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endurance time limit for each subject. T_{re}, heart rate, 3-site skin temperatures, head temperature in the skin-air space between each hood, and the T_a were recorded continuously. Automatic dew point temperature sensors were also placed adjacent to the head thermocouple site which were used to measure water vapor permeation continuously. The rise of mean body temperature per exercise time ($\Delta\bar{T}_b/\Delta t$, °C/h) served as an indicator of heat strain to garment and environment. Nude body weights were determined before and immediately after the experiments to determine total sweating rate ($\dot{m}_{sw}$). Predicted evaporation (E_v) through each garment configuration was calculated from partitional calorimetry using the effective Woodcock permeation constant to total clo value (i.e., i_m/I_t) from direct copper manikin evaluation. Subjects were well-hydrated prior to entering the chamber but not allowed fluid replacement during the 100 min attempt. In general, use of a 70-mil permeable hood integrated to a standard overgarment gave no significant advantages compared to a standard OG in reduction of: heat strain, improvement in vapor permeation to a given clo insulation (at most only 10-12% $>E_v/\dot{m}_{sw}$ at high air movement), and extension of endurance times. Although carbon-lined hoods offer optimal chemical protection for the head region, the use of a butyl hood with the M-40 mask suggests a preferable heat transfer option because of the reduced thickness of the hood (about 9 times less than the permeable hood) which offers an augmented i_m/clo with high wind speeds.

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UNITED STATES OF AMERICA

HUMAN BIOPHYSICAL EVALUATION OF A PERMEABLE HOOD ATTACHED TO A CHEMICAL PROTECTIVE OVERGARMENT

by

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ABSTRACT

This report focuses on the physiological and biophysical evaluation of a prototype 70-mil permeable hood integrated into the standard 90-mil chemical protective overgarment and its potential in reducing heat strain during continuous exercise. Each of 14 CB-trained Marines (in two groups of seven) did treadmill exercise (heat production, M=470W) in six randomized environmental sequences: ambient air temperature (T_a)=32°C/80% rh/V=1 $m \cdot s^{-1}$ and 5 $m \cdot s^{-1}$; 35°C/50% rh/V=1 $m \cdot s^{-1}$ and 5 $m \cdot s^{-1}$; and 43°C/20% rh/V=1 $m \cdot s^{-1}$ and 5 $m \cdot s^{-1}$. Each group used a similar uniform configuration each day until completion of the above environmental exposures, then altered the uniform configuration for additional runs. Uniform configurations were: permeable attached hood integrated to 90-mil standard overgarment (OG) in the closed configuration with underwear and MX-40 respiratory mask, (P-40); standard butyl rubber hood with OG and either the MX-40, (B-40) or the M17A respiratory mask (B-17). Subjects exercised until rectal temperature (T_{re}) reached 39° C and/or heart rates remained at 180 beats/min for 5 min. This cut-off was designated as an endurance time limit for each subject. T_{re}, heart rate, 3-site skin temperatures, head temperature in the skin-air space between each hood, and the T_a were recorded continuously. Automatic dew point temperature sensors were also placed adjacent to the head thermocouple site which were used to measure water vapor permeation continuously. The rise of mean body temperature per exercise time ($\Delta T_b/\Delta t$, °C/h) served as an indicator of heat strain to garment and environment. Nude body weights were determined before and immediately after the experiments to determine total sweating rate ($\dot{m}_{sw}$). Predicted evaporation (E_v) through each garment configuration was calculated from partitional calorimetry using the effective Woodcock permeation constant to total clo value (i.e., i_m/I_t) from direct copper manikin evaluation. Subjects were well-hydrated prior to entering the chamber but not allowed fluid replacement during the 100 min attempt. In general, use of a 70-mil permeable hood integrated to a standard overgarment gave no significant advantages compared to a standard OG in reduction of: heat strain, improvement in vapor permeation to a given clo insulation (at most only 10-12% $>E_v/\dot{m}_{sw}$ at high air movement), and extension of endurance times. Although carbon-lined hoods offer optimal chemical protection for the head region, the use of a butyl hood with the M-40 mask suggests a preferable heat transfer option because of the reduced thickness of the hood (about 9 times less than the permeable hood) which offers an augmented $\dot{i}_m$/clo with high wind speeds.

INTRODUCTION

A. Theory and Function

The apparent efficacy of a prototype permeable hood attached to the U.S. Army CB Battle Dress Overgarment, either worn alone (with underwear) or with a Temperate Battle Dress (TBDU) placed underneath, is a highly relevant but up to now unknown problem. Typically, if substantial water vapor permeation (i_m) were possible with such a garment, while the wearer engaged in a continuous work regimen during heat stress, purported significant reductions in heat strain and extensions of work time might be possible given that other variables are constant (hydration, heat acclimation, etc.).

The U.S. Army Natick Research, Development and Engineering Center (Natick), Individual Protection Directorate (IPD) recently developed an overgarment with a quick-doff 70-mil attached permeable hood. A 70-mil standard foam/nylon swatch exhibits some 29.5 $cm^3 \bullet s^{-1} \bullet cm^{-2}$ air permeability compared to a 20.3 $cm^3 \bullet s^{-1} \bullet cm^{-2}$ air permeability value of a standard 90-mil, roughly a 45% increase.

The theory of the function of a more permeable attached hood to the standard 90-mil overgarment stems from the fact that the effective permeation (i_m) specified by the Woodcock (10) non-dimensional factor describing latent heat transfer might increase in respect to a given dry thermal insulation (clo) in accordance to Fick's first law (9).

In previous studies, we have measured water vapor permeation in standard and purported "permeable" overgarments, classified in terms of i_m, both for the UK and our armed services. The permeability is not impressive; values evaluated in still air ($0.3\ m \bullet s^{-1}$) and in $5\ m \bullet s^{-1}$ wind ranged from 0.10 i_m/clo in Polyox/Goretex to a high of 0.27 with meltblown/BDO CB ensembles. However, in one study a prototype 90-mil foam suit, worn in the closed configuration with mask (M-17), butyl hood and gloves, the effect of a 6 mph wind (2.6 $m \cdot s^{-1}$), caused a 22% decrease in dry thermal insulation, an 8% increase in i_m and an overall 45% increase in the i_m/clo values.

