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ON THE LABOURING FORCE OF THE HUMAN HEART

THERE is no organ in our bodies that has a more important influence upon health, at all ages of our lives, than the heart, whose rhythm and force are governed by laws of nerve-force, of which we are at present almost totally ignorant. Regarded, however, from a mechanical point of view, as a hydraulic pumping machine, our knowledge of the heart is more accurate, and may yet lead the way to greater knowledge of the physiological action of this vital organ.

I propose, in the present communication, to give an estimate of the daily labouring force of the human heart, and to compare it with that of other muscles, such as those used in rowing or climbing, reserving for a future communication the proof of the data to be now employed.

The heart, regarded as a pumping machine, consists of two muscular bags (*ventricles*), one of which drives the blood through the lungs, and the other through the entire body. This blood is forced, by a pumping action, repeated seventy-five times each minute, through both lungs and body, and experiences in each case a resistance which is measured by the hydrostatical pressure of the blood in the pulmonary artery and aorta. The resistance offered to the circulation of the blood, by the capillary vessels of the lungs and body, is different; but the total quantity of blood that passes through the lungs and body in a given time, must be the same; from which it follows, that the resistance offered by the capillaries must be in the proportion of the hydrostatical pressure in the great arteries leading from the ventricles of the heart. If, therefore we knew that pressure for one side of the heart, and the relative forces of the two ventricles in contracting, we should know the entire resistance overcome by the heart at each of its beats.

If, in addition to the hydrostatical pressure in one ventricle, and its ratio to that in the other ventricle, we knew also the quantity of blood forced out of each ventricle against this pressure, we should have all the elements necessary to calculate the labouring force of the heart, as will be presently shown.

I demand, therefore, that my reader shall grant me, provisionally, the following postulates, which are necessarily three in number :—

I. That three ounces of blood are driven from each ventricle at each stroke of the heart.

II. That the hydrostatical pressure in the left ventricle and aorta, against which the blood is forced out, amounts to a column of blood 9·923 feet in vertical height.

III. That the muscular force of the left ventricle, in contracting, bears to that of the right ventricle the proportion of 13 to 5.

With these postulates granted, we may now proceed to calculate the daily labouring force of the heart as follows. At every stroke of the heart, three ounces of blood are forced out of the left ventricle against a pressure of a column of blood 9·923 feet in height. The work done, therefore, at each stroke is equivalent to lifting three ounces through 9·923 feet. This work is repeated 75 times in each minute, and there are 60×24 minutes in the day. Hence, the daily work of the left ventricle of the human heart is $3 \times 9{\cdot}923 \times 75 \times 60 \times 24$ ounces lifted through one foot; or, since there are 16 ounces in the pound, and 2,240lbs. in the ton, the work done by the left ventricle of the heart in one day is $\frac{3 \times 9{\cdot}923 \times 75 \times 60 \times 24}{16 \times 2{,}240}$ tons lifted through one foot. Multiplying and dividing out this quantity, we find the daily work of the left ventricle is 89·706 foot-tons. The work done by the right ventricle is five-thirteenths of this quantity (post. III.); the daily work of the right ventricle is therefore 34·502 foot-tons. Adding these two quantities together, we find for the total daily work of the human heart 124·208 tons lifted through one foot.

It is not easy for persons unaccustomed to these calculations to appreciate quickly the enormous amount of labouring force denoted by the preceding result; but in order to facilitate this appreciation, I shall compare it with the following descriptions of labour :—

1. The daily labour of a working man.
2. The work done by an oarsman in an eight-oar boat-race.
3. The work done by locomotive engines, or animals climbing a height.

1. The daily labour of a working man, deduced from various kinds of labour, from observations spread over many months, is found to be equivalent to 354 tons lifted through one foot, during the ten hours that usually constitute the day's work. This amount of work is less than three times the work done by a single heart, beating day and night for 24 hours: thus, three old women sitting beside the fire, alternately spinning and sleeping, do more work, by the constant beating of their hearts, than can be done in a day by the youngest and strongest "navvy."

2. If an Oxford eight-oar boat be propelled through the water at the rate of one knot in seven minutes, the resistance offered by the water may be estimated at 81·36 lbs. by calculation, or at 74·15 lbs. by actual observation. From this result, and from the fact that 575 ounces of muscle are employed by each of the eight oarsmen, we can calculate that 15 foot-pounds of work are expended by each ounce of muscle during each minute of work.

No labour that we can undertake is regarded as more severe than that of the muscles employed during a boat-race; and yet this labour, severe as it is, is only three-fourths of that exerted day and night during life by each of our hearts.

The average weight of the human heart, which increases with age (for obvious reasons), may be estimated from the following tables :—

	Average oz.
1. Meckel	10·0
2. Cruveilhier	7·5
3. Bouilland	8·4
4. Lobstein	9·5
5. Boyd (æt. 30—40)	10·4
6. Boyd (æt. 40—50)	10·5
Mean	9·39

From this weight, and the work done by the heart in one day (124 foot-tons), we can calculate the work done by each ounce of the heart in one minute, as follows :—

Work done by the human heart, in foot-pounds per ounce per minute, $\frac{124{\cdot}208 \times 2240}{9{\cdot}39 \times 24 \times 60} = 20{\cdot}576$ foot-pounds.

