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Haughton's principles of animal mechanics.

Longman & Co 1873

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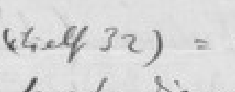
Principles of Animal Mechanics
by Rev Samuel Haughton FRS. MD. Longman 1873 f 28

Preface. It is the work of leisure hours during 10 years
I have met numerous instances in muscular mechanism of the principle of least action — the work is done with a less expenditure of force than by any other possible arrangement: — probable that this fact is of much wider occurrence & if so it shows some of the mechanism by which the conservation of species is insured.

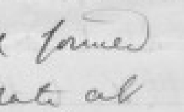
1. Elementary muscular fibres all of them extend whole length of muscle even up to 2 feet — Diameter in humans about $\frac{1}{350}$ inch varies 3 fold.
(So that there are 350^2 = 35 35 175 105 122500 in a square inch = a million in 8 square inches)
There are 3/4 million in the 2 muscles which hold the forearm flexed at right ∠s viz biceps & brach: anticus. The fibres are polygonal with blood vessels at the angles. The fibre is contained in a sheath & bundles of fibres in a sheath
3. lubricated with fat
Striped muscles are not the voluntary, the heart is striped. They are those with fixed attachments & a strain straight between, in close sphincters. He thinks they are due to same cause as cleavage planes ⊥ to line of pressure (!! This is ? due to flattening out air bubbles of the softer parts) The vermicular acting muscles are unstriped). Fibres are also divided into fibrillae
5 Nature of contraction — no change of volume, the fibres shorten & thicken, it is accompanied among other things, by a loss of statical electricity, and a discharge of the opposite electricities of the outer & inner portions of the muscular bundles & fresh blood must be admitted to restore the
7 tension & to relax the contraction (rigor mortis), and convulsion in animals before death
8. Hanging. He omits the factor due to the resistance to fracture being as the cross section of the vertebra & therefore as the $(\text{weight})^{\frac{2}{3}}$.
14. Nature of muscular contraction is wave like. a wave of tension passes through it. Each particle contracts for an instant of time & then transmits the contracted phase to the next particle (? when rigor mortis are not all the particles simultaneously contracted) so that the entire muscle is never contracted together. Rate of wave of contraction in a frog is only 3 feet a second but that of action of its motor nerves is 88 ft & of sensation of man 97. Personal equations

15 Though personal equation & therefore velocity of wave varies, it is probable that each particle of nerve or muscle takes the same time in going through its own phase, the variation lying in the difference of interval between consecutive particles going through their phases. In softening of the brain we see how the personal equation changes. but a large part of this is due to blood action in the brain itself (? have no experiments been
16 made) – Whatever the rate of ~~muscular contraction~~ wave motion may be the susurrus gives the time of molecular vibrations viz the t in the usual wave formula $\lambda = vt$. – Wollaston first called attention to the susurrus. put a finger gently in the ear & forcibly contracted the muscles of the hand & forearm. – the sound, he says, like the sound of carriages at a great distance passing over a pavement. (h.e. the granite blocks are 4 inches long & a cab driving eight miles an hour would produce
17 35 impulses a second) Haughton tried many experiments & finds
20 it from 35 to 30 vibrations a second. The tinnitus aurium in his case was 5 octaves above or 32 times as fast in vibration as the muscle itself 32) = 1024 a second. It is the sound of a well formed hand bell 4 inches diameter. He thinks it ~~is~~ a sign of the rate at which nervous action goes on in the brain (? is it not primarily due to
21 congested blood vessels in the ear) Dr Collongues arrived at similar results & invented a "biometre" of which a description is
23 given – In a case of paralysis agitans the susurrus was only
24 4 beats per sec: & in another only 4 – By fatigue, it is lowered. It exists after tetanus death & is said in amputated limbs

Statical work done by muscles in contraction. W = weight ~~[illegible]~~ held in hand
a = " of arm



α length of arm



t time till fatigue completely exhausts "

x = distance of centre of gravity from shoulder
θ = ∠ through which the arm would move in time t "
ω = unknown angular velocity (uniform)

$(W+a)\,x\,\theta$ = total work done; but $(W+a)\,x = \alpha\left(W+\frac{a}{2}\right)$ & ~~[illegible]~~ $\theta = \omega t$

