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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

PHYSICAL EXERCISE FROM THE STANDPOINT OF PHYSIOLOGY[1]

MYTHOLOGISTS tell us that Æsculapius, the god of healing, was slain by a thunderbolt from Zeus because of complaints which had reached that deity that Æsculapius had become so skilful in his art that Hades was fast being depopulated. His tragic end, however, did not deter his courageous daughter, the goddess of health, from carrying on a vigorous propaganda; and, whatever the immediate result of her efforts, I am quite sure that her followers, the hygienists of the present day, are even more successful than are the doctors in delaying the day of our entrance into a future life. It has been many centuries since offerings to Hygeia were laid on her altars on the Grecian hills, but the aim of her cult has not changed. This aim, as I conceive it, is to bring to, and maintain at, its highest efficiency the organic machine. An unhealthy body is a pathological body, and any method is a legitimate hygienic method which tends to keep the body in a physiological status. Hygiene has been well called applied physiology.

What are the criteria of efficiency in a living body? One criterion is that the body's chemical processes shall proceed

[1] An address delivered in a symposium on "The Regulation of Physical Instruction in Schools and Colleges, from the Standpoint of Hygiene" before Section K (Physiology and Experimental Medicine) of the American Association for the Advancement of Science, Baltimore, December 29, 1908.

in a rapid, orderly and economical manner. Chittenden has taught us to beware of an excessive quantity of protein food, even though it may be questioned whether it is most economical to reduce our daily protein intake to as low a point as forty or fifty grams. Digestion should not be delayed. Oxygen starvation is most deleterious; and the two requisites for a sufficient intake of this essential element are, first, a sufficient supply outside the body and, secondly, an efficient respiratory mechanism. It can hardly be questioned that a rapid anabolism and a rapid katabolism are advantageous. The storage of much nutriment in the cells, in the form of glycogen or fat, is like putting one's money in a safe-deposit compartment, where it lies with no interest return to its owner. Food should be quickly utilized, either to form protoplasm or to yield energy. There is also reason to believe that intermediate katabolic products are harmful to the tissues, and that they should be quickly turned into the final excretory products and cast out. Thanks to the labors of Starling and others, we are now beginning to realize how far-reaching is the control of the various tissues by distinct chemical bodies, or hormones, produced in other tissues. Any interference with the production of hormones is obviously an obstacle to efficient action.

A second criterion of efficiency is that the body's physical, as distinct from its chemical, processes shall be adequate to the body's needs. Voluntary and involuntary muscles should possess size, toughness and contractile power sufficient for both ordinary and extraordinary demands. The heart should be able to resist a high blood pressure without detriment to its muscle fibers or valves. The capillary bed should be capacious. Vasomotor response should be ready. Respiratory organs should be capable of quickly bringing in oxygen and quickly eliminating carbon dioxide. Osmotic exchange should be rapid. Secreting and excreting organs should be richly supplied with blood and lymph, and capable of quickly supplying their products. The amount of energy utilized in mechanical work should be as high as possible in proportion to the total amount of energy expended, and the work of Zuntz and others has shown that the former can be largely increased by training.

A third criterion of efficiency is accuracy and delicacy in the activity of the organs of special sense.

And a fourth criterion of efficiency is a skilful working central nervous system, playing its part effectively, whether with or without psychic accompaniments, and by means of excitation and inhibition exerting an adequate coordination and control of all the bodily processes.

From this summary of some of the factors that make up physiological efficiency I turn to one of the most important obstacles to its development. This is fatigue. Fatigue is a general biological phenomenon —wherever protoplasm exists, there fatigue is possible. Given everything else, it is fatigue that loses races and it is absence of fatigue that wins games. Fatigue occurs in both physical and psychical processes. It is normal, and yet it may easily overstep its ill-defined normal boundaries and become markedly pathological. While originating, it may be, in one tissue, it radiates to all others and touches the most remote. It manifests itself in striking physical phenomena, yet it is primarily a chemical one —a phenomenon of metabolism. It seems strange that, with all the centuries during which mankind has struggled against it, fatigue should still remain largely an unsolved problem. We seem to be on the

right track, but our progress seems immeasurably slow.

Not only logic but experiment tell us that fatigue has a twofold cause—diminution of substances essential to protoplasmic activity—and here oxygen and carbohydrate loom large—and accumulation of toxic products of katabolism, among which we reckon carbonic dioxide, paralactic acid and monopotassium phosphate.

That lack of oxygen is a potent factor seems probable from Hill's recent results, which seem to demonstrate the efficacy of pure oxygen taken into the lungs in quickly restoring one who is suffering extreme fatigue.

