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PHYSIOLOGICAL EVALUATION OF THE RACAL PUSHER FAN IN 0, 20, AND 40 ^{o}C ENVIRONMENTS

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The RACAL Pusher Fan attached to C2 canister on M40 NBC Respirator (mask) was evaluated in MOPP IV. RACAL use was intended to reduce physiological burden via improvement in pulmonary function, physical performance, and thermal comfort. Twelve males and three females, 19-25 years old, exercised at 20 °C or 0 and 40 °C at 3 mph and 0° grade on a treadmill for two 50-min periods, separated by 10-min rest. Results show limited significant physiological advantages using RACAL. Heart rate changes were not consistent. RACAL appears to lower inhalation resistance without changing exhalation resistance. RACAL produced no decrease in rectal temperature or thermal stress and no increase in total test time. However, RACAL warmed mask inlet air temperature at 0 °C and cooled it at 20 °C. No frostbite resulted at 0 °C. Via a questionnaire, volunteers rated speaking, hearing, and vision unchanged using RACAL. They judged RACAL airflow satisfactory. Based on these results, RACAL does not offer substantial benefits to soldiers wearing M40 protective respirator in MOPP IV ensemble.

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PREFACE

The work described in this report was authorized under Project No. 10162622A553D, Individual Protection. This work was started in April 1991 and completed in October 1991.

In conducting the research described in this report, the investigators adhered to Army Regulation 70-25, Research and Development -- Use of Volunteers as Subjects of Research, dated 25 January 1990, as promulgated by the Office of the Surgeon General, Department of the Army. The use of human volunteers was approved by the Human Use Committee of the U.S. Army Chemical Research, Development and Engineering Center (CRDEC) (Protocol No. 9101S).

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This report has been approved for release to the public.

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*When this work was performed, ERDEC was known as CRDEC, and the authors were assigned to the Physical Protection Directorate.

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PHYSIOLOGICAL EVALUATION OF THE RACAL PUSHER FAN IN 0, 20, AND 40 °C ENVIRONMENTS

1. INTRODUCTION

The U.S. Marine Corps requested the U.S. Army Chemical Research, Development and Engineering Center (CRDEC) perform a laboratory evaluation of the RACAL Pusher Fan attached to the C2 canister on the M40 NBC Respirator. The primary reason for using the RACAL Pusher Fan with M40 protective respirator is reduction in physiological burden while in mission oriented protective posture level IV (MOPP IV) ensemble. This reduction would result from improvement in pulmonary function, physical activity performance, and thermal comfort. The purpose of this study was to compare the physiological and psychological responses with and without the pusher fan in a 2-hr exercise/rest scenario. A volunteer questionnaire was used to obtain subjective advantages and disadvantages associated with the pusher fan. The study was conducted at the Advanced Protection Systems Integration Laboratory (APSIL), Aberdeen Proving Ground (Edgewood Area), MD. The protocol for this study was approved by the CRDEC Human Use Committee (Log No. 9101S).

2. METHODS

2.1 Volunteers.

Fifteen volunteers, 12 males and 3 females, 19-25 yrs old successfully completed the study. Five males and 3 females were university students. Two males were civilian personnel employed at the Edgewood Area of the Aberdeen Proving Ground and 5 males were enlisted Marines from Camp Lejuene, NC. Each volunteer passed a comprehensive physical examination by an independent contractor medical service prior to study acceptance. Volunteer characteristics are shown in the Table.

2.2 RACAL Pusher Fan.

The RACAL (Racal Health and Safety, Inc., Frederick, MD) is a commercial respirator pusher fan. The RACAL pusher fan attaches to the C2 canister of the M40 respirator by means of a flexible rubber collar that fits snugly on the canister. The blower is powered by a rechargeable NiCad battery that drives the pusher fan at rated airflow for 8-12 hr, supplying about 30 L/min airflow to the volunteer in the M40-C2 configuration. The RACAL pusher fan collar is 11 cm diameter by 3.5 cm deep, motor-blower assembly is 6 cm diameter by 7 cm deep, and the overall assembly is 17 cm long and weighs 235 gm. The power supply which attaches to the user's belt is 7.5 x 10.5 x 4 cm and weighs 400 gm.