Hence total work $= \omega\alpha\left(W+\frac{a}{2}\right)t$

(1.) $W=0$, work done = 3350 ft lbs in 507 secs
(2.) $W = 2$ lbs, " = 2354 " 224

He had reason to believe that total work before exhaustion varies inversely as rate of work
or as ~~total work / t~~ rate of work $= \frac{\text{total work}}{t}$ i.e. total work $= C \times \frac{t}{\text{total work}}$
or $\frac{(\text{total work})^2}{t} = C$

28 Calculating from this (1) : (2) :: 1 : 1.11.
which is very fair.

28 & 29 $\left(\frac{\text{Total work}}{t}\right)^2 = C$ or Work × Rate of work = C

the second is an hyperbola referred to its asymptotes as axes of coordinates
first — parabola — as tangent & diameter " "

thus a man walking at the usual rate can walk 30 miles before he is tired
If he walks twice as fast he will be tired in 15 miles ~~rated~~ ~~[illegible]~~ & in 1/4 the original time

let t = 8 hrs $\left(\frac{30}{8}\right)^2 = C$ $C = \frac{900}{8} = 115$. $\frac{15}{2}$ ... $= \frac{1}{2}$

$\frac{W^2}{t} = 115 \cdot t$

let W = 15 ... $W = (\frac{1}{2} \cdot 30)^2$ ... $t = \frac{900}{4 \times 115} = \frac{1}{2}$

Hence if you double the work the man must take 4 times the time to do it (? Sleep)

30. In order to find weight of muscle that gives out definite work one must proceed indirectly (can't cut up living people). It comes

32 out that the weight of muscles to hold unloaded arms horizontally is 45 lbs. and assumes

$w\alpha(w + \frac{a}{2})t$ = total work & that $w = 1$ the work per ounce of unloaded arms per sec. = 1.46 ft lbs

of loaded = 2.3 ft. lbs.

34 similar experiment on the muscles which keep the forearm flexed to the arm & loaded with a weight of 8 or 9 lbs. work per ounce per sec was 1.028 ft lbs

37 First attempt to calculate a formula for law of Fatigue, based on periodicity of muscular action as proved by intervals. If all the muscle contracted simultaneously there would be 32 contractions & relaxations per sec.

He concludes that the action is identical as if the arm fell freely

39 for 1/32nd of a second & was then raised. He gets $t = \frac{A(3w + a)^2}{(2w + a)^4}$

This gives results closely correct for Mr S. Jevons experiments but imperfect

42 for certain cases. Any curve of a hyperbolic form will coincide with experiments. He gets then total work $= w\alpha(w + \frac{a}{2})t$

rate $= w\alpha(w + \frac{a}{2})$

by law of fatigue the product of these is constant or $w^2\alpha^2(w + \frac{a}{2})^2 t$ = constant

or $(w + \frac{a}{2})^2 t = A$.

43 This is a cubical hyperbola whose asymptotes are $t = 0$ & $w + \frac{a}{2} = 0$

t becomes zero when w is ∞ & t has no maximum between 0 & +∞

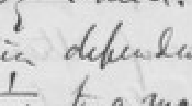
44. To find relation between useful work done & w

useful work = wt substituting for t $u = \frac{Aw}{(w + \frac{a}{2})^2}$ a cuspidal cubic

whence it will be shewn (p.), that u is a maximum when $w = \frac{a}{2}$

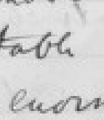
(in which case $u = \frac{A \cdot \frac{a}{2}}{(\frac{a}{2} + \frac{a}{2})^2} = \frac{A}{4}$)

