A CONTRIBUTION TO THE STUDY OF FATIGUE.

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"Fatigue is the one field that has been thoroughly ploughed over by science and practical life in the course of the last decade[1]."

Confronted with this optimistic statement the student of fatigue problems, whether from the standpoint of psychological theory or of industrial and scholastic life, is somewhat disappointed when he attempts to survey this voluminous literature, for, of anything approximating to positive evidence there is but little, while the final issue of many of these oftentimes laborious researches permits of no conclusion more general than that, in the words of one of the most recent writers, "signs of fatigue differ according to the individual" or that the tests used as fatigue indexes cannot be regarded as adequate[2].

The present investigation, undertaken at the suggestion of Mr McDougall and carried out under his supervision, is a continuation of some work published by him in this journal in 1905[3]. It is there suggested that one reason for the inadequacy of so many of the fatigue tests is, that there is no guarantee that the subject maintains the same

[1] Münsterberg, *Psychology and Industrial Efficiency*, 1913.

[2] Cp. Stanley Kent, *Report on Industrial Fatigue*, 1915.

[3] Wm McDougall, "On a New Method for the Study of Concurrent Mental Operations and of Mental Fatigue." This *Journal*, 1905, I. 435–445.

attitude towards the task throughout the investigation; and, even if, as with the Kraepelin school, interest is kept at a minimum, there is still the difficulty that there is no criterion of this minimum interest: boredom, variations of zeal, the stimulus of nearing the end, all militate against the successful measurement of a test. Reversing the usual procedure McDougall argues that a more hopeful plan would be to keep the interest of the subject at a maximum throughout, and use a test of the nature of a sprint, so as "to provide the subject with a task demanding for its execution a continued maximal voluntary concentration of attention."

The machine devised by McDougall for this purpose is "a mechanical device whereby a continuous band of paper tape about one inch wide is drawn behind an opening or window in the top of the desk by a weight-driven clockwork movement." The rate at which the tape travels can be adjusted so that the subject works at his maximum speed. Along the width of the band small red circles are distributed in as irregular a manner as possible. The test consists in marking the red circles with a stylographic pen as they pass before the subject's field of vision[1].

The task is too exciting to allow a subject to acquiesce in failure: should failure occur at any stage the interest aroused prompts to renewed effort and not to acquiescence or despair, so that each experiment represents the best work of the subject under the given conditions[2].

But the tests themselves are not the only reason for the negative character of so much fatigue work. Investigators have in many cases set themselves a too difficult problem. That fatigue is produced through daily work is a familiar fact, but it does not follow that the tests which happen to have been selected by experimenters will necessarily be fine enough to detect fatigue on such a small scale as might be engendered, for example, by the working of sums for two hours; while to wait until the exigencies of life produce in the subject unmistakable fatigue is not unlike a physicist waiting for the occurrence of a thunder storm to pursue investigations into electricity.

Expecting less from the test, it was decided to make certain, for experimental purposes, of a fatigued condition; and for this purpose the simplest plan seemed to be to reduce the amount of sleep for a

[1] For a full description of the machine see this *Journal*, III. 153. Burt, *Experimental Tests of General Intelligence*.

[2] After an almost daily experience of using the machine for three years I yet find it intensely interesting.

definite time. If the selected test proved adequate as a revealer of fatigue on a large scale then further investigations could be made to see with what degree of refinement it would work.

The object of this research was to seek answers to the following problems:

1. Is it possible to measure fatigue objectively?
2. What are the immediate effects of fatigue? Do they differ in any measurable degree from the remoter effects?
3. How long does it take to return to a normal condition as estimated by an objective standard after undoubted fatigue, and what is the nature of the recovery curve?
4. What is the effect of fatigue on an already fatigued state?
5. What is the relation between fatigue as experienced by the fatigued person and fatigue as estimated by some objective standard?

Control Precautions.

The writer was the subject of the experiments, and every precaution was taken to keep conditions constant, the fatigue effects to be the only variable; so every day the same length of tape was dotted, and the mistakes counted, for several weeks before inducing fatigued conditions, and continued after the return to a normal condition, as estimated by the number of errors, in order that sufficient data for normal variations should be available: in fact for over three years, except for vacations, the same experiment was performed on an average of five days a week[1].

The experiments too were done at approximately the same time of day: where this was not possible the usual amount of tape was dotted to keep the practice constant, but such records were not included in the results.

DESCRIPTION OF THE TESTS.

1. *The Dotting Machine Experiment.* A length of the tape six metres long was the standard amount. This consisted of 1200 small red circles, and the machine was so adjusted that the circles passed before the field of vision at a uniform rate of 5·8 a second, and each was to be dotted with a stylographic pen as it passed. In each metre fifteen circles at irregular intervals were coloured beforehand and these, when they appeared, were not to be dotted, but instead, the right hand

[1] Unless investigators have evidence of the normal variations, which all experimenters who have done continuous tests over a long period know to be great, it is useless to assign variations after work to fatigue only.

had to be lifted to avoid marking the circle, while to prevent the subject profiting by these irregular rests, with the left hand a key had to be tapped, which being attached to a pen arrangement under the lid of the machine marked the tape when tapped. By this means a valuable test of the subject's power of inhibition was obtained and also the rather remote possibility of the pattern becoming known was lessened.

It was a simple matter to compute the number of errors in each strip. Errors were reckoned thus: a circle unmarked or a coloured circle marked, or an extra dot inserted between two circles, counted as one error; a lateral or vertical deviation of less than 2 mm. counted as half an error[1].

2. In some of the later experiments, in order to isolate the purely mental factors from the mental and muscular combined which the dotting experiment involves, a modified form devised by Mr McDougall of the associated words test was used[2]. The test required that the subject should appreciate a relationship between words, and secondly be able to reproduce the words in the right sequence. A list of forty words drawn up by a collaborator was read to the subject; the list was so arranged that there was a connection between the first word and the second, between the second and third and so on, a connection which the subject could grasp by an act of attention, *e.g.* a typical list is as follows: mountain, plain, ugly, beauty, Venus, Greece, oil, smooth, rough, rude, cultivated, refined, sugar, sweet, salt, sea, sky, heaven, angel, spirit, brandy, bottle, cork, Ireland, Ulster, cloak, cape, etc. In such a list the subject naturally notes the connection between 'mountain' and 'plain' as geographical terms: but the following word 'ugly' involves the recognition of the meaning of 'plain' in aesthetics; beauty is related as the negative of ugly and the connection with 'Greece' is obvious, but the following word 'oil' demands the realization of the same sound as used in another sense; and so on with the complete list.

