Muscular Power and Endurance of the Human Body

As Revealed by the Mechanics of Motion

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IN view of the increasing demand for information concerning the endurance of men in violent exercise of short duration, the author recently conducted experiments to see whether such a physical quality could be represented graphically so that it could be studied. Exercises were selected that bring into action practically the entire body, such as running up a steep incline, swimming, running on a level track, and by weight lifting. The first of these exercises would be represented in military functions, for example, by a charge and the last would be quite analogous to the work of "digging in." No attempt was made to determine the amount of work men can do in long periods of time such as in the eight-hour day, nor was it the purpose to estimate human power in terms of the unit, the horse-power, when effort was controlled and extended over several hours of time. The investigation was limited to a study of endurance when working continuously at the very peak of exertion as in a race or in various military operations.

To explain the procedure adopted and to bring out

Fig. 4. Work-time curve for person raising a 32.5 lb. weight from the floor to the height of reach

the significance of the results it is necessary first to outline in some detail the exact meaning of the terms work, power, energy, and speed, and to differentiate between them. First in regard to the use of work it must be thoroughly understood that the operation it expresses is independent and absolutely unconcerned with time. A host of ants marshalled into harness would by working many weeks do exactly the same amount of work in carrying a half dozen sacks of wheat, grain by grain, up to the farmer's attic as the farmer himself carrying a sack at a time. The science of mechanics defines work as the product of force into distance. This definition does not bring in the notion of time. Inasmuch as work is the product of two factors its unit of measure must indicate these factors. Thus a boy drawing his wagon up hill may exert a pull of 20 pounds. When he has pulled the wagon through a distance of 10 feet he has done 200 foot-pounds of work. A man weighing 150 pounds climbing a ladder has done 600 foot-pounds of work when he has ascended 4 feet, irrespective of whether it took him a few seconds to do this or as many hours.

While the use of the term work demands some explanation, this is still more imperative in regard to power and energy. Maurer's Technical Mechanics recognizes this need in showing the variety of uses to which the latter words are put. "In common parlance the word power has many meanings. Thus we hear of the power of a giant, power of example, power of the press, etc.; and of things mechanical, we hear such expressions as a powerful derrick, a powerful cannon, a powerful pump, etc. On reflection we note that the adjective in these three expressions probably does not refer to the same feature of the derrick, cannon and pump. A derrick is probably called powerful because it can lift a very heavy body, or exert a great lifting force. A cannon is generally called powerful because it can project a heavy shot with great velocity. A pump is probably called powerful because it can elevate or transport a large quantity of liquid in a short space of time, or perform much work per unit time." The word is here used to express three distinct ideas, in the case of the derrick it means force, in the

cannon it denotes energy, and in the pump, rate of doing work. Technical terminology restricts its use to the last idea entirely. Power is defined as the rate of doing work. To the two factors necessary to define work we must add the third, time. By extreme exertion an invalid weighing 150 pounds may climb 4 feet in 10

Figs. 1 and 2. Distance-time and speed-time curves for a person assumed to be running on a horizontal track

seconds. His power would then be $\frac{150 \times 4}{10} = 60$ foot-pounds per second. A normal man of the same weight by maximum effort may be able to do the 4 feet in 3 seconds. His power would be $\frac{150 \times 4}{3} = 200$ foot-pounds per second. The unit of power here used is the foot-pound per second. A larger unit is the horse-power

Fig. 3. The author's differentiating machine

Fig. 6. Fatigue curve traced by an ergograph, showing effect of exercise in increasing the force of the muscles

which is approximately the power of a common horse working a day and is defined as the power of the machine which does 550 foot-pounds of work in one second. The normal man climbing the ladder has $200 \div 550 = 0.364$ horse-power for the short period of 3 seconds.

As an interesting diversion to determine the horse-power a normal person exerts in ascending stairs at a rapid pace, the author conducted a few trials with persons of varying weight running upstairs from the first to the fourth floor of an office building. The time required was on the average about 14 seconds and the power for this time interval ranged from .7 to 1.2 horse-power for the different individuals.

The definition of power introduced the idea of rate, power is the time rate of doing work. Velocity, or speed when direction is of no importance, is spoken of as the time rate of displacement. It will be necessary to distinguish average speed from instantaneous speed. Thus if a boy in running covers 10 feet in the first second

Fig. 5. Power-time or endurance curve obtained from the work-time curve of Fig. 4 by differentiation

his average speed is 10 feet per second for the first second. If he covers 12 feet in the next second his average speed for the second interval is 12 feet per second and his average speed for the first two seconds is $\frac{10+12}{2} = 11$ feet per second. If he covers 14 feet in the third second his average speed during the third second is 14 feet per second and his average speed for the first three seconds is $\frac{10+12+14}{3} = 12$ feet per second, etc. The boy's speed is changing continuously as he runs, and the question naturally arises how far would the boy run during the fourth second if at the end of the third second his speed remained constant; in other words what is his instantaneous speed at the end of three seconds?

