Work and Heart Disease

II. A Physiologic Study in a Steel Mill

By Amasa B. Ford, M.D., Herman K. Hellerstein, M.D., and David J. Turell, M.D.

Knowledge of the cardiovascular requirements of various types of work is essential in making work recommendations for cardiac patients. In a previous study the stresses of work in a light metal manufacturing plant were shown to be small. The present study is an evaluation of the physiologic requirement of a typical day's work in an open-hearth furnace and other areas in a steel mill. The oxygen consumption, pulmonary ventilation, respiratory rate, and other physiologic responses in cardiac patients are compared to those of normal subjects performing the same tasks.

Much of the work in a modern American factory involves little energy expenditure by the worker and evokes only small physiologic changes. Most workers with heart disease are able to perform their jobs in light metal manufacturing plants with no greater evidence of physiologic strain than is shown by their healthy co-workers. These findings in the first part of the present study emphasized the advantages of regular employment for patients with heart disease and showed the stresses of work to be very small—probably less than those of nonworking activities. In heavy industry, however, the energy expenditure and physiologic responses of men with and without heart disease may differ. Our observations have therefore been extended to workers in a steel mill and are reported here.

Materials and Methods

There were 53 subjects, of whom 20 had heart disease, 14 were control subjects (a man without clinical evidence of heart disease doing the same job as one with heart disease), and 19 were normal men holding typical steel-mill jobs in which no cardiac subjects happened to be engaged. All the subjects were men. The average age of the cardiac group was 50±9 years, which was significantly greater (p = <.001) than the control group (34 ± 11 years) or the normal group (40 ± 10 years). There were 3 Negroes among the 20 with heart disease and 7 among the 33 control and normal subjects.

The 20 subjects with heart disease had been identified through employment physical examinations, illness at work, or reports from physicians following illness. All the subjects were evaluated by methods of a medical history, physical examination, and standard 12-lead electrocardiogram. Of the 20 men with heart disease, 12 had arteriosclerotic heart disease (9 with previous myocardial infarction confirmed by electrocardiogram), 7 had hypertensive cardiovascular disease, and 1 had a pronounced and unexplained tachycardia. The total cardiac group was distributed according to the classification of the New York State Heart Association as follows: Class I, 13 subjects, and class II, 7 subjects; none in classes III or IV (symptoms produced by less than ordinary activity). Therapeutically, 2 were classified A (no restrictions); 17, B (restriction of unusual exertion); and 1, C (moderate restriction of ordinary activities). Men with heart disease were found working in all major areas of the steel mill and at some, but not all, of the most strenuous jobs. Table 1 lists the jobs studied and shows the distribution of the cardiac subjects.

The average body surface area of the steelworkers, as estimated from height and weight, was 1.96 ± .13 M,2, as compared to 1.86 ± .15 M,2 for the light metal workers. The average length of service of the subjects studied was 13 years (range, 1 month to 40 years), and there were 17 men who

* Standard deviation.
†† Test for groups of unequal size.
had been employed in this mill for 20 years or more.

The subjects were studied at their usual work throughout a typical day's shift by the methods previously reported, with certain modifications. The samples of expired air were collected in butyl rubber bags and analyzed at the plant within 3 hours of collection by a Beckman para-magnetic oxygen analyzer supplied with a portable vacuum pump. Energy expenditure was calculated according to the formula of Weir. Radiant heat was measured with a black globe thermometer, air speed with an Alnor "velometer," and wet and dry bulb temperatures with a bulb psychrometer. Heat stress was estimated from the charts of Belding and Hatch, and values in this report will be referred to as "estimated heat stress."

Data on each subject were entered on punch cards and analyzed by means of a Univac computer. These data included descriptive information (age, diagnosis, etc.), environmental conditions (time breakdown, heat stress, etc.), and physiologic responses, totaling 33 items. Groups of subjects were compared for each parameter by the t test for unpaired groups of unequal size. Subjects with heart disease were also individually matched with control subjects performing the same job and compared by the t-test for paired groups.

Rates of energy expenditure (calories per minute) are expressed as totals, including resting rates, except as noted in figures 1 and 3.

RESULTS

Job Characteristics

Two major types of stress characterize work in a steel mill: heat and energy expenditure. Figure 1 shows the average energy expenditure and heat-stress index for each of the 5 principal job categories.