It is of course necessary that the writer of the list should keep the material and the relationships within the compass of the subject's experience. If the test is used with educated adults there is no difficulty in framing many lists, as there is a large field of well-known literary, historical and general knowledge upon which to draw: in the case of children greater care must necessarily be exercised, as will also be the

[1] With subjects less practised than the writer at this particular test it is quite sufficient to have each circle marked simply without the complications described above.

[2] Cf. Norsworthy, "Psychology of Mentally Deficient Children." Lists of related words were used but all the words of each list were connected with one subject.

case if the social class of the subjects be different from that of the writer of the list.

The list was read through at a uniform rate of one word in two seconds. After the list had been read through once, the subject, having been given the first word, had to reproduce verbally the complete list in right sequence: failure to give the correct word within ten seconds counted as one error: a wrong word corrected within ten seconds counted as half an error.

3. *The Windmill, an Illusion of Reversible Perspective.* It is a matter of common observation that if one gazes with one eye at the rotating arms of a windmill, while standing at some distance away and a little to one side, the movement of the arms apparently changes its direction from time to time, the movement of the arms in the upper part of their orbit being sometimes towards the observer, sometimes away from him.

A laboratory windmill or revolving cross was fixed up, a description of which has been given by McDougall[1]. Prior to the fatigue experiments considerable individual differences in the number of phases seen in a minute had been found, and this prompted the enquiry into the effect that fatigue would have[2].

4. A few experiments on speed of tapping, for which a modified form of the usual tapping test was used. Four telephone counters as manufactured by the Veeder Manufacturing Co. were mounted on a wooden stand. To each counter is attached a handle which on being pressed registers automatically, on the principle of the cyclometer, that it has been pressed. The test lasted for four quarter-minutes. The numbers registered by the counters were noted at the beginning: the subject at the given signal began to tap as quickly as possible for fifteen seconds on 'counter' 1; at the command 'change' from the experimenter he went on to number 2, the word 'change' being again called at the end of the second fifteen seconds, and so on with the third and fourth. The number of taps made in the minute could easily be computed.

A wooden handle with an india-rubber tip was used as the instrument for tapping the counters.

5. *The Learning and Re-learning of Nonsense Syllables.* This test consisted in learning sets of twelve nonsense syllables under the usual conditions, and of re-learning the same twenty-four hours afterwards.

[1] McDougall, "Physiological Factors of the Attention Process," *Mind*, N.S. xv.

[2] Cp. Flügel, "Fatigue in Illusions of Reversible Perspective," this *Journal*, VI. Pt I.

For the sake of clearness I have briefly summarized here the tests used, but not all were used for the first fatigue "cycle," by which I mean the period covered by the time of shortage of sleep and the return to a reliable normal.

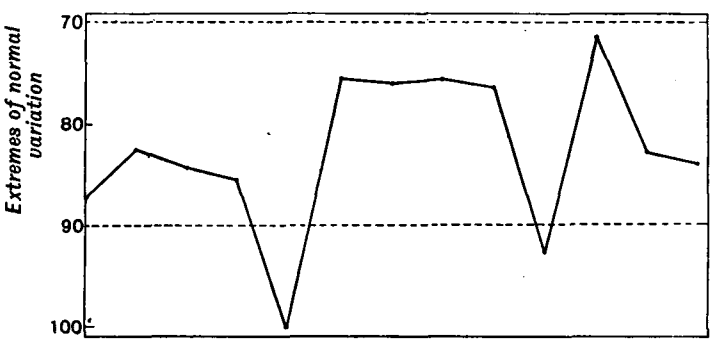
The first experiment was confined to applying the dotting machine as a register of changes in mental efficiency resulting from the fatigue due to loss of sleep.

Method of Inducing Fatigue.

To ensure fatigued conditions the normal[1] amount of sleep was curtailed for three successive nights: on the first night's vigil only one and half hours' sleep were taken, on the second three and a half, and on the third five and a half hours', *i.e.* for three nights less than half of the normal amount of sleep was taken[2].

RESULTS.

1. *The Dotting Machine.* Under normal conditions the number of errors including all types lies between 70 and 90. Those ranging round 70 I looked upon as good normals, those round 90 as bad; by a



GRAPH 1. A typical fortnight showing daily variations. The two occasions when the records were below normal were due to slight temporary excitement.

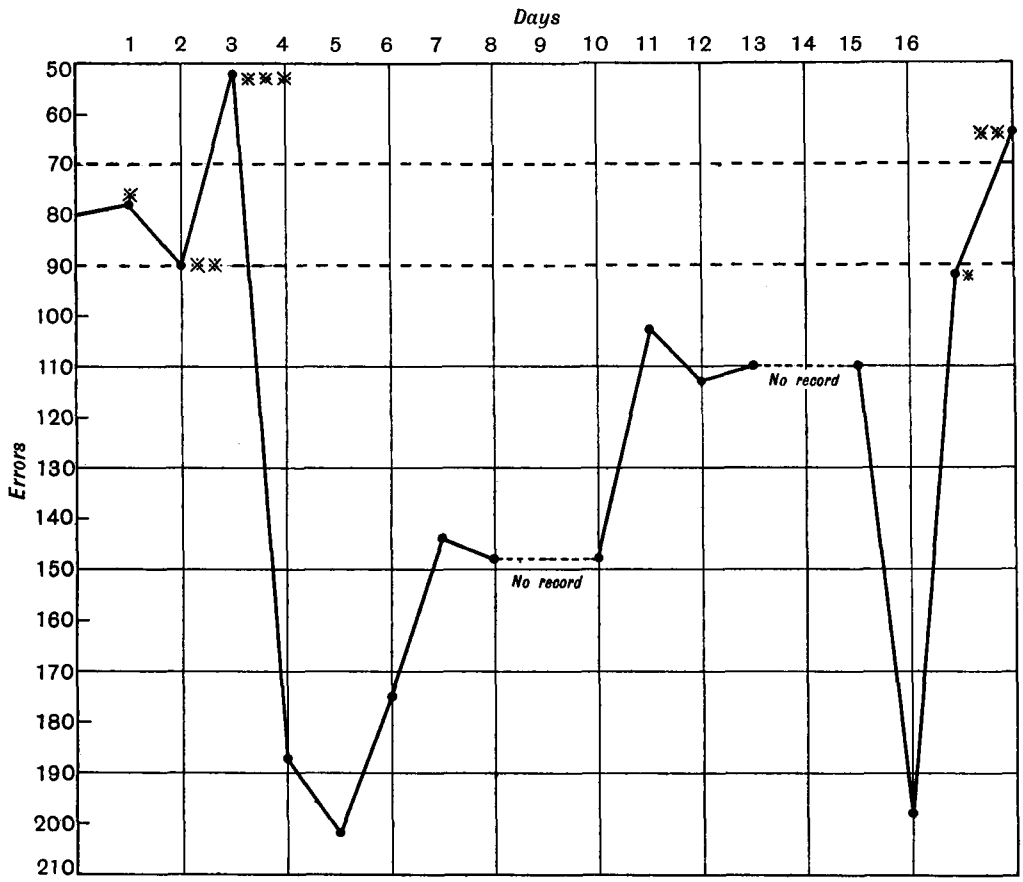
bad normal I understood a slight deviation due either to extraneous circumstances, *e.g.* an unexpected noise, or to temporary disturbances,

