**Some Effects of Environment on Efficiency and Safety (Based on the
Work of the Industrial Fatigue Research Board).**

By D. R. WILSON, M.A., Secretary to the Industrial Fatigue Research Board.

AMONGST the requirements of modern industrialism, few are more important than a proper knowledge of the scientific principles governing human effort in work, and none has been more neglected in the past. The lack of such knowledge was clearly seen during the long parliamentary battles that were fought throughout the nineteenth century over every legislative proposal for limiting the hours of work, when no information based on actual experiment was available to confirm or refute the widely divergent views expressed as to the possible consequences to industry. Indeed, apart from a few sporadic instances of experiment on the part of far-seeing employers,* no attempt was made to explore the relation between physiological well-being and work until a very few years ago.

The importance of the study of the human factor in industry was first realised in America, and to Taylor, Gilbreth and others belong the credit of having raised this study to the level of a definite science. In this country, apart from some investigations carried out for the Home Office by Stanley Kent,† almost complete ignorance prevailed until well on into the war; it was, in fact, tacitly assumed that the human organism, like a machine, would respond to almost any demands made upon it, so that increased hours of work would bring about a proportionate increase in output.

The fallacy of this conception was conclusively proved by Vernon in 1916, in an investigation carried out for the Health of Munition Workers' Committee,‡ when he showed that in many operations production actually improved when the very long hours then being worked were reduced, the hourly output increasing so much as more than to compensate for the shorter periods of employment. The same Committee carried out several other investigations into the fatigue and efficiency of munition workers, and these constitute the first attempt in this country to deal with the subject on an extensive scale.

* *E.g.*, Mather, Wm., "The Forty-Eight Hour Week," Manchester, 1894.

† Kent, Stanley, "Industrial Fatigue by Physiological Methods" (Interim Report) (Cd. 8,056), 1915. (Second Interim Report) (Cd. 8,335), 1916.

‡ Health of Munition Workers' Committee, Memoranda Nos. 12 and 18. (Cd. 8,344 and 8,628), 1916 and 1917.

On the disbandment of this Committee in 1917, the Industrial Fatigue Research Board was appointed by the Medical Research Council and the Department of Scientific and Industrial Research jointly to continue this side of the work and to take over certain outstanding investigations which were being temporarily controlled by the Welfare and Health Section of the Ministry of Munitions. Since July, 1918, the Board has conducted many investigations with a staff of about 20 investigators; twelve reports on different subjects have already been published, and four others are now under consideration.

The terms of reference to the Board were as follows :—

“ To consider and investigate the relations of the hours of labour and of other conditions of employment, including methods of work, to the production of fatigue, having regard both to industrial efficiency and to the preservation of health among the workers.”

On analysis it will be seen that they specify three causal factors (*viz.*, hours of labour, other conditions of employment, and methods of work), and two effects (*viz.*, industrial efficiency, and the preservation of health amongst the workers), each cause and effect being related through the common factor of fatigue. The reference, therefore, was a very wide one, but the present paper is confined to a short description of the results obtained up to now from the study of the second of these causal factors, *viz.*, *conditions of employment* apart from hours of work, as being perhaps the particular side of the Board's work of more especial interest to the Conference. This description, however, includes only part of the task on which the Board is engaged, and definite and important results have already been obtained in respect of the other causal factors mentioned.

Factors in Environment.—The pathological aspect of the workers' conditions of employment, in other words their relation to health, has for many years been the subject of inquiry, particularly by H.M. Medical Inspectors of Factories, but so far as can be ascertained no systematic investigation has ever hitherto been undertaken into their physiological and psychological effects. Yet the latter, concerning as they do the normal man, have a special importance due to their universality, and careful research must eventually result in the discovery of principles having a direct and important practical bearing on the efficiency and well-being of the work.

The actual factors in environments are perhaps more numerous than might at first be imagined. The following for instance have all been considered by the Board at different times :—

Temperature, humidity, ventilation, lighting, noise, vibration, and dust.

The present paper is confined to the first four of these, for the reason that the Board's work has not yet progressed far enough to enable anything definite to be said about the remainder.

