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Physiology of Exercise.

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ON THE PHYSIOLOGY OF EXERCISE.[1]

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ONE of the principal obstacles to the success of any comprehensive effort to make physical training an integral factor in the education of American youth, is found in the very general misapprehension as to what physical education is, and what its effects are. If the teachings of modern physiology and psychology in regard to the functions of the muscular and nervous systems of the human body were apprehended, even by those classes which we are wont to call educated, it would be a comparatively easy matter to secure the votes and appropriations necessary for the adoption or trial of rational and approved systems of physical exercise.

The fundamental and essential characteristics of exercise are so generally misstated and its proper effects so frequently overlooked, that I have chosen the physiology of exercise as my theme. I cannot hope to present a complete and satisfactory theory of exercise, but I may be able to point out the situation of quarries whither we may repair with profit, for the foundation-stones on which such a theory should be based.

Exercise is so comprehensive and elastic a term, when taken in its general sense, that it may easily be made to cover a multitude of actions, and some sins. The word is so nearly synonymous with practice that it has come to be used oftenest by those who devote themselves to preaching on conduct, on education, or

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on health. One need not make lengthy or frequent excursions into the domains of theology, of pedagogics or of hygiene, to discover that the meanings of exercise are many and mixed. The casual reader will hardly be struck by the points of resemblance between the exercises made use of by the Greek athlete and the Roman gladiator in preparation for their contests, and the exercises ordained for the training of catechumens and of aspirants for canonization. To the ancient Puritan a week-day sermon was a delightful "exercise," while most of his less serious contemporaries held that shooting, hunting, and riding "which be martial exercises," were the only kinds of exercise proper for gentlemen. At first sight there appears to be no common element in such exercises as the foregoing, and those which our modern teachers of French, of pugilism, and the piano, are accustomed to set their pupils, unless it be the exercise of patience. Still, speaking broadly, it is possible to find in all the secondary meanings of the word, some trace of its primary signification; namely, a repeated action for the sake of training or practice.

It is interesting to note that our word exercise and *exercitus*, the Latin word for the body of best-trained men in the State, the army, are derived from the same verb *exerceo*. The Greek synonym for *exerceo* is ἀσκέω and meant originally to work raw material. In classic times it meant to exercise, to train in the strict athletic or gymnastic sense; later, in the early days of the Church, it signified to discipline the flesh, to mortify the body, and to it in this sense the English word ascetic owes its origin and present meaning. The original ascetic was simply an industrious and careful gymnast or athlete.

Our universal friend, the average man of to-day, is theoretically in favor of exercise. "Exercise," you frequently hear him say, "does a man good." The average woman has not attained to the same degree of certitude. If you ask the average man to define his notions of the good which exercise does, he will probably indulge in cloudy generalities concerning its influence in realizing the *mens sana in corpore sano* ideal. It is astonishing what an amount of service that line of pagan Latin has done in confusing thought and preventing inquiry as to the nature of exercise. Press the average man a little to abandon the general and become specific, and you may learn that muscular exercise is particularly good for opening the pores; for cleansing the blood; for quickening the spirits; for getting up one's muscle; and that it is above all valuable for enabling the rising generation to work off its superfluous animal spirits. Every such alleged advantage of exercise is vague or meaningless in the light of our present knowledge. The physiological terminology and ideas of the average man are seldom so recent as the revival of learning, and in many instances antedate the Christian era. The facts that we are in search of have not been quarried on the windy heights of hortatory literature or in the fat meadows of the common mind. If they have been brought to light anywhere it is in fields where physiologists and physicians have been digging so profitably during the last two hundred years.

The best comprehensive definition of exercise that has come under my notice is that given by Du Bois Reymond, Professor of Physiology in the University of Berlin. "By exercise, we commonly understand," he says, "the frequent repetition of a more or less complicated action of the body with the coöperation of the mind, or of an action of the mind alone, for the purpose of being able to perform it better." Practically all human actions are comprised under the two heads of this definition of exercise. Bodily actions demand our first consideration, since without them mental power, artistic feeling, and spiritual insight cannot be made to answer any earthly purpose.

It is far easier to underrate than to exaggerate the part which muscular actions play in human life. Imagine the condition of a man perfectly formed, generously endowed, and in his prime, whose single lack should be that sensible, warm motion that has its seat in the muscular tissue. The position of a fly in amber would be lively and preferable to the isolation of such a man. Of course he could not "do business"; but he could think and fear and hope. He must face the future, lying like a log in whatever position he may happen to fall. His face will be absolutely destitute of expression, and his eyes fixed under closed lids. He can neither smile nor weep. His hunger cannot be appeased, nor his thirst slaked. His heart may "burn within him," but it shall not pump blood; so that he will be pulseless as well as breathless and bereft of speech. Unable to stir the tip of a finger or to raise a hair; he will be powerless to express his thought or aspiration, or to impress his conceptions or wishes upon any creature. In short, such a man would be an incorruptible cadaver. Spirit we might not call him, in face of the belief that ghosts are privileged to take nightly walks.

Without muscular tissue, then, *we* cannot live or move. Its importance to the body is also to be inferred from its mass and weight. Nearly, if not quite, one-half of the body, by weight, is made up of muscular tissue. In it is contained one-quarter of the blood; and by it, fully one-fourth of the energy stored up in the body is turned into work. This tissue consists of fibres which are, for the most part, collected into the distinct organs, which we call muscles. The muscles of the lower animals are familiarly known to us as lean meat; our own have been, at various times, stigmatized as fleshy members. All muscle-fibres are endowed with contractility, by virtue of which they shorten when acted upon by certain agents, termed stimuli.

A large class of human muscles are stimulated by the action of the will, and are, therefore, called voluntary, though some of them habitually, and all at times, respond to other stimuli as well. There are more than five hundred muscles in the human body which are under control of the will. They are mostly arranged in pairs, as, for instance, the muscles of the two hands are alike in number, and identical in form and function. Muscles which do not respond to volitional stimuli are termed involuntary. They are found in the walls of bloodvessels, in the intestinal canal, and other organs.

