THE ERGONOMICS RESEARCH SOCIETY

SYMPOSIUM ON

FATIGUE

EDITED BY

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EDITOR'S PREFACE

This book brings together a number of contributions dealing with the many-sided and complex problem of fatigue. The papers were given originally at a Symposium on Fatigue held by the Ergonomics Research Society in March, 1952, at the College of Aeronautics, Cranfield. The Society was founded in 1949 to bring together anatomists, physiologists and psychologists, with engineers and others interested in the design of machinery and equipment for human use. Each of these different approaches to the problem of fatigue is represented here. It has not been possible to include all the papers given at the symposium, but a complete list of the speakers and the titles of their papers is given in the Appendix.

Utter exhaustion from exceedingly heavy muscular work can involve systems of the body other than that of the neuro-musculature, as Professor Hohwü Christensen points out in his paper on page 93. When heavy muscular work is performed under physiologically satisfactory environmental conditions and without net fluid loss, it seems reasonable to relate the amount of fatigue to the amount of work done or to the rate of working per unit of work, the work being measured perhaps as calories expended in bodily effort. Professor Christensen has gone a step further, and suggests indices based on physiological measurements (oxygen consumption, pulse rate, body temperature and metabolic rate) which take into account, for example, the thermal loading effect on the body of a hot environment such as is found in many factories in the iron and steel industry.

There is little dispute about the reality of fatigue in these circumstances, although its nature in physiological terms is but incompletely understood. The reduction of such fatigue is largely a matter of ad hoc remedial measures as, for instance, the use of suitable protective clothing or the provision of increased ventilation. Often, something can also be done to even up the work-load on the members of a team or to reduce the peaks of heavy work, although these may be too closely tied up with the design of the process for much to be achieved.

In tasks which do not demand heavy muscular effort carried out in environments which do not impose a severe load on body mechanisms, it is nevertheless a common experience that fatigue occurs. It is in these circumstances that the psychological aspects of fatigue are invoked to explain the change in performance or decrease in output which is observed. The physiological factors may not be unimportant even here, but they are more elusive than with heavy work, where large and measurable changes in the body systems can usually be demonstrated.

The psychologist studies the behaviour of the whole organism relating performance to stimulus, movements to visual or auditory display. This approach
has been developed with notable success by Sir Frederic Bartlett and his colleagues at Cambridge. The physiological explanations which underlie the psychologist’s account of human performance have yet to be studied in the detail required for a physiological understanding of these problems. Our limited knowledge of the central nervous system is one of the larger obstacles to such an understanding. Probably, in the light work situation, fatigue is largely a central nervous system phenomenon. There is no doubt, as the psychological papers in this volume show, that the phenomenon of fatigue is complex, and that it is often difficult to distinguish from kindred phenomena such as boredom. Physiological and psychological considerations are closely linked, and many of the contributors, while concerned primarily with one or the other, have discussed problems in which both are interwoven. It is for this reason that in setting out the Table of Contents we have found it impossible to divide the papers clearly into physiological and psychological groups.

Fatigue, in the form of the allowances made in industry to permit recovery from the fatiguing effects of work, costs industry a vast sum of money each year. It is difficult to estimate just how much, but a figure of tens of millions of pounds is possibly not too high. The problems of fatigue are thus a challenge to productivity, as well as to anatomy, physiology and psychology.

W. F. FLOYD.
A. T. WELFORD.

April, 1953.
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PHYSIOLOGICAL VALUATION OF WORK IN
NYKROPPA IRON WORKS

