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Fatigue: a key-word in the birth of Applied psychology

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Abstract

This paper analyses the development of the concept of fatigue, taking as its starting point the research into the *human machine* carried out in the 18th and the 19th centuries, when J. Liebig linked animal mechanical energy with the heat produced by food combustion, R. Mayer stated that heat was equivalent to work, E. H. Weber proved the existence of a force sensation, and H. Helmholtz spoke about energy conservation. Consequently, there was an increase in the construction of devices for recording the «fatigue curve», as H. Kronecker called it in 1871.

A. Mosso, M. L. Patrizi, and Z. Treves measured fatigue in their Turin Laboratory using a new instrument, the ergograph, which converted muscular work into mechanical work thus proving the existence of individual fatigue curves. As work was understood to be mechanical energy, the Torinese techniques assumed importance in the early days of applied psychology.

Keywords: Fatigue, work, Applied psychology

The question of whether economic growth can be brought about by changing the way in which workers perform their tasks led to the study of *ergonomic efficiency*, which meant the optimum use of human muscle structure. Essentially, this was among the core teachings of *scientific management* as expounded by Frederick Winslow Taylor and his followers. However, it should be pointed out that the proponents of *scientific management* were also well aware that other factors, including material and psychological incentives, contributed critically to an increase in individual output. Similarly, a detailed investigation of the number of the hours worked and the nutritional status of the workers could not be neglected.

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Although research into work was developed in earnest in the 19th and the 20th centuries, some studies were carried out in the 17th and –to a greater degree– the 18th century, when industry needed sources of mechanical power capable of continuous operation. Muscle power was the dominant power technology: the total work produced by men, horses, and oxen in fields, roads, mines, mills, and harbors probably exceeded the combined power of all steam engines, waterwheels, and windmills. It is revealing that in the 1740s J. O. de La Mettrie spoke of the *human machine* (de La Mettrie, 1748), as did, in 1918, one of the pioneers of the scientific study of work, the American physiologist Frederic Schiller Lee (Lee, 1918), who spent 1886 in Leipzig working with Carl Ludwig on electrical phenomena of muscle contraction, and that Taylor was not the first, and certainly not the last, engineer to concern himself with this problem. At the end of the 18th century Charles-August de Coulomb, the French physicist, paid serious attention to the measurement and analysis of work in looking for its constant. To arrive at a definition of fatigue, Coulomb felt it necessary first to define work (or action, as he called it). «Action –he wrote– I call the quantity resulting from the pressure that a human being produces, multiplied by the speed and the time that this action lasts» (Coulomb, 1785, p. 257). He assumed that the average man weighed 70 kg and found that when workers carried what they considered the maximum amount possible in one day, they had to rest for the following two days (Coulomb, 1785, p. 264).

Early attempts to determine how much physical labour a man could be expected to do in a day had been made around 1700 at the Académie Royale des Sciences in Paris. Inquiries continued through the 18th century. Bernard Forest de Bélidor, Coulomb, John Theophilus Desaguliers, Johann Euler, and Philippe de La Hire were among those who addressed related questions of a fair day's work and the comparative strength of men and horses. No consensus was reached, but a large body of data was generated.

In this context, work in terms of human muscular strength was tested by the ability to lift or move standard weights. In 1699 the natural philosopher, mathematician, and astronomer Philippe de La Hire made to the Academy the following observation on a man lifting a weight: «I consider first that such a man as I have supposed, having both knees on the ground, can rise putting his own weight only on his toes and keeping his knees together. As this action is performed by means of the leg muscles, it is evident [...] that the leg muscles have sufficient force to raise 140 pounds, that is, the weight of the subject himself [...]; as for the strength of the arms for pulling and lifting a weight, one may suppose it to be 160 pounds» (de La Hire, 1699, pp. 153-162).

This method had obvious disadvantages. Firstly, there was no agreed international standard for weight, and thus no real possibility of comparison other than within the local populace. John Theophilus Desaguliers, a French-born Englishman, noted in 1763, in the context of a comparative study of the strength of leg muscles of the English and the French, that the French measurement system was different from the English one (Desaguliers, 1763, vol. I, p. 253). A second difficulty was that only certain groups of muscles could be tested, and that it was impossible to standardise body position or lifting technique. The third difficulty was that the use of dead-weights did not allow a practical scale of strength to be used; no real recording of a continuum was possible, and hence the sensitivity of the strength tests was limited to the series of available weights. Finally, the comparative study of strength through such biological techniques as using people at a capstan or in a tug-of-war was obviously too unverifiable for any serious scientific endeavour.