Besides the attractiveness of a "quick-don and doff" property for exercising humans, the effects of "exercise pumping" in which wind speed and internal bellows is a prominent factor in the permeation through clothing (3,6). By the latter mechanism, along with the combined effects of convective heat exchange and improved evaporative heat transfer coefficients, a permeable hood attached to a standard 90-mil overgarment might be a useful addition. The i_m/clo would increase enough during continuous moderate activity to attenuate the overall heat strain up to a critical time period greater than that of a completely impermeable suit.

The U.S. Army Research Institute of Environmental Medicine, Military Ergonomics Division conducted a comparison of the physiological and biophysical properties of a prototype overgarment with a "quick-doff" 70-mil attached permeable hood. This study also allowed the comparison of compatible M-40 and M-17 respiratory masks used with the standard 90-mil overgarments and standard butyl rubber hoods.

B. Purpose

The purpose of this study was to evaluate such a prototype uniform by a series of six parametric environmental tests conducted in a climatic chamber under tropical and hot-dry conditions. This study is part of a continuous effort by our Division to test: a) the effective evaporative efficiency in vivo; b) the potential reduction in heat strain as exhibited by changes in the rise of internal body and skin temperature during exercise; and c) to arrive at endurance time (minutes) before heat casualties are discerned (3,7). The latter are generally determined by rectal temperature = 39.4° C (103° F) and/or heart rates above 180 beats/min for 5 continuous minutes.

2. METHODS

a. Subjects. Fourteen, healthy, physically fit male Marines from the 2nd Marine Division, Camp Lejeune, NC or NBC MCAs, Cherry Point, NC served as test volunteers (Table 1). They were informed of the purpose, procedures and risks of the study, and their right to terminate participation at will without penalty. They all expressed understanding by signing a statement of informed consent.

b. Test design. All testing was conducted in a tropic chamber beginning in late September at the U.S. Army Natick, Research, Development and Engineering Center, Natick, Massachusetts. The study lasted one month. This included three weeks of medical evaluation, testing and any time required for make-up. Before the tests, weight, height, skinfold thickness and per cent body fat were measured (Table 1). Maximum aerobic power was assessed in each of the subjects (except for one who had a cold) by conventional methods (4).

On the initial test day, subjects practiced walking on the treadmill in a cool environment (T_a=20° C, 50% rh) in the standard 90-mil chemical protective overgarment without the mask/hood. The test subjects wore shorts, T-shirts, socks and boots. This test day allowed the measurement of metabolic rate which enabled us to determine the exact speed of the treadmill for the test days. During these initial exposures, subjects rested for 10 min and walked on a treadmill by designated group at 1.56 $m \cdot s^{-1}$ (3.5 mph) and 1.1 $m \cdot s^{-1}$ (2.5 mph) on a level mill for 50 min. $\dot{V}O_2$ at end of 2 runs per subject was determined by the Douglas bag technique.

Subjects then underwent 12 days of testing, in order to evaluate the permeable hood attached to the overgarment as well as the standard overgarment system in each of three environments. The environmental conditions are outlined in Table 2. Each test day consisted of an attempt to complete a continuous exercise bout up to 100 min preceded by a 20 min rest period for an overall heat exposure no more than 120 min. Typically, Group I subjects were exposed in the morning (0800 h) and Group II in the afternoon (1300 h) for the first six tests. The order was then reversed. No effect of time of day on rectal temperature was evident (basal T_{re}=37.1° C±0.3 AM and 37.0° C±0.4 PM).

For the purpose of evaluating effects of modified MOPP 4 configuration with the attached 70-mil permeable hood and M-40 respiratory mask or the butyl hood with both the M-40 and conventional M-17 respiratory mask, it was necessary to separate the Marines into two equal groups. Group I was composed of 7 Marines with anthropomorphic characteristics shown in Table 1. This group was more experienced than Group II with 5 of the 7 holding military occupational specialties (MOS) in NBC duties, and 2 others had a MOS of combat engineer and administrative clerk. Group II was composed of a younger age group (Table 1) with 2 of the 7 holding a MOS in NBC and the rest had a variety of duties: artillery, missile gunner vehicle operators. All individuals had extensive NBC training and experience.

During the heat exposures, subjects walked on a level treadmill at a speed (about 1.4 $m \cdot s^{-1}$) which elicited a mean metabolic rate of 473 W. Each subject wore underwear under each designated chemical protective fabric system, in modified MOPP level 4 configuration but without the helmet. This included overgarment, overboots M-40 or M-17 mask with hood and gloves. The clo value (copper manikin) for each configuration was determined in a separate study (Table 4). The overgarment with attached 70-mil permeable hood displayed a clo value of 2.02 and an overall i_m of 0.32 with an i_m/clo value of 0.16. The latter i_m/clo was some 18% higher than the conventional overgarment with butyl hood (i_m/clo of 0.13).

c. Measurements. During all heat exposures, rectal temperature was measured with a thermistor inserted approximately 10 cm beyond the anal sphincter. The electrocardiogram was obtained from chest electrodes (CM5 placement) and displayed on an oscilloscope and cardiotachometer unit. On the test days, we also measured skin temperatures on the chest, arm and leg and with thermocouples (within the hood); these temperatures were used to estimate mean skin temperature (T_{sk}) and vapor pressure at the skin. Additionally, dew point sensors (4,8) were placed within the permeable hood and standard butyl hood configuration in order to measure effective vapor permeation while walking. Pre- and post-exposure nude body weights and clothing weights were measured in order to calculate total body sweating rate ($\dot{m}_{sw}$). All subjects were well-hydrated with 1/2 canteen (0.5 liter) of spring water consumed prior to exercise.

Predicted evaporation (E_v, g/min) through each garment configuration was calculated using the relation

$$E_v = L_a \cdot 6.46 \cdot i_m/\text{clo}\ [A_d/40.8]\ (P_{sk} - P_w), \quad \text{g/min} \qquad (1)$$

where, i_m/clo = the effective Woodcock permeation constant to total clo value (i.e., i_m/I_t) derived from direct copper manikin evaluation;

L_a = the Lewis relation (2.2° C/torr or 16.5 K/kP$_a$);

A_d = the DuBois surface area (m^2)

6.46 = conversion constant clo/($m^2 \cdot K \cdot W^{-1}$)

40.8 = latent heat constant (W•min/g)

(P_{sk}-P_w)= the gradient of saturation vapor pressure at the skin surface (P_{sk}) and water vapor pressure in the ambient air (P_w), (Torr or kPa).

