Physiological effects of cold air inhalation during exercise

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Selected physiological responses of six normal subjects were observed, during rest and exercise, while they breathed a) ambient, and b) cold (−35°C) air. All experiments were 10 min in duration, and the exercise experiments consisted of pedalling a bicycle ergometer at loads requiring approximately 60% and 75% of each subject's $\dot{V}O_2$ max. Heart rates and minute ventilations during the most strenuous exercise averaged approximately 170 bpm and 70 *l*, respectively. Diastolic blood pressure was significantly higher, and expired air temperature was significantly lower, during cold air inhalation. Oxygen uptake, respiration rate, and rectal temperature were not affected by cold air breathing; and no subject complaints were attributable to cold air inhalation. Recent studies in the literature suggest that cold air is not fully warmed in the upper respiratory passages; however, the present study observed only slight changes in measured physiological responses to rest and exercise with cold air breathing.

THE PROTECTIVE CLOTHING which provides man with thermal protection during rest and work in cold environments does little or nothing to temper the cold air which may be inspired. Although the physiological effects of cold air breathing are not fully known, studies on animals and humans have shown that the warming effects of the upper respiratory passages preclude the possibility of cold injury to lung tissue (12,15). On the other hand, breathing extremely cold air has been found not only to damage the epithelial linings of the upper respiratory tract in normal men and dogs (9,12), but also to induce angina pectoris and electrocardiographic (ECG) abnormalities in cardiac patients (7,13) and bronchospasm in asthmatics (1,2).

Studies on normal humans breathing cold air during rest or light work have found benign changes in pulmonary function (6,8) and cardiovascular dynamics(10). Little is known, however, about the effects of cold air inspiration during the greater flow rates and ventilatory requirements of strenuous exercise. The purpose of this investigation was to study the physiological effects of breathing cold air in normal humans during moderately strenuous and strenuous exercise.

MATERIALS AND METHODS

Experiments were conducted on six volunteers whose characteristics appear in Table I. Each subject performed a multistage treadmill test (17) to determine maximal oxygen uptake ($\dot{V}O_2$ max); and, except for one who had mild diastolic hypertension at rest, all exhibited normal cardiovascular responses to exercise.

Experiments were performed in an air-conditioned laboratory with a mean temperature of 24°C and a relative humidity of 45%. Each experiment was 10 min in duration and the subject was seated on a bicycle ergometer. Cycling resistances for the exercise experiments were set to require approximately 60% or 75% of the subject's $\dot{V}O_2$ max. Each subject was observed under six experimental conditions in random order: breathing a) room air and b) cold air (approximately −35°C)—at rest, and at each of the two workloads.

The experiment began with the subject seated at rest for 2 min on the ergometer prior to data collection. Expired air was collected during the last 5 min of the resting experiments and during the 5th and 10th minutes of exercise. Systolic and diastolic blood pressures (SBP and DBP, respectively) were taken by auscultation at rest and during the 5th and 10th minutes of all experiments. The ECG, heart rate (HR), expired flow rate, and all temperatures were recorded each minute during the experimental period.

Cold air was supplied from a refrigerated chamber via insulated tubing to a breathing valve (Fig. 1). Chamber temperature averaged −55°C, but inspiration alone did

The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 80-33. The research reported in this paper was conducted by personnel of the Crew Technology Division, USAF School of Aerospace Medicine.

TABLE I. CHARACTERISTICS OF SUBJECTS.

Subject	Sex	Age (yrs)	Weight (kg)	Height (cm)	($\dot{V}O_2$ max) (l/min)	($\dot{V}O_2$ max) (ml/kg•min^{-1})
1	M	44.5	64.0	177.8	4.00	62.5
2	M	41.8	80.0	187.4	4.31	53.9
3	M	40.9	79.4	182.1	3.33	41.9
4	M	38.0	69.8	170.8	3.52	50.4
5	F	37.0	50.0	157.5	2.00	40.0
6	M	31.4	88.9	176.2	2.93	33.0
Mean		38.9	72.0	175.3	3.35	46.95
S.D.		4.6	13.8	10.4	0.82	10.7

not move enough air through the tubing to maintain the desired inlet temperature. Compressed air was therefore pumped into the chamber to insure a positive flow to the valve. Vents allowed unused cold air to escape (Fig. 1).