When examined microscopically, voluntary muscle-fibres show certain faint cross-lines or striæ, and are, therefore, often called striated or striped muscle. Similarly, involuntary muscle is called smooth or plain muscle-tissue, because its fibres are destitute of striæ. The heart, though an involuntary muscle, is made up of striped fibres, intermediate in character between the sorts named. For our present purpose, it is best to confine our attention wholly to muscles of the voluntary sort.

A freshly-dissected muscle of one of the higher animals presents a smooth surface, rounded outlines, and a glistening appearance. It is usually red in color, though it may be pale or colorless. It is usually distinguishable into three well-marked parts, namely, a soft, red, contractile, central portion, termed the belly, which tapers towards each end; and its two terminal tendons, which are dense, white, inelastic cords, whose function is to connect the muscle with its points of attachment. The surface of the fleshy portion of the muscle is covered by a smooth, glistening sheath of connective tissue. Inward prolongations of this sheath pass into the substance of the muscle, and divide it into bundles of fibres, technically called fasciculi or packets. Each fasciculus consists of a number of fibres running parallel to each other. The fibres are separated from one another by connective tissue, just as the fasciculi are. The muscle-fibre is the ultimate and essential element of muscular tissue. Each fibre consists of a soft, contractile, semi-fluid substance, contained in a tubular sheath — the sarcolemma, the word means flesh-skin — which is transparent, tough, and elastic. Fibres vary in diameter from $\frac{1}{600}$ to $\frac{1}{100}$ of an inch, and are seldom longer than $1\frac{1}{2}$ inches. These fibres are arranged in linear series, and do not inosculate with each other. The amount of shortening in a contracting muscle is equal to the summated contractions of its individual fibres.

It may aid you to picture to yourselves the structural features of muscles, to liken the ultimate muscle-fibre or cell to a single sausage. The sarcolemma would then correspond to the sausage-skin, and the contractile contents of the sarcolemma to the sausage-stuff. The muscular fasciculus would represent many parallel rows of sausages, placed end to end, and bound together and invested by a tough, elastic membrane, so as to form a kind of rope. The muscle, as a whole, would stand for a collection of such ropes, lying parallel to one another, in the form of a large bundle, widest in its middle region, and tapering towards each end. If to each end of the packet of sausages you attach a dense cord, made up of inelastic fibres, you would complete a structure which should be roughly comparable with some of the typical single muscles, so far as the mere arrangement of their muscular tissue is concerned.

If we lay bare a muscle in a living animal, we may cause it to contract before our eyes, either by bringing a heated body close to it; by giving it a slight tap; by applying certain chemical substances to it, such as ammonia, lime-water, or common salt; or by giving it an electric shock. The details of muscle-physiology have been worked out chiefly through the study of cold-blooded animals, since their tissues are longer-lived, and suffer less injury from the manipulation required in making experiments than do those of warm-blooded animals, like the dog and cat. But a sufficient number of observations have been made upon the higher animals, including man, to warrant the belief that their muscles act in essentially the same way as the muscles of frogs and turtles.

When a muscle outside the body is acted upon suddenly by an appropriate stimulus, it quickly shortens ; and then, if it has been loaded with a weight, rapidly returns to its former length. A weighted muscle outside the body, or one in the body, which acts against resistance, does work every time it contracts. Its work is chiefly of the sort which physicists have named mechanical work, and is equal to the product obtained by multiplying the weight lifted by the distance through which it is lifted against the force of gravity. Its measure is expressed in foot-pounds. A muscle with no weight attached does no "work" when it contracts ; nor does it do any work if it is loaded with a weight too heavy for it to lift. Of two muscles equal in cross-section, the longer can do more work; whereas, if two muscles are of equal length, that which contains the greater number of parallel fibres will do more work than the other. It is estimated that a square-centimetre of human muscle can just lift a little more than twenty pounds. Muscles are somewhat elastic; and, in the body, are slightly over stretched.

But a single muscle is a more complicated structure than you would suppose from my description of it; and, under normal conditions, is excited to contract by nervous stimuli, and not by any of those which have been mentioned. It was necessary to mention them, as showing what is termed the independent irritability of muscle. Besides its contractile substance, its tendon, and the sheaths which invest its fasciculi and fibres, every muscle has bloodvessels and nerves, whose functions must be considered before we can arrive at a clear understanding of muscular exercise. Fresh blood is supplied to the muscle-substance by the heart, through its arteries, and the fine network of arterial capillaries formed by the minute subdivision of the arteries. As elsewhere in the body, the arterial capillaries open into, and are continuous with, the venous capillaries, which, becoming united into larger and larger vessels, form the veins of the muscle, or the channels by which the blood is returned to the heart from the muscle. Muscle-arteries, and veins usually lie alongside of each other in the connective tissue which surrounds the fasciculi, while their capillaries form a fine meshwork of vessels, lying between and upon the muscle-fibres, but without penetrating the sarcolemma of any fibre. The walls of the capillaries are permeable to lymph, as the fluid portion of the blood is called. The fibres are, therefore, bathed in lymph, and derive their food-supply from it by absorption through their tubular sheaths.

Before considering the part which nervous stimuli play in muscular contraction, we must glance at the structure and functions of the elements which make up the nervous system. Nerve tissue like muscular tissue is irritable, in that it is responsive to stimuli, but it is irritable in a vastly higher degree; unlike muscular tissue it is in nowise contractile. The elements of the nervous system take the form either of nerve fibres, or of nerve cells. An aggregation of nerve cells constitutes a nerve ganglion. The fibres serve for the conduction of stimuli and connect central nervous organs, such as parts of the brain and spinal cord, with organs at the periphery of the body, such as the eye and the hand. Nerve cells not only transmit impulses, but also act as physiological centres for regulating motion, sensation, nutrition, secretion, etc. Nerve fibres are known as afferent when they conduct impulses toward nerve centres, and as efferent when they transmit impulses outwards from nerve centres. Since stimuli which are transmitted centripetally from organs in the periphery give rise to sensations, afferent nerves are very commonly called sensory ; and since impulses which are transmitted centrifugally to the motor organs from the centres give rise to motion, efferent nerves are called motor nerves. A single instance will serve to illustrate the use of sensory and motor fibres. If a fly alight on my forehead the sensory fibres of the skin are stimulated. Afferent impulses then travel up the fibres to centres within the brain. As a result of the slight shock imparted to the nerve cells, that part of me which is in communication with that group of cells is rendered conscious of a new sensation, and I feel disturbed. If I am sufficiently disturbed to feel irritated, my will causes the centre to send efferent impulses along motor nerves, which pass to the muscles of my arm and hand, and my hand is moved to brush off the fly, which, being amply furnished with sensory and motor organs of his own, usually retires in glee or terror, as the case may be, before my hand can reach him.