[1] Normally I sleep about eight hours and do not suffer from insomnia. In the experiments described I also fell asleep as soon as my time limit, fixed beforehand, was up.

[2] During the vigils I spent the time for the most part engaged in ordinary occupations, reading, marking essays, knitting, working out results of experiments; anything of a mathematical nature kept me awake better than light reading. I found it advisable to make out a programme for each hour, of such a nature that by working hard I could complete the set task: otherwise there was a tendency to fall into a light doze or a state of such acquiescence in mere existence as hardly to warrant being called awake.

physiological or mental, which did not affect me for more than one day, *e.g.* slight headache or worry.

It is always necessary when judging any particular day's performance to take into account not only that day's record but the weekly average: a high average deviation is invariably significant of some nervous instability, or of unusual conditions, *e.g.* in the above graph the two days when the records are worse than normal there had been slight excitement.



GRAPH 2. 1st fatigue cycle showing the effect of three nights of diminished sleep and the gradual return to normal interfered with by further vigils. The dotted lines represent the extremes of normal variation. June, 1912.

*=effect of 1st vigil, **=effect of 2nd vigil, ***=effect of 3rd vigil.

Note the effect of further lack of sleep in bringing back the errors from nearly 200 to 91.

As a result of three nights with little sleep the immediate effects are either normal records or records showing marked diminution in the number of errors, *e.g.* during the first cycle the record after the third night is fifty-three errors, the lowest number I had ever attained: as soon, however, as I made up for the loss of sleep by extra sleep on succeeding days the errors rose to over 200 and continued to range between 110 and 202 for sixteen days, at which stage the return to normal was interfered with by another experiment. I have pooled all the errors, as the improvement at first and deterioration afterwards affect equally all types. See Graph 2.

The loss of control as evidenced by the inability to restrain the hand from making unaimed extra dots is very marked and is as characteristic of the fatigue state as the loss of efficiency shewn by the ineffective aiming.

In all the other sets of experiments with the dotting machine, and there are five under exactly the same conditions, extending over a period of three years, there are similar results, viz. improved or normal records at first, followed by a period of slow and irregular return to normal, the normal being reached about the sixteenth day[1].

The subjective records, written in all cases before knowing the result of the dotting, are also instructive. During the rather prolonged period of recuperation the impression that the dotting was good was very common, *e.g.* on a day when actually there are 202 errors the note runs, "am quite sure I am in good form; thought the dotting very good[2]." Under ordinary normal conditions I rarely speculated about the success or otherwise of the work[3].

The Effect of Fatigue on the Associated Words.

Under normal conditions the average number of errors in a list of 40 words was 5 (extremes 4 and 7); the immediate effect of three vigils is to reduce the average to 3, followed by such records as 12, 13, 10, 16, 26, 18 and so on until on the sixteenth day the normal of $6\frac{1}{2}$ errors is reached.

[1] The record on the day following the first vigil I called the first day and so on.

[2] This particular delusion occurred so frequently that it became a subjective index of the reverse.

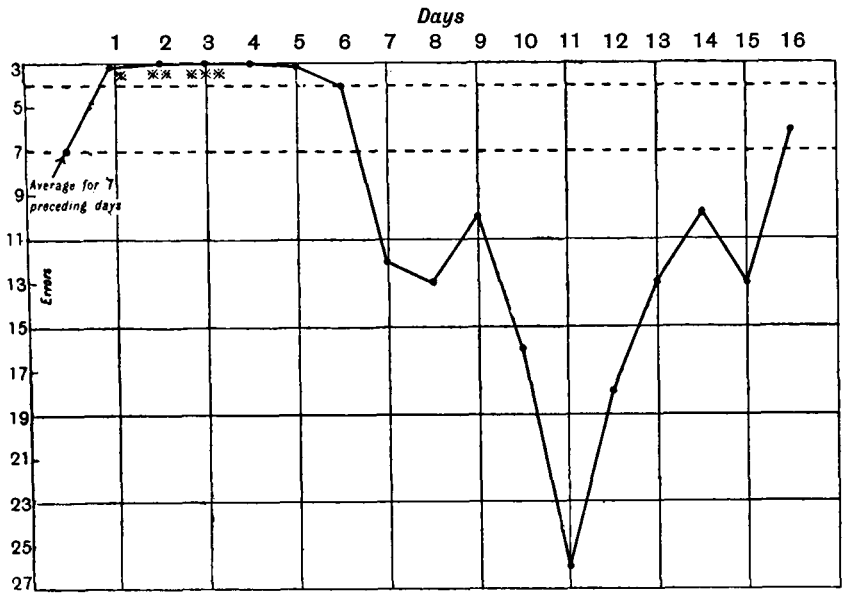
[3] At another time I got the effect of one night with one and a half hours' sleep. The result is analogous, viz. to improve the dotting on the following day, to give a normal record on the succeeding day and to increase considerably the errors for the next three days; on the sixth day there is a return to normal.

In two 'cycles' there are complete records of the words and they are similar in character. I have illustrated the later one, as the return to normal was not complicated by other experiments.

Such lists involve two quite distinct factors:

(1) Power of attention to note each connection,

(2) Ability to reproduce the connections that have been seen. Under the second phase of fatigue there is conspicuous failure in both, *e.g.* sometimes certain sequences were not consciously attended to; at other times it was recognized that the connections had been appreciated at the time but could not be recalled[1].