That lack of carbohydrate is in part responsible for fatigue seems evident from the abundant testimony, coming not only from daily human experience, but from many laboratory experiments, conducted by a great variety of methods, to the effect that sugar restores the working power of the fatigued neuro-muscular mechanism. In view of the complexity of the chemical changes involved in protoplasmic activity, it seems hardly possible that fatigue substances are limited to two end products of metabolism, carbonic dioxide and a phosphate of potassium, and one intermediate product, paralactic acid. Indeed, Weichardt has gone beyond this and claims to have found among the products of extreme muscular activity a specific toxin, which is analogous to bacterial toxins and capable of producing the symptoms of fatigue when injected into animals. And he further claims to have produced, by methods analogous to those employed with bacterial toxins, a specific antitoxin possessed of striking recuperative powers. These claims he supports by a large amount of experimental evidence. Without a repetition of his procedures—and I am unaware that any one has yet done this—it is difficult to express an opinion of value concerning the existence of his toxin and antitoxin. That he obtained from the tissues of his fatigued animals a poison of a high degree of toxicity seems undoubted; that this is capable of ready neutralization is less clear; and a sceptic may be inclined to be dubious of the specificity of Weichardt's products. The preparation of his antitoxin in this country is now protected by patents issued from Washington, and it is gratifying to feel that if it prove to be the long-sought antidote to fatigue, now commercialized it will come within the provisions of our pure food law.

Whether future research justifies Weichardt's claims or not, our conception of fatigue substances is bound, I think, to become extended. My study of the physiological actions of the three now recognized, and the similarity of these actions to those of β-oxybutyric acid, indol and skatol, have brought me to the conviction that we shall in the future probably find many intermediate products of metabolism which have the power of depressing protoplasm and putting it into the condition wherein it manifests the physical characteristics of fatigue. If this conviction proves to be well founded, we shall in the future recognize many fatigue substances. It may be convenient to regard some of these as normal and some as pathological, although I am inclined to interpret the difference between these two hypothetical groups as one of quantity rather than of kind.

We are still in the dark as to the respective parts played in the production of fatigue by its two so-called causes. Verworn's limitation of the term fatigue to the result of poisoning by toxic substances, and of the term exhaustion to the effects of the lack of substances essential to activity, is a convenient usage, but it should be borne in mind that both processes go hand in hand throughout the activity of the tissue, and even in what is popularly understood by

the term exhaustion there are evidences of the profound action of toxic substances.

Ever since Eukles, the progenitor of Hayes, Dorando and Longboat, ran and won the first Marathon race and gave his life for the privilege of announcing to the Athenians the victory of Miltiades, the phenomena of fatigue have been of profound interest. The cause of the death of Eukles can only be conjectured, but the laboratories, the gymnasia and the race tracks of modern days have given us many data of value. Without attempting to review completely the chemical, physical and psychical phenomena of fatigue, let us consider some of the most common and most striking of these. The universal characteristic of fatigued muscle is that its lifting power for a given stimulus is diminished. In the voluntary muscles of cold-blooded animals the process of relaxation is always slowed, often enormously, but this does not seem to occur with warm-blooded muscles. There seems no doubt that the muscles can endure, without detriment, great abuse from both of the factors engaged in the causation of fatigue. Any one who has observed the activity of an isolated and electrically stimulated muscle, from which the blood stream has been cut off and from which the accumulated fatigue substances are occasionally washed by a stream of oxygenated physiological salt solution, can not fail to be impressed by the long continuance of the muscle's activity and the enormous resistance to exhaustion which it shows, even when no food enters it. The muscle possesses within its cells material for performing an incredible amount of work. And no less resistance is shown by the trained muscle to the action of fatigue substances. Thurston estimates the average amount of a man's work per day as two million foot pounds. Carpenter calculated that in the last of the old-style six-day bicycle races, held in New York in 1898, the winner, Miller, performed on the first day more than fifteen million foot pounds of work, and on each of the six days an average of more than nine and one half million foot pounds, the latter being nearly five times man's daily average. Notwithstanding this great effort, Miller competed during the following month in a twenty-four hour race, and two months thereafter he won a second six-day race, breaking his previous record.