From their appearance nerve fibres are divided into white fibres and gray fibres; and from their structure the white fibres are termed medullated, or fibres with a pith; and gray fibres are called non-medullated, or fibres without a pith. The medullated fibres are the more highly developed of the two. The essential, conducting part is in each kind of fibre known as the axis-cylinder. It consists of a very fine cylindrical thread or strand of fibrils of transparent, semi-fluid, and highly irritable protoplasm, when alive. In medullated fibres the axis-cylinder occupys the central fourth of the fibre. Outside it and surrounding it, just as the wax of a candle surrounds its wick, is the medullary sheath of white substance, and outside of the medullary sheath is another sheath known as the primitive sheath, or neurilemma, which serves as a protection to the parts within. The neurilemma is comparable to the sarcolemma of the muscle fibre. Medullated fibres, which vary in breadth from $\frac{1}{12000}$ to $\frac{1}{3500}$ of an inch, are aggregated into bundles termed *funiculi* or ropes, corresponding to muscular fasciculi. The funiculi are enclosed in connective tissue sheaths. An aggregation of funiculi forms a nerve trunk, the "nerve" of ordinary speech. The main difference between non-medullated and medullated fibres is this: the former has no medullary sheath interposed between the neurilemma and the axis-cylinder. The medullary sheath of the latter gives it its white appearance and its name of white fibre.

Nerve cells present too many and too varied forms for description here. Suffice it to say that the simplest forms are roundish in shape; others, oval in shape with prolongations at each end, are termed bipolar; others are irregular in shape with many branches or processes. All of them contain living and highly irritable protoplasm of a granular gray appearance, usually enclosed by a sheath or cell-wall. It only concerns us to remember that some of the processes serve to connect cells with other cells, and that the axis-cylinders of nerve fibres are direct and unbranched prolongations of the irritable cell substance.

To return to the motor nerves of the muscles. The nerve fibres found in the muscles are of the white or medullated sort. The motor nerve belonging to a muscle usually enters the muscle at its middle point. It then divides and subdivides into so many branches that every muscular fibre receives a nerve fibre. Where the nerve fibre pierces the sarcolemma the axis-cylinder spreads out, forming an eminence of protoplasm within the sarcolemma. This eminence is known as the "motorial-end plate." The branches of the axis-cylinder traverse this end-plate, and subdivide into fibrils which penetrate the contractile substance of the fibre. Only the axis-cylinder of the nerve passes within the sarcolemma; since the outer sheath of the nerve fibre coalesces with the sarcolemma itself, and the medullary sheath ends at the sarcolemma.

We have, then, the contractile substance of the muscle fibre connected with the irritable stimulus-generating and transmitting substance of the central nerve cell, the connecting link being the axial fibre of the motor nerve, which is simply a portion of the nerve cell's contents long drawn out, in the form of a strand, until it reaches the muscle fibre, where it spreads out to form the end-plate, and then subdivides into fibrils which penetrate the muscle substance. What is true of a single muscle fibre is true of all the fibres in a given muscle ; and what is true of one voluntary muscle is true of the entire five hundred. Voluntary muscles have sensory as well as motor fibres. They are the channels for the impulses which give rise to muscular sensibility, and are connected with centrally situated nerve cells which minister to our muscle sense. The sense, that is, which keeps us informed concerning the condition of the muscles, and the extent to which they are contracted.

A single muscle then is to be considered as an aggregation of a vast number of contractile fibres, arranged in myriads of linear series which in turn are gathered into bundles, all of which, along with their accompanying nerve fibres and nutrient bloodvessels are supported and bound together by means of elastic connective tissue. The muscle, so made up, has its own special sheath, and is bound by its inelastic tendons to the bones which it is set apart to set in motion. It was stated that muscular contractions could be brought about through the direct application of chemical, thermal, mechanical, or electrical stimuli to the muscle itself. If the nerve of a muscle be excited by pinching it, by beating it, by applying certain chemicals to it, or by electrifying it, the muscle is indirectly stimulated to contract by means of the motor impulses discharged into it through its motorial-end plate. The motor nerve may be stimulated at any part of its course. Again, the muscle may be set in action through stimulation of the centres whence its nerve fibres emerge. The same stimuli have no effect upon the muscle when applied to the centre, if the path between the centre and the muscle have been blocked by severing or compressing the nerve. Such severance or compression may take place in the body as the result of certain diseased conditions of the nerve, or the parts adjacent. Motor paralysis is then the result.

The effects of exercise upon a muscle and the parts connected with it next demand our attention. It must suffice merely to note the most important of them. Immediately a muscle begins working, under whatever stimulus, the blood-stream passing through it becomes changed, both in respect of quantity and quality. The arterial twigs which ramify within it dilate; more blood is poured into the capillaries surrounding its fibres; and more blood flows through the veins from the muscle.

The blood which enters the muscle is bright red in color, rich in oxygen, and poor in carbonic acid. That which leaves it is dark blue in color and of a higher temperature; richer in carbonic acid, and poorer in oxygen; and contains various products, due to the chemical changes which take place in the food-material supplied to the muscle-substance, and in the muscle-substance itself. If the supply of arterial blood to a muscle is cut off or diminished, its irritability is lowered, that is, a stronger stimulus is necessary to make it contract. The same result follows, also, if it is fed with blood deprived of oxygen, or otherwise poisoned; or if the muscle-vein is tied, and the waste-products, normally drained off through the veins, are retained within the muscle. The irritability of a muscle is also lowered by prolonged stimulation, even when its in-going and out-going blood-streams are unobstructed. If these disturbed conditions do not persist until the muscle-fibres pass into the condition known as death-stiffening; the irritability of the muscle may be restored, either by sending fresh blood through it, by sending a stream of some indifferent fluid through it, or by ceasing to stimulate it.