By

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From the physiological point of view a labour investigation must have as one
of its objects the production of an optimum work environment, which will
render possible large output with the least possible fatigue of the worker. The
workman need not experience fatigue even with a heavy class of labour if the
rate of work and the load of work are rightly adapted to the working capacity
of the body. Suitable breaks and sufficient rest and recreation should render
possible a complete restitution of the energy expenditure. That the working
capacity mostly declines after middle age need not be shown by a reduction of
skill. As a rule it is caused by processes of degeneration due to age, which in
the main take place independently of the character of the work. The fact that
a working capacity reduced by age is more often observable in heavy work
than in lighter work need not be due to fatigue, but may be occasioned quite
simply by the fact that, with advancing age, the margin is reduced which exists
between the maximum capacity of output and that part thereof which is normally
employed; compare, for example, the capacity of output in sports which is
already reduced in the thirties. Even in heavy work, such as forest work, the
heaviness of the work or the intensity of the work during long periods is seldom
greater than about 50 per cent. of the maximum capacity of output of the
individual in question. Among other things, from a recruiting point of view it
is obviously of the utmost importance in heavy work if it is possible to deal
by rationalization with those peaks which demand very great intensity of work
or are in any other way a special strain. In such a case it should be possible to
extend the recruiting basis and also keep the older workmen. This may be of
great importance not least with regard to the present distribution of ages and
that during the next few years, among the part of the population capable of
labour. Furthermore, this is of the utmost importance if male labour might
have to be replaced by female labour. In by no means few occupations it is
certainly these peaks which, even if they only cover a small percentage of the

* This paper is part of a report to the Uddeholm Co., which initiated and partly
payed for this investigation.
entire working time, are a contributory cause in limiting the supply of suitable labour. A first condition precedent for rationalization according to the principles here sketched out is, of course, that the task shall have been subjected to a thorough analysis likewise from the physiological standpoint so as to know where the peaks occur and what their nature is. The Nykroppa investigations are an attempt in that direction.

If a skilled and an unskilled workman are compared at a certain work task it is obvious that the skilled man works more economically. He often succeeds at the first attempt, while the unskilled man requires several attempts in order to solve the same problem. The result, at the end of an eight hours' working day, may possibly be the same for both, but the skilled man has attained his result with considerably less expenditure of energy and effort and is less tired than the unskilled man. In the case of very heavy work, the same distinction may be observed between the muscularly strong and the muscularly weak workman. The practical efficiency may therefore be better for the skilled and muscular workman than for the weaker and unskilled. With occupations presenting an identical work task, therefore, the physiological burden may vary considerably. Certainly these factors should be borne in mind to the fullest extent in new appointments, especially in occupations involving heavy physical work.

The suitability of a person for long continued heavy work may be judged, inter alia, by determining the capacity for absorption of oxygen, as it is the processes of combustion which form the basis of his work output. Even if the maximum oxygen absorption capacity of an individual is, for example, 4 litres per minute, still, in accordance with the above, no higher value is found as a rule for the oxygen absorption than about 2 litres per minute during the exercise of an occupation which requires a more continuous labour input. That does not entail an unnecessary wastage of working power but is an expression of the fact that the human organism, in a similar way, for example, to a combustion engine, has a certain optimum performance at which the degree of efficiency is at its maximum and the fatigue relatively small. When the extreme limit of the capacity of output is approached, the degree of efficiency falls off rapidly, and the period of restoration, which is necessary in order to completely renew the working capacity, is disproportionately long.

With certain work tasks of short duration it may, however, for practical reasons, be necessary that the optimum working intensity from the physiological standpoint should be exceeded. The energy is supplied, however, not only by combustion (aerobic) but also by the formation of lactic acid (anaerobic). The degree of efficiency is then low, perhaps only half of that at optimum intensity. Fatigue supervenes rapidly and the period of restoration is relatively long.

In certain work tasks the expenditure of energy increases in direct proportion to the intensity of work, in so far as the maximum limit of the latter is not approached. According to a similar curve the degree of strain, which is not
Fig. 1.—Merchant mill rolling.
FIG. 2.—Determination of O₂-intake during slag removal.

FIG. 3.—Determination of body and skin temperature during roughing (wire rod mill).
objectively measurable, undoubtedly increases. Therefore, according as the absorption of oxygen is great or small, certain conclusions can be drawn with regard to the degree of strain in a certain stage of work under certain constant conditions. Care must, however, be taken not to apply the energy output as the only measure of strain, especially if entirely different work tasks are compared. So-called easy work may be strenuous (1) if it is distributed over a few relatively weak groups of muscles; (2) if it is to a predominant extent of a static character; (3) if the working position is awkward; or (4) if the work is carried out at a high temperature. The degree of strain undoubtedly increases heavily with the load per sq. cm. of muscular cross-section. To lift 10 kg. by bending the fingers may be considered as a strain, while, for example, the knee muscles, which have many times larger cross-section, can without strain lift a much greater weight.