The results of fatiguing muscular effort are not confined to the muscles. The proper conditions for fatigue are, at the same time, presented to the nervous system, partly because of its own efforts and partly through the fatigue substances of muscular origin circulating in the blood. It is unfortunate that we know so little regarding the capability of fatigue of the nervous system. The one certain fact is that the nerve fiber can be fatigued only with difficulty. The former and still common idea that the brain and spinal cord are readily fatiguable and, in fact, are the first part of the individual to succumb in a contest, seems not to be justified by the experimental work of Hough, Storey, Woodworth, Joteyko, Kraepelin and others. In attempting last year to discover an efficient method of fatiguing the spinal cord by artificial stimulation, I could find no conclusive evidence that genuine fatigue had been accomplished. Sensations of fatigue are a resultant, chiefly, of the fatigue of tissues situated outside the brain and spinal cord. It seems not unreasonable, therefore, to believe that the central nervous system is highly resistant to fatigue. It is a noteworthy fact that it is the last part of the body to lose in weight in starvation—all the other tissues contribute of their substance that it may be preserved. In certain diseases, too, it is the last tissue to be attacked. When one considers the indispensable rôle which it plays in the drama

of the organism, and the fact that if it succumbs all will be confusion and the curtain must be rung down, the resistance of the central nervous system to fatigue would seem to be, like the known resistance of the nerve fiber, an essential fact of the animal economy. Yet nervous fatigue is an undoubted fact and is manifested by easily recognized physical and psychical phenomena. Fatigue from overwork is one of the common causes of neurasthenia.

The behavior of the heart in a fatiguing physical effort is always a matter of great interest. When an individual is called upon to perform intense and especially prolonged work, the heart is largely the key to the situation. There is no question but that the work of the heart is then enormously increased, partly because of the heightened arterial pressure, and partly because of the greater demands of the tissues for oxygen. McCurdy found that during a combination of the back and leg lift used in the physical examination of college students, the blood pressure, as measured in the upper arm by the sphygmomanometer, rose more than sixty per cent. After long-continued efforts, such as in the Marathon runs, the heart is always dilated, and often there are murmurs, indicative of valvular insufficiencies. It is not clear whether cardiac dilatation results solely from the excessive arterial and intraventricular pressure, or whether this undoubted cause is not reinforced by diminution of the tonus of the heart muscle due to the action of the fatigue substances. Indeed, the direct action of fatigue substances on heart and arteries is much in need of study. A sudden and acute dilatation may be a very serious matter, either endangering the life of the individual at the time or leaving permanent pathological effects. In a well-trained heart, however, there ought to be hypertrophy, as there is in a well-trained voluntary muscle, and it does not appear that dilatation and hypertrophy are necessarily deleterious results of severe physical effort.

Besides cardiac dilatation, severe effort may produce other mechanical effects, such as hernias, the rupture of muscles and of blood vessels, and even the fracture of bones, but these must be looked upon as adventitious phenomena, possible but not probable sequelæ of excessive effort.

Both albumin and casts are very frequently found in the urine after excessive physical effort, usually so with Marathon runners. Why this occurs is not clear, but from the apparent causative connection of the toxins of infectious diseases with albuminuria, it may be questioned whether the albuminuria of fatigue may not be due to the action of fatigue substances on the renal cells. In this connection a recent discovery by Pearce and Sawyer is interesting. They found that the serum of dogs suffering from artificially produced nephritis, when injected into normal dogs, caused protein to appear in the urine. This discovery suggests the question whether there is a fatigue toxin which acts upon the kidneys as a nephrotoxin.

Excessive effort frequently brings on a high temperature, which may last for days afterward. It seems probable that this fatigue fever, like the fevers caused by bacterial toxins, is due to the action of toxic fatigue substances, but here again accurate study is wanting.

The metabolic changes in the body involved in fatiguing effort are much in need of investigation by modern methods. Our present knowledge of these changes need not here be discussed.

Fatiguing effort may thus result in a large variety of phenomena. Some of these have purely mechanical causes, but the majority of them may probably be traced primarily to the action, on the tissues, of the specific fatigue factors. The phenom-

ena are naturally more pronounced in those persons who are physically untrained. I shall not deal here in detail with the physiology of physical training, with its resulting hypertrophy of heart and voluntary muscles, and increase in strength, and in quickness and accuracy of movement. But I would emphasize one point, namely, that a most important element in training is the adaptation of the tissues to the toxic fatigue substances. Without this all the other benefits of training would avail nothing. It is well known that the body can adapt itself remarkably to even large quantities of poisonous drugs, when those are taken first in small and then in gradually increasing doses, extending over a long period. Exactly the same thing is found in physical training properly conducted. Moderate but increasing amounts of exercise, producing moderate but increasing amounts of fatigue substances, put the tissues into a state of tolerance or resistance, such that when the supreme effort is demanded of them, they do not succumb. He who wins is he who can best resist the poisons of fatigue.

What now is the teaching of physiology regarding physical exercises and physical contests?