GRAPH 3. Showing the effect of fatigue on the associated words—daily variations. Normal variations fall between the dotted lines. July, 1915.

The Effect of Fatigue on the Windmill Illusion.

During one fatigue cycle almost daily records were obtained with the windmill illusion. Under ordinary circumstances, and assuming the attitude of trying to maintain the windmill revolving in one direction as long as possible, in my own case I got on an average seven changes

[1] That these two factors can be isolated is well brought out in the Effect of Alcohol, details of which will be published later.

a minute. The immediate effect of fatigue was to increase the number of changes to between thirteen and forty for several days[1].

The Effect of Fatigue on the Learning and Re-learning of Nonsense Syllables.

This test, which is of the nature of a motor habit[2], was only used during one cycle of fatigue experiments. It consisted of learning twelve nonsense syllables, noting the number of repetitions required before they could be reproduced, and then of re-learning them 24 hours afterwards. Although the effects of fatigue are not as well marked as in the other tests yet they are not in conflict with the others. The learning process remains normal during the first phase, characterised in the other tests by improvement, and then falls off for a period about equal in duration to the second phase of the dotting. The re-learning is equally adversely affected. Normally I require seven repetitions to learn a group of 12 nonsense syllables and three to re-learn after 24 hours. The effect of fatigue after the first phase was to increase the number of repetitions for learning to an average of thirteen and for re-learning to an average of seven.

It is to be expected that a process involving habit[3] should not be as seriously affected as one of the higher processes; there is also the difficulty that it is not easy to maintain the same attitude throughout the learning, the tendency being to fall into a condition of relative passivity during some stages of the fatigue process, the test not being exciting enough to demand the greatest possible effort.

The Effect of Fatigue on Speed of Tapping.

In this test, too, the effects are not as striking as in the case of the dotting and words, but they are significant. The first phase of strain gives normal and abnormally good results followed by a gradual deterioration in the number of taps made in one minute. Unfortunately it was

[1] Little importance can be attached to the later figures as unfortunately for the purpose it is difficult to rule out suggestions, *e.g.* knowing after a few days' experience that the number of phases per minute had increased I could not be certain that I was as successful in controlling the direction as before. The immediate results quoted above are quite reliable as I had no preconceived theory on the subject and did not know what to expect.

[2] Cp. Bergson, *Matière et Mémoire*, p. 75.

[3] The correlation between the learning of nonsense syllables and pure motor habit has been found to be ·6. Details of these experiments will be published later.

not possible to complete the records until a normal was regained, nor were daily records obtainable[1].

The Effect of loss of Sleep on the Dotting and Lists of Associated Words Combined.

In order to test the reality of the improvement characteristic of the first phase, experiments were made on the effects of the same loss of sleep on the dotting and words combined, *i.e.* instead of performing the two operations of dotting and reproducing lists of words at different times, a list of fifty words was read through twice by a collaborator while the writer dotted the usual length of tape under the usual conditions. Read at the rate of one word in two seconds, the fifty words read twice lasted the same time as the dotting. At the end, the list was reproduced and errors counted in the usual way. In this case the problem was to perform together two operations both demanding concentrated attention. Before using it as a fatigue test I had had almost daily practice in performing the combined operation for seven weeks so that the improvement due merely to practice was well passed. The average number of errors in dotting for three weeks immediately preceding the fatigue period was seventy-four and for the words twelve (extremes eight and sixteen). As a result of one night with one and a half hours' sleep the errors in dotting fall to sixty, and the words to four, followed by similar records for several days. The improvement resulting from marked fatigue is thus clearly shown[2]. See Graph 4.

On the 5th day the dotting and the words show deterioration, 107 errors in dotting and ten errors in words. On the 12th day there is a return to normal of both; but whether this would have been

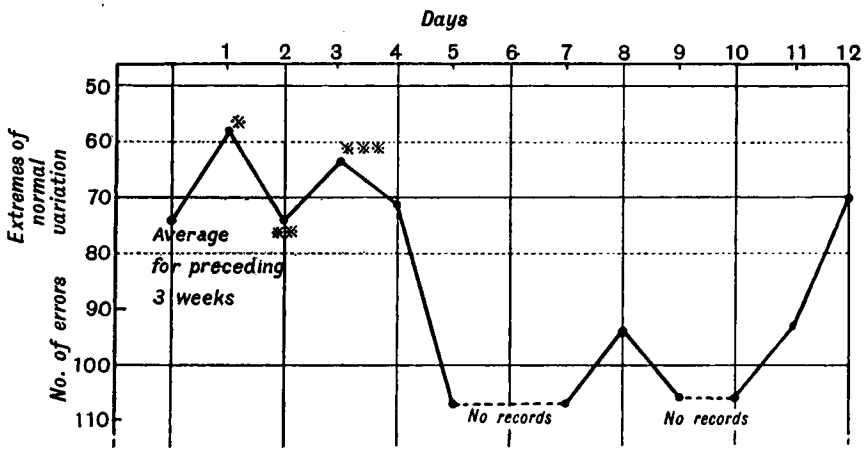
[1] Another subject undertook to cut down her usual amount of sleep to one-third for three nights. The tests used in her case were:

(*a*) A slightly modified form of the dotting, only the alternate circles being marked.

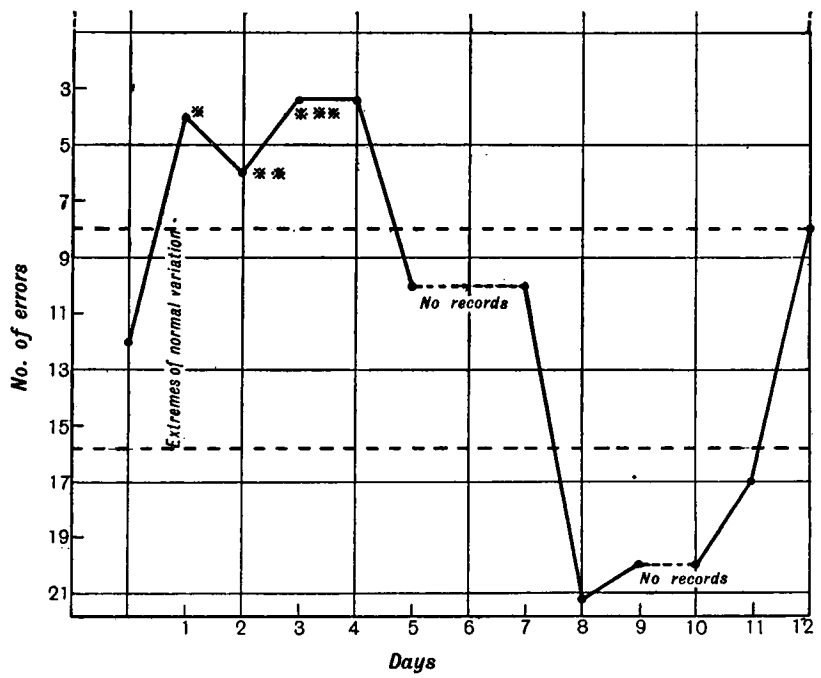
(*b*) A list of 100 words, as described above, read twice and reproduced immediately afterwards.