In the early 18th century a need had arisen for a technique that would measure muscle strength, that would record along a continuum, and that would allow easy standardization. This was possible thanks to the introduction of appropriate instruments.

Desaguliers was one of the first scientists to make apparatus to demonstrate how the principles of physics applied to human muscle action. On the basis of the idea that muscles and bones as lever systems were anatomically related to each other, he invented a dynamometer to measure grip strength. In this way, he made quantitative dynamometry practical for the first time, established the importance of a standard position when a particular muscle was tested, and defined the variation, from person to person, of the strength of an individual muscle compared with body stamina as a whole. As he wrote, «all men are not proportionately strong in every part, but some are strongest in the arms, some in the legs» (Desaguliers, 1763, pp. 290-291).

Combating fatigue and the recovery of the body's energy thus became the focal points of various fields of research. As part of a series of observations on «vital force», the chemist Justus von Liebig linked animal mechanical energy with the heat produced by food combustion and furnished prescriptions for the restoration of the organism's muscle capacity. The physician Robert Mayer concluded that heat was equivalent to work – both being energy, or *force*, and both comprising the energy-economy of the living organism. The physiologists Wilhelm and Eduard Weber affirmed that if bones were considered to be mechanical levers, then this proved the existence of a force sensation capable of perceiving the degree of muscle effort necessary to overcome resistance to movements. Hermann Helmholtz spoke about energy conservation. There was a consequent increase in the construction of devices that made it possible to record the muscle modifications caused by fatigue. Like dynamometers, myographs were used to measure the force generated by a contracting muscle: the Helmholtzian myograph recorded the curve between the time when the stimulus was given to the nerve or directly to the muscle and the muscular reaction (*myogramme*) (Helmholtz, 1850, pp. 276-364). They testified to the great interest at the time in the mechanical function of muscles, which were considered the active organs of the *animal machine*, as Étienne-Jules Marey called it in 1873, taking inspiration from the industrial machines whose active parts produced energy transformable into useful work. «Just as machines are regulated to obtain a useful effect with a minimum expenditure of energy –he wrote in 1886– so men can regulate their movements to produce the desired effects with a minimum expenditure of energy, and consequently a minimum of fatigue» (Marey, 1886, pp. 66-67).

On the other hand, Marey's perception of physiology was a natural outcome of his early enthusiasm for physics and thus had more in common with the viewpoints of Helmholtz and Carl Ludwig: like the Germans, he too believed in an intelligible causality underlying all life processes, which could be measured because they were reducible to the laws of physics and chemistry.

As early as 1857 the Polish naturalist W. Jastrzebowski studied man at work and coined the term «Ergonomics» in the *Treatise on Ergonomics, or the science of work based on truths drawn from* *the natural sciences*. Thirty years later, in 1889, in Modena, Italy, Mariano L. Patrizi organized a laboratory of experimental psychology applied to work and in the following year he became assistant to Angelo Mosso, whose ergographic techniques he examined closely.

As we can deduce from the psychological reviews published between 1880 and 1920, the topics were man at work, and the instruments for measuring fatigue. Alongside the concern that scientific planning and experimental method should coincide, in order to meet purchasers' requirements technical instruments capable of defining human abilities would be developed. Such requirements were the consequences of the industrial revolution, which had led to men interacting with machines in artificial conditions for the first time in history. The Man on the Assembly Line might be performing a simple task endlessly, hour after hour, unable to control either the quantity or quality of his work, psychologically alone in a passing stream of machines and machine-like men, and waiting for the end of the shift or for a providential breakdown of the line. Fatigue was then the *medium* of work and was to be studied in its physical and structural peculiarities that had to be transformed in order to obtain greater efficiency and a better adaptation of man to machine.

