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HEAT TRANSFER PROPERTIES OF MILITARY PROTECTIVE HEADGEAR

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Army Natick Laboratories
Natick, Massachusetts

January 1974

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The heat transfer properties of headgear have been determined in chamber studies using a physical model (copper manikin). The evaporative heat transfer (im/clo) from a head in "still" air was constant above a standoff distance of 1.270 cm. for helmets with a constant head area coverage (67%). Reducing the head area coverage from 67% to about 50% was necessary to increase the evaporative heat transfer for a helmet standoff distance of 1.270 cm. The effect of wind on the heat transfer properties of selected headgear with varying designs was to decrease the values of insulation (clo) by about 60% and increase those for the evaporative heat transfer (im/clo) by about 4 times the "still" air values.

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TECHNICAL REPORT
74-29-CE

HEAT TRANSFER PROPERTIES OF MILITARY PROTECTIVE HEADGEAR

by

G. F. FONSECA
US Army Research Institute
of Environmental Medicine

Project Reference:
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January 1974

Clothing and Personal Life Support Equipment Laboratory
US Army Natick Laboratories
Natick, Massachusetts

FOREWORD

For the first time, a systematic study of military helmet design variables and their effects on heat transfer from the head is available. This study is one of many interdisciplinary efforts involving materials, ballistics, human factors, systems analysis and engineering design which form the technical bases upon which a new infantry helmet design will rest.

The new infantry helmet is being developed under the Army Materiel Command Five Year Personnel Armor Program. Project officers, W. D. Claus, L. R. McManus and P.E. Durand, were responsible for the work unit under which this study was carried out. The project officers designed and supplied custom shells for the head of the copper manikin conforming to the parameters of this experiment which included variable stand-off and variable area coverage. In addition, production helmets were provided from C&PLSEL's collection of world-wide military headgear in order to establish base line comparisons. The work was performed by G. F. Fonseca of the U.S. Army Research Institute of Environmental Medicine, Military Ergonomics Laboratory.

The author wishes to thank Dr. Ralph Goldman, Director, Military Ergonomics Laboratory, for reviewing the report.

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ABSTRACT

The heat transfer properties of headgear have been determined in chamber studies using a physical model (copper manikin). The evaporative heat transfer (im/clo) from a head in "still" air was constant above a standoff distance of 1.270 cm. for helmets with a constant head area coverage (67%). Reducing the head area coverage from 67% to about 50% was necessary to increase the evaporative heat transfer for a helmet standoff distance of 1.270 cm. The effect of wind on the heat transfer properties of selected headgear with varying designs was to decrease the values of insulation (clo) by about 60% and increase those for the evaporative heat transfer (im/clo) by about 4 times the "still" air values.

1. INTRODUCTION AND BACKGROUND

The U.S. Army Research Institute of Environmental Medicine is providing physiological research support to the AMC Natick Laboratories program for the design and development of a new helmet for the infantry soldier. This study, as part of this support, presents a review and analysis of experimental approaches using data (clo (6), im (11), and im/clo) obtained on the sectional manikin. Thermal evaluations, measured under both "still" and forced air conditions of available standard U.S. and foreign helmets are also included.

a. Review of Existing Physiological Head Studies

Three publications are of particular interest in any study of the heat transfer properties of headgear. Siple (8) stated that exposure of the head in the cold accounts for a large percentage of body heat loss since heat is lost in increasing quantities from the head as the thermal gradient increases. This prediction was verified by Froese and Burton (5) who directly measured the nonevaporative heat losses from a bare head using a temperature gradient calorimeter. This study showed that because there is little or no vasoconstriction in the head when it is exposed to cold temperatures, the heat loss from the head amounts to half of the total resting heat production of a man. Finally, Edwards and Burton (3) investigated the distribution of skin temperature over the surface of the head and presented a figure showing a detailed mapping of these surface temperatures.

b. Review of Published Helmet Studies

Winsmann's report (10) deals with the thermal protective characteristics of a CVC (Combat Vehicle Crewmen, e.g. tankers) helmet in arctic and hot environments. His results were based on head temperatures and subjective comments and indicated that the CVC helmet provided environmental protection equal to the field, pile, cap at 23.4C air temperature and about 1.3 meters/second air flow. Environmental protection in a heat stress situation was about equal to the field, cotton, cap at 29.4C air temperature and about 1.3 meters/second air flow.

van Graan and Strydom (9) investigated the effect of reducing heat stress by providing ventilating holes in helmets. They compared a helmet without holes with a second helmet with two 1.27-cm. diameter holes at the top of the helmet and with a third with six equally spaced 0.635-cm. diameter holes around the circumference of the helmet. These helmets were compared on the basis of temperature results using three thermocouples, one located at the top of the subject's head, another spaced 2.54-cm. from the top of the head, and a third placed at the inside crown area of the helmet.

Their results showed no difference in head surface temperature or helmet surface temperature among the three helmets. The air temperature above the head showed no difference wearing the helmet without holes or the helmet with two 1.27-cm. diameter holes at the crown of the helmet. However, the results for the helmet with six equally spaced 0.635-cm. diameter holes around the rim appeared to indicate that the inside helmet air temperature at the thermocouple measuring posiition was higher with the six holes than with the two 1.27-cm. diameter holes or no hole for the cool air environmental conditions when the subjects were at rest and registered a lower temperature when the subjects were doing a step test in the hot dry condition. These latter two findings appear to indicate that some of the incoming air was diverted through the six holes around the rim of the helmet rather than passing over the top of the head. However, these air temperature differences had no significant effect on head cooling since for all helmets, head and helmet temperatures showed no difference for any of the respective experimental conditions and subject activity levels.

Coleman and Mortagy (2) studied the heat retention qualities of five different models of football helmets. These helmets differed primarily in the design and composition of their suspension systems. Air temperatures measured "with thermistors inserted 2.5-cm. into the right anterior and left posterior quadrant of each helmet" showed a significant difference among the helmets with web suspension systems (lower air temperatures), and those with form fitting inflatable and hammock-suspension systems.

2. PREVIOUS USARIEM HEAT TRANSFER STUDIES ON HELMETS WITH VENTILATING FEATURES

Both "snugly-fitting" and "close-fitting" headgear with ventilating holes were studied (DF reports ME-E6-69 and ME-E11-70) using a physical model (electrically heated sectional copper manikin). A "close-fitting" original Hayes-Stewart helmet containing an air ventilation opening at the top (see Figure 1) was evaluated on the manikin to determine if this ventilation opening significantly improved head cooling in "still" air or in air flows up to 5 meters/second. Table I shows that the ventilating opening provides little advantage in increasing evaporative heat transfer (im/clo) from the head in "still" air conditions, although with the higher air flows there appears to be a slight adventage; both helmets provide an air space around the head which is readily disturbed in wind.

A "snugly-fitting" standard West German tankers helmet consisting of a foam-rubber liner and reinforced from skull to nape of the neck by a flexible polyethylene strip was also studied. Ventilation is obtained at the sides by 3 screen grommets and through two air passages running from the front to the back of the head (see Figure 2). This helmet was evaluated on the manikin to determine the effect of the air-ventilating grommets on the evaporative heat transfer (im/clo) from the head. The results showed that sealing the ventilating grommets on the side of the helmet made little difference in the evaporative heat transfer from the head in "still" air.