The ratio of E_v to $\dot{m}_{sw}$ was compared for all garment configurations.

d. Environments. Each day the tropic chamber was set for a different environmental condition in a randomized design. Four experiments were run per week with Mondays "off". This prevented excessive fatigue in the subjects, improved morale and allowed adequate drying of the garments. The environmental conditions are shown in Table 2.

e. Maximal aerobic tests. Maximal aerobic power ($\dot{V}O_2 max$) was determined from an intermittent treadmill running test. During these tests expired air was collected in Douglas bags. The volume was measured in a Collins Spirometer and converted to standard environmental conditions (STPD), and the O_2 and CO_2 concentrations were measured with an Applied Electrochemistry Model S-3A O_2 analyzer and Beckman LB-2 infrared CO_2 analyzer. Heart rate was calculated from R-R (ECG) intervals recorded on a Hewlett-Packard Model 1511A Electrocardiograph. All subjects participated in all six environmental tests in each of two configurations. Group I (n=7) was exposed to the above environments while wearing the permeable hood overgarment with M-40 respiratory mask configuration (P-40) and also with the standard overgarment with butyl hood with M-40 respiratory mask (B-40). Group II (n=7) was additionally exposed to the environments in P-40 configuration, but also were exposed to standard butyl hood with the conventional M-17 respiratory mask (B-17).

f. Statistics. For each distinct group the differences between configuration (P-40 or B-40 and P-40 or B-17) of rise in mean body temperature ($\Delta T_b/\Delta t$) per exercise time and endurance time were tested separately for significance by a two-way (configuration x environment) analysis of variance with repeated measures. Cross tabulation or pair-wise comparisons were tested for significance ($p<0.05$) using Tukey's test. In addition, analysis of covariance was run on the change in rectal temperature per time ($\Delta T_{re}/\Delta t$) with T_a varying and relative humidity and wind speed as covariants or alternatively %rh and wind speed varying and T_a or one of the other factors as covariants.

RESULTS

We chose the rise of mean body temperature ($\Delta T_b/\Delta t$) per time as a suitable indicator of the efficacy of reducing heat strain to garment and environment exposure. The mean body temperature (T_b) is a weighted average of rectal temperature (89%) and average skin temperature (11%). Any evaporative cooling possible would be reflected in skin temperature (T_{sk}) and this would thus become evident in the T_b. The T_b was calculated every 30s by regression analysis for each subject's response, averaged by group and converted to °C/h. Additionally, endurance time (min) was used as a marker of heat strain; this indicator is prevalent for limitations owing to severe discomfort, leg cramps, excessive heart rate at 180 beats•min^{-1} or other causes which prevent the subject from completion of the experiment prior to a rectal temperature rise of 39° C (102.2° F) which we used as our limit. This rectal temperature limit was used instead of 39.4° C as a heat casualty limit to help curb excessive fatigue in the Marines brought on by daily exposures.

Group I

Figure 1 shows clearly that a T_a of 32° C, high humidity environment, the 70-mil permeable hood with M-40 mask rendered a higher gain in $\Delta T_b/\Delta t$ compared to the standard overgarment with butyl hood. This elevation in $\Delta T_b/\Delta t$ was especially prominent at the higher wind speeds (5 m•s^{-1}) at 32° C and at 35° C, 50% rh. In the 35° C, 50% rh, low wind speed tests and the 43° C, 20% rh low and high wind speed tests, equivalent effects on the $\Delta T_b/\Delta t$ were evident. In these environments the deduction is that no one garment configuration is more efficacious than another within each heat stress condition.

Analysis of variance due solely to the effect of environment (Figure 2) on $\Delta T_b/\Delta t$ with each constant garment configuration showed that: a) with the 70-mil permeable hood and M-40 configuration, the less strenuous environment was 35° C/50% rh/5 $m \cdot s^{-1}$ followed by 32° C/80% rh/1 $m \cdot s^{-1}$, 35° C/50% rh/1 $m \cdot s^{-1}$ and 43° C/20% rh/1 $m \cdot s^{-1}$; b) with the butyl hood, M-40 overgarment configuration, less heat strain ($\Delta T_b/\Delta t$) was found in 32° C/80% rh/1 $m \cdot s^{-1}$, 32° C/80%/5 $m \cdot s^{-1}$ and 35° C/50%/5 $m \cdot s^{-1}$ environments.

Figure 2 shows that there were no significant differences between P-40 or B-40 configurations in the 32° C/80% rh and 35° C/50% rh at each wind speed. At 43° C/20% rh with lower wind speed, there was a significantly lower maximum endurance time (50.4±2.6 min) with the butyl rubber hood/M-40 overgarment configuration compared to the P-40 (76.4±11.7 min).

One prominent feature evident in Figure 2 is the overall higher maximum endurance times of the Marines with each type of overgarment configuration over the environmental heat stress and exercise intensity (473 W or 4.7 mets). Previous studies (1,3,7) and a heat stress predictive model analysis (2,5) estimated some 38 to 45 minutes of continuous work at this metabolic level and at comparable environmental stress before 50% heat casualty levels. These results possibly indicate the extent of subject training and/or motivation. Analysis of variance due solely to the environmental heat stress showed that: a) with the 70-mil permeable hood and M-40 configuration a higher endurance time ($p<0.05$) occurred in the 35° C/50% rh/5 $m \cdot s^{-1}$ compared to 32° C/80% rh/1 $m \cdot s^{-1}$ environment; b) with the butyl hood and M-40 configuration, the higher endurance times were at 35° C/50% rh/5 $m \cdot s^{-1}$ > than 35° C/50% rh/1 $m \cdot s^{-1}$ and 43° C/20% rh/1 $m \cdot s^{-1}$.

<u>Group II</u>

This team comprised subjects who were tested with the permeable hood with M-40 and the butyl hood with the M-17 configuration (i.e., conventional configuration). Analysis of variance with repeated measures on the $\Delta T_b/\Delta t$ between garments at each environment (Figure 3) showed no statistically significant differences attributed to efficacy of one configuration over the other in all environments. Analysis of variance due solely to the environmental heat stress indicated that: a) with the permeable hood/M-40 configuration, $\Delta T_b/\Delta t$ was less ($p<0.05$) in the 35° C/50%/5 $m \cdot s^{-1}$ environment compared with the 43° C/20% rh/1 $m \cdot s^{-1}$ environment; b) with the butyl hood/M-17 configuration, $\Delta T_b/\Delta t$ was less in the 32° C/80% rh/5 $m \cdot s^{-1}$ compared to the 32° C/80% rh/1 $m \cdot s^{-1}$, 35° C/50% rh/1 $m \cdot s^{-1}$ and 43° C/20% rh/1 $m \cdot s^{-1}$ environments.