Let us attempt to find a runner's instantaneous speed at the end of the tenth second. We will need some data for this purpose which may be readily obtained. By placing persons with stop watches at uniform intervals along a running track, say at 20-foot stations and starting all watches at the instant the gun is fired and the run is begun, the time to reach each station will be obtained. This may be plotted against the distance. Such a graph is shown in Fig. 1. From this curve it will be seen that at the end of 10 seconds the distance covered is 65 feet and at the end of 20 seconds the distance is 180 feet, so that the average speed for this ten second interval is $(180-65) \div 10 = 11.5$ feet per second. It is represented geometrically in the triangle ACD by the ratio of CD to AD. In other words the average speed is given by the tangent of the angle CAD. Similarly the average speed for the interval from 10 to 15 seconds is given by the tangent of the angle BAD and is here $\frac{110-65}{5} = 9$ feet per second. Now as the time interval is taken shorter and shorter the point B approaches A and the chord AB approaches as a limiting position the tangent to the curve at A while the angle BAD approaches the angle the tangent at A makes with the horizontal, that is the angle α . But the average speed is measured by the angle the chord makes with the horizontal, and since the chord approaches the tangent as a limit as the

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time increment becomes indefinitely small, the angle between the tangent and the horizontal measures the limiting speed, that is the speed at the instant when ten seconds have elapsed. This means that if the runner has kept up exactly the same speed for the next ten seconds as he had at the end of the tenth second the distance he would cover during that interval would be given by DE.

To proceed from the given distance-time curve to the instantaneous speed-time curve shown in Fig. 2 is a simple matter. At the ten second division on the horizontal line we will erect to some scale the value of the tangent of the angle at A, at the 15 second division the value of the tangent at the angle α at B, etc. Connecting these points gives the smooth speed-time curve of Fig. 2. While this is a simple operation the labor involved is quite large. The author's differentiating machine of Fig. 3 performs the entire operation mechanically, thereby saving a great deal of time. It has for its function the plotting of the tangents without measuring the angle, performing the operation of the calculus known as differentiation.¹

One step further takes us from the speed-time curve to the power curve, for by simply multiplying velocity by force we get power. Thus if a man raises his weight against the force of gravity at a certain speed as in climbing a ladder or in running up stairs, he exerts

Fig. 7. Distance-time curves for men running up-hill a distance of 450 ft. A is the curve of an untrained man but a good runner, and B is the curve of an athlete

power; and the power a man has rather than the instantaneous force he can exert measures his effectiveness in action, that is his endurance.

To determine the endurance of the human body for work demanding primarily the use of the back, shoulder, and arm muscles an experienced weight lifter was asked to raise a 32.5 pound weight from the floor to his height of reach. The distance through which the weight was raised multiplied by 32.5 gave the work done in each lift. The time for each five lifts was read, giving all the data the work-time curve of Fig. 4. Operating upon this curve with the differentiating machine gave the curve of Fig. 5 which may be called the endurance or power curve for this particular individual in weight raising. Different weights would of course give curves varying both in height and length. The points to be noted in Fig. 5 are first that the maximum power is obtained at the start, as may be expected, and that the power decreases uniformly with time up to the end of two minutes, when the expenditure of energy had reached the point at which it was almost impossible to raise the weight another time, and being completely exhausted the man "gave up." It must be borne in mind that the weight lifting was carried on with a maximum effort throughout the test. The initial power of 127 feet-pounds per second or 0.23 horse-power is the effective or useful power, namely that of lifting the weight. The internal power, that is the power expended in lowering the weight and in raising and lowering the body should of course also go to the person's credit but it is so indeterminate that it was not considered here. Probably if these expenditures were known the maximum power developed would have been very near one-half horse-power.

The remarkable similarity between the power curve

and the ordinary fatigue tracing should be noted. Fig. 6 shows a tracing obtained by Professor Aducco² to bring out the effect of training on the strength of muscles. The tracing was made by ergograph, an instrument recording the range through which a weight is lifted by a finger. The curve is in reality also a power curve. Since the abscissae represent time and the ordinates are equally spaced, each ordinate stands for the work done during the same time interval, that is power. Like the fatigue tracing, successive power curves will indicate

Fig. 8. Speed-time curves obtained from the distance-time curves of Fig. 7 by differentiation

Fig. 9. Speed-distance or endurance curves for trained men running up-hill

Fig. 10. Speed-distance or endurance curves for untrained men running up-hill

improvement in endurance. A study of power curves taken at various times while a person is under training should present a fertile field of investigation, one that would be of great interest and importance to athletic directors and officers in charge of military training camps.