In the first place, physiology teaches that the human body is capable of responding to enormous demands for physical effort. One's latent power in all of the three varieties of physical exercise—of strength, of speed and of endurance—is never realized except in emergencies, and then it often proves remarkable.

Secondly, physiology teaches the great value of proper training in increasing one's latent power. Yet training can easily defeat its object. As Darling rightly says:

> The physiological effects of training, on the heart and kidneys in particular [and we might add, on the nervous system], may approach unpleasantly near to pathological conditions.

The physiological basis of overtraining is not altogether clear, but the fact of overtraining is undeniable.

Thirdly, physiology teaches that the fatigue of one tissue from over-use means the fatigue of all tissues. Extreme activity of the muscular system involves not only lessened muscular, but also lessened mental activity.

Fourthly, physiology bids us to beware of physical excess. According to Tissié there are three degrees of fatigue—slight fatigue or lassitude, which gives tone to the body; fatigue which irritates, excites and enervates; and fatigue which weakens; and he adds that the two latter degrees of fatigue should be absolutely avoided. With this view I can in general agree, and yet I would not here be an extremist. If I read aright the teachings of physiology, they are that physical exercise, carried to the point at which it produces extreme fatigue, and persisted in, can not fail to be harmful. The human body is, indeed, wonderfully resistant and capable of apparently complete recovery after a considerable degree of abuse. But it is not to be denied that extreme physical exertion is a debauch and, like any other debauch, leaves the individual mentally, morally and physically depleted. It is also not to be denied that the chances of continued well-being are enhanced if the debauch is never indulged in. No sharp line can be drawn between what is normal and what is pathological in fatigue. What is normal for one person may be pathological for another. Training should extend the boundaries of the normal. But it is safest to avoid those physical exercises that force the organism to the border line beyond which the abnormal lies. The one may pull his all in the tug of war or wield his oar in the four-mile race, or run his twenty-five Marathon miles. But it is the physically exceptional man who can do these things, and the physically average

man would best leave them to him who is exceptional. It is the physically average man who does the world's work, and if he becomes physically incapacitated, as he may easily become if he tries to become physically exceptional, not only the individual but the world suffers. It is not only the teaching of physiology, but it is the teaching of common sense to avoid physical excess. Common-sense hygiene should have its place in a liberal education. What a liberal education should do for the individual is so well put by Huxley that I am tempted to quote his words:

> That man has had a liberal education who has been so trained in youth that his body is the ready servant of his will, and does with ease and pleasure all the work that, as a mechanism, it is capable of; whose intellect is a clear, cold, logic engine, with all its parts of equal strength, and in smooth working order; ready, like a steam engine, to be turned to any kind of work, and spin the gossamers as well as forge the anchors of the mind; whose mind is stored with a knowledge of the great and fundamental truths of nature and of the laws of her operations; one who, no stunted ascetic, is full of life and fire, but whose passions are trained to come to heel by a vigorous will, the servant of a tender conscience; who has learned to love all beauty, whether of nature or of art, to hate all vileness, and to respect others as himself.

Physiology tells me that this is the education which we should give to our youth.

FREDERIC S. LEE
COLUMBIA UNIVERSITY

DEPARTMENTAL ORGANIZATION FOR THE REGULATION OF PHYSICAL INSTRUCTION IN SCHOOLS AND COLLEGES FROM THE STANDPOINT OF HYGIENE[1]

PHYSICAL instruction or physical education in the past has been handled largely from the standpoint of physical exercise. Gymnastics, or calisthenics, or games, or athletics have constituted the chief and often the only work done in physical instruction in many of our institutions. The word "gymnasium" has been and often is now, synonymous with the words "department of physical education." The objects of physical instruction have been predominantly those attainable through physical exercise. Many of our departments are even now interested mostly in bulk of muscle or in strength, speed, endurance and coordination; or in the development of a winning team or a star athlete; or in the perfection of bilateral symmetry and the production of grace of movement. And so we find the curriculum of the department including only, or chiefly, such individual and class work as may be handled from the standpoint of physical exercise. An anthropometric examination has been a common requirement because it has been assumed that by comparing the individual with the standard, his need for special developmental physical exercise would become apparent. He could then specialize more or less along certain lines of physical exercise and correct his deficiencies in form, symmetry, bulk or strength of muscle. Certain special medical data have been secured frequently because it was found that physical exercise might easily produce a serious effect upon unusually weak organs.

Further, the curriculum always provided some sort of work in physical exercise. This might be applied to the individual or to groups or classes. It consisted of mass drills or apparatus exercises, games, contests, swimming or athletic sports, or combinations of any two or more of these various phases of physical exercise. Special exercise was planned in many cases for those individuals who ap-

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