Furnacemen. The men who tend the blast and open-hearth furnaces have the heaviest work, such as banking the furnaces and cleaning the runners of cooling slag. As a group, their average energy expenditure for the shift was 3.03 calories per minute (1,435 calories in the shift). The most demanding job in the mill is that of second helper in the open-hearth furnace. The 2 normal subjects studied on this job spent an average of 4.25 and 4.75 calories per minute during the shift. It has been estimated that 5 calories per minute is the maximum tolerable limit of sustained energy expenditure for a healthy man.

<table>
<thead>
<tr>
<th>TABLE 1.—Types of Jobs Studied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnacemen—17 subjects</td>
</tr>
<tr>
<td>A. Blast furnace</td>
</tr>
<tr>
<td>First helper</td>
</tr>
<tr>
<td>Water tender—3 subjects*</td>
</tr>
<tr>
<td>Cinder snapper—2 subjects*</td>
</tr>
<tr>
<td>B. Open-hearth furnace</td>
</tr>
<tr>
<td>First helper—4 subjects**</td>
</tr>
<tr>
<td>Second helper—2 subjects</td>
</tr>
<tr>
<td>C. Pouring platform and pit</td>
</tr>
<tr>
<td>Pourer—2 subjects*</td>
</tr>
<tr>
<td>First platform man</td>
</tr>
<tr>
<td>Nozzle setter</td>
</tr>
<tr>
<td>D. Reheat oven</td>
</tr>
<tr>
<td>Heater helper</td>
</tr>
</tbody>
</table>

Maintenance Men—13 subjects

Motor inspector—3 subjects**
Pipefitter—3 subjects**
Stockman—2 subjects*
Tool maintenance man*
Assembler burner
Boilermaker
Mason
Mason helper

Foremen—5 subjects

General foreman (docks)*
By-product foreman (coke works)*
General foreman (coke works)*
General foreman (blooming mill)—2 subjects

Hot-Strip and Slab Handlers—8 subjects

A. Hot-strip mill
Gauger—2 subjects*
Coil marker—2 subjects*
Bander

B. Slab yard
Crane follower
Stock checker
Scarfer*

Controls Operators—9 subjects
Rougher motor operator—2 subjects*
Elevator operator (stationary)—2 subjects*
Scale-breaker operator
Pit-cover operator
Tractor operator
Stripper-crane operator—2 subjects

Miscellaneous—1 subject
Laborer—shoveling scale

*Each asterisk represents one subject with heart disease.
Most of the men who worked in the furnace areas were, at times, exposed to intense radiant heat. The "heat-stress index" is an approximate measurement under specific conditions of the balance between the heat load of the unclothed body (radiation, convection, and metabolism) and possible heat loss (radiation, convection, and evaporation of sweat, depending on air temperature and humidity). A heat-stress index of 100 represents a balance of heat load and heat loss of the body at the maximum rate of sweat production.

The furnacemen experienced an average estimated heat stress of 50 during the shift. Every man working in the furnace area was, at some time during the shift, exposed to an estimated heat stress of 140 or more, and three quarters experienced stresses of over 200. Maximum heat-stress conditions are presented in Table 2. The 2 second helpers on the open-hearth furnace experienced the highest estimated heat stress (averages of 113 and 116) as well as the highest energy expenditure.

Maximum estimated heat stress and its cumulative duration are indicated in Figure 2. Similar data for maximum energy expenditure are presented in Figure 3. It is evident that, from a consideration of maximum as well as average energy and estimated heat stresses, the furnacemen had the hardest jobs. The furnacemen walked an average of 5.5 miles per shift with a range of 1.8 to 10.2 miles.

Maintenance Men. The maintenance men ranked second in terms of average energy expenditure (2.58 calories per minute) and third in terms of average heat-stress index (29 units). Their work is more irregular. Maintaining large machinery requires walking, climbing, lifting, and forcing, so that large exertions are required on each shift (Figure 3); but only 2 maintenance men averaged as much as 3.5 calories per minute for the shift. Heat stress was variable but less than that in the furnace areas. The average distance walked in a shift was 2.5 miles.