Figure 1. Photographs of the Original Hayes-Stewart Helmet: (a) Front View, (b) Side View

TABLE I. Thermal Characteristics of Original Hayes-Stewart Helmet

	Air Flow								
Headgear	"Still" Air			2 Meters/Second			5 Meters/Second		
	CLO	im/CLO	im	CLO	im/CLO	im	CLO	im/CLO	im
Helmet	1.12	0.49	0.55	0.53	1.2	0.64	0.42	2.4	1.0
Helmet/Ventilating Cap	0.91	0.50	0.45	0.49	1.3	0.64	0.38	2.6	1.0
Bare Head	0.64	0.97	0.62	0.43	1.6	0.68	0.33	3.0	1.0

However, in an air flow of 3 meters/second, sealing these ventilating grommets reduced the evaporative heat transfer by about 10% (see Table II). Apparently, since this helmet fits snugly to the head, increasing the air movement around the head with the ventilating grommets sealed has little effect on the evaporative heat transfer from the area of the head covered by the helmet.

3. OUTLINE OF USARIEM EXPERIMENTAL TECHNIQUES

Headgear heat transfer properties are being studied in support of the AMC 5 year armor program by USARIEM. Manikin head section clo, im, and im/clo values were determined by the methods described in an earlier paper (4) following the standardized, experimental procedures set forth in the Standard Manikin Procedure memoranda (2). The head section of the manikin is considered as the test section; the remaining five sections (torso, arms, hands, legs, and feet) are considered as guard sections. The manikin is completely enclosed in a skin of form-fitting underwear material and dressed in a basic clothing ensemble consisting of tropical combat fatigues, 1 pair of socks, and a pair of black leather boots (see Figure 3). In these studies, the manikin was placed in a standing position near the center of an environmental chamber facing two fans which directed air at the head of the manikin. A helmet was placed on the manikin's head and the insulation value (clo) was determined for normal chamber air flow (i.e. "still" air condition, with the two fans off) and for a forced air flow condition (i.e. with the two fans running). Similarly, after the manikin's skin (underwear material) was wet, the evaporative heat transfer value (im/clo) was determined for the "still" and the forced air conditions.

4. THERMAL PROPERTIES AS A FUNCTION OF STANDOFF DISTANCE FROM THE HEAD

There was little or no systematic data on the evaporative heat transfer cooling range (im/clo) for any close-fitting helmet system. Such information for a selected close-fitting helmet configuration, added to information on similar helmets with less or greater spacing distances from the head, should define an optimum spacing from the head for evaporative heat transfer, if any such optimum exists.

A master mold of the manikin's head was made, and a set of molds were cast which contained a controlled amount of standoff. Five helmets were vacuum formed with standoff distance from 0-cm. (snugly-fitting) to 2.54-cm. (very loosely-fitting) in 0.635-cm. increments. All five helmets provide a constant head area coverage of approximately 67% of the total manikin head surface area (see Figure 4).

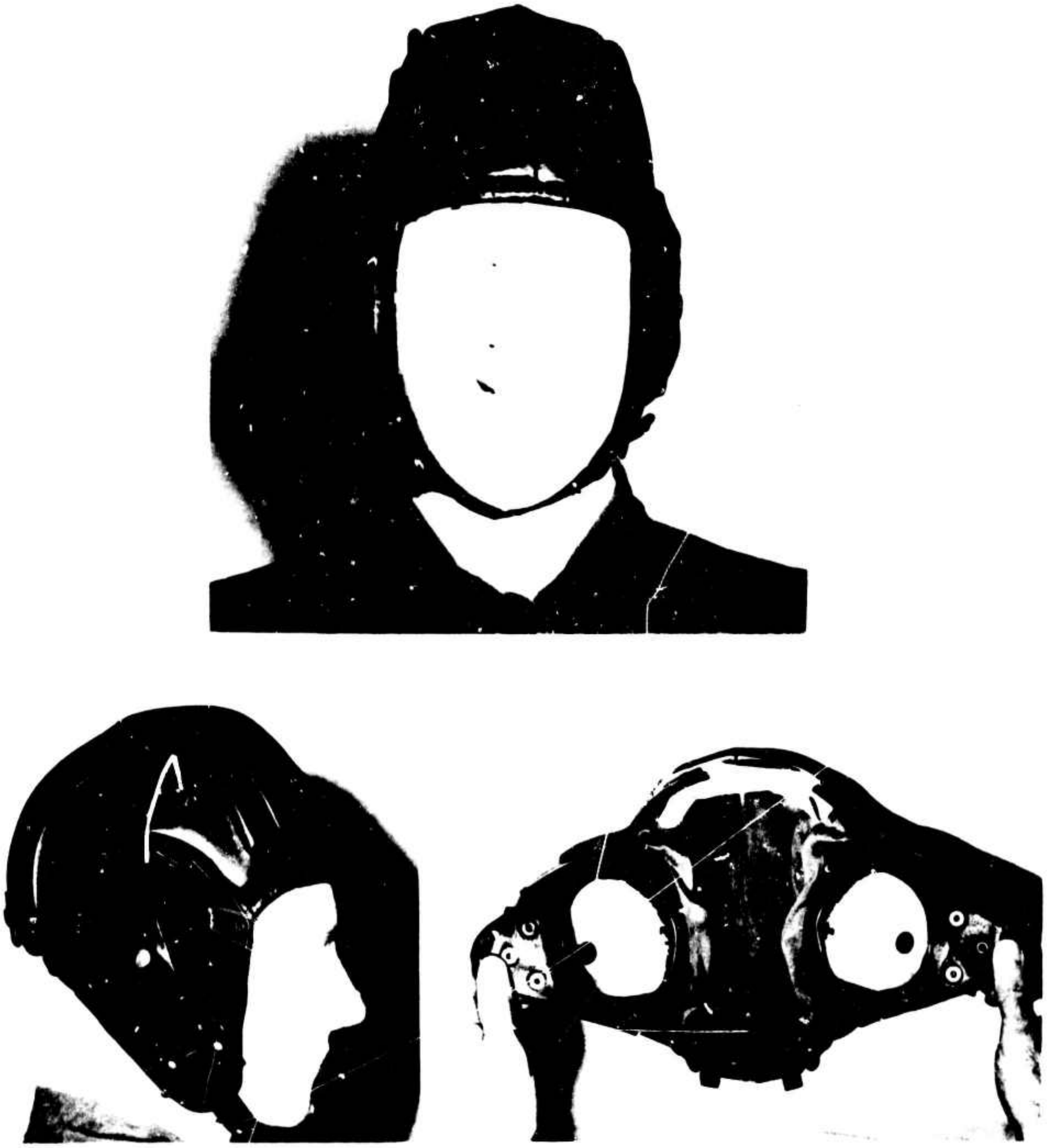

Figure 2. Photographs of the Standard West German Tankers Helmet: (a) Front View, (b) Side View, (c) Interior View