Methods of Investigation.—The main test of the effects on the worker of his environment has been his performance as measured by rate of output. At first sight this might perhaps be regarded as a test of universal application, but there are two important limitations to its use :—

- (a) Output depends on the machine as well as the man, in fact the part played by the human factor may vary from 100 per cent. (in completely manual processes) to almost 0 per cent. (in completely automatic processes).* In practice, allowance can sometimes be made for this, but the sensitiveness of the test obviously diminishes as the mechanical factor preponderates, until the point is reached when the margin left is too small to be informative. For this reason variations in output can only be adopted for certain purposes, a subjective test being required for others.
- (b) Variations in output can be caused by other conditions than the one under consideration. For the proper study therefore of any one condition (*e.g.*, temperature), it is necessary that all others (*e.g.*, hours of work, nature of product, conditions of manufacture) should be kept constant. In practice this is generally impossible to achieve on anything like a large scale, and as an alternative recourse has often to be had to calculation intended to correct the effects of the conditions that cannot be controlled. If neither of these methods can be adopted, output is obviously unreliable as a measure of any one of the conditions.

Another "effect" of environment, referred to in the present paper, is accident incidence. Whether accident incidence is related primarily to speeding up in production, to fatigue, or to the psychical condition of the worker is still a matter of controversy, but even without this knowledge it is of interest to discover the conditions of employment which in practice tend to produce the maximum or minimum incidence.

EFFECTS OF ENVIRONMENT ON OUTPUT.

1. *Temperature.*—Vernon has shown that in heavy work, involving exposure to high temperatures, production undergoes a consistent seasonal variation, being with very few exceptions greater in winter than in summer.†

* Cf. Industrial Fatigue Research Board Report No. 7.

† Industrial Fatigue Research Board Report No. 5.

The particular processes studied were rolling in tinplate manufacture, charging of blast-furnaces, steel-smelting (open hearth and Bessemer processes), steel ingot rolling and puddling. On comparing the output records for December to March (Winter) and for June to September (Summer) over a long period, it was found that out of 26 factories, percentage reductions of 13·6 to 1·5 occurred in summer in 21 cases whilst small increases (4·0 to 0·2 per cent., due generally to technical considerations) occurred in 5 only.

More definite results as to the effects of temperature were obtained by Vernon in tinplate rolling mills,* by grouping together all the weekly output data in each factory according to the mean weekly outside temperatures as recorded at the local meteorological station. The results are given in the following table :—

Factory.	Total weeks Investigated.	Mean External Temperature during Week.						
		Under 40°	40° to 44·9°	45° to 49·9°	50° to 54·9°	55° to 59·9°	60° to 64·9°	65° and over.
A ...	115	102·1	102·3	100·0	99·6	98·9	98·1	94·0
B ...	332	104·8	103·3	100·8	98·9	98·1	96·7	93·7
C ...	193	100·3	103·9	103·5	100·5	99·1	93·4	95·5
D ...	203	105·3	105·2	102·3	99·9	98·6	96·8	94·0
E ...	55	110·0	105·7	102·3	102·2	99·6	94·4	90·0
Total weeks at each temperature ...		78	167	200	122	184	130	17

from which the dependence of output on temperature is clearly seen. Vernon points out, however, that the weekly output variations by no means fully express the full effect of temperature, since in each week the variations of temperature from day to day and from shift to shift are considerable and must have a corresponding effect on the output at the moment.

An opposite effect (viz., increase in output with temperature) is suggested by observations made in Silk Weaving by Elton,† who plotted the average hourly rates of output in a silk weaving mill against the average temperatures for each half day for 12 weeks. The results are not conclusive, but they suggest that between 58° and 65° Fahr. output tends to increase with temperatures. It should be observed, however :—

- (1) That as the investigation was made during the winter the temperatures are low and do not approach those studied by Vernon.

* Industrial Fatigue Research Board Report No. 1.

† Industrial Fatigue Research Board Report No. 9.

- (2) That the temperature of the air probably has a physical effect on the weaving itself, a moderate rise being beneficial.

Humidity.—Some relationship between air humidity and output is stated by Vernon* to exist in the case of the rolling process in tinplate manufacture. He found, for instance, in one factory that during 60 weeks with a mean temperature of 60° or more, the mean output fell by about 3 per cent. when the relative humidity of the air was above 80 per cent. A similar but smaller effect was found to exist for two factories during weeks when the mean temperature was 55° or more, though in another factory no relation between humidity and output could be traced.

