an apron.

The long-term nature of the Arctic Test Center's need gave the Natick Laboratories an opportunity to try to develop an American-made glove from materials available in this country. Previously, the only electrically heated gloves available were of English make, which these Laboratories redesigned to improve their performance. The goal is an electrically heated glove which will be superior in performance to the English item and easily manufactured at low cost by American industry.

In their survey into the possibilities of American industry producing such an item, these Laboratories found several available materials which could be made into gloves by knitting. A knitted material has the stretch and flexibility to cling snugly to a working hand, and thus gives better protection with an economy of electrical power.

One such knittable material is carbonized yarn, a delicate lightweight material used to a limited extent in commercial items, such as heated draperies and car seats. The yarn has also been used experimentally to heat certain areas of aircraft and in special heating blankets.

Several gloves were manufactured successfully from the yarn, proving it is possible to manufacture a low-cost glove which gives uniform heat with a low-voltage system. However, the soft yarn was subject to damage and could not be handled unless a light coating, such as rubber, was applied to one side of the material. Such a coating, however, reduced the flexibility of the product. Other attempts to protect the carbonized yarn have included suspending it between two layers of impermeable material, and spinning a layer of nylon over the yarn.

The value of carbonized yarn lies in its ability to give a continuous grid of heating surface when one strand is crossed with another. Because of this unique feature, investigation into use of the yarn continues despite the problem of protecting it from damage.

Another material being considered is a thin protected wire. An electrically heated glove manufactured of this wire would be even less expensive than the carbonized yarn product, since the wire needs no supplementary protection.

6. CONCLUSIONS

a. The physiological need for auxiliary heating for the hands in extreme cold, particularly for workers required to make delicate adjustments of equipment, has been clearly demonstrated in all studies of the subject. It is also clear that such handwear definitely reduces the danger of cold injury and increases the efficiency of personnel by prolonging the time they can work.

b. Recent developments in materials, particularly in the capability of developing inexpensive knitted constructions for such handwear, have brought this art to the point where quantity production will be both possible and of low cost.

The dollar cost of the electrically heated glove is small compared to the value of the tasks it makes possible. Yet complex, costly equipment and weapons systems developed for cold climate use may not be operated satisfactorily unless such handwear is provided.

c. The provision of lightweight, rechargeable batteries, where such power is required, has become much more practical. Similarly, the feasibility of plugging such a system of electrically heated handwear into an available power supply in vehicles and mounted weapons is definitely a smaller problem than it was a few years ago.

d. The need for electrically heated gloves should be recognized accordingly, and such handwear should be provided to personnel whose tasks are of such a nature that they cannot expeditiously carry out required adjustments or repairs in cold environments without it.