TABLE II. Thermal Characteristics of the Standard West German Tankers Helmet

	Air Flow					
	"Still" Air			3 Meters/Second		
Headgear	CLO	im/CLO	im	CLO	im/CLO	im
Helmet/Ventilating Holes Sealed	1.49	0.17	0.25	0.87	0.69	0.60
Helmet/Ventilating Holes Open	1.46	0.18	0.26	0.83	0.77	0.64

Figure 3. Photograph of the Sectional Manikin Dressed in Tropical Combat Fatigues

The results (see Table III) show that helmet No. 1 with 0-cm. standoff, practically eliminated any evaporative heat transfer from that area of the head covered by the helmet; essentially all the evaporative heat transfer from the head occurred over the uncovered area of the head (about 33% of the head surface area). Furthermore, for the "still" air condition, there is little difference in im/clo between this helmet which fits snugly on the head, and the one (helmet No. 2) spaced 0.635-cm. away from the head. Apparently 0.635-cm. spacing around the top of the head consists of essentially dead air space. Once the standoff distance reaches 1.27-cm., there is little difference in im/clo among the 3 helmets covering the 1.27 to 2.54-cm. spacing range. Thus 0.635-cm. is too small to have much effect on evaporative heat transfer in "still" air while 1.27-cm. produces as much as 1.905 or 2.54-cm. Figure 5 shows insulation (clo) and evaporative heat transfer (im/clo) as a function of standoff distance for these 5 helmets. It is seen that the insulation values (clo) reach a maximum value at a 0.635-cm. standoff distance and then decrease with increasing standoff distance.

Although in "still" air the snugly-fitting helmet (0-cm. standoff distsnce) showed the lowest insulation value, because there was no air space to provide insulation between the head and the helmet, at 3 meters/second the snugly-fitting helmet provides greater insulation than any of the other helmets, except for the 0.635-cm. standoff helmet; the "dead" air space between the helmet and the head at standoff distances beyond 0.635-cm. is now disturbed. Conversely, the evaporative heat transfer from the head, which did not show an increase in "still" air conditions until the 1.27-cm. standoff distance was reached (again because of the dead air space with the 0.635-cm. standoff helmet), with moving air (3 meters/second) shows a disturbance of the "dead" air in the 0.635-cm. space; the value for the 0.635-cm. standoff increases toward the nearly constant evaporative heat transfer value of the 1.27, 2.005, and 2.54-cm. helmets. Figure 6a is a graphical presentation which demonstrates these combined effects of the clo and im/clo values for these 5 helmet standoffs, in "still" air, in terms of the theoretical environmental limits at which thermal equilibrium could exist with respect to the head area of men who need to lose 25 watts from their head surface. The lower ambient temperature limits for the helmets are given by the vertical lines on the left side of the figure. These vertical lines are based on the insulation value (clo) of a given helmet and represent the lowest ambient temperature at which thermal equilibrium of the head can be maintained. The concept of environmental range is not considered in this clo calculation but occurs when both clo and im/clo values for a given helmet are considered. These values (clo and im/clo) give the sloping lines on the right side of the figure and represent the upper environmental ranges for thermal equilibrium of the head. Within the area bounded by a vertical line on the left and a corresponding sloping line on the right, all combinations of ambient temperature (horizontal axis) and ambient air vapor pressure (vertical axis) will allow a fixed rate of heat

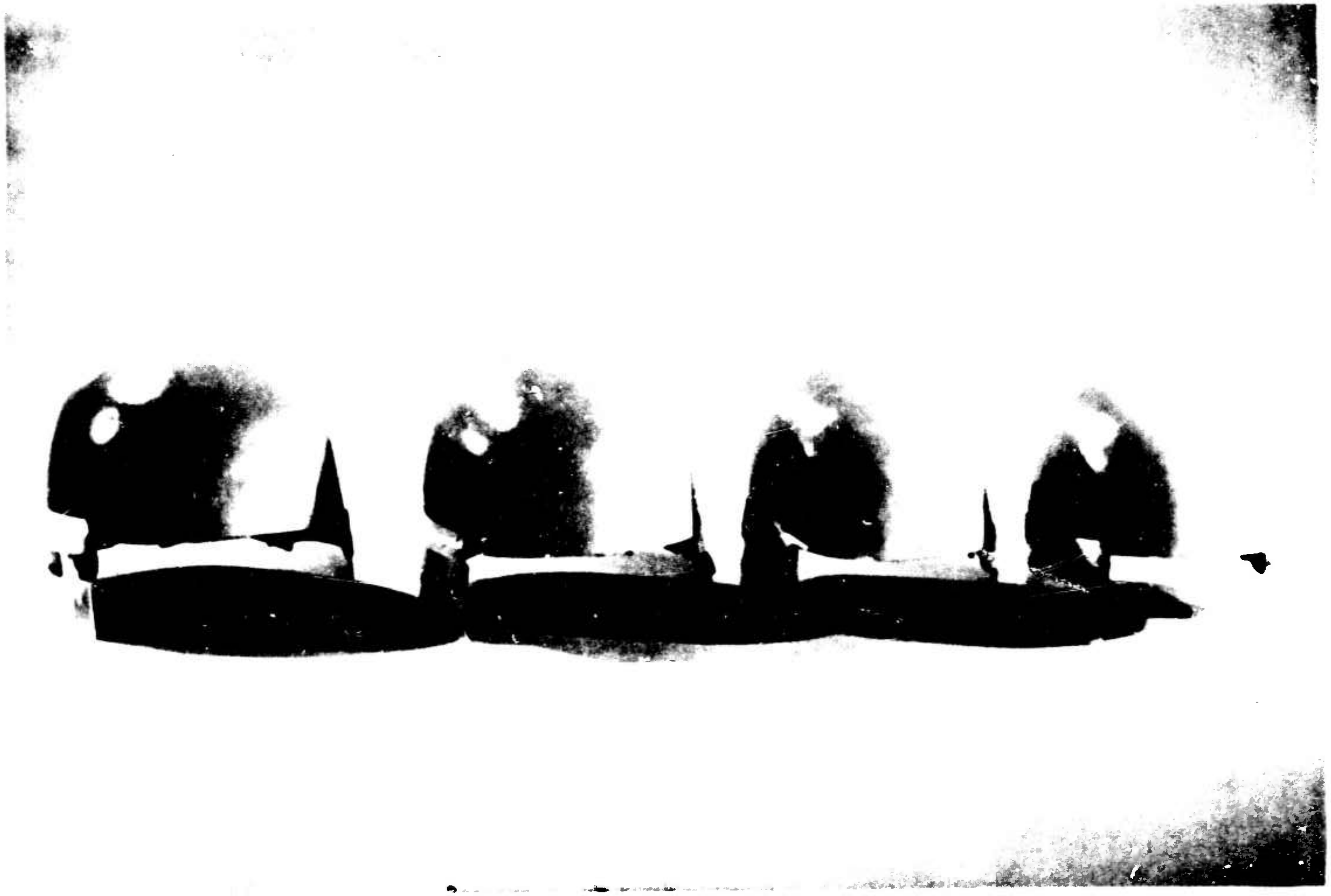

Figure 4. Photograph of 4 of the 5 Experimental Standoff Helmets Showing, Left to Right: 2.540-cm., 1.905-cm., 0.635-cm., and 0-cm. Standoff Helmets