The study of air humidity in relation to output is often complicated by the fact that the technique of a given process is affected by the humidity of the air at the time. An instance of this is to be found in the report on silk weaving, in which Elton states that he was unable to discover any relation between humidity and efficiency owing to the disturbing effects of variations on the different classes of textile yarns (silk, cotton, wool and viscose) used in the material produced.†

Another case of a rather similar type occurred in connection with the seasonal variations in output observed in blast-furnaces referred to above,‡ and illustrates the necessity in estimating fatigue effects of ensuring that other conditions are either constant or allowed for. A marked reduction in the rate of charging blast-furnaces, for instance, was observed during the summer months, but before this can be ascribed to lowered efficiency, any differences on the technical side occurring in the summer must be compensated for. All air contains moisture, which in its passage through the furnace is decomposed with the absorption of heat. Now the amount of moisture in the air and therefore the heat absorbed for a given volume is greater in summer than in winter, with the consequence that the productive efficiency of the plant is somewhat lowered. Vernon investigated this point in the case of two furnaces over 5 and 3 years respectively, and found that on the average the output was 1·5 per cent. greater in winter than in summer. He concludes, therefore, that even supposing that the whole of the observed seasonal variations of output were due to this cause, it cannot account for more than a small fraction of the much greater seasonal variations observed in the rates of charging.

Ventilation.—In considering the effect of ventilation on fatigue and output, care must be taken to define the particular aspect concerned. The

* Industrial Fatigue Research Board Report No. 1.

† Ibid Report No. 9, page 40.

‡ Industrial Fatigue Research Board Report No. 5.

change of air in the environment (if we may so define ventilation) may obviously be regarded from different points of view in respect of its effects on the workers. Pathologically, it may be considered as a vehicle for the removal of dust or of the germs of infection, physiologically as a stimulus to muscular activity, and psychologically as a means of reproducing to some extent the invigorating conditions of outside air. The work hitherto carried out by the Board is concerned with the second of these effects, and in particular the cooling power of moving air.

Some striking results in this respect were obtained by Vernon in the tinplate industry.* Some of the rolling mills were provided with artificial means of ventilation such as puddles or air douchers, whilst others simply depended upon natural means. The difference in the seasonal variations in output (see above) between the two kinds of mill is clearly shown in the following table :—

Factory.	State of Artificial Ventilation.	Mean Output in :—		Reduction in Summer.
		December and January.	July and August.	
A ...	Good.	100.5	97.5	3.0
B ...	Moderately good.	102.5	97.0	6.4
C ...	Moderate (or none).	105.5	94.5	10.4
D ...	None (good natural).	104.5	93.0	11.0
E ...	None (poor natural).	108.0	93.5	13.4

The effect of the good ventilation is clearly shown in the evenness of output in Factories A and B compared with Factories D and E.

The extent to which atmospheric conditions vary in their physiological effects has been explored by Hambly and Bedford by means of the kata-thermometer in a large number of boot factories.† The kata-thermometer, an instrument designed by Leonard Hill‡, consists of a large bulbed thermometer so constructed as to enable the time taken for the column to fall from 100° F. to 95° F. (*i.e.*, through a range approximating to the temperature of the body) to be measured when exposed to air at a lower temperature than itself. When the bulb is uncovered, the instrument is known as the dry kata and when covered with thin fabric moistened with water as the wet kata. The dry kata measures the cooling power of the air due to convection and radiation, and the wet kata due to convection, radiation and evaporation. By suitable conversion factors the rate of cooling of the bulb

* Industrial Fatigue Research Board Report No. 1.

† Industrial Fatigue Research Board Report No. 11.

‡ The Science of Ventilation and of Open Air Treatment (Medical Research Council Report No. 32.)

172 *Effects of Environment on Efficiency and Safety.*

can be expressed in terms of millicalories per square centimetre of surface irrespective of the particular instrument used.

Hill has suggested definite numerical standards indicating air conditions suitable for different types of work (sedentary, heavy, very heavy), and in proper hands the instrument can be used to give very valuable information as to the physiological aspect of ventilation. It might, for instance, be used to test the adequacy of methods adopted in tinplate rolling, mentioned above.

The report by Hambly and Bedford deals solely with the kata-thermometric data collected, and the correlation of the conditions observed with fatigue and efficiency is not yet complete.

