INDUSTRIAL HYGIENE

Notes on Industrial Hygiene

STUDIES IN INDUSTRIAL PHYSIOLOGY

THE Lannelongue Institute of Social Hygiene of Paris was founded in 1916 under the will of the late Professor Lannelongue for purposes of scientific and educational work and organisation with a view to fostering the vitality of the French people. A committee on industrial physiology, of which Mr. Arthur Fontaine, President of the Governing Body of the International Labour Office, is chairman, has been set up by the Institute to investigate fatigue and output. The Institute has published three numbers of a series of *Notes and Memoranda* (1), the contents of which are briefly summarised here.

One of the most important studies in the series is that of Mr. Frois and Mr. Caubet, who deal with output, industrial fatigue, and women's work in a powder factory. The first two sections of the report deal with matters which have long been familiar, though they were no doubt new to those in France who read the report when first published. The points dealt with include the relation between output and scientific arrangement of work, fatigue, the output of labour, and accidents. The authors then rapidly describe and criticise the principal tests of fatigue, such as output curves, sickness curves, calorimetric methods, respiratory exchange of gases, and chemical, physiological, and psychological methods. The point of chief interest in the report, however, is the study of the work of women in bundling (2) at the Ripault powder mills.

Analysis of the job and time study show that for each complete operation the worker has to perform a series of twelve movements in a comparatively short time — 16½ seconds on the average. The performance of the work involves the use of almost all the muscles and of the higher functions, such as will (in order to maintain speed),

---

(1) INSTITUT LANNELONGUE D'HYGIÈNE SOCIALE : *Notes et Mémoires*, Nos. 1, 2 and 3. 104, 107, and 101 pp. Paris, Alcan.

No. 1 contains *Le rendement de la main-d'œuvre ; La fatigue professionnelle;* and *Le travail féminin au bottelage des poudres* ; by M. FROIS and B. CAUBET.

No. 2 contains *Introduction au test de la fatigue musculaire basé sur la chronaxie*, by L. LAPICQUE ; *Modification de l'excitabilité musculaire par la fatigue*, by L. and M. LAPICQUE ; *Etude physiologique du travail de rivetage*, by M. FROIS ; *Recherches sur les modifications des phénomènes respiratoires que produit chez l'homme le travail musculaire*, by M. MAGNE.

No. 3 contains *Recherches préliminaires sur les signes psychologiques de fatigue*, by H. PIÉRON ; *Les modifications des échanges respiratoires pendant l'exercice musculaire*, by H. MAGNE.

(2) The powder is manufactured in the form of paste and rolled into strips a few millimetres thick, which are cut into small rectangles. The work of bundling (*bottelage*) consists in taking a number of these rectangles, up to an approximate weight, setting them in a pile in a hand press, and compressing them. The bundle so made is then tied on either side and removed from the press.

judgment in certain of the operations, and attention. The work may be done either seated or standing, and, although fairly light when measured mechanically (35,000 kilogramme-metres (3) of work done per day, corresponding to 82 calories), it is very trying when carried on day after day. This illustrates the fact that mechanical measurement of a job is no criterion of the fatigue occasioned by it.

Muscular force as measured with a dynamometer decreases towards the end of the day, showing a mild form of muscular fatigue which disappears by the following morning. Auditory acuity is also very considerably diminished. Reaction time shows a marked increase, especially towards the end of the week, indicating a slight cumulative effect of fatigue. The work always produces an increase in arterial pressure and in pulse rate, and this is much more marked in women who work standing than in those who sit. The starting effort is the greatest, and decreases progressively from the beginning of the day's work onwards, thus indicating adapation of the system to the work. After work arterial pressure falls first suddenly and then more slowly, while the pulse rate falls very rapidly below normal, subsequently rising gradually to normal again. It is therefore most important that measurements should be taken immediately work is finished.

The authors consider that the results of their tests are satisfactory, but, as fatigue affects the whole system, it would be a mistake to attempt to localise its effects in studying industrial work. In order to be able to draw correct conclusions regarding fatigue, the investigator must not limit himself to the results of a single test.