Foremen. The foremen expended about as much energy (2.48 calories per minute aver-
Table 2.—High “Heat-Stress” Conditions of Certain Jobs in the Furnace and Strip-Mill Areas

<table>
<thead>
<tr>
<th>Job</th>
<th>Area</th>
<th>Activity</th>
<th>Second helper</th>
<th>First helper</th>
<th>“Cinder snapper”</th>
<th>Gauger</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open-hearth furnace</td>
<td>controlling “tap” of molten steel</td>
<td>160</td>
<td>95</td>
<td>165</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td>Open-hearth furnace</td>
<td>banking furnace</td>
<td>28.3</td>
<td>34.5</td>
<td>34.5</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>Blast furnace</td>
<td>controlling “cast” of molten iron</td>
<td>29.3</td>
<td>30</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Strip mill</td>
<td>gauging coil of hot steel</td>
<td>29.3</td>
<td>30</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metabolic heat production (cal./min.)</td>
<td>50</td>
<td>350</td>
<td>100</td>
<td>650</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cumulative duration of exposure to these conditions during shift (min.)</td>
<td>78</td>
<td>57</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat-stress index*</td>
<td>over 250</td>
<td>220</td>
<td>over 250</td>
<td>over 250</td>
</tr>
</tbody>
</table>

age) as did the maintenance men. The majority of this energy was spent in walking an average of 4.5 miles per shift, but neither distance walked, maximum, nor average energy expenditure approached that of the furnace men except in the case of one vigorous 24-year-old temporary foreman who averaged 3.9 calories per minute and walked 7.5 miles. The foremen seldom encountered sustained severe heat stresses.

Hot-Strip and Slab Handlers. These jobs involve the handling, marking, or measuring of hot steel, either as slabs or coils of sheet steel. The average energy expenditure of 2.12 calories per minute is unimpressive, being less than twice the average resting level, and there are few high peaks. The stress of this work comes from the radiant heat of large masses of hot steel producing the highest average estimated heat stress of all the jobs studied (59 units) but not reaching the dramatic peaks experienced by the furnace men during a tap (table 2). These men walked an average of 1.2 miles.

Controls Operators. Workers in this group drive machinery from a sedentary position, either moving with the machine (tractor and crane) or remaining stationary (scale breaker, pit cover). Their average energy expenditure (1.81 calories per minute) and estimated heat stress (15 units) are the lowest of any group, and they seldom show significant peaks. The crane cabs and operating "pulpits" are air-conditioned in hot areas.

Work and Rest Time. The proportion of working to nonworking time was quite uniform throughout the mill, except for the foremen, who rested only 29 per cent of the shift, as compared to 41 per cent for the furnace men, 42 per cent for the hot-strip handlers, 48 per cent for the controls operators, and 54 per cent for the maintenance men. These figures represent the fraction of time between check-in and check-out not actually spent at work and include meals, changing clothes, and breaks, both voluntary and routine. In light metal manufacturing plants, nonworking time accounted for 35 per cent of the shift.

Physiologic Responses of Normal and Cardiac Workers

Pulse Rate. The resting pulse rate rose from an average for the total group of 77 ± 12 beats per minute before work to 90 ± 13 at the end of the shift. This change was statistically significant (p = .001) in the cardiac, control, and normal groups. The men with heart disease showed a higher average resting pulse rate throughout the day than did their matched controls (fig. 2). The differences, averaging 9.4 beats per minute, were significant statistically (p = .05). Among the cardiac subjects, those with hypertension tended to have higher resting pulse rates than did those with arteriosclerotic heart disease, although the differences were significant only at the end of the shift (p = .05, .02) (fig. 5).
Eighty-five per cent of the rise in average resting pulse rate occurred within the first hour of the shift, although this pattern varied from one type of job to another. Figure 6 shows that the foreman experienced a striking rise in resting pulse during the first pause after starting work (within the first hour) with a subsequent fall, whereas the hot-strip and slab handlers and controls operators showed a gradual rise during the shift, and the other jobs conformed to the general pattern. These differences may be related to the fact that the foreman's job is unpredictable, with a high degree of responsibility, while the controls operators and hot-strip and slab handlers have the most routine type of work, suggesting that the resting pulse rate increases early when anxiety-producing factors are present. The pattern of average resting pulse rate did not correlate with average energy expenditure or heat stress.

Maximum working pulse rates of 140 per minute or higher were observed in 17 of the 53 subjects (8 with heart disease, 9 without). In 14 of the 17, tachycardia (140 to 170) could be accounted for by energy expenditure (>4 calories per minute) or estimated heat stress (>200). Three men with hypertension developed pulse rates of 140 to 168 per minute, which were not the result of their energy expenditure or heat stress and which might therefore be considered excessive. The fourth individual had an unexplained tachycardia, with an average resting pulse rate of 120 per minute and a maximum of 212 per minute.