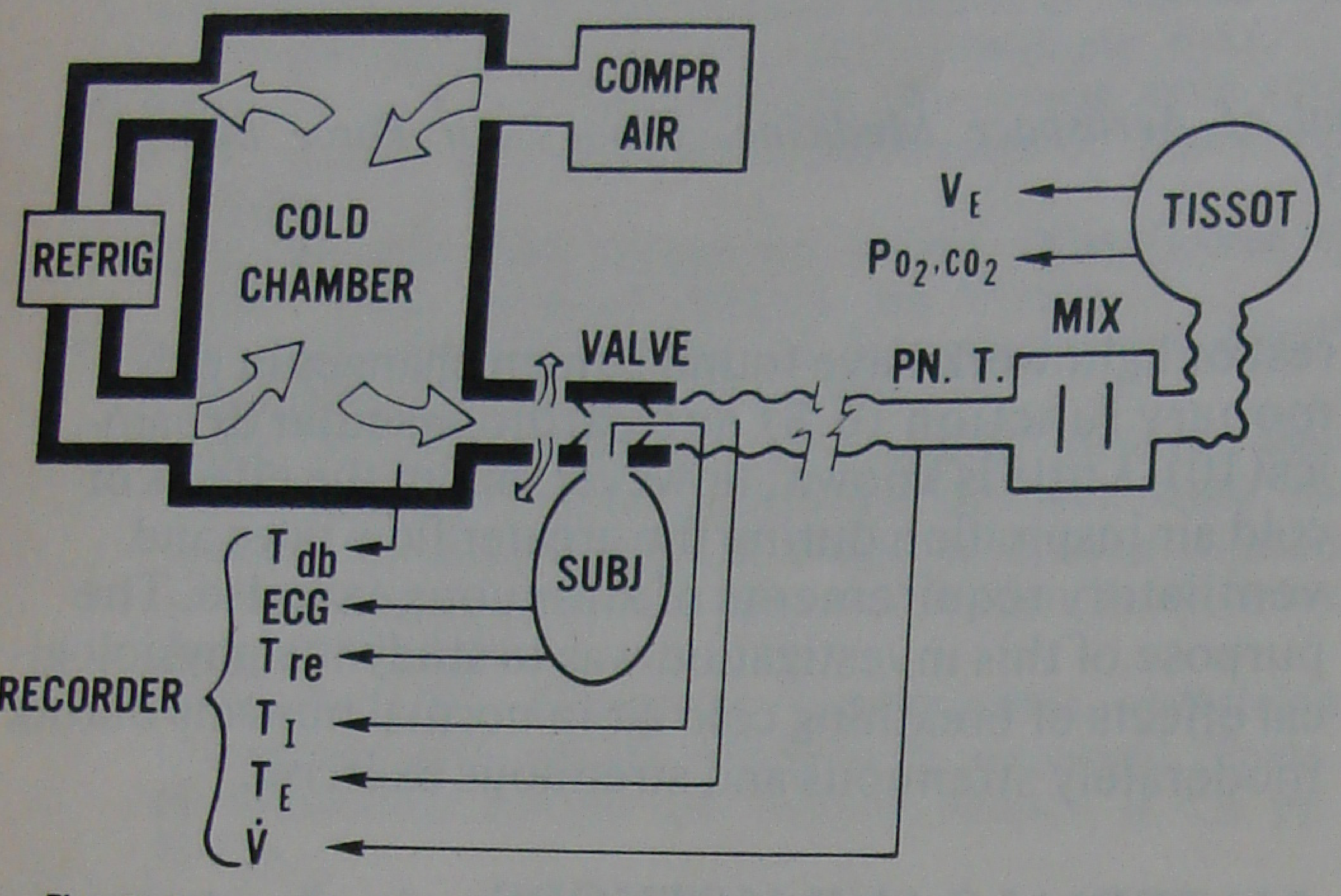

Fig. 1. Schematic diagram of equipment for cold air breathing.

Inspired air temperature (T_I) was measured by a rapid-response thermistor extending through the mouthpiece into the oral cavity; the thermistor was exposed to the cold air stream only at the time of reading T_I, since the bead otherwise tended to ice over.