Figure 5 shows the results of maximum endurance time for Group II data. There was no significant effect of garment type on maximum endurance times with each specific heat stress condition. However, effect of environment or endurance times were significantly different within each garment configuration ($p<0.05$). In summary:

a) with the permeable hood/M-40 configuration;

T_a °C	rh %	wind speed $m \cdot s^{-1}$		T_a °C	rh %	wind speed $m \cdot s^{-1}$
32	80	1	>	43	20	5
32	80	5	>	43	20	5
35	50	1	>	43	20	5
35	50	5	>	43	20	5

b) with the butyl hood/M-17 configuration;

T_a °C	rh %	wind speed $m \cdot s^{-1}$		T_a °C	rh %	wind speed $m \cdot s^{-1}$
32	80	5	>	32	80	1
			>	35	50	1
			>	35	50	5
			>	43	20	1
			>	43	20	5

Analysis of covariance (ANCOVA). Because of the possibility that specific garment configuration was modifying physiological responses unequally by one environmental factor over another, an analysis of covariance (ANCOVA) was run on the data for changes in rectal temperature per time ($\Delta T_{re}/\Delta t$) which reflects heat storage solely without complications of the skin cooling. In other words, differences in the $\Delta T_{re}/\Delta t$ will be accounted for in respect to garment configuration after accounting (holding constant) for the effects of any specific covariants. Table 3 gives a summary of the ANCOVA analysis.

In general, the results of the analysis confirmed the fact that the rise in body temperature per time during the exercise was significantly lower (except for the highest air temperature) with the butyl hood/M-40 mask configuration in Group I. As would be expected, the effect of elevated T_a increases the gain in heat storage, and generally the effect of elevated wind speed reduces gain in $\Delta T_{re}/\Delta t$ coupled perhaps with any exercise "pumping effect" (6). In Group II, $\Delta T_{re}/\Delta t$ with the P-40 configuration was significantly lower than the conventional overgarment with butyl hood and M-17 mask in only three circumstances (Table 3): a) when effect of % rh (most likely due to ambient water vapor pressure) and wind speed are not separate factors, $\Delta T_{re}/\Delta t$ was lower at T_a of 35° C; b) when effect of environmental temperature and wind speed are not coupled forcing factors, $\Delta T_{re}/\Delta t$ was lower at 50% rh; c) and when environmental temperature and % rh (vapor pressure most likely) are held constant, $\Delta T_{re}/\Delta t$ was lower at wind speed of 1 $m \cdot s^{-1}$.

In general, use of a 70-mil permeable hood integrated to a standard overgarment gave no significant advantages compared to a standard OG in improvement in vapor permeation to a given clo insulation with, at most, only 10-12% $>E_v/\dot{m}_{sw}$ at high air movement ($P<0.05$) (Figure 5).

DISCUSSION

Static copper manikin evaluations at 0.3 $m \cdot s^{-1}$ wind speed, which were run in unison with this study, showed that there is a slight increase (some 16%) in the evaporative potential of the prototype 70-mil attached permeable hood configuration compared to standard overgarment configuration.

Table 4 is a composite of these values in comparison with other overgarments. The results of the physiological evaluation provided a less provocative impact of the permeable hood in reducing heat strain. More interesting was the responses of the subjects with the butyl hood/M-40 respiratory mask which, to our knowledge, is the first study to focus on such configuration. As the results show, this latter overgarment configuration provided the greatest overall decrease in heat strain as apparent from the differences in $\Delta T_b/\Delta t$, maximal endurance times and covariance analysis of $\Delta T_{re}/\Delta t$ (heat storage) in all environments.

Several reasons are apparent why a semi-permeable hood attached to a 90-mil overgarment is not overly efficacious in reducing heat strain. One reason is that the thickness of the 70-mil attachment is still too large, compared to the conventional butyl hood, and thus excessive thermal resistance to heat transfer occurs (i.e., 4 clo/inch). We measured the thicknesses of both hoods in multiple garments that were used. The butyl hood was about nine times less thick. Sufficient sensible heat flux down a temperature gradient when ambient temperature is lower than head skin temperature is thus not favored with the 70-mil attached hood, as is apparent in Figure 5.

Additionally, there is only a small driving force for insensible heat loss when the humidity is high (inside the hood), due to excessive skin wettedness (induced by thermal sweating) and the outside of the hood when a critical ambient water vapor pressure ($P_w \geq 20$ Torr) is reached (Table 3).

As shown in this study, elevated wind speed reduced heat strain exhibited by $\Delta T_b/\Delta t$ and improved maximal endurance time in many of the experiments. This is expected by the accompanied increase in convective heat transfer coefficient which thus potentiates dry heat exchange over each overgarment configuration especially at or below 35° C. The effects of exercise pumping properties also may play a part in the improvement of heat strain (6). However, any improvement of evaporative heat transfer through the attached hood by such a pumping coefficient, due to metabolic activity, is mutually incompatible with protection against chemical agents which would use similar entry ways rendered by any bellows mechanism.

Although carbon-lined hoods offer optimal chemical protection for the head region, the use of a butyl hood with the M-40 mask suggests a preferable heat transfer option because of the reduced thickness of the hood (about 9 times less than the permeable hood) which offers an augmented i_m/clo with high wind speeds. A more useful alternative to consider in further studies might be the effectiveness of a wettable cover over the attached hood with overgarment configuration. Breckenridge (2) and others (5) showed the improvement in heat exchange provided by such a cover over conventional CB overgarments in diverse environments.

SUMMARY

In summary, use of the 70-mil permeable attached hood to a 90-mil overgarment gave no decided advantage in heat strain compared to the standard MOPP 4 configuration as determined by rise in mean body temperature per exercise time ($\Delta T_b/\Delta t$) and maximum endurance time before pull-out due to rectal temperatures $\geq$39° C or heart rates $\geq$180 b•min^{-1}. In fact, the use of the butyl hood with the M-40 mask is probably a preferable option because of the reduced thickness of the hood (some nine times less than the permeable hood) which offers the advantage of an augmented i_m/clo with high wind speed when sensible heat

loss is not possible (as in the case where $T_{sk}=T_a=35°$ C). This option would be further reduced by wearing of a helmet with each ensemble.