There is a rough correlation between rate of working energy expenditure and pulse rate at low heat stress. At high heat stress, the pulse rate tends to be higher for a given rate of energy expenditure (fig. 7). Factors influencing the working pulse and recovery pulse sum (total beats in 3 minutes after work) were studied by analysis of variance, using heat-stress index, energy expenditure, and age as the "treatments." There were 2 replications of 8 normal subjects each. Heat-stress index was related to both working pulse rate and recovery pulse sum, and this relation was statistically significant at the 5 per

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**Fig. 4 Top.** Average resting pulse rate at 3 points during the shift for cardiac, control, and normal subjects. Standard deviations are of the order of 12 pulse beats per minute. "Early" refers to the first pause after starting work (within the first hour).

**Fig. 5 Middle.** Average resting pulse rate at 3 points during the shift for subjects with hypertensive and arteriosclerotic heart disease. Standard deviations are of the order of 12 pulse beats per minute.

**Fig. 6 Bottom.** Average resting pulse rate at 3 points during the shift for all subjects in 5 job categories. Standard deviations are of the order of 12 pulse beats per minute.
cent level. The influences of energy expenditure and age were not statistically significant. Other studies have shown a correlation between heart rate and energy expenditure, but this effect is overshadowed under working conditions in a steel mill—particularly by the effect of high heat stress.

Pulse rate, under working conditions in a steel mill, is therefore influenced by heat load and energy expenditure and by the individual characteristics of the worker, particularly those of heart disease and anxiety.

Blood Pressure. Few marked elevations of blood pressure were observed. It was difficult to obtain satisfactory blood pressure readings during work because of noise, activity, and protective clothing. Observations were made immediately after work or during stationary activity, while the pulse rates were recorded by electrocardiograph during work.

Sixteen individuals developed blood pressures greater than 150 mm. Hg systolic or 99 mm. Hg diastolic or both. Seven of these had hypertension at rest, and 4 had arteriosclerotic heart disease with elevated or borderline resting blood pressure. Five men without recognized heart disease developed systolic pressures in the range of 154 to 160 mm. Hg or diastolic pressures as high as 100. Three of these otherwise normal subjects had borderline systolic blood pressures at rest (140 to 160 mm. Hg).

The maximum increase during, or immediately following, work averaged 6 mm. Hg systolic and 3 mm. Hg diastolic for the 33 noncardiac subjects. These changes were no greater in high heat stress, at high rates of energy expenditure plus high heat stress, or for the men with arteriosclerotic heart disease. Only the 7 hypertensive subjects showed a greater average increase of blood pressure, and then only of systolic pressure (11 mm. Hg).

Thus, the blood pressure data suggest that within the limits of the observations, most steel-mill workers experience only moderate increases in blood pressure, but that certain individuals, some with recognized hypertension and some not, have a more exaggerated elevation of blood pressure under the same working conditions.

Respiration. Pulmonary ventilation, on the other hand, is so closely correlated with energy expenditure and so uniform in groups of normal individuals that one quantity may be predicted from the other. The data of this and previous studies have been analyzed for this correlation.

The correlation between ventilation and energy expenditure is not affected by the presence of heart disease (fig. 8) or by high heat stress (fig. 9). The average pulmonary ven-
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Table 3.—Electrocardiographic Changes During Work

<table>
<thead>
<tr>
<th>Case</th>
<th>Diagnosis</th>
<th>Age</th>
<th>Activity</th>
<th>Electrocardiographic changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.W.</td>
<td>normal</td>
<td>46</td>
<td>nozzle setting 5.3 cal./min., heat stress 300</td>
<td>nodal premature beats, aberrant conduction; 45° counterclockwise shift T-vector</td>
</tr>
<tr>
<td>R.T.</td>
<td>arteriosclerotic heart disease, non-transmural anterior infarction</td>
<td>45</td>
<td>shoveling, smoking, etc.</td>
<td>S-T segment depression of 1 mm.; 120° clockwise shift T-vector</td>
</tr>
<tr>
<td>J.B.</td>
<td>arteriosclerotic heart disease, right bundle branch block</td>
<td>64</td>
<td>running up stairs (emergency)</td>
<td>ventricular premature beats</td>
</tr>
<tr>
<td>R.B.</td>
<td>sinus tachycardia</td>
<td>54</td>
<td>walking</td>
<td>S-T segment depression of 1 mm., pulse rate 120-212</td>
</tr>
</tbody>
</table>