THE NYKROPPA INVESTIGATIONS

In the course of the investigation, which was begun on June 15 and completed on July 15, I had as collaborators Dr. P. O. Astrand, Miss Irma Rhyming, Mr. Astrid Lidholm, all from the G.C.I. physiological institution, and Miss Brita Johansson, from the Munkfors laboratory.

The methods which were employed rendered necessary the installation of a complete laboratory of work physiology. The object of the investigation was, to a large extent, to determine a number of factors of physiological importance in the work of the iron foundry. This was carried out on the basis of certain relatively simple physiological studies. Figs. 1, 2 and 3 show Nykroppa operatives at work while physiological observations were being made.

The Nykroppa foundry is not very modern, and certain tasks in the factory are of such a character that the heat radiation, together with the heaviness of the work, may render rationalization measures desirable. In Nykroppa there are three basic Martin furnaces, one larger one having been constructed in 1946. The rolling mill department consists of a modernized castings rolling mill with corresponding furnace and soaking pits. There is also a medium rolling mill and a fine rolling mill of older date, and likewise two steam hammers. The product consists chiefly of the material for the Storfors Rorwerk (Storfors Tube Works). It is hammered and chiselled clean of incrustation in a separate section of the works. For the rest, rolled steel rod and rolled wire is produced. The steam hammers forge the material in the first place.

The work which formed the subject of the labour physiology investigations and is dealt with in this paper is as follows.

Martin Furnace Works

Removal of Slag.—A small portion of the slag which is formed in the melting process is collected in a pit under the tap of the Martin furnace. About four
hours after tapping off, this slag, which still has a very high temperature, is taken away. The work is carried out by three men and occupies fifteen to sixty minutes. It recurs about once per shift. The room temperature is high, and the radiated heat is intense.

Shovelling Dolomite.—After the furnace has been tapped the bottom is lined with burnt dolomite. This is done partly by hand, the dolomite being shovelled into the furnace. As the door of the furnace is open during the course of the work, the workmen are exposed to intense heat radiation. The work is carried out by three men and occupies usually fifteen to twenty-five minutes about every seventh hour.

Turning Chills.—When the castings have to some extent been rolled in chill moulds, they are raised and tipped over by means of a hook. The work is not particularly heavy but, as the chill is of a brown reddish heat, the radiation of heat is intense. The work takes about sixty minutes and recurs every seven to eight hours.

Coarse Rolling

Looking after the furnace requires the turning round of the castings, which is done by three men, while the fourth is at rest. The effective working time per casting is about two to three minutes and from eight to ten castings are taken out per hour. Owing, however, to the alternative heating arrangements the casting-heating furnace is only in operation about half the time.

Hand Rolling.—Ingots of circumference between 110 and 210 mm. are hand-rolled. For this purpose the substance is held by means of tongs and is directed inwards in straight rolling tracks. The rolling team consists of three to five men and the working time is about two minutes per casting. The output varies from ten to fifteen castings per hour.

Looking after the Sawing Pit.—When the materials are finished rolling they are sawn or cut into the specified lengths, and then drop down into a loading trolley. One to two men are ready to intervene with hook or tongs. The staff alternates but the work viewed as a whole is continuous.

Fine Work

Cogging Down.—The work is not mechanized. The rolling is done by three men while the fourth rests. The effective working time amounts to about 75 per cent. and the workmen are exposed in part to the action of heat from "their own" heaters, and in part also from passing material from the casting-rolling work.