Unfortunately daily records were not available, but during the period of cutting down sleep the records obtained of the dotting are either normal or unusually good, *i.e.* between 80 and 100 errors, and for six days from the beginning of the experiment there are no bad records: on the 7th day they rise to 159 and the average for that week is 128 and for the following week 135. With the words the average number of errors under ordinary conditions was 23 (extremes 18 and 35). During the period of stopping up the number is normal, viz. average 27, but the errors rise to 43, culminating nine days after in 71, after which there is a gradual fall to 20, sixteen days from the beginning of the experiment.

[2] Experiments to be published later show that there are abnormal conditions where one task improves at the expense of the other. This did occasionally also occur under apparently normal conditions, but only rarely.



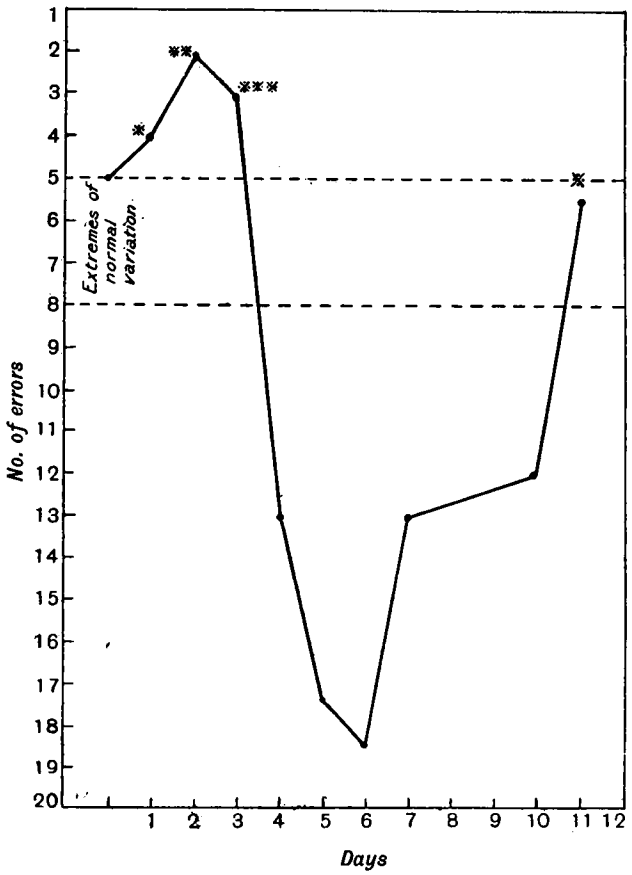
Fatigue effects shown by errors in 'dotting' when combined with 'words.'



GRAPH 4. Errors in 'words' when combined with 'dotting.'

maintained cannot now be known as incipient influenza made all the following week's records extremely variable[1].

(This test involving the double task might be valuable as a means of estimating the effect of distraction.)



GRAPH 5. Effect of loss of sleep on associated words. Also effect of further loss of sleep on a state of fatigue.

*=effect of 1½ hours' sleep, **=effect of 3½ hours' sleep, ***=effect of 5½ hours' sleep.

[1] Note on Graph 4. I only give this graph to show the effect of fatigue on the double test and it is only of value for the first phase as the second phase was complicated towards the end by the effects of a severe cold.

Effect of Fatigue on a Fatigued State.

So far we have only considered the effect of fatigue on a normal condition; the effect of fatigue on an already fatigued state is also important.

To show this there are in this research two sets of experiments:

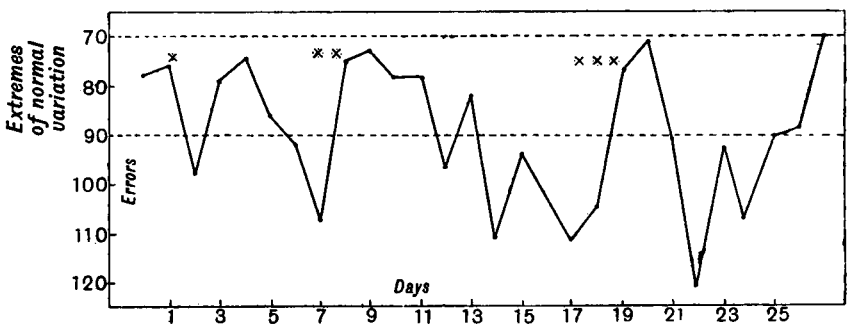
1. The effect of a night of one and a half hours' sleep when the influence of the three nights with curtailed sleep was still apparent. (See Graph 1 and Graph 5.)

2. The effect of the same loss of sleep in so far as the actual number of hours were concerned, but with the vigils separated by intervals of several days instead of being in immediate succession.

The first type is illustrated in Graph 5 on the preceding page, which shows the effect on the associated words, and in Graph 2 (page 333) which shows the effect on the dotting test.

It will be seen that the immediate effect is to bring back the errors to a good normal at a time when the deteriorating influence of fatigue is well marked, *i.e.* from 12 to 5½ in the case of the words and from 200 to 91 in the case of the dotting. The other records show that a normal result would not have occurred at this stage without the intervention of some other factor.

The second type is illustrated thus:



Graph 6. Showing the effect on the dotting of the same loss of sleep at intervals. July 1914.

*=effect of 1½ hours' sleep, **=effect of 3½ hours' sleep, ***=effect of 5½ hours' sleep.

The method of procedure was as follows. I stayed awake the first night as in the previous experiments; after an interval of seven days, by which time the second phase was in evidence, I stayed up part of another night for a time equal to the second night of previous experiments; after a further interval of ten days, which again allowed

for the full sway of the second phase, I stayed up part of another night equal to the third night of previous experiments.