As a second measure of endurance, tests were made on men running up hill. Fifty foot intervals were marked off on a walk having a uniform grade of 10 per cent, and recorders with stop watches were stationed at each division. At a given signal all the watches were started and the runner left his mark, the time being taken at the instant the runner passed each of the stations. This data plotted gave curves of which the two in Fig. 7 are representative. A is the curve of an untrained man and B that of an athlete. Inasmuch as the walk upon which the test was conducted had an uphill grade of 10 per cent, each 100 feet passed over represents the work of lifting one's weight vertically through a distance of 10 feet. Now if the runner reaches a maximum speed of 25 feet per second he raises his weight 2.5 feet per second so that if he weighs 150 pounds his power for that speed is $\frac{150 \times 2.5}{550} = 0.68$ horse-power. Multiplying velocity in the vertical direction by weight gives the power in foot-pounds per second and dividing by 550 gives it in horse-power. Here again, this is not total power but

Fig. 11. Speed-distance or endurance curves for two men running on a horizontal track a distance of 800 feet

only what may be called external power, namely that of working against the external force of gravity. To obtain the total power we would have to add that lost internal work such as body friction, radiation, etc. By analogy it would be called internal power. Comparing the human body as a machine with the steam engine we might say that total power would correspond to indicated power in the engine, internal to friction power, and external to brake power.

The curves of Fig. 8 are the result of operating upon the distance-time curves of Fig. 7 with the differentiating machine. While the ordinates represent speed, they also represent power to some other scale as explained. Figure 8 then is a graphical record of endurance in running uphill. Two points are significant, first that the maximum power is not attained at the start as was the case in weight lifting, but in the interval from ten to twenty seconds after the start, second, that the peak once attained the power of the untrained man falls very rapidly while the trained man loses power only gradually. In a charge the soldier must possess enough energy after having reached his destination to execute his orders of attacking or "digging in." His capacity of doing this is measured by the ordinate to the power curve at the time corresponding to his supposed arrival at the destination. The psychological element enters of course, but it is not unreasonable to assume that courage is as much determined by power as power is the result of courage.

Figures 9 and 10 show the variation of power with distance. The curves were obtained by finding the speed at certain instants from the speed-time curve and the distance at the corresponding instants from the distance-time curve. B and D of Fig. 9 are the curves of trained runners, A and C of Fig. 10 the curves of untrained men. The effect of training is so obvious that explanation is unnecessary. We can readily imagine the difference in execution of which B and D are capable

¹A description of the differentiating machine will be found in the SCIENTIFIC AMERICAN SUPPLEMENT of February 12, 1916, and The American Mathematical Monthly, October, 1916.

²Fatigue by A. Mosso, translation by Margaret Drummond and W. B. Drummond, page 95

after having run 450 feet in comparison with A and C. The ideal time for action would correspond, of course, to that of maximum power, for it is at that time that the blood circulation and muscle stimulus have reached the intensity for the best effort of which the individual is capable.

In Fig. 11 are given the speed-distance curves of two men running on a horizontal circular track over a distance of 300 feet. Here again the maximum speed of the trained runner E is both greater and occurs at a later time than that of F, an untrained man, and the falling off power which is necessarily measured by speed alone is more rapid in the latter curve. In such exercise the body remains on the same level, hence no external work is done and all the energy is consumed in internal work, that is power in running in a horizontal track is entirely internal.

The endurance curves of Fig. 12 are for three men swimming various distances. They all have one characteristic in common, namely that the maximum speed or power is attained at the very start as is the case in weight lifting. The curve A is for a 100 yard dash man, B for a 200 yard swim, and C the curve of an untrained swimmer trying his time on a 60-yard swim. The preceding curves,

Fig. 12. Endurance curves for men swimming

namely the distance-time and speed-time curves were omitted because they showed nothing further than is

shown in the speed distance curves of the figure. The marked dip in B's curve at 135 yards indicates a slowing up for a short distance, possibly to catch the "second wind." A swam a crawl stroke and B and C each swam the breast stroke.