Table. Physical Characteristics of the Volunteers in RACAL Evaluation Study

Volunteer No.	Sex	Age (Yr)	Weight (Kg)	Height (Cm)
1	M	19	71.8	168
2	M	19	97.0	193
3	F	21	56.8	160
4	M	24	59.3	166
5	F	19	59.1	165
8	M	23	70.8	185
9	M	24	90.5	180
10	M	22	79.1	174
11	M	20	85.9	183
12	F	22	50.5	170
13	M	21	83.6	178
14	M	25	62.3	168
15	M	22	84.1	183
16	M	22	88.4	203
17	M	20	89.8	178
X ± SD:		22 ± 2	75.3 ± 14.7	177 ± 12

2.3 Measurements.

Heart rate (HR) was determined from the electrocardiogram (ECG) which was monitored continuously using either a Quinton model Q3000 monitor or an ECG amplifier (Gould Incorporated, model 13-4615-65 Biotach) with HR digital readout (Weston, model 2460). The ECG lead II configuration was used employing standard adhesive-backed electrodes for stress testing.

Pressure within the nosecup of the M40 respirator was measured with a variable reluctance differential pressure transducer having a 0-50 cm H_2O range (Celesco, model LCVR).

Rectal temperature (T_{REC}) was monitored continuously by a rectal temperature probe [Yellow Springs Instrument (YSI) model 401], inserted approximately 10 cm past the anal sphincter.

Inlet air temperature (T_{IA}) was measured using a thermistor (YSI model 44033) located on the inside surface of the M40 respirator near the face immediately below the left eye.

Chamber air temperature (T_{AMB}) was measured using an air temperature probe (YSI model 405) in close proximity to the volunteer exercising on the treadmill.

The volunteer, dressed in undergarments, military battle dress uniform (BDU), and MOPP IV ensemble with the M40 respirator, was weighed immediately prior to and after completion of each test. In addition, the military ensemble worn by the volunteer was weighed separately, both prior to and after test completion. Weighing was made on a Potter Model 33B Patient Weight Monitor. The volunteer's evaporative and total water losses were calculated for each temperature/stress exposure.

Each volunteer filled out a questionnaire at the completion of each test, in order to provide psychological data for comparing subjective advantages and disadvantages of wearing the M40 Respirator in MOPP IV ensemble with and without the RACAL pusher fan. The questions address areas of breathing and thermal comfort, heat tolerance, and hearing and vision effects. Each volunteer weighed specific responses on a scale of 1-7 for quantitative evaluation.

2.4 Experimental Procedure.

Volunteers, dressed in BDU and MOPP IV ensemble, were tested wearing the M40 respirator and C2 Canister with and without the attached operating RACAL Pusher Fan, the latter as control. Volunteers were exposed to three temperature environments (0, 20, and 40 °C), volunteers 1-5, 8, and 9 to 20 °C and volunteers 10-17 to both 0 and 40 °C. Exercise was performed on a motor-driven treadmill (Quinton, model Q65) for a maximum 2-hr period at each temperature. They walked at 3.0 mph on a level (0° grade) treadmill with a wind velocity of $\leq$5 mph for a 50-min period, followed by a 10-min rest and a second 50-min exercise period. The duration of exercise was limited by the time period required for the volunteer's core temperature to increase by 1.5 °C from his/her resting temperature. Each volunteer was hydrated with fluids by drinking up to one/half liter of water prior to test commencement.

Prior to beginning the exercise tests, each volunteer stood on the stationary treadmill and his/her preexercise physiological functions were measured for a 4-min period. The first exercise then started (up to 50 min), followed by a 10-min midrest. The second exercise period (up to 50 min) commenced, followed by a postexercise 4-min rest period. Physiological measurements were taken every minute over the test duration.

2.5 Data Analysis.

The data acquisition system read the data for 35 sec during each 1-min period over the test duration. The readings were averaged over each 35-sec period to give a single value for each 1-min period for each physiological function. Individual data were obtained for five exercise periods [i.e., preexercise

(PreE), first exercise (1stE), midrest (MidR), second exercise (2ndE), and postexercise (PostE)]. Data were analyzed using the two-factor analysis of variance (ANOVA), with significance at $p < 0.05$. A repeated measures multivariate analysis was performed on the physiological data to determine interaction effects of test temperature (0, 20, and 40 °C) and exercise for the two RACAL conditions. The ANOVA with multi-variate analysis was done on the volunteer psychological data with and without RACAL across test temperatures.

The data analysis examined the two exercises (1stE and 2ndE) and the midrest (MidR) period and compared using the operating RACAL pusher fan attached to the M40 C2 canister to not using the pusher fan (i.e., M40 mask with C2 canister alone).