TABLE III. Thermal Characteristics of Experimental Helmets with Different Standoff Distances from the Head

Helmet Number	Standoff Distance CM	Air Flow					
		"Still" Air			3 Meters/Second		
		CLO	im/CLO	im	CLO	im/CLO	im
1	0.000	0.88	0.33	0.29	0.42	1.1	0.46
2	0.635	1.08	0.33	0.36	0.47	2.0	0.94
3	1.270	1.07	0.40	0.43	0.41	2.3	0.94
4	1.905	1.05	0.44	0.46	0.39	2.3	0.90
5	2.540	1.00	0.44	0.44	0.37	2.3	0.85

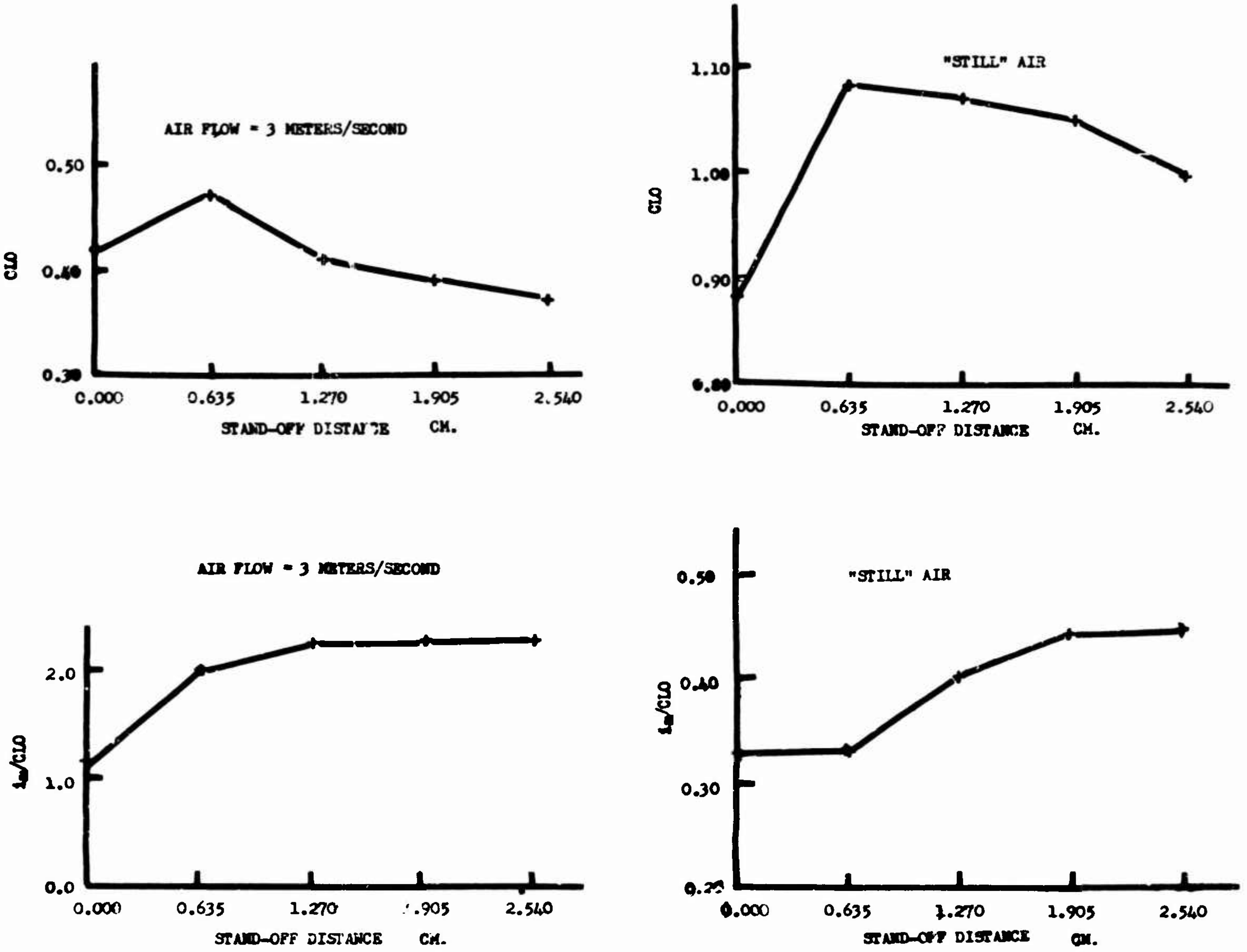

Figure 5. Curves of Clo (a) and Im/clo (b) as Functions of Helmet Standoff Distance