Among the practical results of the study, it may be mentioned that in the view of the authors rapid processes of manufacture are not necessarily detrimental to the physical well-being of the workers, provided that the various factors in the work and the conditions affecting output and fatigue are very closely and minutely studied. The main question in industrial work is whether the methods adopted for its execution are consistent with normal activity on the part of the worker. In the particular case of the powder mill it was possible to increase output considerably and to double wage while decreasing hours of work, restoring the weekly rest day, and abolishing night work. In addition a decrease in morbidity was noted, as a condition of normal fatigue entirely disappeared after the Sunday's rest.

The fact that the absolute or relative demands of a job can be determined by physiological investigation suggests that it will be possible to organise vocational guidance and training on the basis of scientific principles. It should also be possible, by studying the physiological effects of the conditions under which the work is done and the time necessary for the system to return to normal, to determine the limits within which the quality and quantity of work may vary.

Among other matters the Committee on Industrial Physiology has considered the possibility of establishing a test of industrial fatigue. Mr. L. Lapicque presents a tentative muscular test. He uses the term *rheobasis* to denote the force of electric current required to reach the galvanic limen, i.e. the minimum electric force required to produce a muscular excitation. The term *chronaxia* indicates the period of application required to reach the excitation limen with a current equal to twice the *rheobasis*. Experiments with the leg (*gastrocnemius*) muscle of a frog show that these two factors vary independently. Fatigue increases *chronaxia* without perceptibly affecting the rheobasis. *Chro-*

(3) Approximately 253,000 foot-pounds.

naxia (which is expressed in thousandths of a second), measured on a muscle or group of muscles, should provide an objective measure of fatigue in man, provided that certain disturbing factors in practical experiment can be located. Industrial experience, special practice, the commencement of work each day, preparation of work, may all cause variations ; but the increase in *chronaxia* owing to fatigue is sufficiently marked and constant to serve as a sign and measurement of fatigue.

Mr. H. Piéron contributes a paper on three psychological tests of fatigue. He bases his study on the fact that, in the course of intense or prolonged work, physiological changes may affect the cerebral functions either through their general influence on the whole system or through direct participation of the cerebral functions in the work itself, as in the case of mental work, physical work requiring a sustained effort of volition, or in complex work.

Although a study of reflex excitability (in the patellar reflex) may provide indications of cerebral fatigue and overstrain, in which condition the limen of the reflex is lowered, the reflex itself is not a flexible and clear index of fatigue, as it cannot accurately reflect the simple phenomena of transitory fatigue. The author observed that the limen of the reflex was not lowered in the course of an effort which gave a dynamographic record of considerable fatigue, but rather that there were slight variations in the direction of a raising of the limen. This indicates increased cerebral inhibition, excitation having overcome fatigue.

The second study was concerned with an enunciation test. The subject was required to name as rapidly as possible objects, colours, or forms which were placed before him. This test involves difficulties which are inherent in every process requiring a maximum effort of volition, and particularly in mental tests. The chief difficulties are that the performance of the test improves with practice and that the subject is not always equally willing to make the maximum effort. The test nevertheless represents in reality the simple and practical equivalent of a series of reaction times with variation in the reaction movement and discrimination in the exciting agent. This test should indicate fatigue in the mechanism of cerebral adjustment, reflecting with fair accuracy decreased precision and rapidity in this adjustment.

Dr. P. Janet having pointed out that in a condition of nervous fatigue and depression the limen of amalgamation of dissimilar retinal impressions is lowered and the persistence of luminous impressions is prolonged, Mr. Piéron thought that this prolongation of persistence would constitute an interesting psychological test of fatigue. In his study he describes his methods in great detail. It was observed that after intense physical effort as measured by the dynamograph there is a steady increase in the apparent persistence of retinal impressions, as determined by the limen of complete amalgamation of dissimilar impressions. This reflects a specific influence of intense work, continued to the point of fatigue, on the persistence of retinal impressions. The real cause of the increase and its exact meaning have not yet been determined. It is possible that the apparent increase is connected with a condition of nervous exhaustion and overstrain, but the author has not yet obtained accurate data on this question.

The work of the rivetter which was studied by Mr. Frois was selected because it requires considerable muscular effort on the part of the worker and "the rivet drivers's work is very simple and almost uniform". Mr. Frois was therefore able to test certain methods of estimating the expenditure of energy by the system and to ascertain

the effect of periodical rests in certain forms of work. Analysis of the job, study of the elementary movements required with the chronometer and cinematograph, and of the physiological changes in arterial pressure, pulse rate, respiration, and reaction time show that the work is heavy and that the workers must be of robust physique. The work was also proved to involve considerable physiological disturbance, especially in the respiratory and circulatory systems, which are subject to very marked rhythmic action.