Expired air temperature (T_E) was determined by another thermistor located in the tubing just beyond the outlet of the breathing valve. Rectal temperature (T_{re}) was measured by means of a thermistor inserted to a depth of 8 cm (five subjects only). Expired air volume ($\dot{V}_E$) was measured in a Tissot spirometer; and mixed expired air samples were analyzed, for percent O_2 and CO_2, by using a mass spectrometer calibrated with standard gases before and after each experiment. Oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$) and respiratory exchange ratio (RER) were calculated using standard procedures.

The data were tested for the difference between ambient and cold conditions by using a two-way analysis of variance (ANOVA). This ANOVA tested for the interaction between air temperature and workload. Where a significant ANOVA ($p<0.05$) was found, either a paired t-test or the Tukey *post hoc* comparison was calculated between temperature conditions at each work level. Missing data values were estimated using the method developed by Yates (14).

RESULTS

Mean physiological responses at rest and during exercise, while breathing cold or ambient air, appear in Table II. Neither respiration rate nor $\dot{V}_E$ differed significantly with T_I at any metabolic level. Expiratory flow rate was significantly higher during cold inhalation at the 60% workload only. The T_{re} was slightly but significantly lower during the cold breathing tests.

The T_I averaged -36.6°C over all cold experiments. The mean workloads were 815 ± 265 kpm and 1,020