The object of this was to find out how long it took to return to a normal condition as compared with the three nights in immediate succession. The results are all quite clear. Each night involving lack of the normal amount of sleep affects the work advantageously, *i.e.* brings the errors back to normal, but it is not until twenty-five days from the beginning of the experiment that normal records are established; the preceding and succeeding fatigue cycles, the vigils being in immediate succession, give a return in sixteen days. It will however be noticed that as a balance to this the errors are not as great.

The deleterious results of fatigue on an already fatigued state are thus exhibited. Such a condition is somewhat analogous to a state of chronic fatigue, *i.e.* continued work on an already fatigued state.

COMPARISON OF THE SEVERAL FATIGUE CYCLES.

If now instead of considering each experiment in isolation we compare five sets which were done under the same conditions as regards loss of sleep and manner of spending the vigils, some striking differences reveal themselves:

1. There is a delay in the onset of the second phase, *e.g.* on the first occasion, June, 1912, this phase set in on the 4th day, *i.e.* immediately the strain was over: on the last occasion, July, 1915, it is not until the 7th day that this phase begins and the intervening experiments illustrate the gradual extension of the first phase.

2. The return to normal is hastened, *i.e.* the duration of the second phase is shortened, *e.g.* in the June, 1912, cycle there was not even an approximation to the normal by the 16th day, whereas in July, 1915, a reliable normal was attained by the 16th day. Full comparisons of the intervening ones cannot be made owing to complications of further vigils to get the effect of fatigue on a fatigued state.

3. If we compare the improvement due to loss of sleep in the June, 1912, series with that of July, 1915, we find that the improvement becomes less marked, *i.e.* the percentage improvement is at first 26 as against 13 in the final experiment. I regret that the lists of words were not used earlier; during only two sets of vigils are they comparable, but during the first time of using them the average number of errors due to the first phase of fatigue is 2·8, on the next vigil, one year later, the number is 3·3. The difference is extremely slight, but considering the reliability of the errors of the test under normal conditions it is

significant as to direction: also in the first cycle there is one occasion of only one error and one of two errors, whereas in the last set the lowest number of errors is three.

It may be that there is here some evidence indicating the possibility of setting up a relative immunity to a particular form of fatigue. Is there produced naturally the antitoxin to fatigue whereby the individual is rendered more and more immune? The fact that in the last series there is a less exaggerated effect of the stimulating actions of fatigue looks as if some neutralising agent were at work preventing the full effect of the fatigue products and helping to conserve the potential forces.

My figures are really only suggestive and many more experiments are needed for proof, but the possibility of such proof is a fascinating prospect. Some biochemical psychologist may one day be able to analyse the fatigue toxin and supply the requisite antitoxin[1]! There is little doubt that people vary considerably with regard to fatiguability, both for specific tasks and for continuous labour. Are some of the famous workers people whose organism protects itself not only by giving premonitory warnings in various subjective fatigue symptoms but also by naturally inoculating itself against the toxins of fatigue[2]?

Subjective Effects of Fatigue.

It is hardly necessary to draw up a list of the various symptoms by which fatigue reveals itself to the individual. It is, however, pertinent to analyse these symptoms carefully, and this analysis will convince the observer that even subjectively the state of fatigue reveals itself as complex, complex not as a mere accumulation of fatigue sensations from various organs, but complex in the sense of being compounded of diverse opposite symptoms and emotional attitudes.

The first phase would, if it were to be described in terms of pleasure-pain, distinctly involve both, *e.g.* the muscular weariness due to the strain of continuous work is particularly noticeable in the heaviness of the eyelids, and the feeling of general tiredness, becoming at times positive pain, sufficiently intense to intrude into the focus of attention spontaneously: mentally, however, the feeling of exaltation, combined with an emotional belief in the power to conquer all things, is distinctly

[1] Hitherto the experiments along these lines have been confined to local muscular fatigue.

[2] Cp. Cannon, *The Bodily Changes in Pain, Hunger, Fear and Rage.* The effect of adrenalin on fatigue is described.

pleasurable. In my own case this double feeling tone is most marked, even though for the most part the pleasurable aspect is dominant.

Another complexity of the fatigue state in its first phase is the feeling of inertia showing itself in a disinclination to begin any work, but when once this inertia is overcome by some stimulus, objective or subjective, work progresses easily and with the feeling that there are unlimited stores of energy available: one's machine, if one may so liken the body, seems to be in excellent working order.

In this state too, hyper-sensitivity is also marked, so that noises to which one is normally indifferent become painful, while the general excitability makes one easily affected to 'smiles or tears[1].' Becoming marked about the third day is a tendency to 'perseveration' so that it is difficult to maintain an interest in continuous unstimulating work owing to the intrusive force of any idea, which, until it receives expression, remains an irritating obsession, *e.g.* suppose I am reading a fairly stiff book, a word in it may remind me of some trifling task that must be done sometime, I find I must get up and do it; I then return to my book and the same process goes on. Normally I should make a note of the task and pursue my reading.

During the second vigil of the first cycle I experienced strongly marked visual hallucinations, viz. opaline spheres, semi-transparent bodies and gossamer threads, sparkles of light at intervals on the dark background of my desk. In none of the later experiments did I get such phenomena. All these symptoms rapidly passed away, none of them surviving the first phase, while, except for a slight headache, and a general lowering of the *joie de vivre* which usually heralded the second phase, a few days of extra sleep soon dissipated any symptoms and apparent normality ensued. Subjectively I had no criterion whatever for the stage when the objective records showed continuous deterioration nor yet for the return to a normal, and yet that the dotting machine and words are not alone in exhibiting this return is shown by the different reaction towards alcohol, which plainly shows two phases even in what is here called the second phase[2].

THEORETICAL CONSIDERATIONS.

The evidence afforded by these experiments opens up several interesting theoretical problems.

If the results are not merely chimerical, then instead of defining

[1] Cf. James, *Principles of Psychology*, II. 539.

[2] Details to be published later.

fatigue in terms of diminished output, we shall have to modify the definition by the addition of 'ultimately' and let fatigue be the state which *ultimately* results in a diminished capacity for work, since we have seen that the immediate effect is to improve the capacity for work: or if we cling to the ordinary definition then the first phase of the fatigue process must be designated by some name other than fatigue and fatigue kept for the second phase, as seems to be Mosso's idea when he says "in many persons extreme fatigue is preceded by a phase of excitation which may last for a long time[1]."