By minute investigation the author succeeded in proving that human energy was badly utilised in the work. Output in rivetting is extremely variable and depends on a great many factors, e.g. the nature of the work, the make-up of the gang and periodical rests. Time study by chronometer for four hours of a single gang working in uniform conditions shows a fall in output of 33 per cent. from the first to the fourth hour. The introduction of a 10-minute rest every 50 minutes during the first three hours kept the output at a practically constant level and the total output for four hours was noticeably higher than it was before. This indicates that in any work requiring muscular effort frequent periodical rests are a physiological necessity.

A number of practical conclusions are drawn from this study. The rivetter's occupation requires considerable muscular strength, and workers in this occupation should be free from any respiratory or circulatory defects. Young persons under 18 years of age should be excluded from the occupation. Even robust and muscular men cannot work at a normal rate, say for eight hours a day, for several days without fatigue. In every hour's work a complete rest of at least ten or fifteen minutes should be allowed. The amount of energy expended should be taken into consideration in calculating wages and production bonuses. Cinematographic study of the work has revealed certain peculiarities which will be of value in vocational training. It is also pointed out that the substitution of machinery for hand labour would have great economic advantages.

The volume of *Notes and Memoranda* containing Mr. Frois' study also includes an exhaustive study by Mr. H. Magne in which he endeavours to show how the phenomena of respiration are modified in the course of muscular work. Respiratory modifications are one of the most significant and important indications of metabolism of the tissues. The author first considers changes in the supply of air to the lungs and the exchange of gases which appear at the commencement of work and indicate adaptation of the system to the work. He observed that practice and fatigue appear to have no influence on the rapidity of this process of adaptation, although they have a certain influence on the manner of the adaptation.

Persons who are accustomed to mechanical work have the power of eliminating more highly concentrated carbon dioxide from the respiratory organs and this enables them to economise pulmonary ventilation. If the work exceeds the physiological capacities of the subject, the normal chemical phenomena which occur in the tissues are disturbed and incompletely oxidised substances produced in the tissues combine their detrimental action with that of the carbon dioxide. This leads to exaggerated ventilation out of proportion to the amount of carbon dioxide eliminated and the amount of oxygen absorbed. This is the most evident symptom of breathlessness. It may be pointed out that, contrary to what the subjective symptoms might appear to indicate, breathlessness does not arise from inadequate ventilation and partial asphyxia. It appears that a subject not accustomed to work

is more susceptible to the action of carbon dioxide, quite apart from any effect of abnormal products of muscular metabolism. Fatigue, on the other hand, appears to have very little, if any, effect on the respiratory phenomena accompanying the work.

Continuing his investigation of respiratory exchanges, Mr. Magne endeavours to show the value of the respiratory method from the point of view both of the muscles and of the respiratory organs. This method enables him to study more especially the expenditure of energy required by the work, the effects of this expenditure, and its variations according to the nature of the muscles involved, the force developed, the weight carried, and speed. The power of the human machine may vary between very wide limits, and its expenditure in work is never out of proportion to its total power. The respiratory method makes it possible to determine the best and most economical conditions for human labour. One general principle may be deduced from the study of various types of work — pedalling, walking, and filing. If the human machine is to be economically used, its work must be rapid and intermittent. Practice, which makes it possible to do a greater amount of work with less fatigue, appears to be a state of better nervous working. Muscle tissue appears to be an apparatus the working of which cannot be greatly improved. If the working of the human machine as a whole is to be improved, it must be by co-ordinating the work of its different organs more accurately. Fatigue, while decreasing the working power of muscle, does not greatly affect its mechanism.

The interesting and original work published by the Lannelongue Institute has been summarised here because, although the science of work is still in its infancy, it is, to quote Mr. Frois, "of such great social importance that wisdom bids us gather its modest results today and wait without impatience for its complete development".

Dust Phthisis in the Granite Industry

A study of dust phthisis has recently been made by Dr. Frederich L. Hoffman for the United States Bureau of Labour Statistics (4) ; its main points are summarised below. The granite industry was selected from among the dusty trades as probably the best illustration of the injurious consequences of continued inhalation of inorganic silicious dust, and the industry located at Barre, Vermont, as offering exceptional facilities for investigation. The co-operation of trade unions, employers, local authorities, and insurance organisations was enlisted in the course of the enquiry and the vital statistics were derived from official State reports.