3. RESULTS

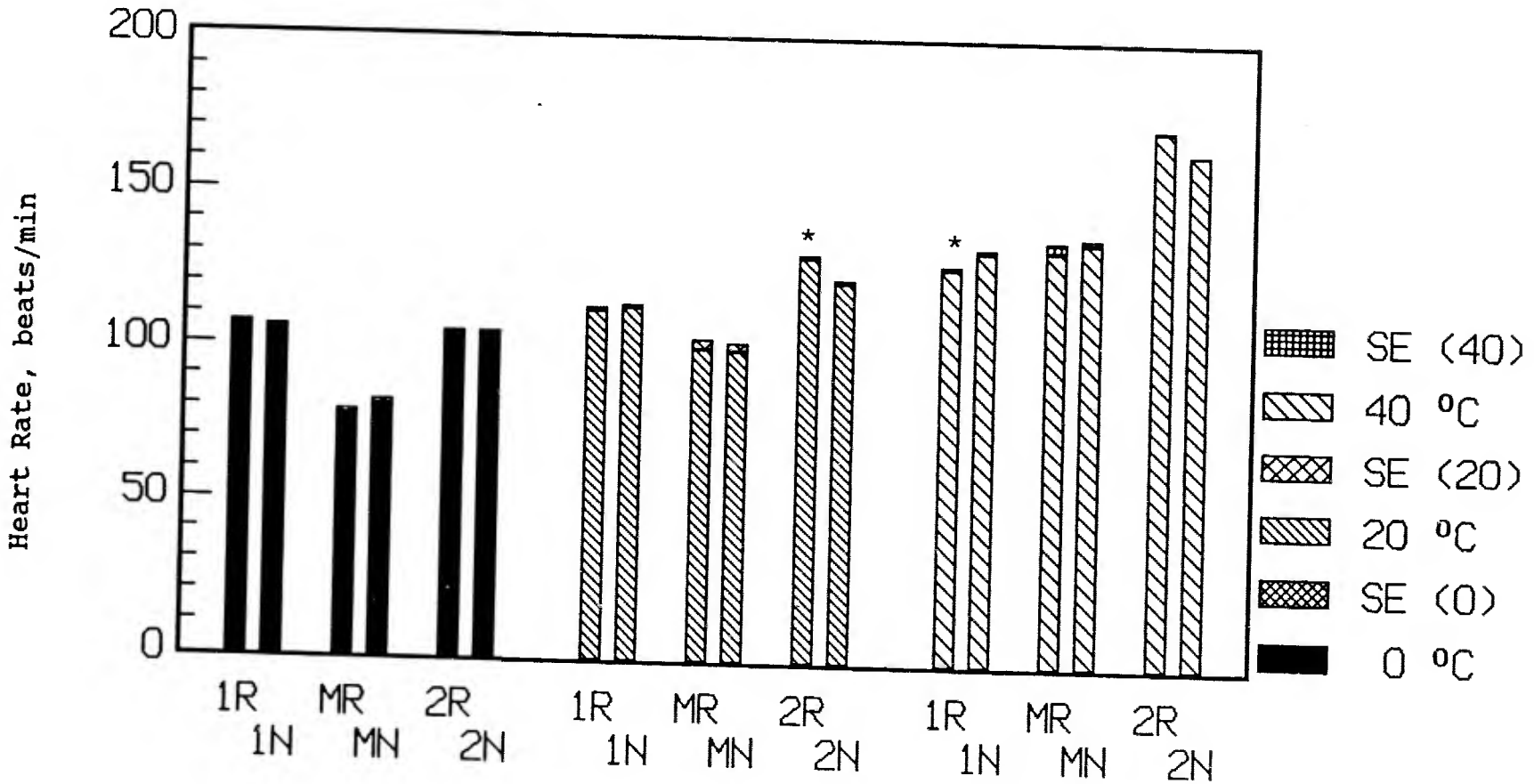
3.1 Physiological Evaluation.

Heart rate (HR, beats/min) during 1stE at 40 °C was significantly lower with RACAL compared to without the pusher fan (mean HR from 132 to 127 b/m), with no changes at 0 and 20 °C. During 2ndE, HR was significantly higher at 20 °C (mean HR from 122 to 130 b/m), with no changes at 0 and 40 °C (Figure 1).

Maximum mask pressure (MSK_{MAX}, mm Hg) increased significantly during 1stE at 0 °C, decreased significantly at 40 °C, and had no change at 20 °C with vs. without RACAL. No changes occurred during 2ndE. During MidR, MSK_{MAX} increased significantly with RACAL at 20 °C. Minimum mask pressure (MSK_{MIN}, mm Hg) showed significant improvements (less negative values) during 1stE and MidR at 0, 20, and 40 °C with vs. without RACAL; similar improvements occurred during 2ndE, except for no change at 40 °C (Figure 2).