This amount of work exceeds the work done by the muscles during a boat-race (as already stated) in the proportion of 20 to 15, or of 4 to 3.

3. There is yet another mode of stating the wonderful energy of the human heart. Let us suppose that the heart expends its entire force in lifting its own weight vertically; then the total height through which it could lift itself in one hour is thus found, by reducing the daily work done in foot-tons (124·208) to the hourly work done in foot-ounces, and dividing the result by the weight of the heart in ounces:—

Height through which the human heart could raise its own weight in one hour $= \frac{124 \cdot 208 \times 2240 \times 16}{24 \times 9 \cdot 39} = 19754$ ft.

An active pedestrian can climb from Zermatt to the top of Mont Rosa, 9,000 feet, in nine hours; or can lift his own body at the rate of 1,000 feet per hour, which is only one-twentieth part of the energy of the heart.

When the railway was constructed from Trieste to Vienna, a prize was offered for the locomotive Alp engine that could lift its own weight through the greatest height in one hour. The prize locomotive was the "Bavaria," which lifted herself through 2,700 feet in one hour; the greatest feat as yet accomplished on steep gradients. This result, remarkable as it is, reaches only one-eighth part of the energy of the human heart.

From whatever mechanical point of view, therefore, we regard the human heart, it is entitled to be considered as the most wonderful mechanism we are acquainted with. Its energy equals one-third of the total daily force of all the muscles of a strong man; it exceeds by one-third the labour of the muscles in a boat-race, estimated by equal weights of muscle; and it is twenty times the force of the muscles used in climbing, and eight times the force of the most powerful engine invented as yet by the art of man.

No reflecting mind can avoid recognising in its perfection, and regarding with reverential awe, the Divine skill that has constructed it.

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THE SCIENCE OF LANGUAGE

Darwinism tested by the Science of Language. Translated from the German of Professor August Schleicher, by Dr. Alex. V. W. Bikkers. (London: J. C. Hotten, 1869.)

IT is not very creditable to the students of the Science of Language that there should have been among them so much wrangling as to whether that science is to be treated as one of the natural or as one of the historical sciences. They, if any one, ought to have seen that they were playing with language, or rather that language was playing with them, and that unless a proper definition is first given of what is meant by nature and by natural science, the pleading for and against the admission of the science of language to the circle of the natural sciences may be carried on *ad infinitum*. It is, of course, open to anybody so to define the meaning of nature as to exclude human nature, and so to narrow the sphere of the natural sciences as to leave no place for the science of language. It is possible also so to interpret the meaning of growth that it becomes inapplicable alike to the gradual formation of the earth's crust, and to the slow accumulation of the *humus* of language. Let the definitions of these terms be plainly laid down, and the controversy, if it will not cease at once, will at all events become more fruitful. It will then turn on the legitimate definition of such terms as nature and mind, necessity and free-will, and it will have to be determined by philosophers rather than by scholars.

Unless appearances deceive us, it is not the tendency of modern philosophy to isolate human nature and to separate it by impassable barriers from nature at large, but rather to discover the bridges which lead from one bank to the other, and to lay bare the hidden foundations which, deep beneath the surface, connect the two opposite shores. It is, in fact, easy to see that the old mediæval discussions on necessity and free-will are turning up again in our own time, though slightly disguised, in the discussions on the proper place which man holds in the realm of nature; nay, that the same antinomies have been at the root of the controversy from the days when Greek philosophers maintained that language existed either φύσει or θέσει, to our own days, when scholars range themselves in two hostile camps, claiming for the Science of Language a place either among the physical or the historical branches of knowledge.

It is by supplying a new point of view for the consideration of these world-old problems, that Darwin's book "On the Origin of Species" has exercised an influence far beyond the sphere for which it was originally intended. The two technical terms of "Natural Selection" and "Struggle for Life," which are in reality but two aspects of the same process, are the very categories which were wanted to enable us to grasp by one effort of thought the reciprocal action of the one on the many and of the many on the one; the mutual dependence of individuals, species, and genus; or, from another point of view, the inevitable limitation of spontaneous action by the controlling influences of social life. I may be allowed to repeat what I said on a former occasion:—"Who has thought about the changes which are brought about, apparently by the exertions of individuals, but for the accomplishment of which, nevertheless, individual exertions would seem to be totally unavailing, without feeling the want of a word—that is to say, in reality, of an idea—to comprehend the influence of individuals on the world at large, and of the world at large on individuals; an idea that should explain the failure of Huss in reforming the Church, and the success of Luther; the defeat of Pitt in carrying parliamentary reform, and the success of Russell? How are we to express that historical process in which the individual seems to be a free agent, and yet is the slave of the masses whom he wants to influence; in which the masses seem irresistible, and are yet swayed by the pen of an unknown writer? Or, to descend to smaller matters, how does a poet become popular? How does a new style of art or architecture prevail? How, again, does fashion change?—how does what seemed absurd last year become recognised in this, and what is admired in this become ridiculous in the next season? Or take language itself. How is it that a new word, such as 'to shunt,' or a new pronunciation, such as '*gold*' instead of '*goold*,' is sometimes accepted, while at other times the last words newly coined or newly revived by our best writers are completely ignored or fall dead? We want an idea that is to exclude caprice as well as necessity—that