Bundling the Wire.—When the rolled rings of wire drop to the ground they are carried at first to an inspection room, where the wire is inspected and the ends are cut away. After this bundling follows, and loading on to the truck. The rings of wire weigh about 60 kg. The work is carried out without mechanical
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$^1$ = warm  
$^2$ = cold  
$^3$ = heavy ingots  
$^4$ = light ingots  
$^5$ = only 1 determination
assistance. With high output the "drop" is unsatisfactory. The bundling work proper occupies 30 to 40 per cent. of the total working period.

**Medium Work**

The rolling is first carried out by four to five men. The work takes place continually during the entire shift, and the weights of material range from 15 to 200 kg.

**Steam Hammer Forging**

The work is carried out by a team of six men who, by means of a revolving crane, hammer castings of up to 2.5 tons. As heating cannot take place continuously the effective working time is relatively short.

**Chiselling**

For the purpose of removal of incrustation the material is chiselled by means of pneumatic hammers. The work also includes transport of the materials before the actual chiselling.

**RESULTS OF INVESTIGATION AND DISCUSSION**

In Table 1 a part of the operations investigated are indicated. The oxygen consumption \( \text{O}_2 \) litres/minute is an expression of the intensity of consumption in the body which the work entails, the heavier the work the greater the \( \text{O}_2 \) consumption. The variations in oxygen consumption are considerable even for the same process, as can be seen, for example, from the extreme values in the handling of the blast furnace. On the basis of the oxygen consumption the production of calories can be calculated. A small proportion of these calories, estimated at 10 per cent., is converted into mechanical work, the larger part degenerates into heat and must be conveyed away from the body. Especially with work in a hot environment, when the climatic conditions impair the radiation of heat from the body, it is of interest to determine the total production of calories.

The pulse frequency per minute is determined both in connection with the absorption of oxygen and by a number of calculations during the shift. This is done *inter alia* in order to check that the intensity of work, at the time of determination of oxygen consumption, was representative. Under normal climatic conditions the pulse is in a specific relation to the oxygen consumption so that, for a given person, a perfectly reliable view of the heaviness of the work can be obtained by calculating the pulse. This relation is, however, disturbed if the work is carried out at high temperature, the increase of pulse per litre extra oxygen can then be considerably higher than normal. The extra increase of pulse is in that way a measure of the specific heat action, including likewise
PHYSIOLOGICAL VALUATION OF WORK

the greater degree of strain in hot work. Excessive water loss from the body may also entail an extra increase of pulse.

The body temperature likewise can give valuable information about the heaviness of the work. The body temperature normally adjusts itself at a constant level after about one hour’s work to a value which depends on the work load. The greater the load—i.e., the greater the rate of development of energy—the higher the temperature. The adjustment of the body temperature to a higher level is therefore not due to the body being unable to get rid of the heat, which is present even if the work is done at a low temperature. At high environmental temperatures, however, the body temperature itself can increase abnormally relative to the oxygen consumption. An increase beyond what is found in a normal climate is again an expression of the specific effect of the high environmental temperature or heat radiation.

The loss of fluid during the shift can also give information about the combined effect of work and heat. A certain amount of perspiration is normal, but it is increased very much if the temperature of the air or the intensity of heat radiation is high. The time of exposure is also a determining factor in the amount of fluid lost.

In order to discover whether, in the course of the shift, there is such an extensive exhaustion of the workman that his working capacity at the end of the shift is considerably reduced, tests of function by the bicycle-ergometer were also carried out at the beginning and towards the end of the working period. If, with a particular work load, a greatly increased pulse is found at the close of the shift, this may point to an exhaustion exceeding what may be considered as normal with a class of work which is to be carried out day by day. The increased pulse may, however, also be due to a drying up of the organism, caused by the loss of liquid through perspiration not being made good.