44 Dynamical work of muscles alternately contracted & relaxed.
To find weight of muscles he dissects & concludes that 50 per cent should be added to those of even the best selected subjects to bring them to a life standard.
Calculates work in an Oars race (not directly by a dynamometer, but going full speed, but indirectly & finds work done per man per race: ~~[illegible]~~ = nearly 4 foot tons — this is 4 times the rate of a hard worked labourer, who in 10 hours gets through 400 ft tons — the rate per ounce of muscle per minute = 15.14 ft lbs (that is per oz per sec 0.25 ft lbs.
44. total muscles of a dead man upper & lower limbs 575 oz to which 50 per cent is to be added
52 see p. 32) Other experiments give per ounce of muscle per minute in climbing 7.38, in mountaineering 5.43
53. Mechanism of walking — is simply the work of lifting the man's weight through the height to which his body is lifted at the commencement of each step (? if this is correct. Much effort goes in horizontal thrust.) — now vertical elevation is found to be 1.248 inch of the centre of gravity when step is 28 inches.
$\therefore \frac{\text{vertical elevation}}{\text{Horizontal transport}} = \frac{1.248}{28.000} = \frac{1}{23}$
or a man walking 23 miles along a horizontal road has done as much work as if he had raised his body 1 mile.
55. Another method of calculation dependent on the slope of the body when walking & then given a ratio of $\frac{1}{20}$ for a man walking 3 miles per hour.
58. Useful work Daily of Dublin hodman 181 ft tons fatigue work his own weight up. Total 182 | 363
Paviours — 352
Box lift in Capt Coignet's plan — 404
62 average 353 foot tons per day (10 hrs) = 2.29 ft lbs per oz of muscle per minute
(he used 575 for weight of muscles instead of 575 + 287 (see p 44) = 861
61. Horizontal transport = 20.65 as much (from p. 55 & 53) this gives similar results
62. All collected in one table Statical & Dynamical work of muscles.
The rate of work in ft lbs per oz of muscle per minute varies greatly. The limits of figures i.e. Statical is 32, 46, 41 is Dynamical 15 boat race, 7 goat, 35 horizontal road walk, 2 day labourer
(here the climbing Monte Rosa p 52 neglects the walking which certainly covers ? miles) —
63 Absolute force of muscles.



moment = (39+2) . 12½ = 502
$\therefore$ muscular force = (   ) = 5.3 K   cross sections are given Biceps 1.9 Brach 1.2
where K is the coeff^t of muscular force per Sq. inch Section $\therefore$ K = 94.7 lbs per sq inch
Donders & Mansfeld give much smaller cross section & 2. a larger value for K

65. Flexors of the leg make K = 110. lbs.
69. mean value for leg & arm K = 102. lbs
as there are 798.000 muscular fibres in biceps &c., the force of contraction (maximum) of a single fibre is 2.87 grains
70. Other observers (Henke & Koster) give a mean for K of 123 lbs
He thinks this is due to their having used sections of muscles in ordinary corpses whereas he took a man who had quickly died of cholera. allowing for this he reduces their K to 95 lbs
It must be recollected that under excitement for a short time K may much increased
72. Force of frogs gastrocnemius is given (not reduced to section again)
73. Borelli's observations (de motu animalium Rome 1680 2 vols 4to)
74. His observations recomputed.
Comparative anatomy of tendons of hand & foot.
75. The cross sections of the tendons must be proportional to strength of muscles on principle of economy of material. whether by doctrine of a final cause, or Lamarckian (this is a further assumption) outsider. p76. human 80, 81, dog different

83. 

(F is friction) P = Pl+F or Pl-F according as a force at P overcomes Pl or vice versa
So a tendon must be stronger than the muscle by the force of the friction
87. a table is given of 14 muscles & their tendons (the ratio varies enormously – it is incredible that the friction sh^d be as great as here ~~represented~~ calculated up to 70 per cent.) The cross section of muscle to tendon is as 28 : 1
90. Similar table for mastiff. friction here mounts to 81 per cent
91. Some doubt thrown upon the hypothesis p75. there is often surplus strength 92 This occasionally strain reappears as heat & so helps to keep up the animal heat (?!!)
93 Monkeys feet.
95 Carnivores feet. – 97 Dog, 100 Otter, 101 Bear
102 Comparative table of friction of long flexor tendons in Carnivores by calculation as before (However experiments to find what it really is)
103 Ungulates. 107 Insectivores &c. 113 Birds
118. a larger comparative table (most irregular) the
120 Summary. The tendons of the toes exceed the tendons of the

muscles in 30 instances out of 34 because in the foot the force is applied from below upwards (? in leaping) to the muscles through the tendons — In the hand vice versa

.120 Flexor tendons of the hand

.121 Man — appropriation of the forefoot to the use of the brain
Curious that in the apes that most resemble man the differentiation of the action of the thumb is most imperfect. Chimpanzee & Gorilla & Orang

122. Startling exceptions in muscles of thumb in men

123 monkeys 124 carnivores, goat which a tiger, his strength required 8 men to hold him 129 dogs — ~~bears ungulates~~.

132 in all these the cross section of the tendons of the fingers is less than that of the common tendon about wrist. — In the ungulates they are equal

134 Comparative table & calculated friction

135 Long ramble explaining what has already been explained about hand & foot

137. Mechanical work done by human heart.

Contents of its left ventricle 3oz. Donders makes it double & more 4.4 oz.