Borderline electrocardiographic changes during work

<table>
<thead>
<tr>
<th>Case</th>
<th>Diagnosis</th>
<th>Age</th>
<th>Activity</th>
<th>Electrocardiographic changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.H.</td>
<td>normal</td>
<td>28</td>
<td>shoveling 4.8 cal./min.</td>
<td>S-T segment depression of 2 mm. (junctional)</td>
</tr>
<tr>
<td>S.K.</td>
<td>hypertensive cardiovascular disease</td>
<td>38</td>
<td>walking</td>
<td>60° counterclockwise shift T-vector</td>
</tr>
</tbody>
</table>

tilation at rest was 9.9 ± 2.1 L per minute, and the average peak was 24.6 ± 6.6 L per minute for the total group.

Respiratory rates averaged 17 ± 4.0 per minute at rest for the total group, and the average of maximum rates was 26 ± 6.0. There was no difference between the cardiac and control groups in this respect.

Pulmonary ventilation and respiratory rate, therefore, appear to be influenced primarily by energy expenditure and very little by heat or individual characteristics such as the presence of compensated heart disease.

Electrocardiogram. Standard 12-lead electrocardiograms were taken at rest. Of the 12 subjects with arteriosclerotic heart disease, 9 had evidence of old myocardial infarctions (1 posterior, 4 lateral or anterolateral, and 4 anteroseptal), 2 had complete right bundle-branch block, and 1 had a normal electrocardiogram but a definite history of angina pectoris. None was taking digitalis, and 2 used nitroglycerin occasionally. Of the 9 subjects who had hypertensive cardiovascular disease, 4 showed left ventricular hypertrophy and 3 had normal electrocardiograms. Among the hypertensive group, none was taking digitalis, and 1 was taking antihypertensive medication. The electrocardiograms of the control subjects were all within normal limits.

For the records taken during activity, the method of electrode placement gave information only in the horizontal plane, i.e., on the x and z axis, equivalent to RV₅, V₄, and V₈. Four men developed changes during or following effort that could be interpreted as an abnormal response, and 2 developed borderline changes. The criteria are those developed for interpreting the Master 2-step test. The details are given in table 3. Two of the 6 showing changes had no recognized heart disease but were working at a high rate of energy expenditure (both) and high estimated heat stress (case S.W.). For the 4 men with heart disease, the activities that produced changes were only moderately strenuous.

Abnormal electrocardiographic changes, like the hypertensive response, appear to be characteristic of an individual. High heat stress or high rates of energy expenditure can bring out electrocardiographic changes in an individual not known to have heart disease, but these stresses, even at the levels encountered in the steel mill, did not induce electrocardiographic abnormalities in most normal individuals nor even in 80 per cent of those with known heart disease.

Multiple Abnormal Responses. An unusual increase in blood pressure, abnormal electrocardiographic changes, and tachycardia not explained by energy expenditure or heat stress have been shown to be characteristic responses of an individual rather than necessary effects of heat or physical activity. Thirty-five per cent of the cardiac group and 10 per cent of the noncardiac group showed
TABLE 4.—Subjects with Abnormal Responses of Pulse Rate, Blood Pressure, and Electrocardiogram

<table>
<thead>
<tr>
<th>Job</th>
<th>Diagnosis</th>
<th>New York State Heart Association classification</th>
<th>Age</th>
<th>Excessive tachycardia</th>
<th>Excessive increase of blood pressure</th>
<th>Abnormal electrocardiographic changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor inspector</td>
<td>malignant hypertension</td>
<td>II</td>
<td>42</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Pipefitter</td>
<td>hypertensive cardiovascular disease</td>
<td>II</td>
<td>33</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Water tender</td>
<td>arteriosclerotic heart disease, right bundle-branch block</td>
<td>I</td>
<td>64</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>First helper, open-hearth furnace</td>
<td>arteriosclerotic heart disease, non-transmural</td>
<td>II</td>
<td>45</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreman</td>
<td>unexplained tachycardia</td>
<td>I</td>
<td>54</td>
<td>+</td>
<td>+</td>
<td>B*</td>
</tr>
<tr>
<td>Pipefitter</td>
<td>hypertensive cardiovascular disease</td>
<td>I</td>
<td>38</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘‘Cinder snapper,’’ blast furnace</td>
<td>hypertensive cardiovascular disease</td>
<td>I</td>
<td>49</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mason</td>
<td>normal</td>
<td></td>
<td>42</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Nozzle setter</td>
<td>normal</td>
<td></td>
<td>46</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laborer</td>
<td>normal</td>
<td></td>
<td>28</td>
<td>+</td>
<td></td>
<td>B</td>
</tr>
</tbody>
</table>