Recommendation. This study was limited to physiological responses in a laboratory study during continuous work activity. Additional studies designed to ascertain the extension of physiological tolerance, wear evaluation, and improved head comfort at various other environments might be helpful prior to any adoption of a prototype attached permeable hood as a suitable chemical protective overgarment. One option is the use of a wettable cover over the permeable hood and the overgarment. This study discounts any useful reduction in physiological heat strain benefits of the present overgarment configuration with a singular attachment hood with thickness greater than 6.4 mm (e.g., 1.57 clo/cm).

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DISCLAIMER

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Table 1: Physical Characteristics of Subjects Means ±SD.

Subjects	AG (yr)	HEIGHT (cm)	WEIGHT (kg)	SURFACE AREA (m^2)	BODY FAT (%)	$\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)	HRmax ($beats \cdot min^{-1}$)
GROUP I	24.4*	177.1	79.1	1.96	18.8	48.7	202
(n=7)	(3.0)	(4.9)	(8.5)	(0.10)	(5.2)	(7.5)	(8)
GROUP II	21.6*	171.3	76.2	1.89	17.8	52.2	206
(n=7)	(1.5)	(6.3)	(9.7)	(0.14)	(4.4)	(6.2)	(8)

*$p<0.04$; Grp I range 20-28; 5/8 $\geq$ 24 years; all other physical factors NS
Grp II range 20-24; 1/8 $\geq$ 24 years.

Table 2: Environmental Conditions

	T_a(° C)	(° F)	rh%	P_w(Torr)
ENV I	32	89	80	28.5
vel = 1 $m \cdot s^{-1}$				
vel = 5 $m \cdot s^{-1}$				
ENV II	35	95	50	21.1
vel = 1 $m \cdot s^{-1}$				
vel = 5 $m \cdot s^{-1}$				
ENV III	43	109	20	13
vel = 1 $m \cdot s^{-1}$				
vel = 5 $m \cdot s^{-1}$				

Table 3: Effect of specific garment configuration on $\Delta T_{re}/\Delta t$ (°C/h)

Variable	Group I (n=7)			Group II (n=7)		
	rh and wind as covariants			rh and wind as covariants		
T_a	P-40	B-40	lower slope	P-40	B-17	lower slope
32	2.15	1.45[a]	* B-40	1.85	1.84[a]	NS
35	2.12	1.64	* B-40	1.68[a]	2.06	*P-40
43	2.01	2.18[a]	NS	2.09[a]	2.20[a]	NS
	T_a and wind as covariants			T_a and wind as covariants		
rh%						
20	2.01	2.18[a,b]	NS	2.31[a]	2.20[a]	NS
50	2.12	1.64[b]	* B-40	1.68[a]	2.06	*P-40
80	2.15	1.45[a]	* B-40	1.85	1.84[a]	NS
	T_a and %rh as covariants			T_a and %rh as covariants		
wind speed ($m \cdot s^{-1}$)						
1	2.24[a]	1.91[a]	* B-40	1.91	2.34[a]	*P-40
5	1.95[a]	1.61[a]	* B-40	1.84	1.73[a]	NS

* between garment configuration ($p<0.05$)

[a] within garment configuration and specific variable (all others constant) difference ($p<0.05$)

[b] significantly lower within garment configuration from 20% rh but not 80% rh

Table 4: Evaluation of CP Overgarment Properties on a Static Copperman

	clo	i_m	i_m/clo
NATO			
a. French integrated hood	2.57	.33	.13
b. UK integrated hood - closed	2.27	.32	.14
c. Netherlands integrated hood - closed	2.49	.27	.11
d. US standard without hood - open	2.24	.35	.16
US standard - closed	2.55	.28	.11
US Permeable Hood			
a. Battle Dress Overgarment with Permeable Hood (70-mil)	2.01	.32	.16
b. Standard Battle Dress Uniform with Impermeable Hood (90-mil)	2.01	.27	.13
Vapor Permeable			
a. Battle Dress Uniform (standard)	1.49	.39	.26
b. Battle Dress with standard rainsuit	2.00	.22	.11
c. Battle Dress with * MVT $450 g \cdot m^{-2} \cdot 24 h^{-1}$ PTFE rainsuit	1.89	.37	.20

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* MVT is moisture vapor transmission based on American Society of Testing Materials (ASTM) guidelines.

FIGURE LEGENDS

Figure 1. Changes in mean body temperature per exercise time (°C per hour) observed in Group I (n=7) Marines exposed to the respective environments at two wind speeds (V=1 m/s and 5 m/s). This group wore the attached permeable hood with M-40 mask (PH) and a standard overgarment with butyl rubber hood and M-40 mask (BH). Asterisks depict significant differences in mean responses to the rise in mean body temperature between the two configurations.

Figure 2. Maximal endurance time (min) of Group I to the heat stress exposure while wearing the overgarment configurations described for Figure 2. Heavy horizontal bar depicts expected time for 50% heat casualties from prediction analysis.