On the basis given in Table 1 an attempt has been made to effect a certain gradation of work tasks from the physiological standpoint. For example, from the average figures for absorption of oxygen per litre per minute, it can be seen that the removal of slag takes the first place, the shovelling of dolomite the second place, the management of the blast furnace in the coarse work (coarse foundry) the third place, etc. If the average values of the pulse calculations, carried out at the same time as the oxygen consumption measurement, is made the basis of the grading, then hand rolling takes the first place, followed by wire bundling, dolomite shovelling, etc. If these figures be totalled up for the several work tasks and divided by the number of observations, we obtain an “average grading figure.” For example, for the management of the casting furnace: 3 plus 6 plus 2 plus 4 plus 3 plus 2 averages 3·3, or the chiselling 10 plus 11 plus 11 plus 10 plus 9 plus 10 averages 10·2. According to this basis of succession the wire bundling becomes No. 1, the management of the blast furnace No. 2, the dolomite shovelling No. 3, etc. The lowest are the fine rolling, chiselling and handling of conveyors.
The gradation here given must be taken of course for what it is—namely, an attempt by physiological methods to attain to an objective valuation of certain working factors. The method must never be applied in a rigid form, because in such a case the result may be entirely meaningless. Among other things, it must be borne in mind that the figures which are the basis of the gradation of work do not in many cases allow for the effective time of work during the shift. The dolomite shovelling, for example, which, according to Table 2, has received average place grading 3, may perhaps occur only once during a shift for a combined time of ten to fifteen minutes, whereas, for example, the rolling in the “fine works” with average grading figure 4 takes place for a longer effective working period.

![Graph showing O₂ uptake, mean values.](image)

**Fig. 4.**—O₂ up-take, mean values.

A, Slag removal; B, Dolomite shovelling; C, Tipping the moulds; D, Tending the heating furnace; E, Hand rolling; F, Tending the saw pit; G, Roughing (wire rod mill); H, Wire bundling; I, Merchant mill rolling; J, Forging; K, Chipping.

On the basis of the analysis of work carried out here we should now be able to indicate where the peaks occur and what is their nature. In Fig. 4 the average values of the production of calories for the various work tasks are reproduced graphically, and at the same time an attempt is made at work classification into very light; light; moderately heavy work; etc. This classification most certainly agrees in main outline with a purely practical valuation. Only one working task, chiselling, lies on the limit between light (5 Cal./min.) and moderately heavy work, while slag removal, dolomite shovelling, management of the furnace and wire bundling are considered very heavy work. From the extreme values in Table 1 it is evident that in a workman at the blast furnace we have reached such extreme values as 16 Cal./min.

With rationalization of work from the physiological point of view, four peaks
must accordingly be taken into account. As regards slag removal and dolomite shovelling, however, it may be pointed out that the effective working times per shift are so short that there is no occasion for measures of rationalization so long as male labour can be recruited among those having the muscular strength here required. As regards management of the furnace and wire bundling, the results show that there is every possible need to render these work tasks easier, especially as the work occurs for a relatively long working period and under the effect of heat radiation.

That the four work tasks which here represent the peaks must in actual truth be accounted very heavy work is furthermore evident from the fact of finding a certain increase of the blood lactic acid values. This indicates that the organism is also having recourse to the anaerobic supply of energy in which glycogen is converted into lactic acid. The highest value of blood lactic acid, 43 mg. per cent., is, however, found in a fifth work task, in medium rolling with weights of material of 140 kg. That medium rolling is not among other peaks in Fig. 4 is due to the fact that the average value in Table 1 contains all determinations with weights of material varying between 32 and 140 kg. All determinations of weights of material from 70 kg. upwards show an oxygen absorption of more than 2 l./min., and come within the category of very heavy work, therefore. The high lactic acid value may possibly be explained by the fact that the rolling of the heavy materials undoubtedly includes a pronounced static factor and a localized heavy load on the muscles of the arm and the back.