Nature and Cause of the Disease

From a careful and detailed study of mortality among granite cutters the conclusion is reached that the disease certified as pulmonary tuber-

(4) United States Bureau of Labour Statistics : *The Problem of Dust Phthisis in the Granite Stone Industry*, by Frederick L. Hoffman ; Bulletin No. 293 ; 187 pp.; Washington Govern. Print. Office, May 1922. This study is a continuation of previous investigations of dusty trades, the results of which were published in the following Bulletins of the United States Bureau of Labour Statistics, as follows : No. 79, *Mortality from Consumption in Dusty Trades* (November 1908) ; No. 82, *Mortality from Consumption in Occupations exposed to Municipal and General Organic Dust* (May 1909) ; No. 231, *Mortality from Respiratory Diseases in Dusty Trades (Inorganic Dusts)* (June 1918).

culosis "is often not a true form of tuberculosis but, strictly speaking, a silicosis or pneumonoconiosis or, in other words, dust phthisis of non-tubercular origin, though possibly in its terminal stage complicated by a superinduced tuberculosis". This has been very little, if at all, recognised among the medical profession. The figures quoted in Dr. Hoffman's report referring to deaths from "pulmonary tuberculosis" should therefore, in the author's opinion, be regarded as referring largely to dealths from fibroid phthisis.

The disease is induced by the continued inhalation of minute particles of granite dust, and the effect is markedly cumulative as trade life advances. The point at which dust infiltration becomes fatal is a matter which requires further investigation. The nature of the dust inhaled is also a factor of supreme importance. The average percentage of silica is in granite 72.96, in sandstone 85.42, while in limestone it is only 1.22. It is therefore not surprising to find the death rate per 100,000 exposed for the stone-cutting industry in Vermont, 1915 to 1918, 1064.5 for granite cutters, 1029.9 for sandstone cutters, but only 425.5 for limestone cutters, with which last the rate for glass bottle blowers, 265.9, may also be compared.

Were the disease a true pulmonary tuberculosis one would expect a very high degree of infection among the wives and daughters of granite cutters. The investigation shows that the opposite is the case, although it must be admitted that the whole subject of infection statistics is very controversial (5).

Assuming the prevalent diseases to be non-tubercular in origin, the author, nevertheless, shows that the respiratory organs once impaired by dust exposure are very liable both to tuberculous and non-tuberculous respiratory diseases and that mortality from these causes among granite cutters is on the increase. The author discusses the use of pneumatic tools, which, with their greater speed and the finer dust produced, have enormously increased the dust hazard. Where they are used in indoor work their effect is almost disastrous, as may be seen by contrasting the death rate for pulmonary tuberculosis for 1912 to 1918 in the New England States (962.3 per 1,000, indoor work during the winter with pneumatic tools) with that for the same period in the southern States (441.1 per thousand, outdoor work all year round). The author even suggests the entire prohibition of the use of pneumatic tools unless an effective dust-removing device can be introduced for indoor work.

Comparative Mortality Returns

There is a marked contrast between the increasing mortality among granite cutters and the decreasing mortality among the population at large. The general mortality rate from all causes for granite cutters in Vermont increased from 11.7 per cent. in 1889 to 25.7 per cent in 1917, while that for the adult male population of 20 years of age and over in New England fell from 20.3 per cent. in 1892 to 18.0 per cent. in 1917. Taking average rates over a period, the general mortality rate from all causes among granite cutters in Vermont for the period 1915 to 1917 was 22.9 per thousand exposed as against 17.7 per thousand of the adult male population in New England.

(5) Figures compiled by Professor Collis for the Brandon flint knappers in Great Britain would also seem to show that the wives of these men are singularly exempt from pulmonary phthisis; not a single death from this disease is recorded among them (1900-1902).

Comparison is also made between the mortality rates from pulmonary tuberculosis only among granite cutters and among the adult population of Vermont, Massachusetts, and other New England States. In Massachusetts the mortality rate from pulmonary tuberculosis among granite cutters rose from 410.2 per 100,000 in 1897 to 1056.3 in 1918, reaching its maximum, 1250.0, in 1916; while the corresponding rate for the adult male population fell from 295.0 per 100,000 in 1896 to 209.2 in 1917.