Physiological treatises discussing the products of fatigue are agreed as to the complex nature of the substance produced: now if we suppose that the final result of the fatigue toxins is to produce a substance allied to the drugs with a stimulating action, then we should get that marked improvement so characteristic of fatigue, whether that fatigue operates on a nervous system already fatigued or unfatigued. Such a result could be accounted for if we assume that the action of some of the fatigue products is to make the energy of the nervous system more accessible, *e.g.* the output of a machine might be increased by the addition of more fuel, or by making the parts work together with greater ease. It is hardly a rational hypothesis that fatigue actually supplies the organism with more energy from without, but if the natural resistance at the synapses[2] were by some means lessened, so that the potential energies of the nervous system were set free, this might account for some of the facts: if too we postulate the 'drainage' theory as expounded by McDougall[3], then the particular channels which happened to be directly stimulated would drain more easily the energy of the neighbouring channels and hence the superior output. The ease and fulness with which in the associated words relations are perceived and reproduced in the first phase of the fatigue state seem to be thus accounted for, and also the subjective feeling of a very tremulous success and hyper-sensitivity so characteristic of the earlier phase: in my own case I found that the maintenance of concentrated attention on an unstimulating task was more difficult and that there had to be a regular reinforcement of the particular problem by the appeal to subjective motives, owing to the intrusive force of any image or idea that happened to be called up. The general state can be designated as one of unstable equilibrium. It is probably akin to those conditions which in some

[1] Mosso, *Fatigue*, p. 236, Eng. Trans.

[2] Cp. Sherrington, *Integrative Action of the Nervous System.*

[3] (*a*) *Physiological Psychology*, p. 37. (*b*) *Brain*, XXVI. ii.

people herald a nervous breakdown, viz. an uncontrolled feverish energy which temporarily is extremely effective but which ultimately leads to disaster. In the case of these experiments the stimulation is temporary, a question of hours, not of weeks or months, and the required rest speedily removes this condition of hyper-excitement. But would one not expect that the return to a normal condition would ensue as soon as the fatigue products had been removed or neutralized. If when a drug effect is apparent another with an opposite action is taken, the resultant normality, in so far as my experience of a very few experiments goes, is final; in fatigue we do not get a speedy return to normal, but on the contrary an exaggerated opposite effect. Evidently the chemical explanation is not the only one. If the subjective symptoms, which appear as soon as the ordinary time for cessation of work looms, were indexes of the exhaustion and not rather premonitory indications —sign-posts as it were that along that path lies fatigue—the individual would be unable to continue his work. Force of will however can conquer, or at least refuse to be deterred by, these indications, and persist in driving the victim along the dangerous path. This, involving as it does the expenditure of considerable nervous energy, which however is not being made up for by adequate rest, necessitates the using up of the stores of potential energy during the first phase which is rendered dangerously easy by the effects of the fatigue products in lowering resistance. It is as if a man who has habitually lived on his income is suddenly confronted with an unforeseen demand for money. He may, as a solution, break into his capital, *i.e.* he will temporarily have command of greater resources than normally are his, but his reserve force is thereby lessened so that he has later less at his command[1].

In the article referred to, McDougall suggests that the function of the resistances is essentially the limitation of activity so that they are protective of the energy of the organism. This seems to be true in all those numerous cases where continuance of work results in a fairly regularly diminishing activity, that is when there is no overstrain.

If, however, the strain is greater than the resistance is normally adjusted to, the protective action cannot operate, and the individual is enabled to work at his will to exhaustion point, so that we get an example of McDougall's second point, viz. that "Fatigue is relative, *i.e.* the expression of the rise of the ratio between resistances and energies, so that if the conditions are such as effectively to call into play all the

[1] Cp. McDougall, "The Conditions of Fatigue in the Nervous System," *Brain*, 1909.

great special sources of energy this ratio may be kept from rising above the normal until the whole organism approaches absolute exhaustion."

Did the synaptic resistance always operate in the same way, we should have an individual incapable of adjusting himself to any excessive demand and hence useless in emergencies. It is at least possible that there are people who are constitutionally better protected, from one point of view, than others in this respect, people farthest removed from the hysterical or neurasthenic type: should this resistance be excessive we should get a type incapable of meeting the demands of a strain; there would be no fear of such exhausting their reserve forces, but there might be a paralysis of action and thought altogether.

But this point of view tends to treat the individual as if when he had returned to normal he was as he had been before the strain. When, however, we treat him as a person of continuous existence, each fatigue cycle must be considered as having its specific effect and rendering the individual different in his reaction for the future, *i.e.* in these experiments, towards the next fatigue cycle. Weichardt[1] maintains that the antitoxin to fatigue is produced during normal functioning activity so that with the appearance of moderate quantities of the products of fatigue there always occurs in the healthy organism an increased formation of the specific antitoxin. If this be so, the ease of the expert as contrasted with the excessive labour of the novice, may be a special case of the formation of the antitoxin.

As mentioned above, a comparison of the several fatigue cycles certainly suggests the setting up of a comparative immunity. Naturally it will only be relative, as immunity to any other disease can be overcome as a result of the circumstances favourable to infection[2].

If fatigue can be treated as a disease with its corresponding antitoxin, then from a practical point of view fatigue within certain limits is a positive advantage to the organism, leaving it not with lowered vitality but with added resistance. Such a thesis, however, could only be maintained for fatigue which was not so excessive as to deplete the very sources of vitality.

Some practical considerations.

The problems of fatigue are becoming more and more insistent in all departments of human life, industrial, educational and medical. The exceeding extravagance of exacting further work from those who

[1] Burnham, "Problems of Fatigue," *Amer. J. of Psychol.* XIX.

[2] Steinberg, *Infection and Immunity*, 1903.

are already under the influence of previous fatigue is not generally realized: even in the case of the very small excess of work, such as the experiments recorded above demonstrate, there is, in an unmistakable form, evidence of the unprofitableness of the transaction. The possibility of the second phase of fatigue extending far beyond the subjective indications is of urgent importance industrially. It has been shown that fatigue involves at least, loss of accuracy, failure of memory, lowering of speed; where such inefficiency, instead of displaying itself in the secrecy of the laboratory, imperils the life of the worker himself or of others, the problem becomes momentous. It is highly probable that a connection might not be realized between fatigue and an accident, if the latter occurred considerably after the fatiguing experience, and yet it is just when the strain ceases to be felt, and the vigilance therefore is relaxed, that the greatest danger occurs. It may be possible some day to discover a means whereby those employed in dangerous trades will be tested regularly as to their fitness, and as stringent regulations made for securing them adequate rest as are made for nurses. What is oftentime called carelessness might well be fatigue manifesting itself in temporary forgetfulness, *e.g.* as in the above memory experiments. Such forgetfulness is unfortunately only too important sometimes, for instance in the case of railway signalmen. Again the oft-expressed surprise that accidents do not increase in number at the end of a given work period, may, apart from various other possibilities, be due to the stimulating effect of excessive fatigue[1].