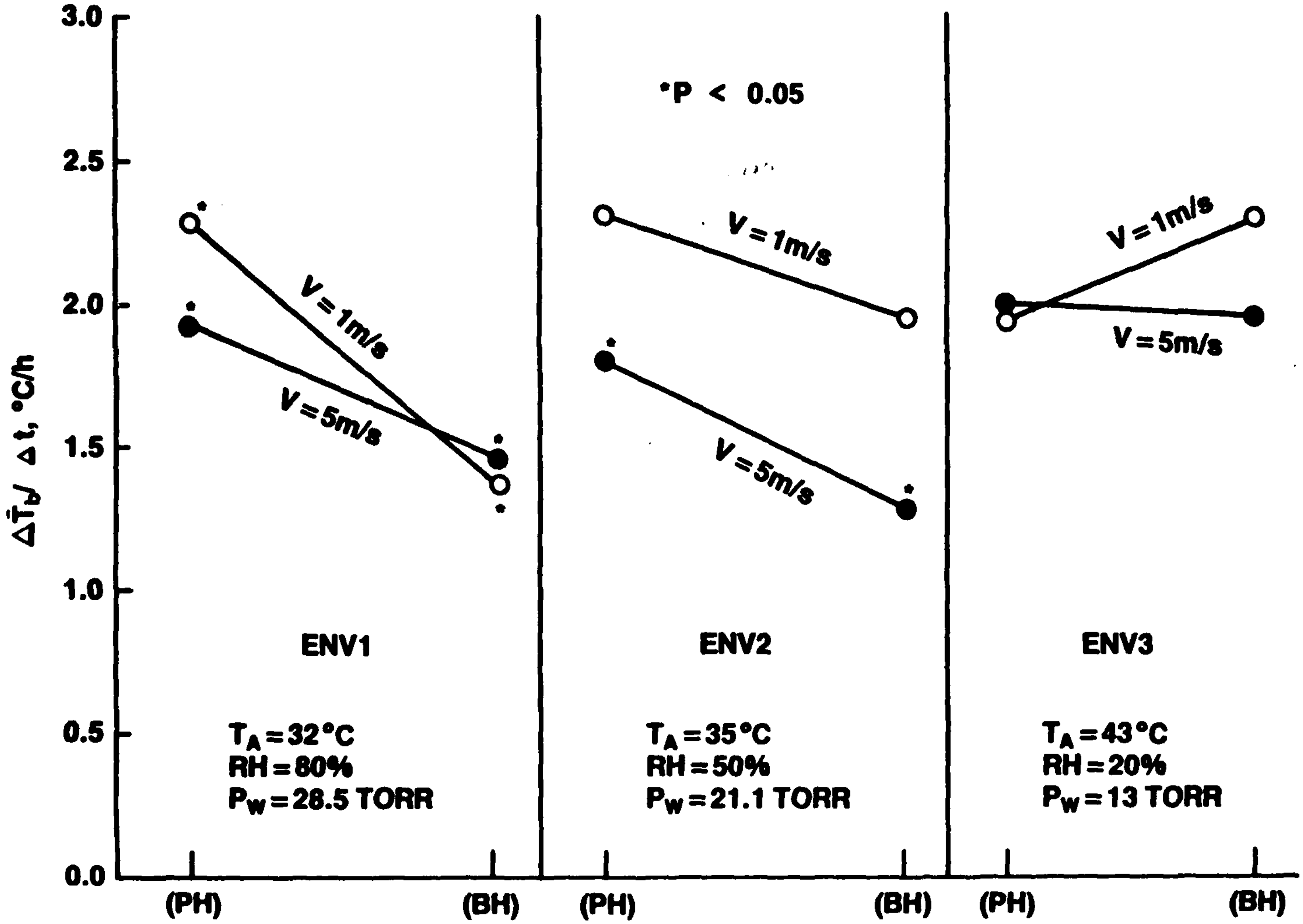
Figure 3. Changes in mean body temperature per exercise time observed in Group II Marines. This group wore the attached permeable hood with M-40 mask (PH) but a standard overgarment with butyl rubber hood and M-17 mask (BH). NS signifies non-significant differences in mean responses to the rise in mean body temperature between the two configurations.

Figure 4. Maximal endurance time (min) of Group II to the heat stress exposure while wearing the overgarment configurations described for Figure 3.

Figure 5. The ratio of predicted E_v (from Eq. 1) to $\dot{m}_{sw}$ compared for all garment configurations and environmental exposures. The asterisk (*) indicates a significantly higher value ($P<0.05$) of the P-40 configuration at 43°C/20% rh/5 $m \cdot s^{-1}$ wind compared to the other environments with the same configuration.