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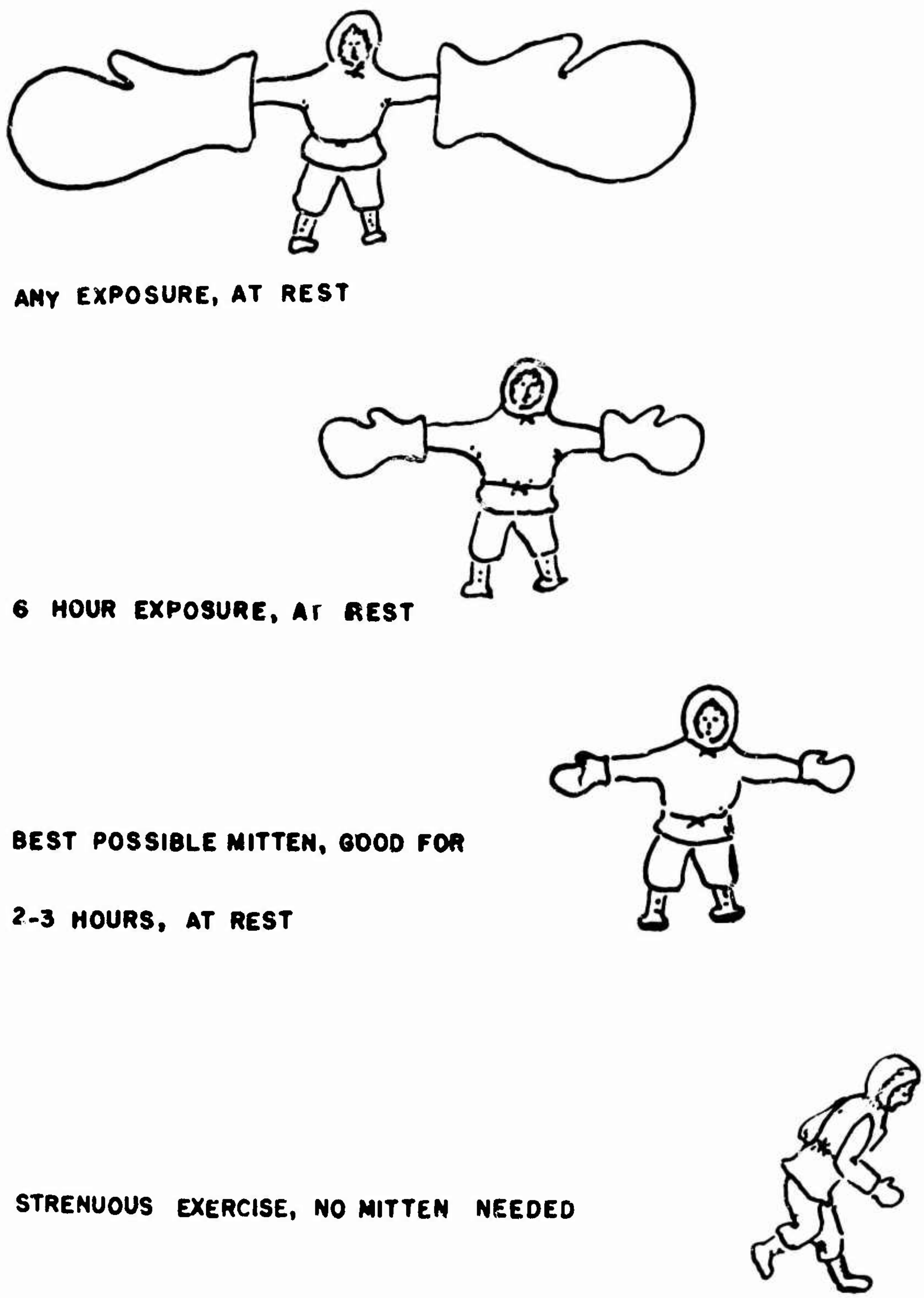

Figure 1

Relative Size of Mittens Needed for Different Exposure Times at -20°F.

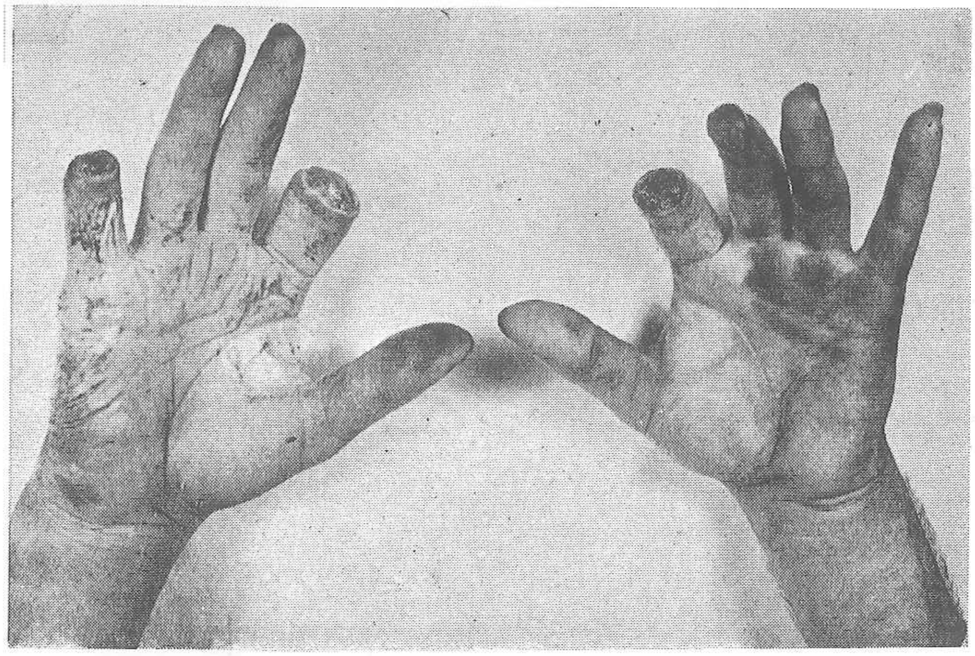

Figure 2

Case of High-altitude Frostbite

Figure 3

Standard Military Arctic Cold-dry Mitten

Figure 4. Type of Electrically Heated Handwear Unit Supplied to an Antarctic Plateau Expedition, Including a Battery Vest with 11 Silver Cadmium, 1.1 volt, 10 Ampere Rechargeable Cells and Wired Glove

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13. ABSTRACT

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Armed Forces Equipment	4					
Protection			8			
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