Further, the striking differences in pulmonary tuberculosis mortality rates among the different groups of stone workers — granite, sandstone, and limestone — are emphasised, as will be seen from the following results, which are here given in tabular form.

MORTALITY RATES FROM PULMONARY TUBERCULOSIS PER 100,000 EXPOSED IN CERTAIN DUSTY OCCUPATIONS IN THE UNITED STATES AND CANADA

Period	Vermont	United States and Canada		
	Granite cutters	Sandstone cutters	Limestone cutters	Glass bottle blowers
1905—1909	719.5	910.5	626.8	381.1
1915—1918	1064.5	1029.9	425.5	265.9

The figures show a fairly well-marked decrease among the limestone cutters and glass bottle blowers, a certain increase among sandstone cutters, but a much larger increase among the Vermont granite cutters.

The author draws attention to the striking fact that the good physique of the workers in the industry and the good housing conditions generally obtaining have not been of avail to protect workers from the onset of disease.

Influence of Trade Life

An enquiry for mortality purposes based on trade life has not, to the author's knowledge, been previously made on an extended scale in any of the dusty trades. The present investigation was limited to pulmonary tuberculosis. No deaths from this disease are recorded during the first two years of trade life and comparatively few during the first eight years. From the ninth year the number of cases increases and attains its maximum at the twenty-first year of exposure, thus confirming other observations that about two decades of dust inhalation are required to bring about conditions favourable to death from pulmonary tuberculosis.

> While normally the rate of tuberculosis frequency diminishes with increasing adult age, the contrary is shown to be the fact as to granite cutters, among whom the death rate from pulmonary tuberculosis at ages of 60 and over reaches truly appalling proportions, so much so that the statistical evidence would seem incredible if it were not supported by the additional and equally suggestive data for non-tuberculous respiratory diseases.

The following figures are remarkable. Of 599 deaths from pulmonary tuberculosis occurring among granite cutters at Barre, Vermont, between 1886 and 1919 none occurred during the first two years of

trade life, 7 after 5 years' exposure, 10 after 10 years' exposure, 16 after 15 years' exposure, while after 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26 years' exposure the number of deaths were respectively 21, 19, 17, 23, 23, 27, 23, 25, 23, 16, and 21.

The author gives tables, which he states to be the first known attempt of the kind, showing the distribution of the workers by years of employment in their present occupation and the number of their previous occupations.

Other Investigations and Statistics

The author makes extensive reference to research and statistics in other countries. Two important German investigations appeared in 1913 and 1915. The first is a treatise on the stone industry in the Grand Duchy of Baden by Dr. Föhlisch and the second an investigation by Dr. Koelsch reported in the *Zentralblatt für Gewerbehygiene* in 1915. The conclusions of these writers are in conformity with those resulting from the Vermont enquiry. Switzerland and the Netherlands furnish useful data for comparative mortality rates in hazardous occupations, e.g. for those of stone cutters, cement workers, lime burners, glass cutters and blowers, workers in the building trades; the periods covered are 1908 to 1911 in the Netherlands and 1879 to 1900 in Switzerland. Comparison is also made with British industrial mortality statistics.

A statistical comparison is made of mortality returns referring to granite cutters in Vermont and those referring to workers in the notoriously unhealthy quartz mining industry at Bendigo in Australia. The figures seem to show that Vermont granite cutting is rapidly rivalling quartz mining at Bendigo as an extraordinarily hazardous occupation. The findings of the Miners' Phthisis Commission of the Union of South Africa are also mentioned, as well as the investigations recently made by Dr. E.L. Middleton in Wales. The evidence in all cases tends to confirm the superior prevalence of non-tubercular silicosis or pneumonoconiosis over tubercular forms of disease among the workers exposed to dust.

The general results of the Vermont enquiry may be summed up in the author's own words.

> At the present time the death rate among granite workers is practically the highest known for any occupation on record, and the increase in the death rate from year to year is lamentable evidence of inefficiency on the part of health-promoting agencies to bring about reduction and control. The problem concerns not only the wage earners, who directly pay a frightful toll in needless deaths and prolonged chronic disease, but the burden also falls, and possibly with crushing weight, upon the industry, which is deprived of skilled workers, indispensable to the trade, and of apprentices, no longer attracted to an occupation recognised even among those not familiar with the statistical facts as one of the most deadly on record.