In the first case, restoration is brought about through the renewal of its supply of food-material and oxygen;

in the second, by clearing out the noxious waste-products ; and in the third, by allowing it to rest awhile. These, then, are the main conditions demanded for the health of a working muscle: A full supply of proper food and oxygen ; unimpeded and sufficient drainage; and rest at due intervals. Given these three conditions in the body and exercise of a muscle causes it to increase in size and weight, through the increased size and number of its fibres. Furthermore, a working muscle differs from a resting muscle in that it is appreciably hotter ; by the presence of a low murmur, called the muscle-sound, which is caused by the more rapid vibration of the particles of the slightly over-stretched fibres; and on account of certain electrical peculiarities which it presents.

A muscle habituated to exercise can do more work, and do it better, than an unexercised muscle, and for two reasons. Exercise makes the muscle larger, harder, and stronger, improving it simply as a tool in all its structure; and secondly, the muscle responds more quickly and completely to the stimuli which stir it up to work. In other words, the muscle becomes more obedient to its stimulators, the nerve-centres, through its better acquaintance with them. A muscle, then, is a neuro-muscular machine for developing power, for transforming the potential energy stored up in its substance, and the blood brought to it, into one or another form of the energy of motion.

If we consider a single muscle as a mechanism for developing energy of motion, it may be compared to a peculiarly-arranged collection of cartridges loaded with powder, and connected by wires with a series of electrical batteries. Each muscle-fibre would, in that case, stand for a single cartridge, the shell of the cartridge being represented by the sarcolemma; the charge of powder by the chemical components of the contractile substance ; the wire from the battery by the motor nerve-fibre, and the cells of the battery by the cells of the nerve-centre; and the electric current by the nervous stimulus, which, passing along the axis-cylinder through the nerve-plate into the contractile substance, gives rise to the phenomena which attend a muscular contraction.

When a cartridge is exploded, chemical actions take place, which result in the sudden formation of gas, accompanied by the development of light, heat, and sound, and the production of a residue of smoke and ashes. If the cartridge-shell be tight and tough, the motion of the molecules of the suddenly-formed gas will be communicated to its particles, and the shell be shaken or moved from its position. By varying the construction and arrangement of the cartridges, we may cause the liberated energy of the explosive to set projectiles in motion, to rend rocks, or to move parts of mountains. The results of chemical explosions in the muscle-cartridges are less violent than those above noted, but they are sufficiently similar and well marked to be called parallel to them. The potential energy of the muscle-fibres is transformed into the energy of motion, through the decomposition of the chemically-unstable contents of the sarcolemma. Heat, sound, electrical changes, and mechanical motion are evolved. The mechanical arrangement of the parts of the muscle are such that the total motion of the mass of its fibres is communicated, by the tendons of the muscle, to the parts of the body with which it is connected. So long as the muscle-fibres are properly nourished, and not too severely stimulated, the muscle-cartridges may be said to reload and maintain themselves in a state of readiness to go off on the receipt of stimuli from the central battery.

Muscles are more perfect power-machines than are steam-engines and rifled cannon, not only because they develop more work out of the energy stored up in the substances on which their activity depends, but also because they are distinguished from all machines of human manufacture by the fact that they are self-improving machines, that is to say, they become tougher and stronger as structures through exercise, and, at the same time, more capable and adaptable functionally. Growth or increase in the size and number of its structural elements and development, or increased facility in its functional activity, are the main effects of exercise in the case of a single muscle. The same is true of the muscular system as a whole. Exercise enlarges and strengthens it on the one hand, and renders it more responsive and discriminative, as regards stimuli, on the other. The body, as a whole, is a machine in which the potential energy of organized material is transformed into the work which we see manifested in motion, animal heat, and the chemical actions involved in nutritive, secretory, and excretory processes. It is estimated that the tissue-changes of which a human adult body, weighing one hundred and forty pounds, is normally the seat, involve the transformation of more than a ton of material in the course of a year. Muscular activity is one of the chief agents in promoting wholesome tissue-changes in all the bodily organs, and in determining the normal growth and development of the organism as a whole.

It is beside my purpose to dwell at length upon the effects which exercise of the muscular system exerts upon the other systems of bodily organs. At the same time, the general effects of exercise are too important to be passed over without notice. The following account of them, given by Dr. G. Wilson, a well-known English writer on hygiene, may here suffice :

" Not only are the muscles themselves benefited by exercise," he says, " because they are brought into action, but, by their action, they increase the rapidity of the onward flow of the blood to the heart; the heart itself beats more vigorously; a larger quantity of blood is sent through the lungs ; more oxygen is absorbed; a greater quantity of heat is engendered ; and the skin and the other organs of secretion are brought into action, to get rid of the superfluous heat and the products of combustion. Thus the heart, lungs, skin, and other organs of the body are brought into more active play by muscular activity; the brain and nervous system are invigorated; the digestion is improved; and the whole machinery of the body is kept in efficient working order. On the other hand, through want of sufficient bodily exercise, the constituents of the food which pass into the blood are not sufficiently oxidized; effete products accumulate; the muscles become flabby or fat; the digestion is disordered; the nervous system becomes enfeebled; the function of secretion is impaired; and ill health or disease ensues. Indeed, it may be laid down as a rule that, other things being equal, those who take a sufficient amount of exercise in the open air, or are employed in active outdoor labor, will enjoy the best health and live the longest; and this is borne out by the statistics of the Registrar-General, which clearly prove that gamekeepers, farmers, and agricultural laborers are among the healthiest classes of the community."

Dr. Wilson holds that, as a rule, the amount of exercise required by a man of average height and weight is equivalent to a daily walk of eight or nine miles along a level road. "This rule, of course," he adds, "only applies to a man in the prime of life, for growing lads or women, who by the way, are rated as physically equal to lads of sixteen, the amount of exercise required would be somewhat less." This rule is for the average adult Englishman, whose height may be set at 5 feet, 6.6 inches, with a corresponding weight of 137 pounds. The height of the average American man is 5 feet 7.69 inches, and his weight is 141.93 pounds. I incline to believe that a growing boy needs more exercise than a mature man, since the boy needs exercise to promote growth quite as much if not more than to keep his bodily machinery in repair and smooth working order.