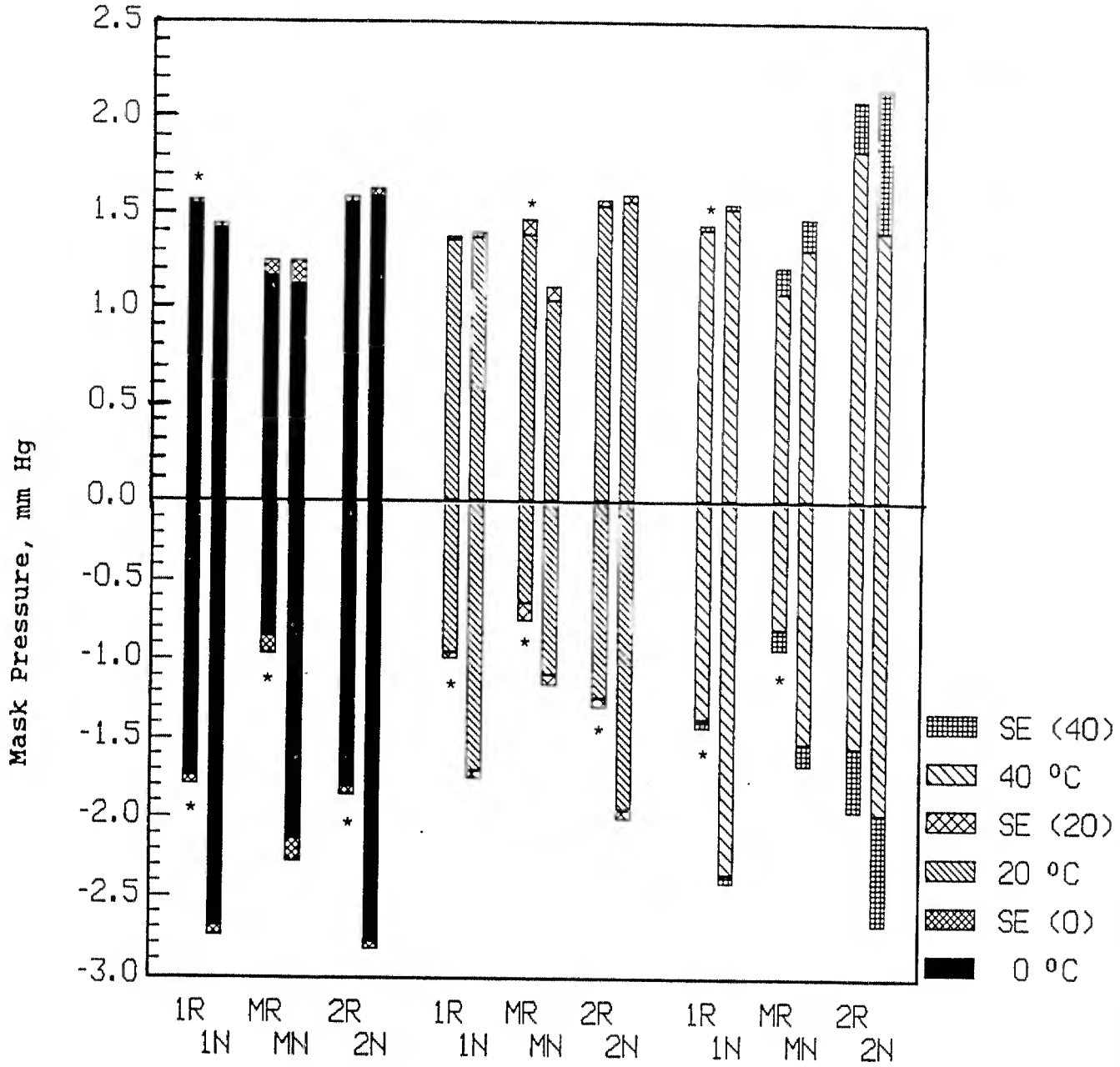
Rectal temperature (T_{REC}, °C) was analyzed both for volunteer temperature at preexercise ($T_{RECINIT}$) and for change in temperature during each temperature/stress exposure (ΔT_{REC}). No changes in $T_{RECINIT}$ were observed for all temperatures with vs. without RACAL. Although no differences in ΔT_{REC} resulted at 0, 20, or 40 °C with vs. without RACAL, a significant increase in the change in rectal temperature occurred both with and without RACAL for increasing test temperatures (40 °C > 20 °C > 0 °C) (Figure 3).

The total test time which includes 1stE, MidR, and 2ndE, was analyzed for test temperatures and RACAL use. Although no differences in total test time resulted at 0, 20, or 40 °C with vs. without RACAL, a significant decrease occurred both with and without RACAL for 40 °C compared to 0 and 20 °C (Figure 4).