Taking into account the extravagance of working on a fatigued state, the possibility of chronic fatigue should be forestalled and due provision made for adequate rest.

The various types of work should be analysed from the point of view of their demands on the human organism and the hours of work adjusted accordingly. To fix an eight hours' day for all branches of all trades would not necessarily prove beneficial: four hours of some work would be more fatiguing than ten hours of another type. And not only must the work be analysed, but the fatiguability of the individual determined so that to each man is assigned that work for which he is best adjusted.

That we are far from being in a position to dogmatize on either aspect is only too true, but the field of work is well worth cultivating.

While recognizing however, that the human organism cannot be

[1] The relaxing of the strain through the knowledge of the imminent cessation of work, or the extra care in order to avoid catastrophe just before stopping, will also play a part.

subjected to fatigue with impunity, nevertheless we must take into account that there will be a gradual adjustment to the conditions of the work, *i.e.* a relative immunity to fatigue, so that one cannot advocate as a universal law the avoidance altogether of even excessive fatigue: it may well be that it is an advantage to be trained in resisting fatigue. And there may be occasions when a man or woman ought to be able to give of his or her reserve forces: the psychologist can but point out that there are results accruing from such action which ought to be taken into consideration, and that due precautions should be taken.

Again, the unshakable belief of most students that to work up to the last moment before an examination is a profitable proceeding may perhaps find its justification in the stimulating nature of over-fatigue. If the examination be of short duration the candidate may manage to get it all within the compass of the first phase; a prolonged ordeal would certainly prove the futility of the lack of rest. Perhaps, too, many of the nervous breakdowns attributed to higher education are due to loss of sleep no less than to the strain of learning, students not being as a rule addicted to early hours.

General Summary.

Within the limits of the evidence afforded by these experiments, the following generalizations seem valid:

1. Fatigue as estimated objectively involves two distinct phases:

(*a*) A phase when fatigue acts apparently as a stimulant, so that work demanding concentrated attention is done more effectively than under normal conditions[1].

(*b*) A phase of longer duration when the body is attempting to make good its losses—which phase is characterized by a general loss of accuracy of aiming, in a weakening of the powers of inhibition, as shown by the increase in the number of uncontrolled dots, in marked loss of the power of concentration, as shown by the inability to attend to the words of a list, and in loss of retentiveness, as instanced by the inability to reproduce the words when the connections have been realized, and in the increased number of repetitions required to re-learn a group of nonsense syllables.

[1] That these apparent improvements are not due to the effect of habit is shown by the fact that the normal records obtained after the whole fatigue cycle was over do not show any deviation from the preceding normals.

2. The subjective feelings bear no relation to the objective demonstration of fatigue, extremely bad work being not infrequently accompanied by a conviction that it is unusually good.

3. There is the suggestion that it is possible to become partially immune to a particular form of fatigue.

4. The time taken to return to a normal condition after the loss of but a few hours' sleep is disproportionately great; and this return is gradual but irregular.

5. Fatigue acts on a fatigued state as it does on the normal, *i.e.* while the strain is present there is improvement, but the return to a reliable normal is considerably delayed.

As a result of the experiments it would appear as if both the dotting machine and the list of associated words were useful instruments to measure fatigue: tapping and nonsense syllables are not refined enough, as such processes will not be affected as quickly as the later developed and so lesser organized processes, such as voluntary attention and rational memory. Of the two the dotting machine is probably the better as it is impossible to insure equality of interest and difficulty with the words; also in the case of the machine there is no possibility of influencing it: the individual must adjust himself at each moment to the machine, he cannot make up by an extra spurt for spasmodic lapses, since the unmarked circles or indifferent aiming are there as records against him. It is temporarily as inexorable as 'the moving finger' of time:

In ordinary work which is under the control of the individual much of it is probably done by 'spurts' and 'rests.' The familiar falling off of 'output' in the afternoon may be due in some cases to a voluntary relaxation after the morning's effort: in such ways the body is protected against the effects of excessive work.

The windmill illusion is more interesting theoretically than practically from the point of view of these experiments.

Note on the Dotting Machine.

As the work of getting daily dotting records progressed, it became evident that the machine was a very subtle indicator of well-being, frequently foreshadowing some physiological change. A not infrequent experience was to find a bad record on a certain day allied with the subjective statement of 'good form,' followed, though on the next day, by the remark 'have a headache.' This could not be due merely to suggestion, for it happened usually that the tapes accumulated for marking, so that I was unaware of the number of errors on a given day.

Again, a week in which there was a considerable average deviation was significant of a departure from the normal health, *e.g.* the mean variation, normally 7, rose to 13, the results alternating between very good and very bad records.

Since completing these experiments I have used the dotting machine as a test of fatigue on a number of girls engaged in clerical work, and get results quite in harmony with those given above.

It also has proved in a few cases, which happened to come to my notice, to be an indicator of nervous disorders. Care must however be taken in interpreting results. It is not merely the number of errors in a given length of tape that is significant, *e.g.* two people in a length of three metres might get 100 errors: suppose *A*'s errors are fairly evenly distributed throughout the length and that the mean variation is small as estimated for 6 half-metres, the figure may reasonably be taken as representing her capacity for such a task: suppose *B*, on the contrary, does one metre almost without error and then suddenly breaks down and either refuses to go on or makes shots wide of the mark unaimed and uncontrolled, then it would be well to make enquiries as to *B*'s physical condition.

As with myself I found that the subjective feeling of success or failure was quite unreliable. A safer subjective criterion was the statement, which some subjects made after a record which proved to have a large number of errors, that the machine was going too quickly. Whenever a subject asked if the pace of the machine had been increased there was invariably a bad record.

The interest aroused by the test is sufficiently great to permit of a wide application. Records from school children carried on over a sufficiently lengthy period might throw some light on the problem of the fatigue engendered by the various school subjects, and also of the accumulative effect of a term's work.

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