In Fig. 5 the pulse values, ascertained at the same time as the calorie production was determined, are given. Here also a classification of the heaviness
TABLE 2

<table>
<thead>
<tr>
<th>Work task</th>
<th>$O_2/\text{min}$ mean value</th>
<th>Pulse rate per min. mean $O_2$ uptake</th>
<th>Pulse rate per min. value by shifts</th>
<th>Maximum pulse values</th>
<th>Maximum body temperature</th>
<th>Lithium fluid discharge exclusive of urine, mean value</th>
<th>Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open hearth:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Slag removal</td>
<td>1</td>
<td>4</td>
<td>—</td>
<td>8</td>
<td>—</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Dolomite shovelling</td>
<td>2</td>
<td>3</td>
<td>—</td>
<td>4</td>
<td>—</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Tipping the moulds</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>11</td>
<td>7</td>
<td>—</td>
<td>12</td>
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<td>Cogging mill:</td>
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<td></td>
<td></td>
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<tr>
<td>Tending the heating furnace</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
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<td></td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>11</td>
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<tr>
<td>Hand rolling</td>
<td>5</td>
<td>1</td>
<td>7</td>
<td>9</td>
<td>4</td>
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<td>7</td>
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<tr>
<td>Tending the saw pits</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>6</td>
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<tr>
<td>Wire rod mill:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roughing</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>4</td>
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<td>Finishing</td>
<td>(10)</td>
<td>-</td>
<td>13</td>
<td>13</td>
<td>6</td>
<td>5</td>
<td>13</td>
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<tr>
<td>Wire bundling</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>1</td>
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<td>14-inch merchant mill:</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Merchant mill rolling</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>8</td>
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<td>Large hammer:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forging</td>
<td>7</td>
<td>7</td>
<td>(6)</td>
<td>(10)</td>
<td>8</td>
<td>(1)</td>
<td>(9)</td>
</tr>
<tr>
<td>Chipping</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Overhead crane:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator</td>
<td>(11)</td>
<td>-</td>
<td>12</td>
<td>12</td>
<td>4</td>
<td>-</td>
<td>15</td>
</tr>
</tbody>
</table>

of the work on the basis of the pulse values has been made. A pulse frequency of 150 has been given as the upper limit for heavy work, while very heavy work lies between 150 and 175 pulses per minute. If the pulse lies above 175 the work is considered unduly heavy. According to this classification the majority
of working stages examined pass into the group “very heavy work.” That the classification according to Figs. 4 and 5 gives such divergent results is due to the fact that the pulse, as already stated earlier, is not only determined by the calorie production, but that the heat effect also comes into operation. The first step in the rationalization of these work tasks is to improve the climatic conditions under which the work is done.

In Fig. 6 the maximum values of the body temperature reached during the shift are shown. As the maximum desirable limit of temperature, 38° C. has been given; and, as the maximum permissible limit, 39° C. In two working tasks, rolling and wire bundling, the maximum limit was exceeded and the majority of the remaining values lie above 38° C. Once again it is heat action which is in the first place responsible for the peaks. The highest maximum attained of 39·5° C. was reached during the afternoon stage on a specially hot day with high output.

Fig. 7 reproduces the loss of fluid during an eight hours’ shift. Here too
there are three well-defined peaks in which the loss of fluid during an eight hours’ stage exceeds 5 per cent. of the body weight.

The result of the analysis of work shows (1) that two work tasks (the handling of the blast furnace and, specially, wire bundling) are so high, from the standpoint of consumption of energy, that measures of rationalization, if they are technically practicable, are desirable; (2) that a majority of work tasks must, by reason of the action of heat, be classed in the category of very heavy physical work, even if the consumption of energy is not specially high.

![Graph showing maximum fluid discharge exclusive of urine.](image)

**Fig. 7.—Maximum fluid discharge exclusive of urine.**

A, Dolomite shovelling; B, Tending the heating furnace; C, Tending the soaking pit; D, Hand rolling; E, Tending the saw pit; F, Roughing (wire rod mill, warm day); G, Finishing (wire rod mill); H, Wire bundling; I, Merchant mill rolling; J, Forging.

In order to obtain an objective view and a quantitative expression of the specific effect of heat during body work, an experiment was made with the same person carrying out a measured amount of work, for example, 600 or 900 kgm./min. on a bicycle ergometer on the one hand in a normal climate—*i.e.*, at an air temperature of about 20° C. and on the other hand at the place where the workman exposed to heat radiation has to perform his work, for example, in the sawing pit. According to our view, such experiments, in which, for example, the pulse during the same work is compared, give the best possible information about the influence of the climatic factors on the workman (see Table 3).