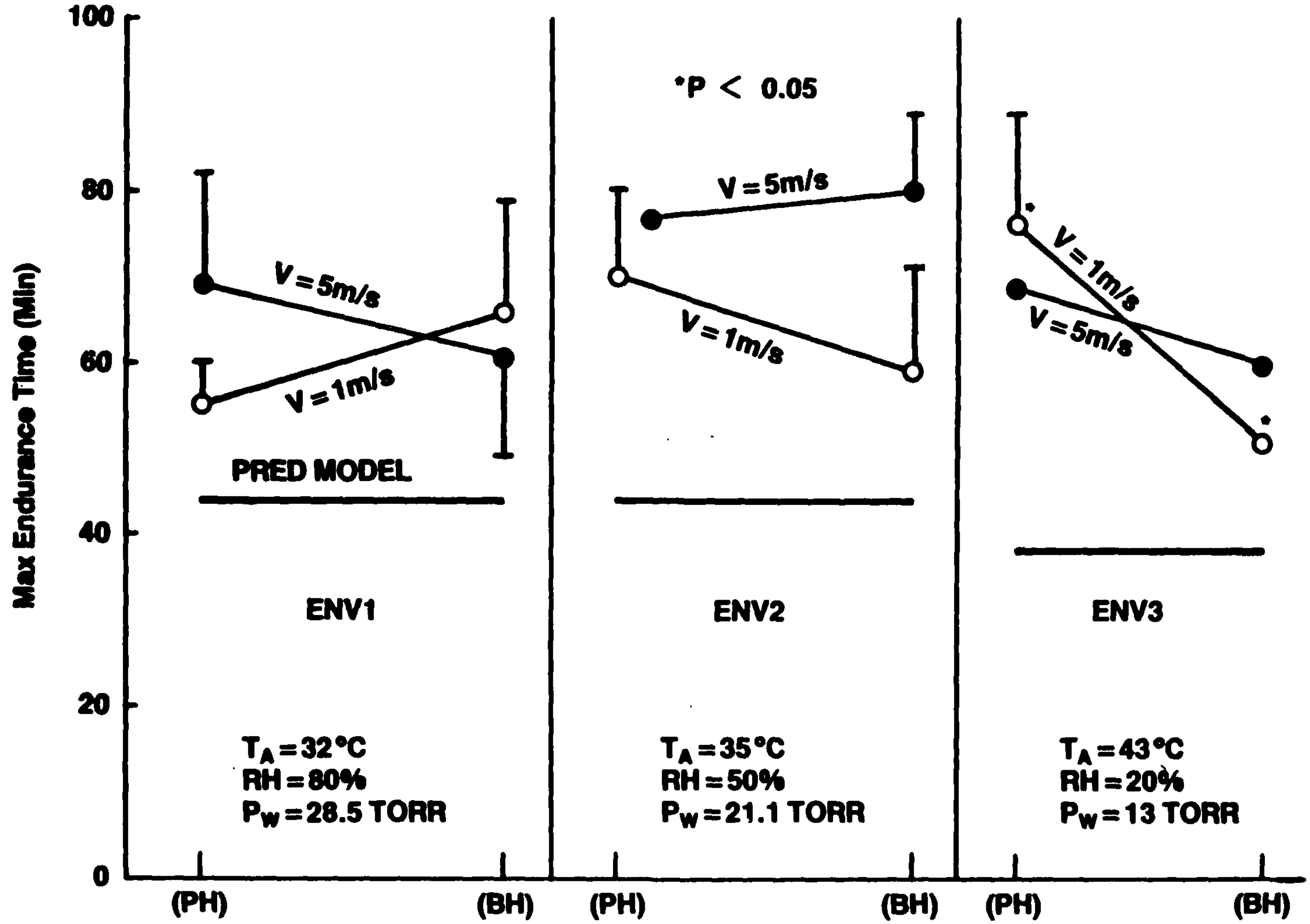
GROUP I MOPP4, 1.35 LO_2/MIN, 473 WATTS

M-40 MASK



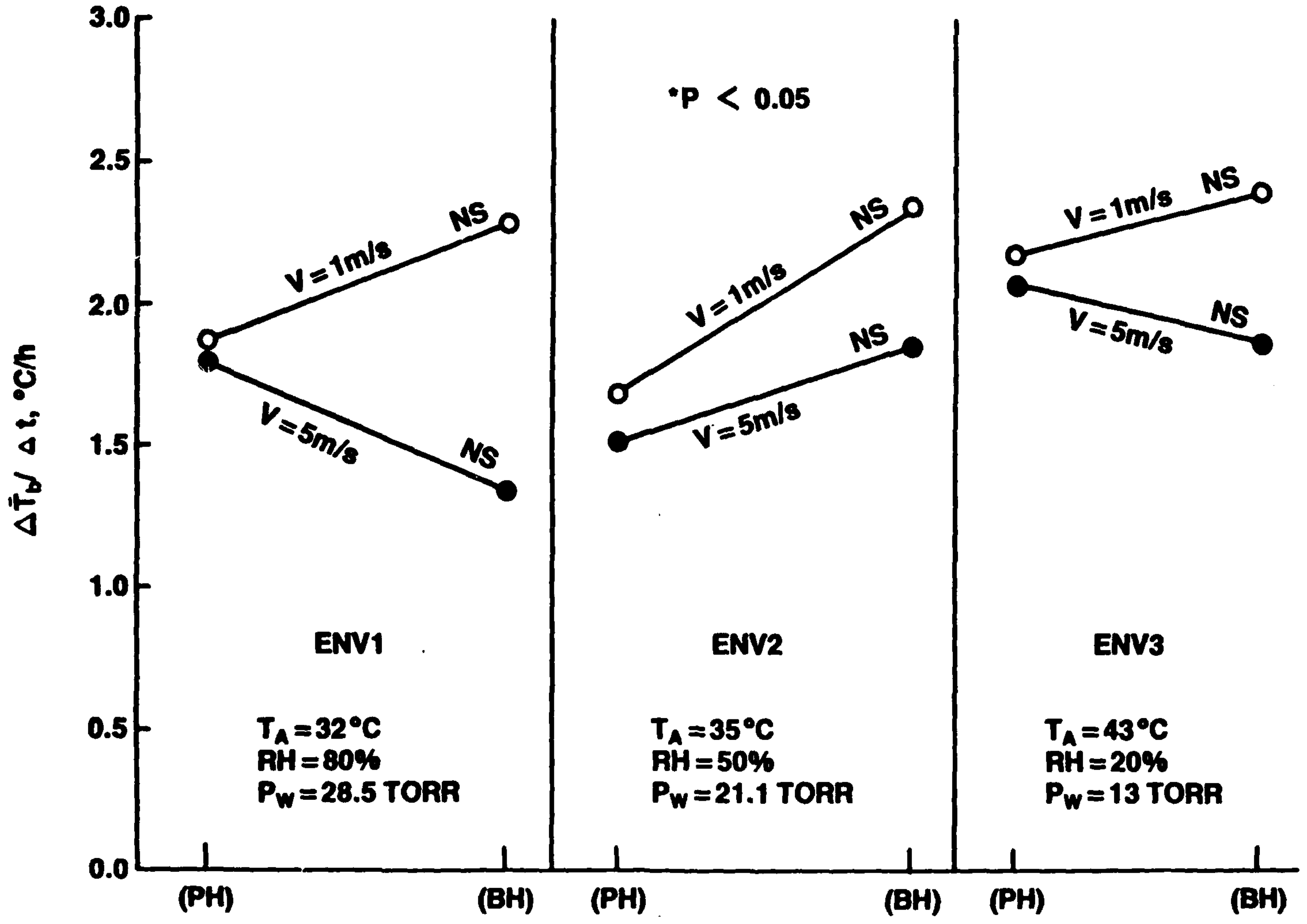
GROUP I(N = 7) MOPP4, 1.35 LO_2/MIN, 473 WATTS