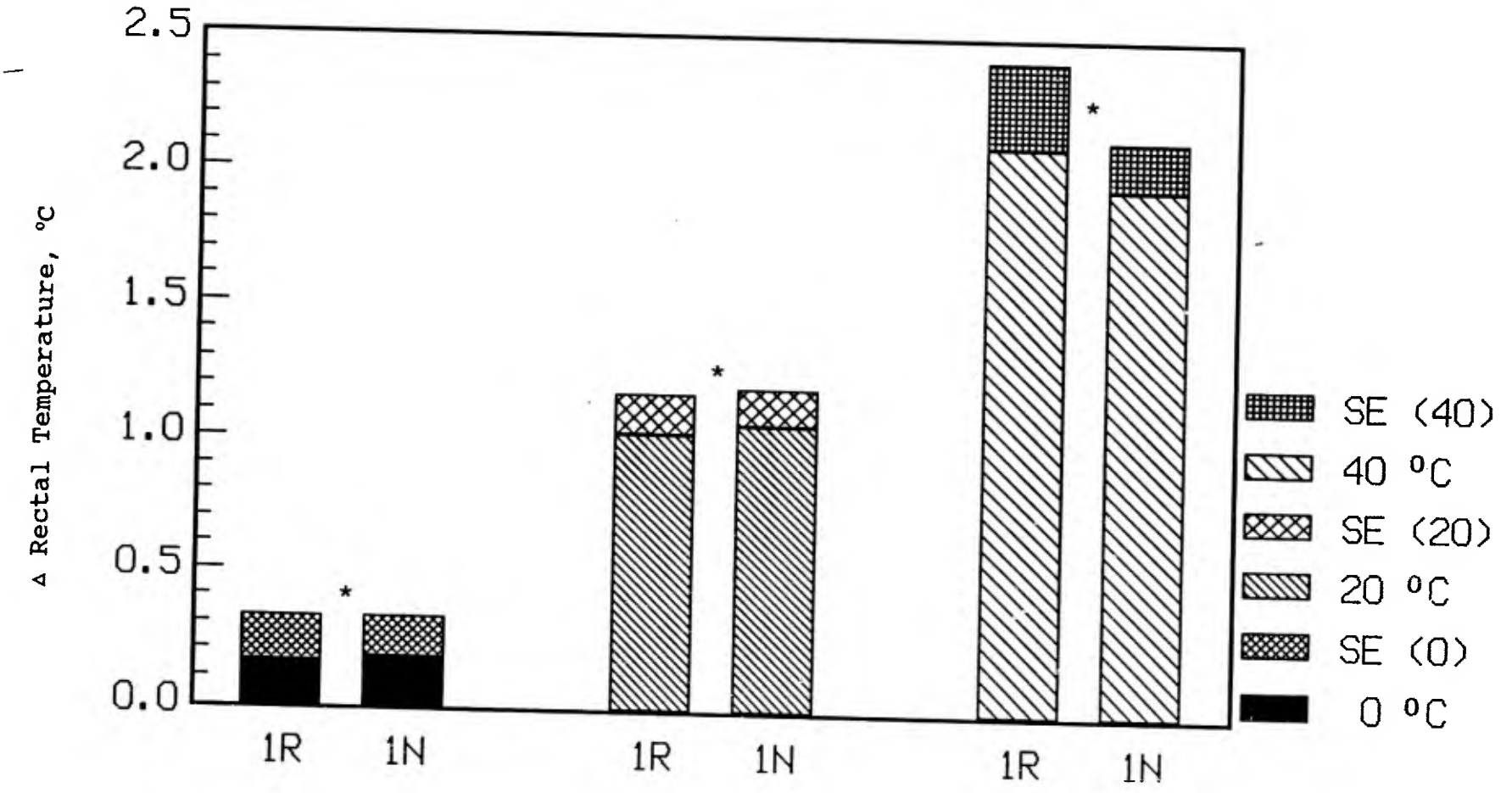
1R - 1stE, RACAL
MR - MidR, RACAL
2R - 2ndE, RACAL
1N - 1stE, No RACAL
MN - MidR, No RACAL
2N - 2ndE, No RACAL
* Significant Change With RACAL ($p < 0.05$)

Figure 1. Heart Rate (Mean, SE) Over Total Test Time With and Without RACAL at 0, 20, and 40 °C



1R - 1stE, RACAL 1N - 1stE, No RACAL
MR - MidR, RACAL MN - MidR, No RACAL
2R - 2ndE, RACAL 2N - 2ndE, No RACAL
* Significant Change With RACAL ($p < 0.05$)

Figure 2. Maximum/Minimum Mask Pressure (Mean, SE) Over Total Test Time With and Without RACAL at 0, 20, and 40 °C



1R - RACAL 1N - No RACAL
* Significant Change Between 0, 20, and 40 °C

Figure 3. Rectal Temperature Change (Mean, SE) Over Total Test Time With and Without RACAL at 0, 20, and 40 °C