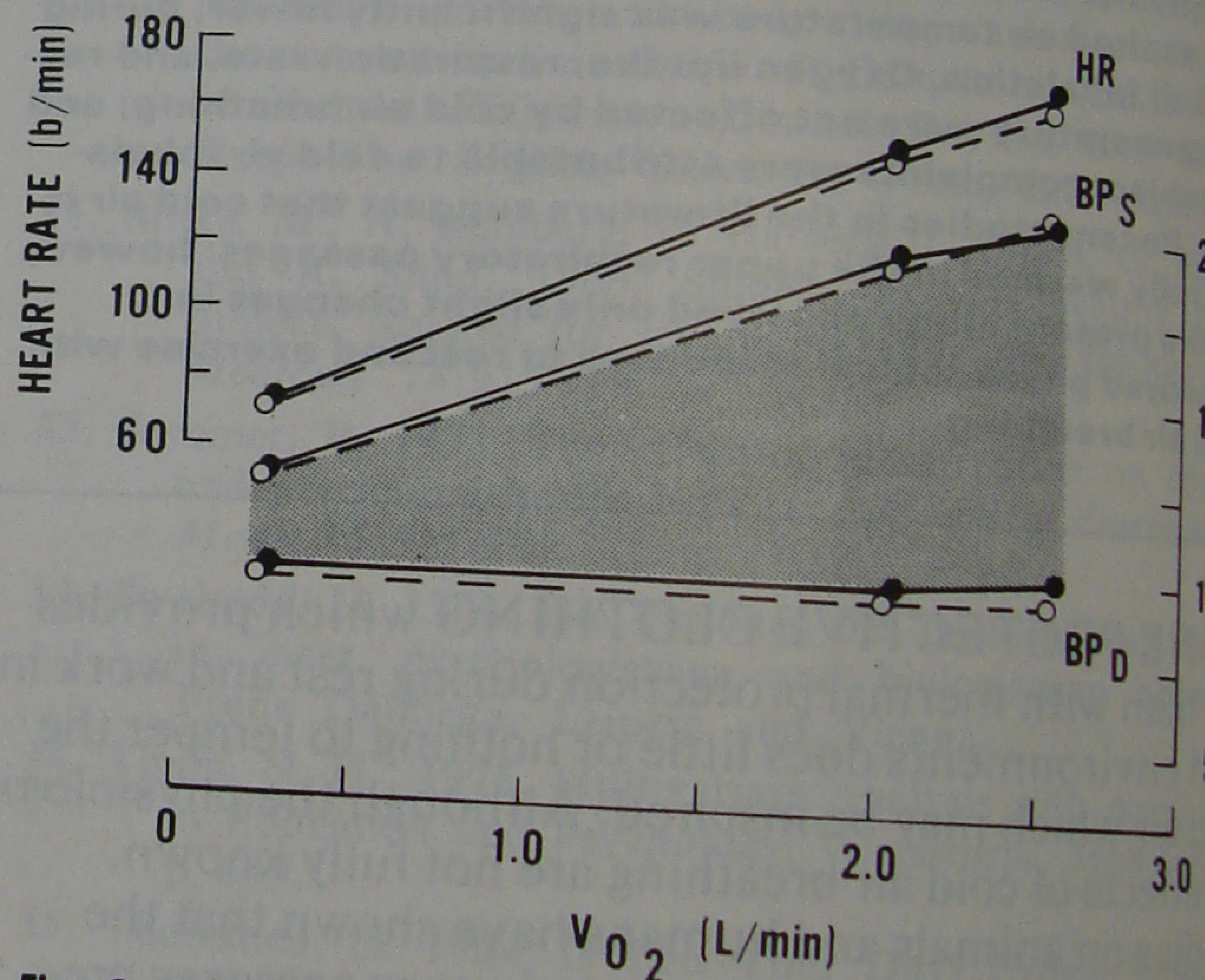

Fig. 2. Cardiovascular responses to cold air breathing at rest and during exercise. Key: ● = mean for cold experiments; o = mean for control condition.

TABLE II. MEAN PHYSIOLOGICAL RESPONSES DURING COLD AND AMBIENT AIR INHALATION.

	Rest Ambient	Rest Cold	60% Workload Ambient	60% Workload Cold	75% Workload Ambient	75% Workload Cold
$\dot{V}_E$ (l/min STPD)	5.9	6.7	48.2	48.8	69.3	70.4
Flow (l/min)†	39.9	41.9	130.8	153.8**	186.4	178.3
T_{re} (°C)†	37.6	37.5	37.4	37.6	38.2	37.9*
T_E (°C)†	30.4	26.3	30.7	24.0	30.5	23.2**

* $p<0.05$ Ambient vs. cold; ** $p<0.01$ Ambient vs. cold; † $p<0.05$ Ambient vs. cold considering all workloads.

265 kpm, at the 60% and 75% levels, respectively. Cardiovascular responses for each temperature condition at various levels of ($\dot{V}o_2$ appear in Fig. 2. Mean DBP was significantly higher during cold breathing (96.3 vs. 92.2 torr) over all metabolic conditions. Both HR and SBP rose as expected with workload, and SBP was not affected by inspired air temperature. Heart rate, however, was significantly higher during cold air inhalation. The T_E was lower during cold breathing at all levels, and the differences were statistically significant during exercise. The effect of T_I on T_E is shown in Fig. 3, in