If we bear in mind that next, perhaps, to an adequate supply of proper food, nothing so promotes the normal growth and development of the body, as well regulated muscular activity ; it is interesting to compare the children of different classes of the population as regards their height and weight. Although Dr. Bowditch, Professor of Physiology in the Harvard Medical School, and others in America have made valuable observations in this field, still, as more interest has been shown in this kind of investigation in England, where classes as such are more easily studied than with us, and the value of exercise, especially that derived from athletic sports, has been longer and more generally recognized, I shall bring forward, here, only English results for the most part.

The very complete and valuable tables published by Dr. Charles Roberts, of London, touching the mean height and weight and annual rate of increase in the case of some 7,800 boys and men, between ten and thirty years of age, belonging to the artizan class on the one hand, and 7,700 males between ten and thirty, belonging to the most favored class on the other, show that the mean height of the artizan class is for the whole period about three inches less than the mean height of those belonging to the most favored class. In the latter class public school boys, military and naval cadets, university and medical students were included. Although the inferior stature of artizans may be to some extent an inherited characteristic, it is held to be chiefly due to "the continuous operation of various conditions of life which retard and arrest growth, and which are most influential when growth is most rapid." Among the conditions so operating, "scanty feeding and wearing toil" as contrasted with "abundant nourishment and moderate exercise" occupy a prominent place. These tables also show a progressive gain as regards weight, on the part of the favored over the industrial class, both absolutely and in relation to height throughout the entire period under review. At the age of ten years the boys of the most favored class exceed the artizans' sons by one pound in weight ; at twelve their excess in weight has increased to four pounds, and at thirteen they are ten pounds ahead. At the age of twenty, well-to-do English youths have a mean weight of eighteen pounds greater than that of handicraftsmen of the same age living in large towns. As regards chest-girth, and well directed exercise tells directly upon chest capacity, the most favored class is clearly superior to the industrial, which superiority is progressively increased until nearly adult life. In another of Dr. Roberts's tables, it is shown that the sons of professional men living in the country exceed town boys, of the same class, by about an inch as regards height, at all ages between ten and twenty, and as regards weight by an amount varying from one to seven pounds. It also appears that the sons of soldiers, policemen, messengers and the like, are from one to four inches less in stature and from four to thirteen pounds less in weight than boys of the same age whose fathers are devoted to intellectual pursuits; that the sons of artizans and factory operatives are the shortest and lightest of all youthful Britons, with the exception of idiots and imbeciles, of the same age, who have a mean height of an inch less even than youths of the artizan class. American boys seem to be a little taller and a little heavier than their English cousins of the same age and class.

Dr. Boulton, another English student of anthropometry, made observations extending over ten years on a certain group of children, all of whom were healthy, and the offspring of well-to-do parents. Dr. Boulton finds that "average English children brought up under favorable circumstances grow from two to three inches a year. A growth of less than two inches or over three should excite apprehension. The former would indicate arrested development. The rate of growth should be regular, and being so prognosticates future good stature." As to weight for height, whether a child grows two, two and a half, or three inches in a year, weight for height should be in each case identically the same, and all healthy children should grow broad in proportion to their height. "Between three and four feet the increase in height should," he says, "be two pounds per inch and, between four and five feet, two and a half pounds per inch. Well nourished children of healthy parents, in favorable surroundings, generally attain these averages. But what of children that fall below the standard? I find there is a seven-pound margin of safety, and that children falling more than seven pounds below this standard are devoid of reserve of stamina on which to draw, and consequently succumb quickly to many constitutional diseases. This then may be called the preventive medicine margin beyond which lies the dangerous land of cachexia."

Cachexia is a medical term signifying a depraved or lowered state of nutrition or of nutrient activity, in which the power of the tissues to repair injury or to resist inherited tendencies to disease is dangerously diminished. Amongst the best-marked cachexiæ are the cancerous, the malarious, and the phthisical. There is a condition of mind and body not infrequently seen nowadays in children and youth, especially among females, which is characterized by an irritable, easily overwrought, and unsteady nervous system, arrested muscular development, disordered digestion, and enfeebled powers of assimilation, which might well be called *cachexia scholastica*, since it is largely, and sometimes directly, brought about by ignorant and foolish parents and teachers who force and cram and overwork the undeveloped brains of children, and at the same time by neglecting or frowning upon their play and exercise, do their best to retard the growth and development which they ought to promote and might regulate.

The late Alexander Maclaren's experience with the first squad of twelve non-commissioned officers sent to him to be qualified as instructors in gymnastics in the British army, may serve to show how systematized and well-directed exercise may be made to influence bodily development in a comparatively short time. The twelve men alluded to ranged between nineteen and twenty-nine years of age, and had seen from two to twelve years' service. At the end of eight months' gymnastic training the increase in the measurements of the men was as follows:

	Weight.	Chest girth.	Fore-arm girth.	Upper-arm girth.
The smallest gain. .	5 lbs.	1 inch.	¼ inches.	1 inch.
The largest gain. .	16 "	5 "	1¼ "	1¾ "
The average gain. .	10 "	2⅞ "	¾ "	1¾ "

"The muscular additions," says Maclaren, "to the arms and shoulders and the expansion of the chest were so great as to have absolutely a ludicrous and embarrassing result, for before the fourth month several of the men could not get into their uniforms, jackets and tunics, without assistance, and when they had got them on they could not get them to meet down the middle by a hand's breadth. In a month more they could not get into them at all, and new clothing had to be procured, pending the arrival of which the men had to go to and from the gymnasium in their great coats."