*BORDERLINE.

2 or more such abnormalities or electrocardiographic changes alone (table 4). The significance of these findings can be determined only by follow-up observation.

At the time of writing, a year and a half had passed since the conclusion of this study, and only 1 subject was known to have died. He was 41 years old and had had a myocardial infarction 3 years previously. On returning to work he was transferred from heavy work in the blast furnace to the job of stockman, which required only 2.25 calories per minute during the shift with a peak of 4.40 calories per minute (stair climbing). He died suddenly at home 5 weeks after the study. An autopsy was not performed. During the study he did not develop any of the abnormalities cited above.

**Effects of Heat Stress.** The outstanding cardiovascular effect of heat stress noted so far has been acceleration of heart rate. This occurs concomitant with an increase in cardiac output and peripheral blood flow through dilated skin vessels where heat loss takes place by radiation and convection. The principal means by which the body loses heat, however, is evaporation of sweat. In the present study, observations were made of water ingestion by 12 subjects working at average heat-stress indices of from 25 to 130. When water intake was plotted against average heat-stress index, a rough correlation was evident that could be described by a line crossing the heat-stress index = 100 line at 0.52 L. of water per hour. This is about half the sweat production predicted by Belding and Hatch for these working conditions. The discrepancy can be explained by 2 factors. First, the sweat secretion of the subjects may have exceeded their water ingestion, resulting in a weight loss. Nude weights could not be taken in this study. Second, the heat-stress index may not represent the actual conditions to which the subjects' bodies were exposed. This index is based on observations on nude or minimally clad subjects whereas steel-mill workers wear heavy clothing, often including an asbestos overcoat. Clothing reflects radiant heat and may impede or facilitate sweat evaporation, but diminishes heat loss by convection. The most important effect of clothing in the high radiant heat areas appears to be to shield the body, thus reducing the stimulus to sweat secretion and reducing the true heat stress.
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![Graph](image)

**Fig. 9** Top. Energy expenditure and pulmonary ventilation during individual activities at high heat stress (greater than 60 units) for 33 noncardiac subjects. The solid line represents the average for these same subjects at low heat stress, and the dashed lines ±2 standard deviations.

**Fig. 10** Bottom. Average energy expenditure during the shift related to average increase in resting energy expenditure during the shift for 40 cardiac and noncardiac subjects.

below the level indicated by the heat-stress index.

**Fatigue.** There was an increase in the average resting energy expenditure from 1.34 ± .24 calories per minute before work to 1.45 ± .32 calories per minute at the end of the shift for the total group. This increase was small but statistically significant (p = <.01). The increase was no greater for the cardiac group than for those without heart disease. When the increments were broken down by type of job, however, there appeared to be a correlation between the average rate of energy expenditure for the day and the increase in resting metabolic rate during the shift (fig. 10). The increments are small, and there is considerable variation, so that the correlation is not statistically significant in the present data. It appears, nevertheless, that in the jobs that require an average energy expenditure of 2.5 calories per minute or more, there may be a small but detectable increase in resting metabolic rate, which represents one form of physiologic fatigue.13

Resting pulse rate also rose during the shift (fig. 4). The rate of energy expenditure is only one of the factors contributing to this rise. Heart disease, anxiety, and heat stress all have important influences, as has been demonstrated. The increase in pulse rate for various groups does not correlate with their energy expenditure. There is, however, a rise in every group, regardless of the presence or absence of other influences. It is possible that a rise in resting pulse rate takes place during the day's work in a steel mill which also represents fatigue, but which is difficult to dissociate from the effects of heat stress, heart disease, and anxiety.