M-40 MASK



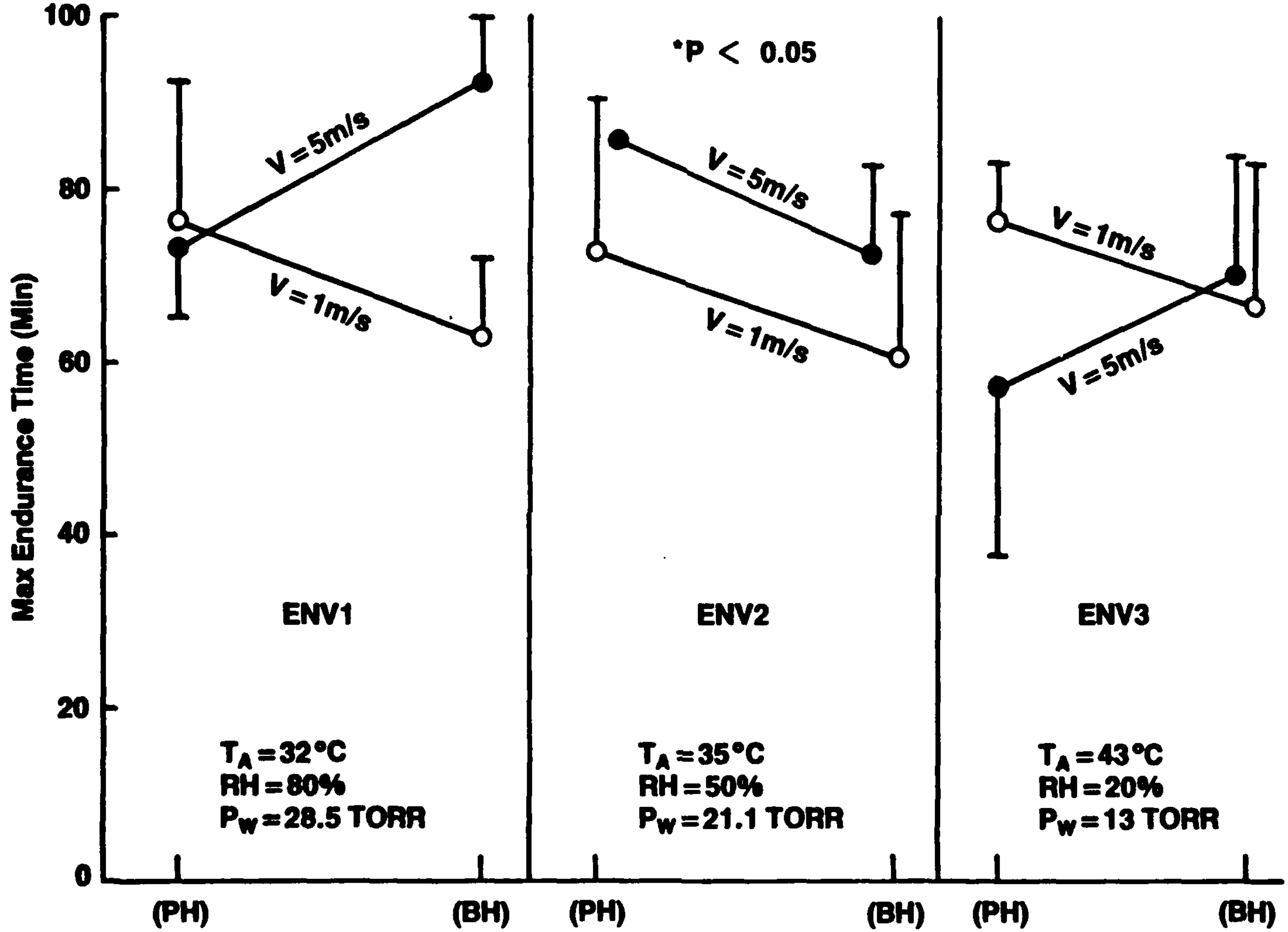
GROUP II(N = 7) MOPP4, 1.35 LO_2/MIN, 473 WATTS

VARIABLE MASKS

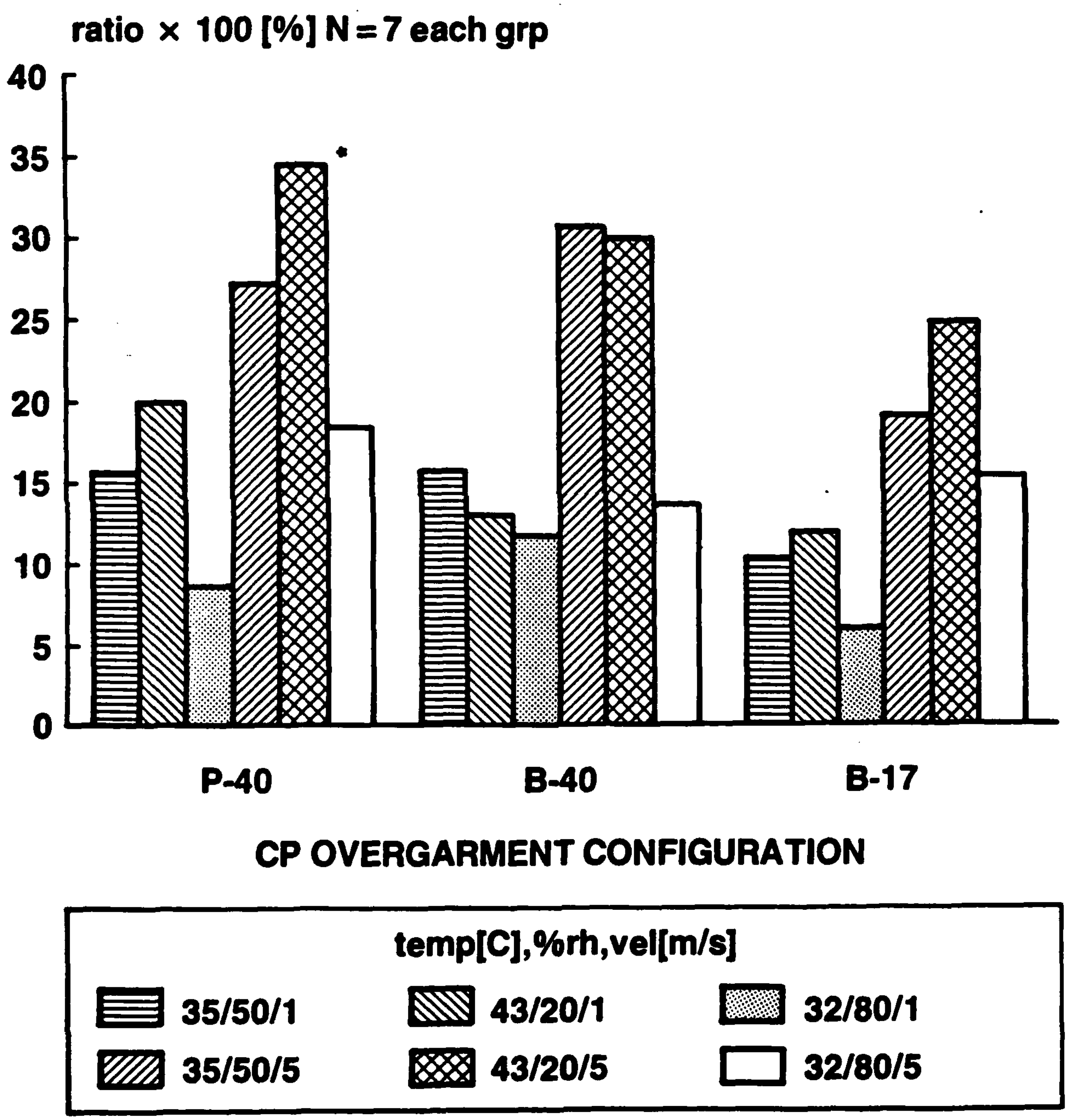


GROUP II(N = 7) MOPP4, 1.35 LO_2/MIN, 473 WATTS

VARIABLE MASKS



EV/SW PROD
Perm vs Butyl Hood



EV = La · 6.46 {Ad/40.8} [Psk-Pw} im/clo