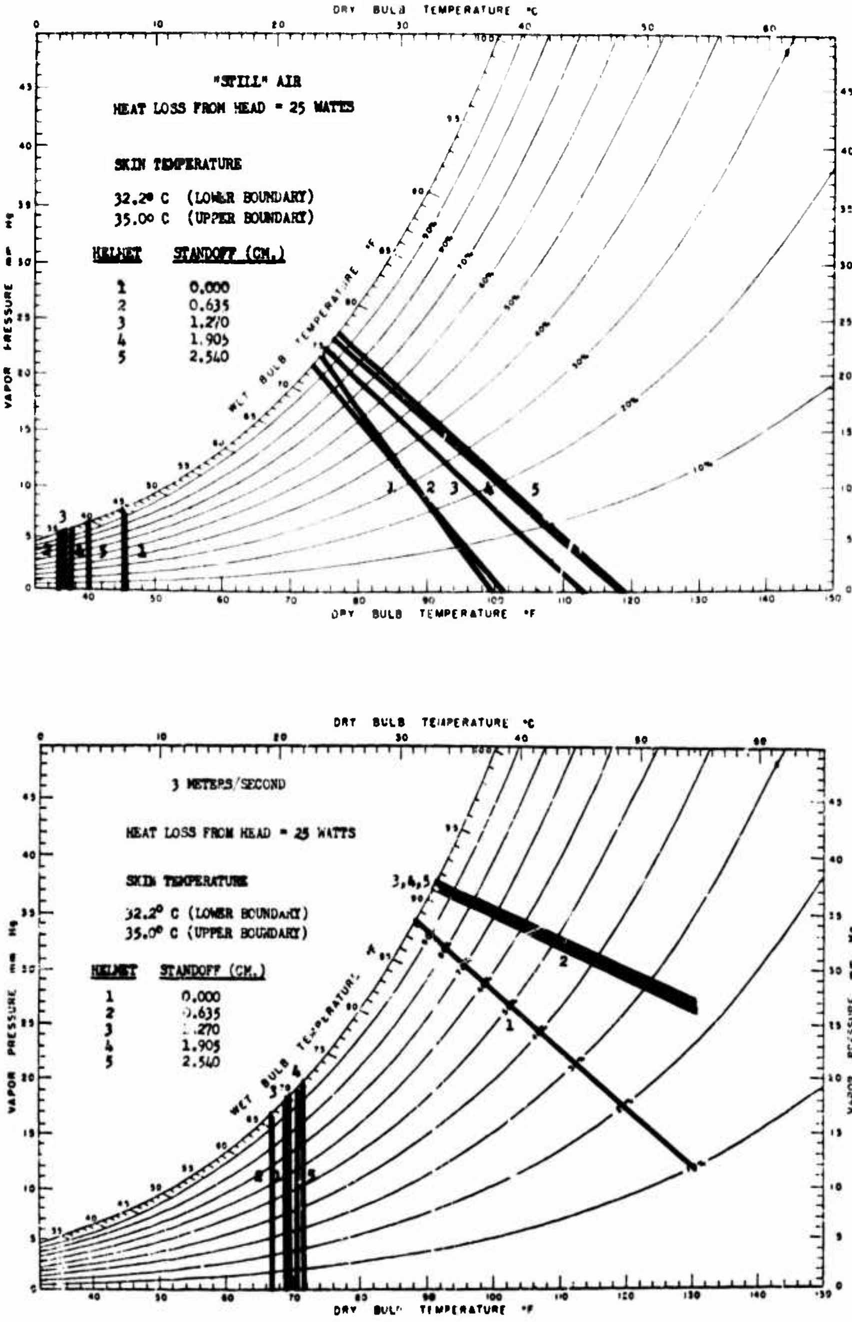

Figure 6. Graphical Presentation Demonstrating the Combined Effect of Clo and Im/clo Values in Terms of Theoretical Environmental Limits for Thermal Eqilibrium of the Head for the Five Experimental Standoff Helmets: (a) "Still" Air, (b) Air Flow of 3 Meters/Second

Figure 7. Photograph of M-1 Helmet Liner Showing Location of the Ten Ventilating Slots

loss of 25 watts from the head. To the left of a given vertical line the heat loss from the head will be greater than the 25 watts equilibrium value. To the right of a given sloping line the heat loss from the head will be less than the 25 watts equilibrium value. This figure presents a simple pictorial representation of the theoretical environmental range over which thermal equilibrium will be maintained in "still" air. A similar graph for wind is shown in figure 6b.

5. EFFECT OF VENTILATING SLOTS IN THE M-1 HELMET LINER ON EVAPORATIVE HEAT TRANSFER

Although neither the helmet study discussed previously using a ventilating cap at the top of the original Hayes-Stewart helmet nor the study comparing miners hard hats with ventilating holes showed any significant improvement in the ventilating properties of the respective helmets, a further look at air ventilating holes in helmets was undertaken to see if a combination of ventilating holes at the top and around the helmet equal to about 8% of the total surface area of the helmet would show a difference in im/clo in "still" air. A M-1 helmet liner was modified by cutting ten ventilating slots equal to about 8% of the total helmet liner surface area. Two of these slots are located on each side of the helmet, two in the rear, three in the front, and one on top of the helmet (see Figure 7). It is apparent from the results given in Table IV that this amount of open area in a helmet and the location of these ventilating slots does allow an increase in im/clo in "still" air, but has little effect at an air flow of 3 meters/second. Since this helmet liner is spaced about 1.27-cm. from the head, these results are important in illustrating the order of magnitude of ventilating holes and their location around this type of "close-fitting" helmet.

6. AREA COVERAGE EFFECTS

The effect on the heat transfer properties of helmet head area coverage was investigated by removing three 2.54-cm. strips from the bottom edge of the experimental helmet with the 1.27-cm. standoff distance. This provided four helmet samples covering the area coverage range from 47% to 67%. The results are given in Table V. The clo and im/clo values are plotted against head area coverage in Figure 8. The clo values in "still" air decrease linearly with decreasing head area coverage; in an air flow of 3 meters/second, they decrease until a head area coverage of about 55% is reached and then they level off. The evaporative heat transfer (im/clo) values in "still" air do not show an increase until about 50% head area coverage is reached; they are relatively constant at an air flow of 3 meters/second. It is of interest to consider the two extreme head area coverage helmets (67% and 47% head area coverage). The quantity of helmet material removed consists of about 30% of the material of the 1.27-cm. standoff helmet. The increase in im/clo in "still" air as a result of this decrease in head area

TABLE IV. Thermal Characteristics of the M-1 Helmet Liner with and without Ten Ventilating Slots which Provide Open Spaces Equal to 8% of the Total Helmet Liner Surface Area

	Air Flow					
	"Still" Air			3 Meters/Second		
Helmet Liner	CLO	im/CLO	im	CLO	im/CLO	im
Open Slots	0.94	0.55	0.52	0.36	2.2	0.79
Sealed Slots	1.03	0.41	0.42	0.36	2.1	0.76

TABLE V. Thermal Characteristics of Experimental Helmets with Different Head Area Coverage

Head Area Coverage	Air Flow					
	"Still" Air			3 Meters/Second		
%	CLO	im/CLO	im	CLO	im/CLO	im
67	1.07	0.40	0.43	0.41	2.3	0.94
60	1.03	0.40	0.42	0.35	2.0	0.70
54	1.00	0.43	0.43	0.32	2.3	0.74
47	0.96	0.48	0.46	0.32	2.4	0.77