**Comparison of Cardiac and Control Subjects**

The men with heart disease were compared with their matched control subjects in order to identify significant differences that might be due to heart disease itself or, indirectly, to a modified pattern of activity resulting from heart disease. Most of the important differences have been cited. Thus, the men with heart disease had slightly higher resting pulse rates, but their working pulse rates were not significantly greater, except in occasional individuals, than those of the control subjects. Resting blood pressures were greater in the cardiac group and increased more during work. Both pulse rate and blood pressure differences were more accentuated in the hypertensive group than in those with atherosclerotic heart disease. Twenty per cent of the cardiac subjects and 6 per cent of those without heart disease developed borderline or abnormal electrocardiographic changes at work.

Perhaps the most striking fact that emerges from the comparison of the cardiac group with their healthy co-workers is that there are many jobs in a steel mill which are performed...
satisfactorily by men with recognized heart disease and that men with heart disease are actually working at jobs of every general type and in every area in the mill. There were no cardiac subjects on the hardest job, that of second helper on the open-hearth furnace, but otherwise, there was a wide distribution (table 1). The sample is not a weighted one, but most of the important jobs are represented.

There is some evidence that the high energy cost of certain jobs in the steel mill may elicit abnormal physiologic responses in men with known heart disease and, occasionally, in men without recognized heart disease. All but 2 of the workers listed in table 4 as showing such changes were in the furnace or maintenance groups, and these 2 groups had the highest average energy expenditure. It is to be emphasized that there is no evidence in this study that these changes were actually harmful to the men who experienced them.

The general pattern of energy expenditure was not found to differ significantly when the cardiac subjects were compared with their controls. Resting energy expenditure, average energy expenditure during the shift and during actual work, maximum energy expenditure, and the proportion of resting to working time—none of these measurements could be shown to differ significantly or consistently between individuals with and without heart disease. This statement stands even in references to comparisons within the furnaceman and maintenance man groups, which had the highest energy expenditure.

**Comparison with Other Studies**

Comparison of the present study with similar observations in Europe indicates that American steelworkers expend less energy and work a smaller proportion of the shift than comparable workers in Europe.

Christensen and his co-workers have made a study of physiologic changes in normal subjects during work in a Swedish steel mill.\(^\text{14}\) They reported that the energy cost of 4 jobs* (slag removal, dolomite shoveling, tending the heating furnaces, and wire bundling) averaged over 10 calories per minute, whereas in the present study the 2 heaviest jobs studied were slag removal (8.3 calories per minute) and shoveling dolomite (7.9 calories per minute). The impression that some jobs actually are harder in Sweden is strengthened by the fact that their study reported 8 jobs at which pulse rates of over 170 were observed and 2 (hand rolling and wire bundling) where the working pulse rate averaged 181 and 183, whereas the present study included only 1 worker whose pulse rose above 170 (the subject with a resting tachycardia). The discrepancy is probably due to the use of more mechanized equipment in the American steel mill. For example, the manual part of lining the open-hearth furnace with dolomite (shoveling) takes 3 men 15 to 25 minutes in the Swedish mill, whereas the operation is almost entirely done by machine in the American mill. Another example is "hand rolling" of hot ingots between passes through the rolling mill—one of the most strenuous jobs in the Swedish study. In the American mill, this operation is accomplished by a seated operator in an air-conditioned control "pulpit."

Studies in iron and steel tempering foundries of West Germany,\(^\text{15}\) although concerned with somewhat different work, show a greater proportion of workers expending large amounts of energy. Thus, 5 out of 15 workers in a German foundry spent over 2,000 calories per shift, compared to 2 out of 53 in the present study. The German workers also rested an average of 20 per cent of the shift, while the steelworkers of the present study rested 45 per cent of the shift.

The energy expenditure of the furnacemen in the present study averaged 1,435 calories for the shift (range 800 to 2,290 calories). According to the studies and calculations of Lehmann, comparably strenuous jobs outside the metal industry are as follows: in agriculture, Alpine dairyman, Mosel wine grower, and Hungarian harvest hand; in mining, coal

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*"Jobs" here refer to single activities rather than types of employment.
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cutter and manual mover; in the stone and earth industry, kiln loader, building stone cutter, and limestone loader; and, in other fields, blacksmith, lumberjack, railway maintenance man, coal passer, and laborers at tasks such as carrying sacks of flour.16

The steelworkers of the present study differed markedly from the workers in light metal manufacturing plants previously studied from this laboratory.1 The steelworkers, in general, expended more energy (1,190 vs. 997 calories per shift), but worked less of the shift (55 vs. 65 per cent of the shift). Many jobs in the steel mill entailed high estimated heat stress, and many of these also required high energy expenditure. Higher rates of pulse and oxygen consumption were observed in the steel mill, and there were somewhat more frequent electrocardiographic changes, but observed increases of blood pressure were no greater.