Enough has been said, I think, to show that muscular exercise exerts a potent and important influence upon the growth of the body, and upon the elaboration and perfecting of its more familiar systems of organs; but, thus far, its most important effect, that upon the nerves and brain, has only been alluded to. The nervous element involved in muscular exercise is oftener overlooked than recognized by the mass of writers on the subject. Maclaren, whose book on "Training in Theory and Practice" is the best of its class, in English, defines exercise as "muscular movement" simply, and declares its object to be "the destruction and renovation of tissue." This is the ordinary view, from which you will find but little deviation in the vast majority of the text-books on physiology, and of the books and articles on exercise, whether they have been written for school-girls or medical students.

I would not have you take this for my individual doctrine, though the statement expresses the result of my inquiry and reading. "We seek in vain in most physiological text-books," says Du Bois-Reymond, "for instruction respecting exercise; if it is given, only the so-called bodily exercises are generally considered, and they are represented as merely exercises of the muscular system. Therefore, it is not strange that laymen in medicine, teachers of gymnastics, and school-teachers believe that. Yet it is easy to show the error of this view, and demonstrate that such bodily exercises as gymnastics, fencing, swimming, riding, dancing, and skating, are much more exercises of the central nervous system, of the brain and spinal marrow. It is true that their movements involve a certain degree of muscular power; but we can conceive of a man with muscles like those of the Farnesian Hercules, who would yet be incompetent to stand or walk, to say nothing of his executing more complicated movements."

The arm of the blacksmith has been brought so often into play by writers and talkers on exercise, that every school-boy credits the statement that muscles grow larger, harder, and stronger when duly exercised, and become weak, flabby, and wasted if they are suffered or forced to remain inactive. It is less obvious, though it can hardly be doubted, that use and disuse work similar effects in the case of nerve cells and fibres, both sensory and motor. There is abundant evidence, though much of it is of the negative sort, to show that exercise of the muscles not only reacts upon the nerves and centres with which they are connected, in such wise as to enhance the power and ease with which they originate and transmit stimuli, but that it also leads to an increase in the size, number, and elaboration of their parts. But this evidence is chiefly to be sought in the writings of those who have made the normal and diseased conditions of the nervous system their special field of study, since text-book makers and the writers of popular articles seldom make use of the material which has been accumulated by professional physiologists, and those who devote themselves to the study and care of the idiotic, the paralyzed, and the insane.

The fact must never be lost sight of, that a single muscle is not a simple organ, but is made up of two clearly-distinguishable, though conjoined mechanisms: a contractile, executive mechanism, the muscle proper; and a stimulating, regulative mechanism, consisting of nerve-fibres and gray-matter nerve cells. Each mechanism has its bloodvessels for supplying food and drainage; and the amount of blood supplied to each is proportionate to its functional activity. If, in life, the two mechanisms become dissociated, or if either suffer from mal-nutrition, unregulated exercise, or structural depravity, the dual organ is thrown out of gear, and its working becomes disordered or abolished, in much the same way as when it is attempted to split a human being into a mental part and a bodily part, and to train the dissevered fractions to functionate as entities. Muscular movement is, then, a resultant effect, due to the balanced working of the conjoined mechanisms alluded to. The nervous mechanism is concerned in a somewhat higher kind of work than that of its muscular colleague, and may be said to represent the movements of which the latter is the seat and instrument. Between the nervous arrangement which represents the twitch of a single subcutaneous muscle, inserted into the base of a hair-follicle, and that which represents and governs the varied and rapid muscular adjustments which characterize the hand and fingers of a cunning craftsman or artist, there exists every grade of complication.

If we compare an adult man and one of the highest of the lower animals, in respect to the movements of which they are capable, we find that they possess many in common, but that man is distinguished from the brute by certain movements, such as those involved in maintaining the erect posture, and in the action of the hands and vocal organs; and that, corresponding to these two classes of movements, there are two classes of nervous mechanisms, by means of which they are represented. These mechanisms have been well termed fundamental and accessory, respectively.

Similarly, it is demonstrable that, while the human infant and adult possess many nervous mechanisms identically alike in structure and function, the adult is characterized by certain other mechanisms, whose structural peculiarities, connections, and powers have been evolved and superadded, as the result of growth and training. The law of evolution, as applied to the nervous system, is now very generally recognized by neurologists. In Ross's "Diseases of the Nervous System," this law, which was originally enunciated by Herbert Spencer, is described as "a progressive integration, both of structure and function, during which there is a passage from the uniform to the multiform, the simple to the complex, from the general to the special. The nervous system of man is, at first, similar to that possessed by all animals which possess a nervous system, or, at any rate, all those which are sufficiently elevated to possess a spinal cord; but, as development proceeds, the nervous system of man becomes gradually differentiated from that of an ever increasing number of the lower animals, while still maintaining a general likeness to the nervous system of the higher animals up to the time of birth. This, then, constitutes the fundamental portion of the nervous system of man; but after birth, the accessory portion, which, up till this time, only appears in a rudimentary condition, now undergoes progressive development. It will thus be seen that the fundamental portion is first developed, and that the super-addition of the accessory portion greatly increases the multiformity, the complexity, and the speciality of the human nervous system, and that it is the latest product of its evolution."

As might be expected, the structural elements of the nervous system follow this law. The many-branched nerve cells, having a process prolonged to form the axis-cylinder of a nerve fibre, are the most highly organized and special of nerve cells, but they begin as small, round, uniform, unbranched cells. The medullated nerve fibre made up of axis-cylinder, sheath of white substance, and outer investing membrane, is the highest form of nerve fibre. At the other end of the series stands the primitive nerve fibril, a bundle of which may be said to constitute an axis-cylinder. Among intermediate forms are axis-cylinders with no sheath whatever, axis-cylinders covered only by a sheath of white substance, and non-medullated fibres, consisting only of an axis-cylinder enclosed in a fine, thin, structureless sheath. At birth the fundamental portion of the nervous system of a human infant is characterized by the presence of branched cells and medullated fibres in contra-distinction from the rudimentary accessory portion which contains small round cells, primitive fibrils, and non-medullated fibres. Later, if all goes well, the round cells become branched, and the non-medullated fibres become medullated.