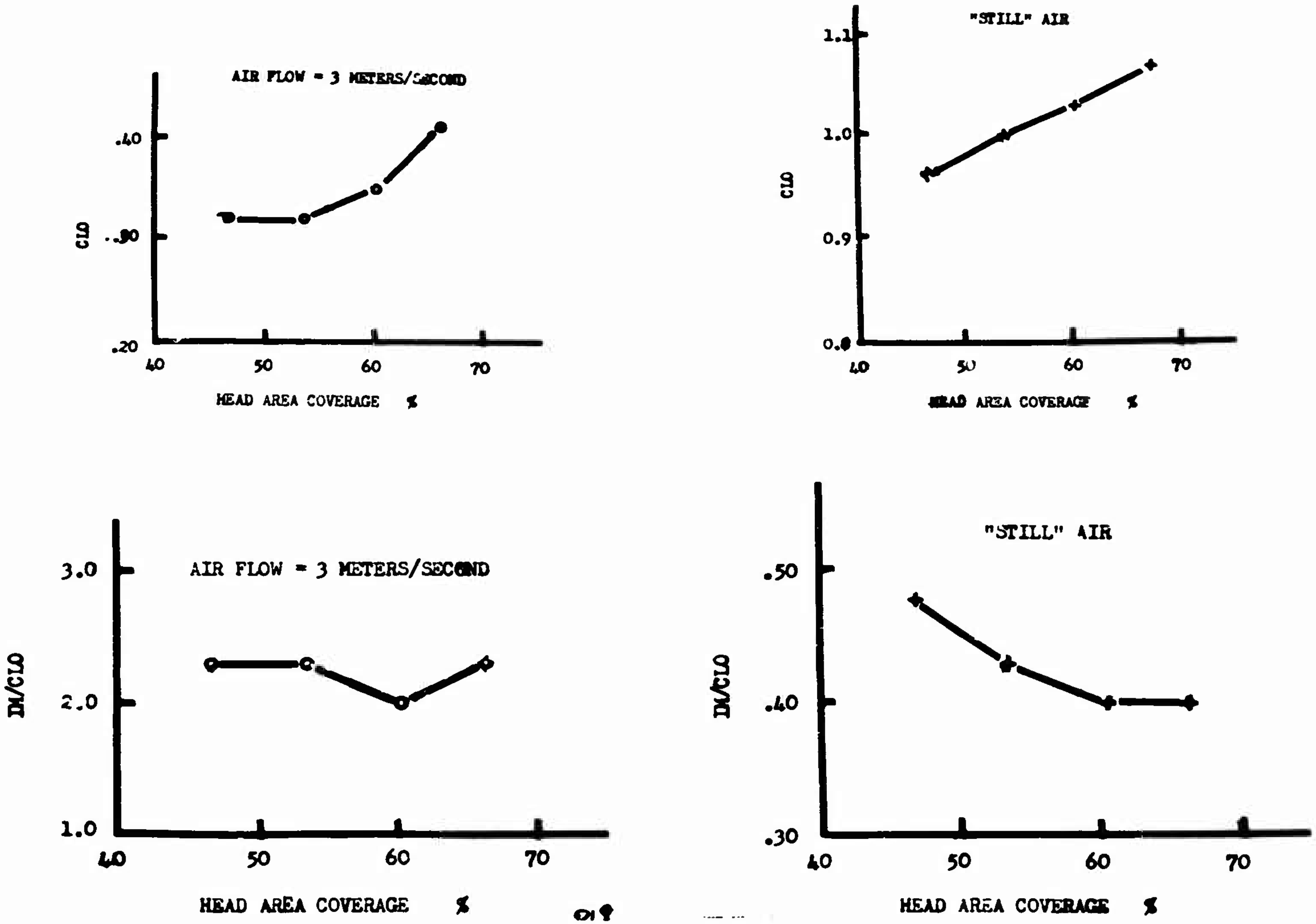

Figure 8. Curves of Clo (a) and Im/Clo (b) as Functions of Head Area Coverage

coverage amounts to about 20%. The helmet liner with the ten ventilating slots equal to about 8% of the helmet liner material increased the im/clo abut 35% in "still" air. Comparing these results with the previous findings with helmets with ventilating holes indicates that the number and locations of these ventilating holes could be more important than the total quantity of helmet material removed.

7. REMOVABLE SUSPENSION SYSTEMS FOR M-1 HELMET LINER

Any given suspension system modifies the evaporative heat transfer properties of a helmet, in part, by the total head-suspension system contact area, the distribution of this contact area over the head, and the material composition and thickness of the suspension system. Three removable suspension systems (see Figure 9) for the M-1 helmet liner (see Figure 10) were studied to determine if any measurable differences in the evaporative heat transfer (im/clo) from a head could be detected. An earlier study (8) using a single circuit copper manikin determined total clo and total im/clo values for these 3 helmet liner/suspension systems as part of a complete ensemble. These experimental results obtained in "still" air are shown in Table VI. Since these values are for the total manikin surface area, the contribution from the head is masked by the contributions from the other areas of the manikin. Table VII shows the im/clo values for these 3 helmet liner/suspension systems determined on the sectional manikin. Although these im/clo values are grouped closely together, comparing the im/clo values for the standard with those for the HEL suspension system suggest that the head-suspension system contact area becomes more important with increasing air flow.

8. FACE SHIELD EFFECTS

A standard M-1 helmet and a commercial riot control helmet (see Figure 11) were studied to determine the effect on the heat transfer properties of the helmets when a face shield is worn in the down position. Table VIII shows that measurable differences in clo and im/clo were obtained when these values were compared for the face shields in the up and down positions. The clo values increased by about 0.1 clo and the im/clo values decreased by about 0.05. Increasing the air flow decreased the clo values of both helmets with face shields in the up or down position by about 60% and increased the im/clo values by about 4.5 times the "still" air values for the standard helmet and for the riot control helmet with the face shield in the down position. The riot control helmet with the face shield in the up position showed about a 5.3 increase in the im/clo value with increased air flow.

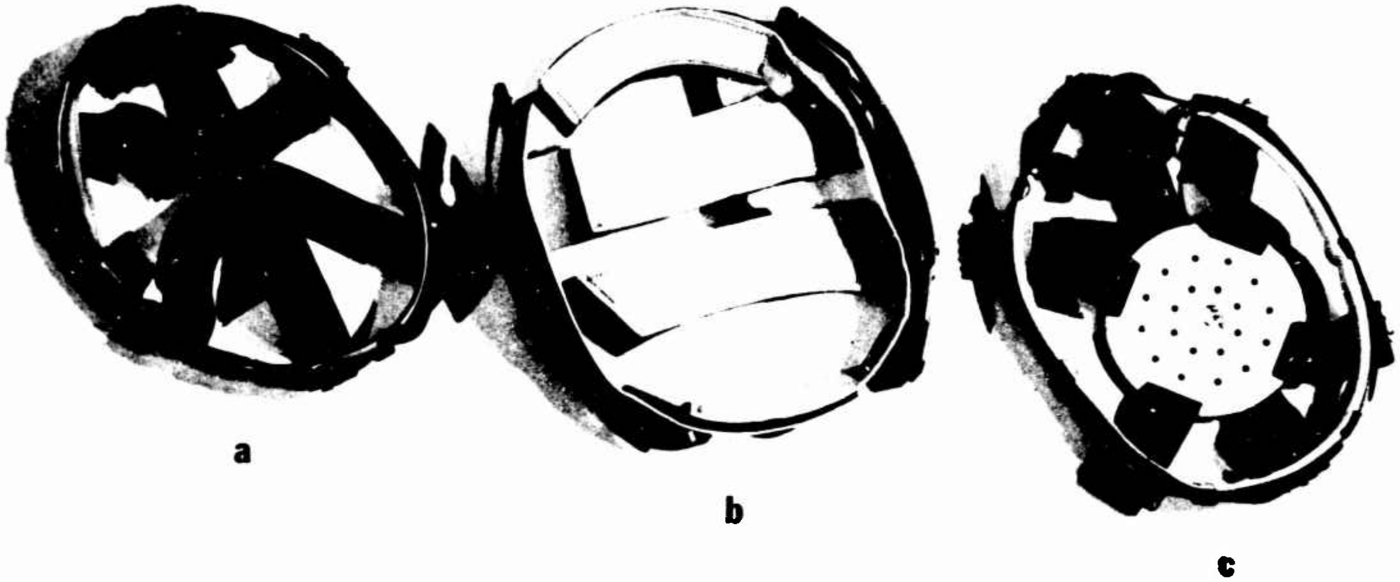

Figure 9. Photograph of Three Removable M-1 Helmet Liner Suspension Systems; (a) Standard, (b) Welson-Davis, (c) HEL

Figure 10. Photograph of the M-1 Helmet Liner

TABLE VI. Total Thermal Characteristics in "Still" Air of a Tropical Combat Fatigue Ensemble Using the M-1 Helmet Liner with Removable Suspension Systmes

Removable Suspension Systems	CLO	im/CLO	im
Standard	1.54	0.23	0.36
HEL	1.57	0.23	0.36
Welson-Davis	1.59	0.21	0.34