It is important to note that in every work area of the steel mill, except the blast furnace and open-hearth furnace, there were jobs requiring low rates of energy expenditure comparable to those found in the light metal plants (average energy expenditure for the shift of less than 2 calories per minute).

Finally, the elevation of resting energy expenditure (oxygen consumption) and pulse rate at the end of the shift suggests a type of physiologic fatigue in the steelworkers that was not found in the light metal workers.

SUMMARY

Fifty-three steelworkers, 20 of whom have heart disease, have been studied during a typical day's work. In certain jobs, particularly in the open-hearth and blast-furnace areas, workers expended an average of 3 to 4 calories per minute during the shift, and 2 approached the estimated physiologic tolerance limit of 5 calories per minute. Estimated heat stresses in the furnace areas and close to hot steel were often high, although jobs were also studied that had low energy requirements and negligible heat stress.

Men with hypertensive and arteriosclerotic heart disease were found working at jobs of many types, and they expended energy at the same rate and worked the same proportion of the shift as normal men. Seven of the 20 cardiac and 3 of the 33 presumably normal men developed either abnormal electrocardiographic changes or increases in pulse rate and blood pressure that appeared excessive for the working conditions.

Oxygen consumption, pulmonary ventilation, and respiratory rate under these conditions varied primarily with energy expenditure. Fluid intake depended on heat stress. Blood pressure increased with energy expenditure but was more influenced by individual characteristics such as hypertension. Pulse rate was regulated in a more complex fashion than any of the other parameters, being markedly increased by heat stress but also measurably influenced by energy expenditure, the presence of heart disease, and probably anxiety. Electrocardiographic changes during work were also characteristic of the individual rather than of a particular stress. There was a slight but significant increase in resting pulse rate and resting metabolic rate during the shift consistent with development of physiologic fatigue.

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SUMARIO IN INTERLINGUA

Cinquanta-tres acieristas, incluse 20 con morbo cardiac, esseva studiate in le curso de un tipyc die de travalio. In certe typos de travalio—specialmente in le areas del furnos a solea e del alte furnos—le homines dispendedeva, al media, 3 a 4 calories per minuta durante le jornata, e 2 approchava le estimate limite de tolerantia physiologic de 5 calories per minuta. Le estimate stresses de calor in le areas del furnos e alteremente in le prox-
mitate de acero calide eseva alte in multe casos, ben que le studio includeva etiay typos de labor con basse requirementos de energia e neglectibile stresss de calor.

Homes con morbo cardiac hypertensive e arteriosclerotic eseva incontrate in occupazione de multe differente typos, e illes expendeva energia al mesme mesura e illes travaliava le mesme proportion del jornata como homes normal. Septe del 20 cardiacos e 3 del 33 presumetemente normal subjectos in le studio disvelopava anormalitates electrocardiographic o anormal augmentos del frequentia del pulso e tensiones de sanguine que pareva esser excessive pro le conditiones de labor con que illos eseva associate.

Le consumption de oxygeno, le ventilation pulmonar, e le frequentia respiratori variava sub iste conditiones primarimente con le expensa de energia. Le ingestion de liquido dependeva del stress de calor. Le tension de sanguine montava con le expensa de energia sed eseva influentiate plus marcatemente per characteristicas individual como per exemplo le presentia de hypertension. Le frequentia del pulso eseva regulata de manera plus complexe que omne le altere variabiles. Illo eseva augmentate marcatemente per stress de calor, sed illo eseva etiam influentiate mesurabilemente per le expensa de energia, le presentia de morbo cardiac e, probabilmente, le presentia de anxietate. Le alterationes electrocardiographic que occurreva durante le travali eseva similamente caracteristic del individuo plus tosto que del presentia del un o del altere typo de stress. Esseva notate un leve sed significative acceleration del pulso in stato de reposo e del metabolismo in stato de reposo in le cursó del jornata in associate con le disveloppamento de fatiga physiologic.

REFERENCES