While the speed distance curves give a good graphical representation of endurance or power, the total muscular power expended cannot be accurately determined, not even in running up stairs although here most of the energy goes into raising the body against the force of gravity and thus may be measured. It seems reasonable to assume that since the maximum speed in running up hill is 25 feet per second and the speed for running on a horizontal track is only 4 feet per second more, and the power expended by a normal person in raising his weight when doing 25 feet per second up hill on a 10 per cent grade is about three-fourths horse-power, the total power in running up hill must be considerably more. A retardation of 4 feet per second enables the man to raise his weight vertically 2.5 feet per second, that is, the retardation corresponds to $\frac{3}{4}$ horse-power, so that it is not at all improbable that a good runner doing a 220 yard dash exerts himself during the run to the extent of $1\frac{1}{2}$ horse-power.

Explorations in the Hawaiian Islands

DURING last summer, Prof. A. S. Hitchcock, custodian of the section of grasses of the division of plants, U. S. National Museum, assisted by his son, A. E. Hitchcock, traveled in the Hawaiian Islands studying and collecting the flora, especially the grasses, making what might be termed a forage survey.

The islands visited were Kauai, Oahu, Lanai, Molokai, Maui, and Hawaii, these comprising all the islands of the main group except the two small ones Kahoolawe and Niihau. These islands are all of volcanic origin and composed of lava, except a very small part which is of coral formation. Kauai, geologically the oldest island, shows the greatest effect of erosion, its deep canyons rivaling the beauty of the Grand Canyon of Colorado. The rainfall on the mountains of the windward side is excessive, that of Waialeale, the highest peak of Kauai, being as much as 600 inches per annum. On the contrary, the lee side of the islands is arid, the rainfall being often reduced to less than fifteen inches per annum.

To the south the islands are successively younger, Hawaii, the largest, being even now in a state of volcanic activity. On this island are situated the two highest peaks of the group, Mauna Kea, 13,825 feet, and Mauna Loa, 13,675 feet in height. There is scarcely any vegetation upon these peaks, above 10,000 feet, especially Mauna Loa, which is made up of comparatively recent lava. Much snow covers the peaks in winter, extensive banks persisting throughout the year. The magnitude of the mountain mass is greater than at first appears, because the cones arise from the very floor of the ocean, 18,000 feet below the surface, thus making the total height over 30,000 feet. So gradual is the slope from the sea to the summit, that the eye is deceived and the great height is not at first fully appreciated. The active volcano Kilauea (4,000 feet) with its pit of boiling lava, is on Hawaii, while Healeakala, said to be the largest crater in the world, is on Maui, the second largest island of the group.

Important agricultural industries of the island include sugar, live stock, and pineapples. The native Hawaiian population is decreasing, and it is only in the less accessible parts of the islands that the primitive customs still prevail. Here may be found the native grass huts made of a wooden frame-work filled in with a thatch of grass. The grass used for this purpose is usually pili, an indigenous grass abundant upon the rocky soil of the lowlands.

The cultivated trees and shrubs are of great variety and beauty, and are drawn from all tropical and sub-tropical land. The introduced flora is very pronounced in the region of the towns, ranches, and plantations, and one must go several miles from Honolulu to find indigenous or native plants. Of 60 species of grasses found on Oahu about fifty were introduced from foreign countries. One of the introduced trees of great economic importance is the algaroba tree, or kiawe, as the Hawaiians call it. It is found in a belt on the lowlands along the shores of all the islands and occupies the soil almost to the exclusion of other plants. The pods are very nutritious and are eagerly eaten by all kinds of stock. Its flowers furnish an excellent quality of honey. The Molokai ranch alone produces 150 to 200 tons of strained honey per year. The prickly pear cactus (a species going under the name of *Opuntia tuna*) has become extensively naturalized in the dryer portions

of all the islands. Ranchmen utilize this for feed when other kinds become scarce, the cattle eating the succulent joints in spite of the thorns. Two introduced shrubs now occupying extensive areas have become great pests. These are guava, whose fruit furnishes the delicious guava jelly, and lantana, with clusters of handsome parti-colored flowers. In the moister portions of the islands large areas have been occupied by Hilo grass which has little value as a forage plant. The kukui or candlenut tree with its light, almost silvery, green foliage is now a common and rather striking element in the valleys and gorges.