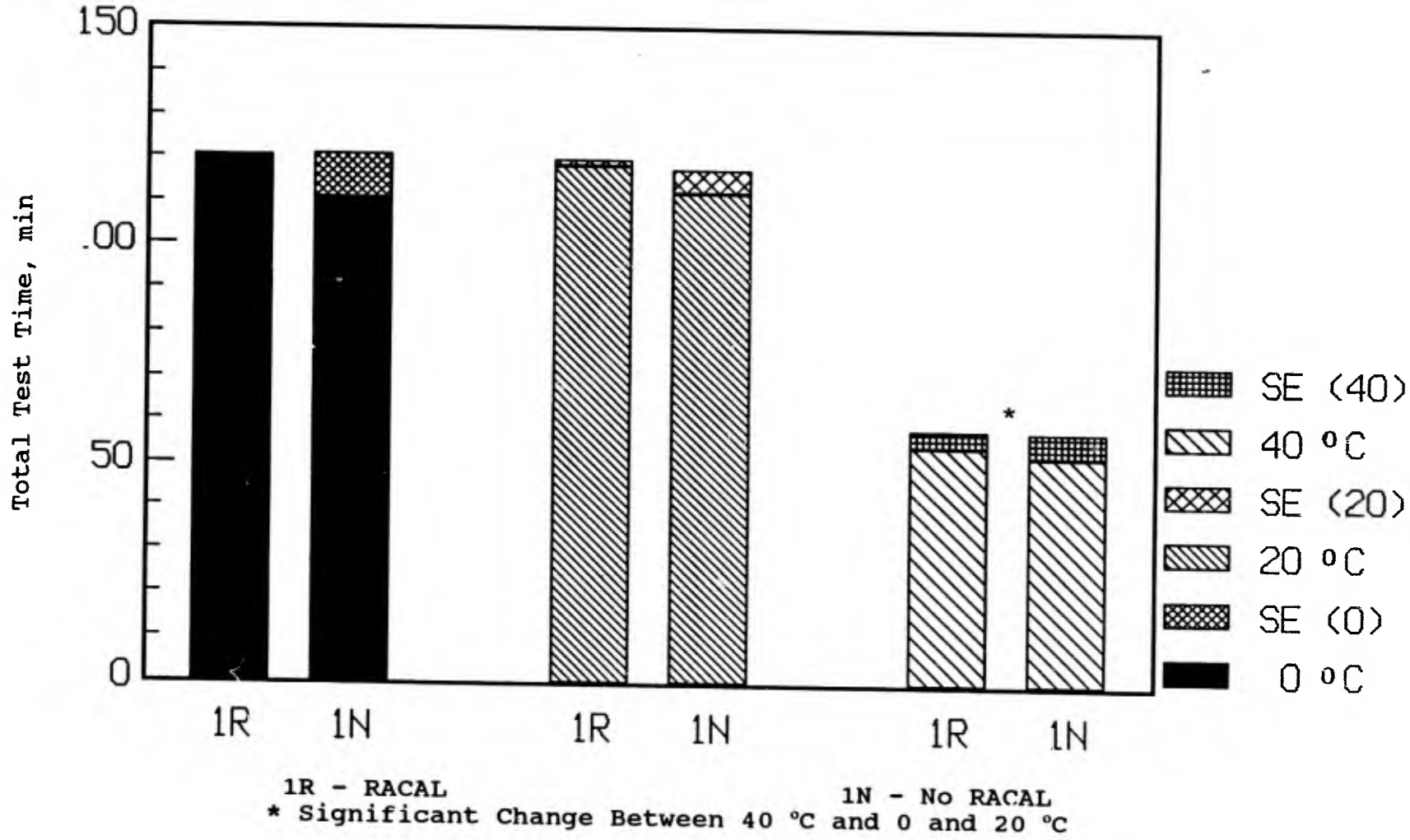


Figure 4. Total Test Time (Mean, SE) With and Without RACAL at 0, 20, and 40 °C

Inlet air temperature (T_{IA}, °C) during both 1stE and 2ndE significantly increased at 0 °C, significantly decreased at 20 °C, and remained unchanged at 40 °C with vs. without RACAL. During MidR, T_{IA} decreased significantly with RACAL at 20 °C (Figure 5).

3.2 Volunteer Water Loss.

In order to evaluate whether the volunteer wearing the M40 respirator in MOPP IV ensemble may sweat less using the RACAL pusher fan, volunteer evaporative water loss (WL_{EVAP}, L) and total water loss (WL_{TOTAL}, L) were determined. The reduction in the volunteer's body weight through sweating during temperature/stress exposure represents total water loss. The sweat absorbed by the clothing and body surface toweling makes up the difference between total and evaporative water losses. The RACAL pusher fan had no effect on either WL_{EVAP} or WL_{TOTAL} at any of the three test temperatures.