Lighting.—Elton has studied the effect of lighting on production in the case of silk-weaving,* which is a fine process peculiarly susceptible to variations in illumination. The investigation was based on hourly output data, recorded automatically on a large number of looms in two weaving sheds over a period of three months. By treating these data in various ways the relation of lighting to output could be clearly traced. The following table, for instance, shows the distribution of output (corrected for certain variables) from 56 looms during the week ended December 20th, 1919.

Period (a.m.).	Output.	Period (p.m.).	Output.
7.30—8.30	45.8	1—2	47.5
8.30—9.45	49.3	2—3.15	52.1
9.45—11	52.1	3.15—4.5	50.9
11—12	48.3	4.15—5.15	41.9

The use of artificial light was confined to the first and last periods, and to this must be attributed in great part the heavy drop in output observed, since at a later season when artificial light was no longer used, the reduction in output at the beginning and end of the period of employment, though still present, was much less marked.

Elton concludes that under artificial illumination, production falls, even if electric light of sufficient intensity is provided. The magnitude of this fall is of the order of 10 per cent. of the daylight value of the rate of output.

EFFECTS OF ENVIRONMENT ON ACCIDENT INCIDENCE.

The relation between accident incidence and human efficiency will probably be generally admitted. The incurring of any accident involves lessened capacity, even though it may be so trivial as not to cause absence

* Industrial Fatigue Research Board Report No. 9.

from work. The requirements in the Factory Acts are framed, generally speaking, to prevent the more terrible consequences of serious accident, but the slighter and more numerous kind can probably be reduced in number by investigating the conditions of employment which tend to produce them.

In an early Report issued by the Board,* Greenwood and Woods adduced evidence tending to show that accident incidence is not a matter of chance, but depends on some quality inherent in the personality of the victim. The further study of this important question belongs to another sphere of the Board's work, and the present paper deals only with relation of conditions of employment and accident incidence.

Temperature.—Some important light on the connection between temperature and the number of small accidents (cuts) experienced at munition factories is afforded in a report by Osborne and Vernon not yet published. The data show that there is a well-defined optimum temperature (namely $67\cdot5$ Fahr.), at which such accidents are at a minimum, and that as the temperature rises above or falls below this minimum the accident frequency increases almost symmetrically.

Lighting.—Several years before the constitution of the Board, an investigation on the relation between lighting and accident incidence, based on the returns of accidents to the Factory Department of the Home Office during 14 months (73,387 in all), was carried out by Wilson and Paterson for the Departmental Committee on Factory Lighting.†

By the use of certain assumptions, they calculated the accident rate per hour during daylight and during artificial light. The results may be summarised as follows:—

Cause of Accident.	Daylight Accident Rate Per Hour.	Artificial Light Accident Rate Per Hour.	Percentage Difference.
Machinery (moved by power)	16·62	19·64	18
Molten Metal	2·58	2·96	15
Struck by falling bodies ...	9·43	12·46	32
Persons falling	7·16	12·32	71
All Causes	61·27	79·19	29

The conclusions, therefore, to be drawn were that the number of accidents (of the kind reportable to H.M. Inspectors of Factories) increased by 29 per

* Industrial Fatigue Research Board Report No. 4.

† First Report of the Departmental Committee on Factory Lighting, Vol. I. (Cd. 8,000), 1915.

cent. during artificial light as compared with daylight, and that this increase rose to 71 per cent. in the case of accidents due to persons falling, a cause presumably specially affected by lighting conditions.

As a check against these results, the number of fatal accidents in mines (non-fatal accidents were not available) in which work is carried on wholly in artificial lighting were investigated. Only the "surface" accidents (involving work in daylight and artificial light) showed a heavy increase during the winter months, the "underground" accidents showing a slight decrease during the winter. The deductions drawn from the main investigation appear, therefore, to be justified.

Conclusion.—The chief value of the class of investigation described in this paper lies less in actual discovery than in enabling definite numerical values to be attached to the effects observed, the occurrence of which is indeed often already well-known.

If by these means proof can be adduced that a serious reduction in output results from causes remediable without much difficulty (as in the case of the tinplate rolling mills), the employer and workman surely have a common object in bringing about the necessary improvement.

But these investigations have an additional and more far-reaching aim, in that they constitute the principal means of studying first principles relating to the optimum conditions of work for the operatives of the future. The average workman spends about one quarter of his adult life in the factory, and his environment there is almost as important as any other condition of his living.