There are certain areas in the gray matter of the fore-brain of man whence proceed, it is now generally held, stimuli to the most important groups of voluntary muscles. In one of these regions are the centres which control the different groups of muscles of the upper extremity; and for the sake of simplicity we may consider that the centres of the muscles, which move the shoulder, elbow, wrist, and fingers lie near to and are connected with one another. The movements of the shoulder and elbow are fundamental and well-organized in the infant, as compared with those of the wrist and fingers which are accessory and later acquired. In order that the movements of the different segments of the fore-limb should be properly coördinated as to force, direction and degree, their motor centres must habitually discharge their stimuli in due sequence and degree. This comes only through practice. Experiments on young puppies show that their motor areas are not sufficiently developed until they are ten days old, for them to make voluntary movements with their limbs. Ferrier declares that "the degree of development and control which a puppy reaches in ten days or a fortnight, is not attained by the human infant under a year or more." The infant, through the growth and development of the appropriate accessory centres, first gains control over its foot and leg, then over its arm and hand, and later over tongue and lips. It is evident that the arms of a blacksmith, and those of a five-year-old boy, and of an infant, differ greatly as regards size, strength, and skill; but the differences which exist between them, reside in the nervous mechanisms which represent the movements of which their respective muscles are capable, rather than in the muscles themselves. Not only are the motor nerves of the blacksmith the largest, but the cells in his motor areas are also more numerous, larger, more branched and more widely connected with other cells. Exercise plays, if not the predominant, at least a very considerable part in producing this result. The effects of exercise are at once seen, if one compares the right and left arms of the average blacksmith with one another. It is well-known that the centres which control the right hand are situated in the cortex or outer layer of gray matter of certain portions of the left fore-brain: and that those which control the left hand are in the right fore-brain. Flechsig, who has made exhaustive studies as to the course and number of the motor fibres which connect the muscles of the two extremities with their respective main centres, concludes that the number of fibres going to the right hand, is to the number of fibres going to the left hand, as three to two.

The mere disuse of a muscle causes it to diminish in size. This wasting is technically termed atrophy. The most extreme forms of muscular atrophy and paralysis, are due to diseased conditions which originate in nerve centres or nerve fibres, though to the uninstructed eye the muscles would appear to be the only organs affected. Lesions in the central nervous system may cause the bones to atrophy, as well as the muscles. The development of a group of muscles of an entire limb, or of one side of the body, may be arrested by reason of certain forms of central nervous disease which occur in infancy and childhood. Observations made upon the brains of persons born with an arm or hand lacking, taken in connection with observations made on the brains of those who have had a hand or arm amputated, go to prove that the suppression or considerable diminution of certain movements brings about a condition of atrophy or arrested development, as the case may be, in those centres which would normally represent such movements. One may attain to the stature and semblance of manhood, and yet, through the arrested development of certain of his motor centres, be nothing better than an infant or a mere animal, as regards his powers of action: while paralysis and atrophy may reduce a man, stage by stage, to the condition of an untrained child, or of a helpless idiot, or even to that of a living corpse.

The functional improvement of the nervous mechanism, which represents any movement, whether it be simple or complicated, automatic or voluntary, is the most important effect of muscular exercise. It is not altogether clear just how it comes about that through trial and repetition, an action which is at first a difficult feat, becomes a pleasurable accomplishment, then a routine performance, and at last an almost instinctive act. But there is a settled conviction, among those who know most about healthy and diseased nerves, that the frequent or habitual passage of stimuli from a given group of cells through definite fibres to the muscles, concerned in a given movement, leads to some kind of rearrangement of the molecules composing the irritable protoplasm of fibres and cells, so that less and less resistance is offered to the passage of subsequent impulses from the same source. Somehow or other, the memory of past actions and the stimuli which evoked them becomes imbedded or organized in the motor centres. The principles of physical training, whatever its aim and end may be, are based upon the power of the nervous system to receive impressions and register them or their effects ; or in other words, upon its ability to memorize the part it plays in acquired movements, and on occasion to recall and revive such movements. His once too vividly impressed sensory centres cause the burnt child to dread flame: and the difficulty of interesting an old dog in new tricks, except so far as he delights to criticise and decry them, arises from the preoccupation of his centres by old impressions rather than from their increasing insusceptibility to fresh ones.

From careful studies made as to the character of the dreams of the blind, it appears that the memory of visual objects is not organized until between the fifth and seventh year of life. Persons born blind do not dream of objects in the outer world: and those who become blind, before attaining their fifth year, do not dream of objects seen by them before their loss of sight. They are blind-minded as well as blind-eyed as regards such objects. There are authentic cases recorded of persons whose memory of objects, seen before the access of their blindness, persisted for twenty, thirty, and even fifty years. Then the record of their visual impressions became effaced and they ceased to dream of objects in the outer world. The case of a man born without either hands or feet, is in point here. Although he had eyesight, he did not dream of executing hand or foot movements; yet he had sufficient use of his stumps to write what is termed a good hand. There was no record of hand or foot movements in the centres which ordinarily control such movements; so that he was unable to dream of movements which he had never executed. On the other hand, the instances are very numerous in which men, who, having lost a limb by amputation, could feel their fingers or toes while awake, and dream in sleep or when awake, of making complicated movements with their lost members. "Persons who have had an arm amputated," says Dr. Weir Mitchell, "are frequently able to will a movement of the hand, and apparently to execute it to a greater or less extent. A small number have entire and painless freedom as regards all parts of the hand." They must be blind-minded, indeed, who can deny in the face of such facts, that muscular exercise plays an important part in the development of brain power.

It is so difficult to find a true and succinct statement of the effects and value of exercise in its relation to the nervous system, that I cannot forbear quoting freely from a most admirable article by an eminent English authority, on insanity and kindred diseases, Dr. J. Crichton-Brown.