Q = weight of blood expelled from left ventricle at each beat

h = height of column equal to compression of blood in vessels
that is maximum pressure inside the ventricle at moment of contraction

$Q \times h$ = work done

138. To find h.. Hales put a tube into the arteries of different animals in horse h = 8 feet in wether h in dog h — But, a cut carotid of a mare does not spout higher than 2 feet (difficult to understand why)
5ft

139. A man is operated on, his artery squirts to just above the same as a horse's (see above) 2.5 feet. Hence concludes h of man same as of horse.

141. A roundabout way of arriving at ~~haemostatical~~ relative capillary coefficient, with a big assumption. Then p 144 he reasons backwards assuming ~~haemostatical~~ capillary coeff pressure in man & horse to be the same he shews the haemostatical pressure to be the same.

On these data he calculates daily work done by heart, both ventricles = 124.[redacted] ft tons. Its weight is 9 oz. its work per oz per minute = 20. ft lbs. this exceeds rate of muscles in boat race (15 lb)

(Helmholtz comes to similar conclusion)

146 It would lift its own weight 19700 feet in one hour. The legs of an active climber can only raise his own body 1000 feet in 1 hour. (quite wrong)

147. Bridge locomotive lifted itself 2700 ft in 1 hour.
Prof Donders makes more than double this estimate, due no doubt to his large estimate of contents of heart.

150 Assuming weight of blood in body at 10 lbs & 75 beats per minute it all passes through heart in 42 seconds.
Injection of iodine in a tumour tested in urine after less than 4 min.

151. Muscular force in parturition.

Lagrange's theorem  T = tensile strain acting tangentially in membrane applied to rupture a band of the membrane 1 inch broad. P denotes all the other forces due to pressure in action perpendic: to surf: of membrane and acting on 1 sq inch surface, ρ_1 & ρ_2 the two radii of principal curvature at the point in question

then $P = T\left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right)$ where a sphere it becomes $T\left(\frac{2}{\rho}\right)$

Extent of uterus supposing it a prolate ellipsoid 12 inches by 8 inch
Mean curvature of uterus call it a sphere = 9 inches
Volume = 402 cubic inches. Surface 278 sq inches.

Weight of muscular fibres 1.5 lb which if of uniform thickness would [be] 0.15 inch, a muscular ribbon 1 inch wide of this thickness (see p. 69) would be capable of lifting [struck] 15 lbs (which is T above)
& $P = \frac{2T}{\rho}$ & ρ is 9 inches. therefore max. hydrostatical pressure is 3.4 lbs
Duncan experimentally finds maximum pressure required to rupture the membranes is 3.10 lbs & least 0.26 lbs. Hence uterine muscles can always rupture them. These muscles weigh only 1½ oz in virgin uterus & therefore

154 increase 16 fold during pregnancy. — Teleological remarks.

157 A pressure of 3.4 lbs per square inch acting on cross section of pelvic canal 4½ inch diameter = 54 lbs. It takes at a maximum 110 lbs to pull a child with forceps out of a dead body Duncan thinks 80 lbs the maximum

158. Teleological (abundantly) Beer & wax

159 Abdominal muscles in aid — Their total thickness is 0.8 inch in a dead body giving a tensile strain of T = 133 lbs. Diameter of longitu: curv: = 22 inch of transverse 12,

5 f5v

162 $\frac{1}{\rho_1}+\frac{1}{\rho_2}=\frac{1}{4\rho}$ which × the 133 lbs = 39 lbs hydrostatic pressure per sq: inch or 523 lbs on cross section of pelvic canal. 54 + 523 = 577 or more than a quarter of a ton pressure on the head of a refracting child.

163 Corroborative trials of two queens placing a loaded disc of 1½ in diam on their navel. Here P came out 38 lbs per sq inch. (? is the experiment fair)

Reflexion on use of chloroform

164 Classification of muscles:

in same plane { fibres parallel & rectilinear; " not parallel & rectilinear; " sphincters 197

bearing curved surfaces { " rectilinear. skew p. 230; " ellipsoidal (first described) p. 210

165. f = contractile force of each fibre, n = their number, total force F = nf (parallel fibres) the resultant of will pass through the centres of gravity  of areas of cross section of the muscle

166  F = nf acting in line ab = nf. sin φ (draw the origins together)

167 Penniform is 2 rhomboidal combined. F total force of each rhomboid R = 2F sin φ

(the puts cos φ having now changed the meaning of φ to 90 − φ)