The indigenous flora is highly interesting though not abundant in species. Two of the commonest trees are the ohia and koa. The former, also called ohia lehua and lehua, resembles, in the appearance of the trunk, our white oak, but bears beautiful clusters of scarlet flowers with long protruding stamens. The koa produces a valuable wood much used in cabinet making, now becoming well known through its use for making ukuleles. Characteristic of the upper forest belt on the high mountains of Hawaii is the mamani, a leguminous tree with long drooping clusters of yellow flowers and long-four-winged pods constricted between the seeds. In the arid regions is found the wiliwili, a deciduous tree with gnarled growth. Its bare branches are conspicuous, as deciduous trees are unusual in the tropics. It has very soft light wood, and bright scarlet seeds. Among the peculiar plants of the islands is the silversword, a strikingly beautiful composite with glistening silvery leaves, which grows only on the slopes of cinder cones in the crater of Haleakala and in a few very limited localities on Hawaii. The family Lobeliaceae is represented by about 100 species belonging to six genera. The numerous arborescent or tree-like species are very peculiar and characteristic. Many of them form slender trunks like small palms, crowned with a large cluster of long narrow leaves. The trunks of some species are as much as 30 or 40 feet high and the large bright-colored flowers are sometimes remarkably beautiful.

The indigenous grasses of the Hawaiian Islands are not numerous. A tall species of *Eragrostis* is the dominant grass upon the plain between Mauna Loa and Mauna Kea. Upon many of the summits of the high mountain ridges in the regions of heavy rainfall are found open bogs which support a peculiar and interesting flora. Many species form more or less hemispherical tussocks which rise above the general level of the bog. A showy lobelia with numerous large cream-colored flowers as much as three and one-half inches long, peculiar violets, and a sundew are found there. These boggy areas are devoid of trees and sometimes occupy rather extensive areas, the one on Mt. Waialeale covering several square miles.

Three species of tree ferns are found on the Islands, and in some places form extensive forests. These plants produce at the base of the stipe, a great ball of brownish-yellow wool called pulu by the natives and used by them for stuffing pillows and mattresses.

Potato Flake Process

EVEN with the best care, it is impossible to avoid the decomposition and germination of potatoes, and this generally amounts to 10 per cent, at least in Europe.

Within the last twenty years the method of preserving potatoes by a drying process has come into prominence, and especially in Germany where their consumption is considerable. It is stated that the number of plants for this purpose has now greatly increased. Dried potatoes serve mainly as food for stock, but when ground to flour, this material is even introduced into "war bread." Potatoes contain 70 to 85 per cent of water, and this must be reduced to 17 or 18 per cent in the dried product. Starch forms the main part of this dried material, or 16 to 20 per cent of the weight of the potatoes the remainder or 5 per cent being composed of various substances. In spite of many efforts, no success has been obtained in whole drying of potatoes, for a crust is formed during the operation which prevents the proper drying of the inside, and again this does not give a good industrial product. Therefore the potatoes are cut up in pieces or in thin slices and put through the drying machine. A more recent method is to reduce the potatoes to a pulp by a treatment with a jet of steam, then this paste is run between a pair of hot rolls so as to expel the water. The resulting product appears in the shape of very light flakes. The following is a summary description of a plant for treating about one ton of potatoes per hour: After passing the washer and cleaner on the ground floor, the potatoes are brought by a conveyor to the top story and stored in a hopper, and from here they pass by way of an automatic weigher into the machine proper which first reduces them to paste and then runs this between the cylinders. The upper part of the apparatus contains a boiling tank in which the potatoes are treated with exhaust steam from the engine, then they drop into the reducing chamber where sets of paddle wheels or rather cylinders crush up the mass and form the pulp or paste. Without leaving the machine, the paste runs vertically between two large heated cylinders, and the dried and flaky substance coming through is scraped off the cylinders by suitable means. It falls to the bottom of the machine containing a breaker, from whence a pneumatic conveyor takes the small flakes to the storage bins. The paste is not absolutely flattened between the cylinders, for these are mounted some 0.06 inch apart, and before going through, a thin layer of paste has been already formed on the cylinders by suitable scrapers placed at the top and a well-combined feeding device. Great regularity is required in the feed and in the spacing of the cylinders, for if the layer is not of uniform thickness, the thin points become over-dried and take a brownish color. This, however, can be avoided by proper precautions. Steam to the amount of 80 lbs. per 100 lbs. of potatoes is usually employed for heating the rolls, and it is preferable to use live steam from the boilers, and a good economy of steam for the whole process has been secured in this apparatus. The flakes coming from the present process form a very light material which is not easy to put up in sacks, so that it requires to be put under press, using generally the type of press employed for treating hops and the like, or again, a screw press such as is used in sugar-making for pressing beet slices. In this way the flakes are reduced to a smaller mass and are usually put up in 125-lb. sacks. That the system of potato drying has now entered into real industrial practice in Germany, will be seen from the fact that the product from the whole number of plants for the year 1916 amounted to no less than 4,000,000 tons.