"The view hitherto taken of exercise in relation to education," he says, "has been far too narrow. The idea has been, and as far as it went, it was a correct idea, that exercise is useful in education, because it sustains and improves bodily health by expanding the lungs, quickening the circulation, shaking the viscera, and promoting growth in the muscles and bones. But we now know that besides doing all these things, exercise may be made to contribute to brain growth, and to the symmetrical development of the mental faculties. In all muscular movements there is action and reaction. When a movement is willed, a current is sent forth from the brain and the muscle contracts. But that is not all; the instant that the muscle contracts the sensory nerves take up the tale, and accurate reports are conveyed to the brain of all that is going on at the scene of action. Nerves distributed to the muscle itself, to the skin covering it, to the joint which it moves, carry back to the supreme centre precise information as to the effects of its mandate, and the information thus received is carefully registered for future guidance. For just as there is a memory of sensory impressions, of the sights we have seen and the sounds we have heard, so is there a memory of motor acts, of the movements we have performed, and of the mode in which we accomplished them. Thus the muscles not only, by the locomotion which they render possible, enormously widen the field from which our sense-impressions are gathered, but also by the experiences which their own activities involve, expand our mental resources a thousand-fold. An analysis of our ideas at once reveals to us that we have few that are of purely sensory origin; our ideas of form are not mere revived optical impressions, which are properly limited to color, but ocular impressions combined with ideal ocular movements. Our idea of a circle is a combination of an ideal colored outline with an ideal circular sweep of the eyeballs, or it may be of the tactile impressions coinciding with an ideal circumduction of the arm or hand, or perhaps both these factors, combined. And so it is with our ideas of weight, distance, and resistance, which all involve sensory and motor factors, and to revive in memory any such ideas is to revive both the sensory and motor elements of their composition, and to repeat definitely in certain nerve centres the processes which correspond with certain motor acts.

"Now the centres of motor ideation require to be exercised in order that they may be properly developed, and may contribute usefully to mental processes; and hence muscular training is likely to assume a more important and precise place in our educational systems of the future than it has hitherto done.

"These facts, that cerebral centres never properly exercised do not develop, and that, when once developed, they are not so liable to waste on the withdrawal of their appropriate stimuli, or when they are cut off from their natural activities, strongly inculcate the importance of educating every centre at its nascent period. and the danger of postponing education till the nascent period is over. A large district of the brain is made up of motor centres, and is concerned in motor ideas. The growth of that district is evidently to some extent dependent on muscular exercise, and if that is withheld, at the growth-period, the development of that district is arrested. It is not only so, but that district is made up of a series of centres in relation with different groups of muscles, and each centre is dependent for its development upon the activity of its own group of muscles; and the defective exercise of any group of muscles during the growth-period of its own particular centre (the growth-periods in most of the motor centres having different starting points) will result in the dwarfing of that centre, and a corresponding hiatus or a general weakness must exist in the whole mental fabric.

"From this, we might deduce that swaddling bands so applied at birth as to restrain all muscular movements, and kept on during infancy and childhood, would result in idiocy — a speculation to which the wretched muscular development of most idiots and imbeciles, and the fact that their mental training is most successfully begun and carried on through muscular lessons, give some countenance. We should also have to infer that, in order to build up a sound and vigorous brain, we must insure free exercise to the different groups of muscles in the order of the development of their centres, and must in no degree interfere with the natural sequence of their evolution. That being so, we must necessarily ascertain what that natural sequence is which is so important a guide to education, for, in our present ignorance of it, we may unwittingly be doing much mischief.

"Suppose that we are encroaching on the time at which hand-centres ought to receive their most valuable education — their nascent period — and are devoting that time to the cultivation of the tongue and lip centres, then we should be impairing the full development of the brain; for the hand-controlling centre, if not fully exercised at its nascent period, can never afterwards attain to the highest cunning. But it seems that not only tongue, but hand, and foot, and eye, and arm, and every muscle of the body, must be trained in due season, if education is to do what we expect of it, and result, not in headaches, and imbecilities, and nervousness, and insanity, but in well-balanced growth of body and mind.

"The differences which we notice between man and man in deportment, gait, and expression are but the outward and visible signs of individual variations in the development of the motor centres of the brain; and the stammerings, grimaces, twitchings, and antics, which are so common and annoying alike to those who suffer and those who witness them, are probably, in many instances, the effects of neglected education of some of those centres, and might have been abolished by timely drill and discipline."

It must be evident, I think, that muscular exercise deserves more attention than is usually given it, and that, when properly chosen, regulated, and guided, it not only does a man good, but makes him better; at least, it may make him a better man, in many respects, than his father was, and enable him to transmit to his progeny a veritable aptitude for better thoughts and actions. Herein lies the power of the race for self-improvement, and the evolution of a higher type of man upon the earth.

"The body of the accomplished man becomes," says Bagehot in his "Physics and Politics," "by training, different from what it once was, and different from that of the rude man; it is charged with stored virtue and acquired faculty, which come away from it unceasingly. . . . The special laws of inheritance are, indeed, yet unknown. All which is clear is that there is a tendency, a probability, greater or less, according to circumstances, but always considerable, that the descendants of cultivated parents will have, by born nervous organization, a greater aptitude for cultivation than the descendants of such as are not cultivated, and that this tendency augments, in some enhanced ratio, for many generations.

"I do not think that any who do not acquire this notion of a transmitted nerve-element will ever understand 'the connective tissue' of civilization. We have here the continuous force which binds age to age, which enables each to begin with some improvement on the last, if the last did itself improve, which makes each civilization, not a set of detached dots, but a line of color, surely enhancing shade by shade. There is, by this doctrine, a physical cause of improvement from generation to generation, and no imagination which has apprehended it can forget it; but unless you appreciate that cause in its subtle materialism; unless you see it, as it were, playing upon the nerves of men, and, age after age, making nicer music from finer chords, you cannot comprehend the principle of inheritance, either in its mystery or its power.

"These principles are quite independent of any theory as to the nature of matter or the nature of mind. They are as true upon the theory that mind acts on matter, although separate and altogether different from it, as upon the theory of Bishop Berkeley, that there it no matter, but only mind; or upon the contrary theory, that there is no mind, but only matter; or upon the yet subtler theory, now often held, that both mind and matter are different modifications of some one *tertium quid*, some hidden thing or force. All these theories admit, indeed they are but various theories to account for the fact, that what we call matter has consequences in what we call mind, and that what we call mind produces results in what we call matter; and the doctrines I quote assume only that. Our mind, in some strange way, acts on our nerves, and our nerves store up the consequences. Somehow the result, as a rule, and commonly enough, goes down to our descendants. These primitive facts all theories admit, and all of them labor to explain."