To define the climate physically in the different working places was found quite impracticable. In the best case the temperature and the air speed could
be defined, but the latter with great uncertainty owing to varying speed and direction. What could not be determined, however, among other things, was the temperature of radiation which, in the iron foundry, is of the very utmost importance. From measurements with sooted thermometers or sooted thermopiles or black body thermometers it was only evident that the intensity of radiation in certain working places was very high and was subject to rapid variation. Quantitatively the radiation could not be determined.

That the climatic factors can undoubtedly be of primary importance as regards production in the iron industry may be illustrated by the following example. A coggging down workman in rolling for finishing, on July 11 (one of the hottest days during the trial period), after sixty-eight minutes of work, had a rectal temperature of 38·1 ° C., while at the same time the mean temperature of the skin was 36·9 ° C., the difference being therefore 1·2 ° C. According to recent investigations, a full grown man can, under favourable conditions, get rid of at most about 3 Cal./min. per degree of temperature difference between body temperature and skin temperature. The workman could therefore at the time of measurement get rid of, at most, 3·6 Cal./min. A simultaneous determination of his production of energy showed, however, that he produced about 7 Cal./min. at that particular work. Therefore there was stored per minute in the body 3·4 Cal./min., which means that the body temperature had to increase by about 1° per less than twenty minutes under the particular conditions.

In order to attain a balance of heat three different alternatives could be imagined as existing: (1) A reduction of the rate of work—i.e., of the output—so that the heat production in the body was reduced to correspond to 3·6 Cal./min. As about 1 Cal./min. always goes to the basic turnover of the body this would mean that the rate of work would have to be reduced to less than half of the normal. (2) The normal rate of work is maintained, but the periods of work are made relatively short and alternating with regular cooling pauses. This measure likewise, of course, reduces the output per workman. (3) The climatic conditions are modified in such a way that the giving off of heat is
not the factor which limits the work. In the case here reported the skin temperature should not exceed about 35° C. From all points of view the last alternative must of course be regarded as the most rational to be realized from a technical point of view.

When this has been done the investigation can then begin as to whether the present figure of production is the optimum or whether it can possibly be increased without other “fatigue factors” in their turn limiting the rate of work. In the case here discussed it was found that local cooling with an industrial blower lowered the air temperature at the place of work by about 10° C. The workmen stated spontaneously that the work was facilitated very considerably.

In this connection the importance of the clothing may be briefly emphasized. At the present time the workmen protect themselves against injury by burning due to radiation of heat from the furnace or incandescent material by means of heavy, heat-insulating clothing. This of course is quite irrational from the heat regulation standpoint. Certain trials with reflecting clothing appear to indicate that an alteration in the clothing may contribute to a considerable improvement of the working conditions.

Only by an effective evaporation of perspiration can the body temperature be kept within tolerable limits. In one particular case the loss of liquid during one stage of work was over 6 litres. In a majority of workers we found considerable loss of weight after the shift owing to the fluid loss not having been made good by drinking. The workmen were often of opinion that the less they drink the less they perspire and the better they cope with their working task. The fact is, however, that the production of perspiration within wide limits is independent of the intake of liquid, and that a large loss of liquid can result in an abnormal increase of pulse and reduction of working capacity. Where there is excessive perspiration, the thirst, especially in untrained workers in heat, is not a reliable indicator as to how much should be drunk. The risk of shortage of salt is greatest in the untrained, because the content of salt in perspiration is greater than in those who are acclimatized to working in heat. The acclimatized workman is therefore thirstier on a certain loss of fluid than the unacclimatized and therefore covers his loss of fluid more easily.

The functional test mentioned earlier, which was carried out on twenty-three workmen at the beginning and end of the shift, showed generally good function likewise at the close of the working stage. In isolated cases, however, the increase of pulse in the test work was considerably higher at the end of the shift, which indicates that the preceding load on the circulation had come close to or gone beyond the limit of what was physiologically permissible. This applies to a couple of cogging down workmen in the fine works (on a hot day), a couple of wire bundlers, and a rolling workman in the medium works, the latter convalescent after a long illness.