3.3 Psychological Evaluation.

The volunteers filled out separate questionnaires with and without RACAL at completion of each test for the three test temperatures.

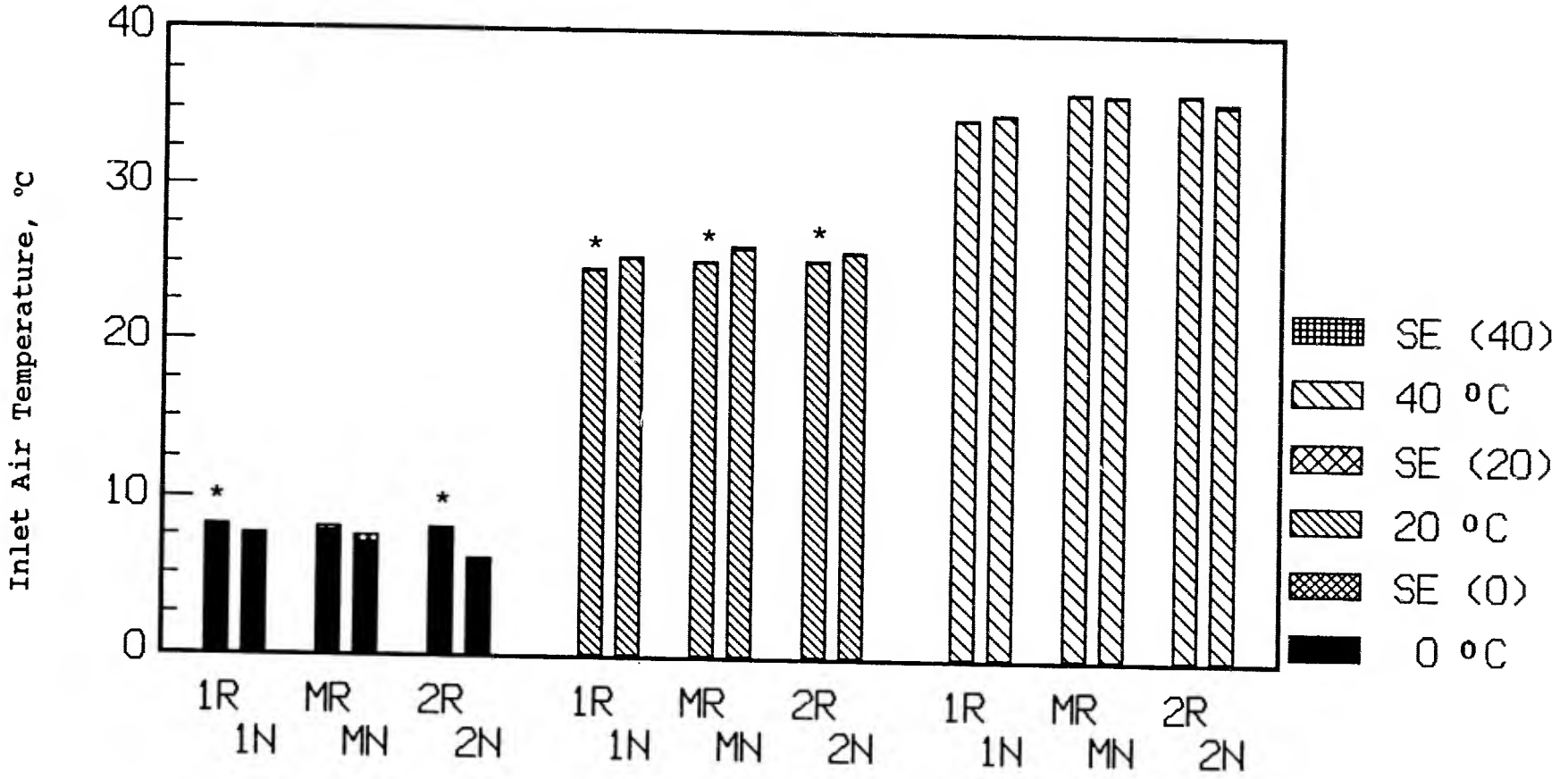
3.3.1 Speaking, Hearing, Vision, Breathing, Head Rotation.

Each volunteer rated six tasks from 1 (extremely difficult) to 7 (extremely easy). The chosen tasks were considered those most likely to be affected by RACAL use while wearing the M40 respirator in MOPP IV ensemble. Volunteer responses ranged from 3 (difficult) through 4 (no change), 5 (easy), 6 (very easy), to 7 (extremely easy).

Speaking, hearing (understanding speech), and vision (ability to see persons/objects) were unchanged. Mean responses for speaking were 4.14 ± 0.58 with RACAL and 4.22 ± 0.54 without RACAL, for hearing 4.96 ± 0.59 with RACAL and 5.17 ± 0.52 without RACAL, and for vision 4.90 ±0.53 with RACAL and 4.79 ±0.42 without RACAL.