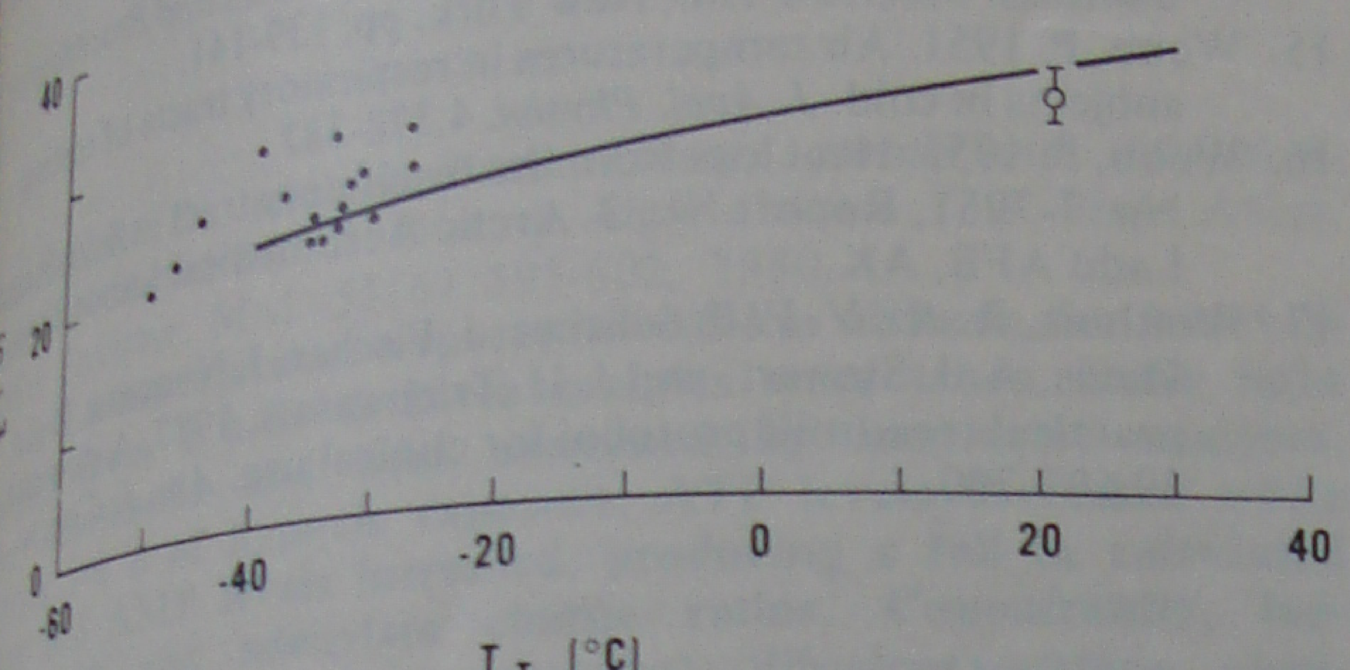

Fig. 3. Effect of inspired air temperature on expired temperature. Key: • = individual values for cold experiments; o= mean value for control condition, with bar showing ± 1 S.D.; Line shows Webb's results (16).

which the solid line represents Webb's data for resting subjects (16).

The relationship between $\dot{V}co_2$, RER, and $\dot{V}o_2$ during both cold and ambient breathing, is shown in Fig. 4. The RER tended to decrease slightly with cold air inhalation, but none of the metabolic measurements was found to be significantly affected by a subject's breathing cold air.

DISCUSSION

The progressive decrease in T_E with increasing work and cold inhalation may be partly the result of air being cooled as it passes through the expiratory side of the cold breathing valve. However, Deal *et al.* (3) recently reported that esophageal temperatures at the level of the carina were significantly lower during exercise when subjects breathed cold air. The same investigators postulated that the temperature of the lower respiratory tract is inversely related to respiratory heat loss, which depends on both T_I and inspired water vapor content (1,2).