That the high pulse rates which we found in certain work tasks were not due to general bad condition in the workmen was evident from the function
tests, in which the pulse values found were clearly on the lower side of the normal values.

From the standpoint of work physiology, it may be interesting to compare iron foundry work with other branches of work in which the work itself is heavy. It would be natural in this case to compare with forestry work which, on the one hand, has been well investigated from the physiological standpoint, especially by the works of Lundgren and Zotterman in Sweden, and on the other hand is one of the heaviest branches of labour. For purposes of comparison a table is reproduced from the work of Lundgren. Table 4 shows the average values of the pulse rate and the absorption of oxygen in various stages of work in the forest. From the table it is evident that the one test person (B.N.) in no case has an oxygen absorption of more than 1.9 l./min., and that the other (T.L.) only goes beyond 2 l./min. in three work tasks. The maximum value is 2.2 litre/min. If we compare these values with the values found by us in Table 1 we see that a majority of work tasks are entirely and fully equivalent from the

<table>
<thead>
<tr>
<th>Individual</th>
<th>Type of work</th>
<th>Pulse</th>
<th>$O_2$ l./min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.N.</td>
<td>Felling trees</td>
<td>106·6</td>
<td>1·69</td>
</tr>
<tr>
<td></td>
<td>Trimming</td>
<td>99·1</td>
<td>1·68</td>
</tr>
<tr>
<td></td>
<td>Cross-cut sawing</td>
<td>94·7</td>
<td>1·41</td>
</tr>
<tr>
<td></td>
<td>Splitting soft timber</td>
<td>107·5</td>
<td>1·89</td>
</tr>
<tr>
<td></td>
<td>Splitting birchwood</td>
<td>104·6</td>
<td>1·76</td>
</tr>
<tr>
<td></td>
<td>Bark Stripping</td>
<td>89·0</td>
<td>1·07</td>
</tr>
<tr>
<td></td>
<td>Stacking logs</td>
<td>93·7</td>
<td>1·18</td>
</tr>
<tr>
<td></td>
<td>Stacking logs</td>
<td>101·0</td>
<td>1·80</td>
</tr>
<tr>
<td>T.L.</td>
<td>Felling trees</td>
<td>137·5</td>
<td>2·28</td>
</tr>
<tr>
<td></td>
<td>Trimming</td>
<td>120·3</td>
<td>1·78</td>
</tr>
<tr>
<td></td>
<td>Cross-cut sawing</td>
<td>122·5</td>
<td>1·79</td>
</tr>
<tr>
<td></td>
<td>Splitting soft timber</td>
<td>128·4</td>
<td>2·07</td>
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<td></td>
<td>Splitting birchwood</td>
<td>128·7</td>
<td>1·87</td>
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<tr>
<td></td>
<td>Bark Stripping</td>
<td>106·9</td>
<td>1·35</td>
</tr>
<tr>
<td></td>
<td>Stacking logs</td>
<td>110·9</td>
<td>1·42</td>
</tr>
<tr>
<td></td>
<td>Gathering in logs</td>
<td>127·1</td>
<td>2·24</td>
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</table>
point of view of oxygen consumption. If we look at the pulse values, the iron foundry work is quite in a special class with very high pulse values.

In a practical valuation of the Nykroppa investigations it must be borne in mind that the determinations were carried out in the hottest season of the year, when the work was required by the company management to be assessed just when the working conditions were most unfavourable for the workmen. At lower outside temperatures the working environment is, of course, far more favourable, and consequently the strain in the majority of work tasks is less.

In this brief review of the result of the Nykroppa investigations it has not been possible to enter upon a full discussion of the numerous problems touched on. It is my hope, however, that the material here set out justifies the method of work physiology for a valuation of various work tasks and, in general, the application of physiological points of view to a rationalization of work, the object of which is to create the best possible conditions for an increased production with a reduced strain on the workman.