It was in this climate that Mosso's research into fatigue gained importance. In the «Année psychologique» his own name and those of his scholars (Arnoldo Maggiora, Zaccaria Treves, and Mariano L. Patrizi) cropped up regularly. Motivated by Hugo Kronecker's studies on the «fatigue curve» with isolated muscles from experimental animals (Kronecker, 1871), in the laboratory of physiology in Turin, where Mosso carried out experiments on the measuring of muscle fatigue *à la Wundt*, using his students and himself as experimental subjects, he invented the ergograph, which would be widely used. Binet and Vaschide, both makers of the spring ergograph, recognized that Mosso's instrument was very useful in the laboratories (Binet, Vaschide, 1897, p. 253). Made by the laboratory technician Luigi Corino, the instrument replaced dynamometers, which could only measure the quantity of pressure produced during the experiment and not the time required to reach the maximum pressure, as A. Binet e Nicolas Vaschide recalled in 1897 (Binet, Vaschide, 1897). Therefore, unlike other instruments which recorded isometric curves, the ergograph could record isotonic curves of fatigue in humans for the first time (Sinatra, 2000, pp. 194-203). It consisted of some devices for immobilizing all parts of a member except the part to be measured, and for recording the latter's movements. The forearm was placed on a cushioned board and held immovable by two sets of clamps; the second and the fourth fingers were held fast in tubes, and the middle finger was attached to a string bearing a heavy weight; in raising and lowering the weight this finger moved alone without bringing any other muscles into play. The recording part of the ergograph consisted of a carriage, to which the string from the finger was attached; it moved on two rods; from this carriage another rod extended, with a quill which marked on a kymograph.

Mosso's point of view was that dynamometers could only measure the highest degree of tension of the flexor muscles of the hand and their *internal work*, since varying pressures caused different muscles to come into play, and the muscles which were not involved altered the experimental conditions. The use of the ergograph, however, allowed the translation of muscular work into mechanical work (i.e. into external work) by isolating the work done by a single set of muscles, and its rate of fatigue and exhaustion (Mosso, 1890, p. 90).

The ergographic curves indicated that: first, there was no common type of fatigue; second, an intense fatigue of the whole bodily musculature or an intense psychic fatigue produced rapid metabolic exhaustion; lastly, certain phenomena of muscle fatigue, rather than being attributable to a central origin as traditionally thought, were to be attributed to the periphery, i.e. to the same muscle, «since the muscles provide –said Mosso– their usual curve whether they are stimulated directly or indirectly» (Mosso, 1890, p. 123). Thus, disagreeing with the physiologist Augustus Volney Waller but in concordance with Hugo Kronecker, he added: «With our will we can exert a greater strength and lift heavy weights, but the work capacity soon finishes and the impulse stimulated by the will becomes ineffective, whereas the nerves keep on working for quite a while with an electric stimulation» (Mosso, 1890, p. 123).

In any case, being convinced that every ergographic curve had a twofold origin, one recording the fatigue of the nerve centres, and the other peripheric fatigue, Mosso concluded: «it is the muscle and not the nerves that gets exhausted after intense brain work» (Mosso, 1890, p. 129).

Maggiora, Treves, P. Warren Lombard, and V. Grandis would complete Mosso's research. The use of much-improved ergographs to record the curves of the forearm muscles led to the following results:

1. the greatest useful effect was linked to a weight threshold; below a certain value there was no sign of tiredness;
2. the slower the rhythm of the weight-lifting, the later fatigue appeared;
3. a two hours interval was necessary to obtain two normal ergographic curves;
4. the work done by a tired muscle was more harmful than heavy work done in normal conditions;
5. continuous fasting and waking accelerated the emergence of fatigue;
6. in accordance with the *principle of maximum weight*, voluntary work obtained optimum efficiency with minimum waste of nervous energy.

The techniques of the Torinese School assumed great importance at the beginning of psychotechnics: since work was understood as mechanical energy, the «new discipline» made every attempt to prevent stress and to adapt workers to working conditions. In this way, the ergograph became a symbol of the rigid scientific nature of the period, which was characterized more by the development of instruments than by attention to human needs. As Frank B. Gilbreth and his wife Lillian M., both engaged like Frederik Winslow Taylor with industry, commented in 1922, during the 3rd International Conference of Psychotechnics held in Milan, «This is the age of measurement. An epoch in the development of a nation is marked when it inventories its efficiency and gathers detailed records of successful methods and devices for doing work, in order that all may use the One Best Way available» (Gilbreth, Gilbreth, 1923, p. 145).

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