TABLE VII. Thermal Characteristics of Selected Removable M-1 Helmet Liner Suspension Systems

	Air Flow					
	"Still" Air			3 Meters/Second		
Suspension Systems w/Helmet Liner	CLO	im/CLO	im	CLO	im/CLO	im
Standard	1.10	0.40	0.44	0.39	2.0	0.78
HEL	1.10	0.38	0.42	0.39	1.8	0.70
Welson-Davis	1.04	0.39	0.41	0.38	1.9	0.72

Figure 11. Photographs of Helmets with Face Shields: (a) Standard M-1 Helmet, Face Shield Up; (b) Standard M-1 Helmet, Face Shield Down; (c) Commercial Riot Control Helmet, Face Shield Up; (d) Commercial Riot Control Helmet, Face Shield Down

TABLE VIII. Thermal Characteristics of the Standard M-1 Helmet and a Commercial Riot Control Helmet with a Face Shield in the Up and Down Positions

	Air Flow					
	"Still" Air			3 Meters/Second		
Headgear	CLO	im/CLO	im	CLO	im/CLO	im
M-1 Helmet System w/Face Shield Up	1.08	0.43	0.46	0.44	1.9	0.84
M-1 Helmet System w/Face Shield Down	1.20	0.38	0.46	0.52	1.7	0.88
Commercial Riot Helmet w/Face Shield Up	1.35	0.38	0.51	0.50	2.0	1.0
Commercial Riot Helmet w/Face Shield Down	1.43	0.33	0.47	0.54	1.5	0.81

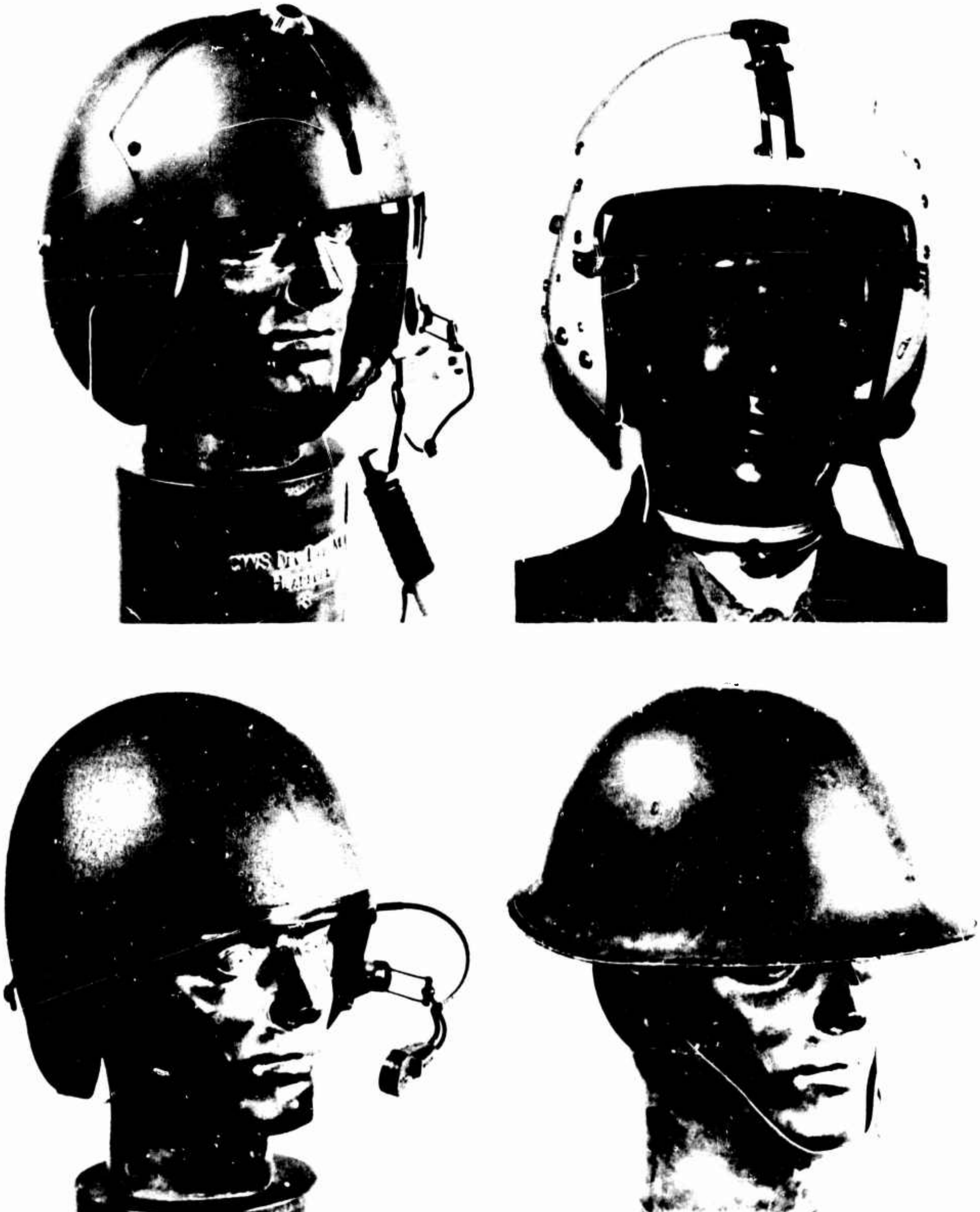

Figure 12. Photographs of Selected Helmets Presented in Table IX: (a) Aircrew AFH-1, (b) Aircrew APH-5, (c) Standard CVC (d) English Infantry.

Figure 12 continued. (e) Football Helmet, (f) Experimental Hayes-Stewart, (g) Italian Infantry, (h) Experimental Parachutist Liner.

TABLE IX. Thermal Characteristics of Selected Helmets

	Air Flow					
	"Still" Air			3 Meters/Second		
Helmets	CLO	im/CLO	im	CLO	im/CLO	im
Aircrew AFH-1	1.72	0.38	0.65	0.48	1.8	0.88
Aircrew APH-5	1.45	0.32	0.47	0.51	1.4	0.72
Standard CVC	1.28	0.36	0.46	0.43	1.9	0.83
English Infantry	0.97	0.45	0.44	0.37	1.9	0.70
Football Helmet	1.16	0.32	0.37	0.47	1.6	0.78
Experimental Hayes-Stewart	1.11	0.35	0.39	0.45	1.9	0.87
Italian Infantry	1.03	0.43	0.44	0.42	2.0	0.84
Experimental Parachutist Liner	1.36	0.37	0.50	0.54	1.5	0.81