Rotating the head side-to-side was unchanged. Mean responses were 3.81 ± 0.42 with RACAL and 4.33 ± 0.38 without RACAL.

Breathing during rest periods was evaluated as significantly easier at 0 and 40 °C with RACAL. The mean response with RACAL was 5.64 ± 0.37 and without RACAL was 4.43 ± 0.47. Breathing during exercise was judged as not different for all three temperatures. The mean responses were 4.85 ± 0.42 with RACAL and 4.06 ±0.52 without RACAL.



1R - 1stE, RACAL 1N - 1stE, No RACAL
MR - MidR, RACAL MN - MidR, No RACAL
2R - 2ndE, RACAL 2N - 2ndE, No RACAL
* Significant Change with RACAL ($p < 0.05$)

Figure 5. Inlet Air Temperature (Mean, SE) Over Total Test Time With and Without RACAL at 0, 20, and 40 °C

3.3.2 RACAL Airflow.

Volunteers rated the level of airflow from the RACAL pusher fan as 1 (too fast), 2 (adequate), or 3 (too slow). RACAL airflow was deemed adequate and not significantly different for all three temperatures. The mean response was 2.19 ± 0.17.

3.3.3 Thermal Comfort.

Volunteers rated the adequacy of thermal comfort as 1 (too cold), 2 (adequate), or 3 (too hot). Thermal comfort was not different at 0 and 20 °C; however, at 40 °C, volunteers felt significantly cooler with RACAL. The mean response with RACAL was 2.08 ±0.21 and without RACAL was 2.49 ± 0.17.

3.3.4 Overall Adequacy.

Volunteers rated the overall adequacy of the M40 respirator with and without RACAL as 1 (good), 2 (satisfactory), or 3 (poor). Overall adequacy was not different at 0 and 20 °C; however, at 40 °C, volunteers felt significantly better with RACAL. The mean response with RACAL was 1.46 ± 0.24 and without RACAL was 1.89 ± 0.21.

4. DISCUSSION AND CONCLUSIONS

The RACAL pusher fan produced minimum changes in heart rate during exercise, being lower at high temperature indicating a possible benefit, but higher at room temperature, a possible detriment. Similarly, at test completion (≤30 min), mean heart rates with treadmill exercise were not different using the M17A1 mask with and without a power-assisted breathing device.[1] Treadmill work performance (≤30 min) in a hot (40.6 °C) environment using the M17A1 mask with hood also produced heart rates that were not different with and without compressed-air power-assisted breathing.[2]

Inhalation mask pressure improved with RACAL, while exhalation pressure changed inconsistently; thus, RACAL appears to lower inhalation resistance without changing exhalation resistance. However, inspiratory resistance was reduced and expiratory resistance increased using a power-assisted breathing device with the M17A1 mask compared to using the M17A1 alone.[3]

As anticipated, RACAL produced no effect on rectal temperature. The RACAL pusher fan provides inhalation airflow to the user without heating or cooling the ambient air. Only limited warming of the M40 mask inlet air at cold temperature and cooling at room temperature was observed. Rectal temperature rise during exercise with the volunteer dressed in MOPP IV

ensemble was a function of ambient temperature, decreasing the total test time the volunteer spent at the high temperature exposure. RACAL did not provide decreased thermal stress.

At cold temperature exposure, RACAL could provide mask inlet air temperature sufficiently cold to produce frostbite. No facial frostbite occurred at 0 °C.

The volunteers experienced limited psychological advantages with RACAL. They felt cooler and better at high temperature, judging RACAL airflow adequate at all three test temperatures. Unchanged were breathing effort and the ability to speak, hear, and see with the pusher fan attached to the C2 canister. In agreement with our study, a 75 L/min airflow associated with a power-assisted breathing device with the M17A1 mask was judged by study volunteers as being pleasant.[3]

Somewhat in contrast to our study, a small group of soldiers evaluated the RACAL miniblower with the M17 respirator in a test at the Yakima Firing Range.[4] All soldiers felt that breathing resistance was considerably less with the blower operating, heat stress was reduced by the cooling effect of air circulation over the face, and work was performed faster and longer, with heavy labor in MOPP IV preferred, using the blower system. Concern for frostbite injury with unheated air blowing over the face in cold weather was noted, with a recommendation that blower use be restricted to temperatures $\geq$40 °F or 4.4 °C.

The results of our study indicate that in terms of physiological performance and psychological response, the RACAL pusher fan did not offer substantial benefits to the volunteer wearing the M40 protective respirator in MOPP IV ensemble.

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