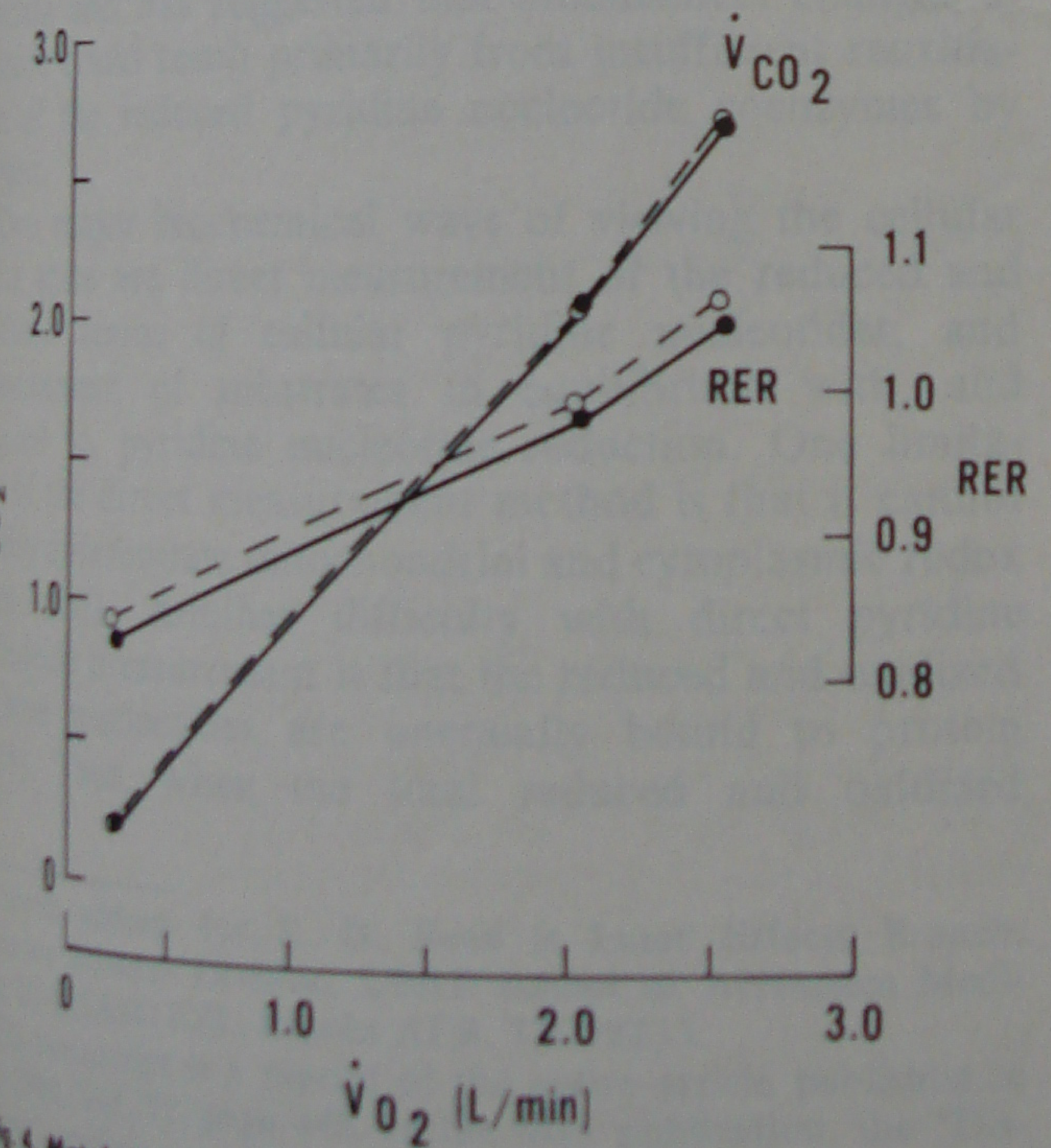

Fig. 4. Metabolic responses to cold air breathing at rest and during exercise. Key as in Fig 2.

The DBP, which usually remains at resting level or decreases with exercise, was significantly increased during cold air inhalation. This observation confirms the findings of others (7,10) and may partially explain the development of cold-induced angina pectoris in some patients with coronary heart disease, since myocardial oxygen demand increases with ventricular pressure increases (5).

The lower T_{re} at the 75% workload during cold inhalation was not expected and may represent chance error in view of the small number of subjects monitored (n=5). The mean difference was so small that its physiological significance is doubtful; calculations of body heat exchange show that a fall in T_{re} is unlikely in 10 min of breathing extremely cold air, even during a high ventilatory effort.

Our mean values for T_E differ slightly from those found by Webb (16). A number of the individual values during cold inspiration fall above the line representing Webb's mean values (Fig. 3). Webb's lowest T_I was −40°C; the relationship may possibly become curvilinear at colder temperatures, rather than for T_E to decrease linearly with decreases in T_I.

Effects of near maximal exercise in cold were reported by Faulkner (4), who studied a 2-d cross-country ski race in Canada in which temperatures were as low as −28°C and wind-chill was estimated at −55°C. The skiers covered 80 km each day with estimated ventilatory volumes of 55-120 *l*/min without any reports of cold injury to the upper respiratory tract, despite numerous cases of frostbite to the extremities. The single report of probable severe injury to the respiratory tract of normal men following exercise in extreme cold (below −55°C) was from the Antarctic at an altitude of 9,200 ft (9); some of the symptoms attributed to cold injury in that report may actually have been caused by high-altitude pulmonary edema (11).

Despite small changes observed in physiological and respiratory responses to breathing cold air during exercise, the metabolic cost of work was not significantly affected. Of course, individuals with certain medical conditions should not breathe cold air. Some cardiac patients develop angina pectoris when inhaling air at temperatures warmer than those used in this study (7). Many asthmatics develop bronchospasm when breathing cold air, especially during exercise when a large minute volume takes heat and moisture from the linings of these airways (1-3). In our study, other than a slight elevation of diastolic blood pressure, no adverse effects were found which would contraindicate vigorous exercise by normal subjects while breathing air as cold as −30°C to −40°C.

REFERENCES

1. Deal, E. C., E. R. McFadden, Jr., R. H. Ingram, Jr., and J. J.