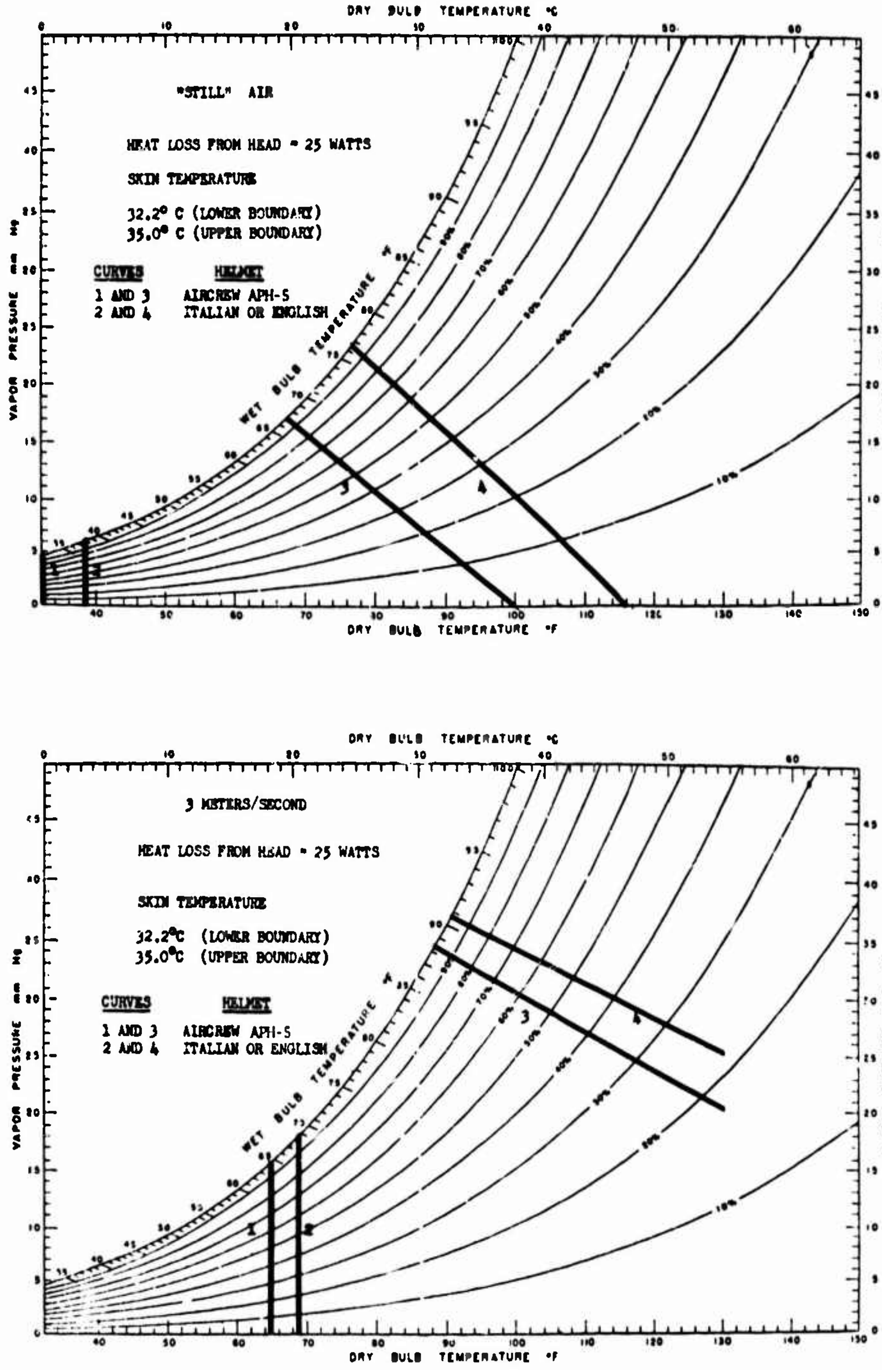

Figure 13. Graphical Presentation Demonstrating the Combined Effect of Clc and im/clo Values in Terms of Theoretical Environmental Limits for Thermal Equilibrium of the Head for Two Helmets from Table IX: Italian Helmet (One of the Largest im/clo Values) and the Aircrew APH-5 Helmet (Smallest im/clo Value); (a) "Still" Air, (b) Air Flow of 3 Meters/Second

9. THERMAL CHARACTERISTICS OF SELECTED HELMETS

The helmets shown in the photographs of Figure 12 are of assorted shapes and sizes ranging from snugly-fitting to loose-fitting, from comparatively rigid suspension systems to flexible suspension systems, and suspension systems fabricated from materials of various moisture permeabilities. From Table IX it is noted that the data for the Aircrew APH-5 helmet are consistently among the highest clo and lowest im/clo values for the "still" and 3 meters/second air flow conditions. This is mainly because of its very close-fitting design. The English and the Italian infantry helmets consistently show the lowest clo and the highest im/clo values, apparently because of their high proportion of uncovered head surface area. Overall, increasing the air flow from "still" air to 3 meters/second reduces the clo for all helmets by about 60% and increases the im/clo by about 4 times the "still" air values. Figure 13a shows a graphical presentation which demonstrates the combined effect of the clo and im/clo values in "still" air in terms of theoretical environmental limits for thermal equilibrium of the head for men losing 25 watts from the head surface when wearing the Italian helmet (one of the largest im/clo values) and the aircrew APH-5 (smallest im/clo value). Figure 13b shows the same information with a 3 meters/second air flow.

10. DISCUSSION AND CLONCLUSIONS

It is difficult to determine differences in "still" air in the heat transfer properties of headgear with and without ventilating holes. Although the M-1 helmet liner with 10 ventilating holes spaced over the helmet and providing about 8% of open space in the helmet liner showed an increase in evaporative heat transfer from the head, simply making several holes around the helmet or at the top apparently is of little benefit in increasing the evaporative heat transfer from the head. Removing strips of material from the bottom edge of a helmet, originally covering about 67% of the head (standoff distance of 1.270 cm.), shows little improvement in evaporative heat transfer until about 30% of the helmet material has been removed. For a constant head area coverage of 67%, the evaporative heat transfer was constant above a standoff distance of 1.270 cm. In wind, ventilating holes appear to increase the evaporative heat transfer for a snugly-fitting helmet but have negligible effect on all other helmets. Increasing the air flow from "still" air to 3 meters/second reduces the clo for all 8 selected headgear items by about 60% and increases the im/clo by about 4 times the "still" air values.

The surface area affected by a helmet is relatively small compared with the total body surface area. Any benefit in the heat transfer properties is more apt to be improved head comfort rather than in extending physiological tolerance. A decrease in headgear insulation of 0.1 clo within a insulation range of 1.0 to 1.5 clo will result in an increase in convective heat transfer from the head of between 0.4 and 1.0 watts. Increasing the im/clo by 0.1 increases the evaporative heat transfer from the head by about 2 watts for a vapor pressure difference between the head surface and ambient air of 10 mm Hg. As an example using two different types of headgear the total im/clo of a complete ensemble (tropical combat fatigues, 1 pair of socks, and a pair of black boots) increases by about 0.02 when the standard West German tankers helmet is replaced by the English helmet. A man exposed to a "still" air environment of 43 C and 20% relative humidity would have a total heat loss of about 188 watts when wearing the snugly-fitting, standard West German tankers helmet. Replacing this helmet with an English helmet would increase his heat loss to about 203 watts or 15 watts greater. Although these differences in the total heat transfer properties are small, the values obtained for the headgear items studied are measurable and reproducible. Future work on headgear items should consider infantry headgear in other climates, e.g. tropical and the effect on the heat transfer from the head of using helmets constructed from materials of different thermal conductivities.

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