BX is shortened by δl & X moves to x. Draw xp ⊥r, xp = δl

the X moves through Xx, is through δl sec φ

R = 2F cos φ or R   R·Xx = 2 F cos φ sec φ δl = 2F δl

Since 2F.δl is the force inherent in the muscular fibres if arranged prismatically, we conclude there is neither gain nor loss of work due to the penniform arrangement

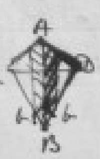
169  contraction is that of an ordinary biceps whose length is = l sec φ

the actual length of the penniform muscle may be great but it produces the same short strong pull. (stronger according to its length)

171 in above diagram AD represent no. of musc: fibres on one side. hence total force at each side is F = nf = AD × f = AB. sin φ. f.

but R = 2 F. cos φ = 2 AB. f. sin φ. cos φ = AB. f. sin 2φ

∝ f. AB. sin CBD.



that is a prismatic muscle of ~~length~~ cross section CD

AB. sin φ = AD   AD. cos φ = DE ∴ AB sin φ. cos φ = DE & 2AB sin φ cos φ = CD

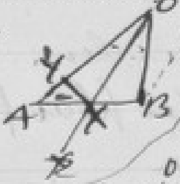
∴ width of Penniform = 2l. sin φ : width equivalent :: bb : CD :: 2l. sin φ :: 2AB. sin φ. cos φ :: l : AB cos φ

width of equivalent = $\frac{\text{width of Penniform}}{\text{length of equivalent} \times \cos\phi}$

174. Comparative table of Biceps & Brachialis (big d[iff] in cross section! (width))

177 Big action of horse due to biceps
Floor of mouth, a penniform muscle

178 Triangular muscles. origin a point & the insertion of the fibres a ~~straight~~ line. The resultant OX bisects AOB. & point X can easily be found since $AX : XB = AO : OB$



For finding AOC making $OC = OB$ ... $OBC + OCB = AOX + XOB$ ...

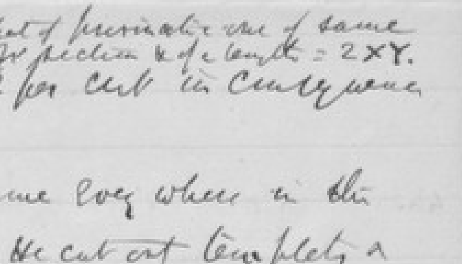
181. Work done by any Δ muscle = work done by a prismatic muscle having the same cross section

and a length = to $\perp^r$ (XY) dropped on the side AB.

183. Work inherent in a Δ muscle
" Work done by a Δ muscle = to that of prismatic one of same cross section & of a length = 2XY.

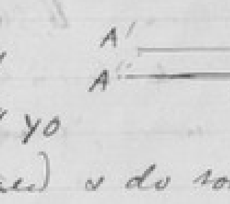
184. In biceps femoris of Lion, loss of 12 per cent in consequence of triangular arrangements
He finds in Buzzard cross section is same every where in the (triangular) pectoral muscle. — Also Heron — He cut out templets & weighs them — Also man

187. There is always a loss of work done in a triangular muscle & in this respect they differ remarkably from penniform



189 In moving AB to A'B' in line YO, if Ox Oy be taken equal & so that xy is ∥ YO
then all fibres to left to xy are shortened & do some work, but none to their full amount & all to right of xy are lengthened & do no work at all, Ox does no work either

190 If the base of insertion be circular, & vertex the centre of the circle



then $\frac{\text{work done}}{\text{inherent work}} = \frac{\sin\theta}{\theta}$
The pectoral of man nearly fulfills these conditions & $2\theta = 90$ whence above Equation becomes $\frac{2\sqrt{2}}{\pi} = 0.90$
or 10 per cent of the work is lost. — It must be considerable
Latissimus dorsi only 2 per cent.
In the temporal of man which has an elliptical insertion

Iris gives maximum loss, it being a circle & semicircle $\frac{\sin\theta}{\theta} = \frac{2}{\pi} = 0.636$ or a loss of 36 per cent.

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192. Deltoid.  trapezius an excellent example is a junction of 2 triangular muscles. consequently loss of work. In trapezius it is 23 per cent

In pectoral muscles of rodents a loss of 34 per cent

194. Sphincters.

209. Muscular fibres forming curved surface. nothing said about its least action

232 Plane surfaces. △

(XY) ⊥

least work. insertion of muscles

Heart. = △

442. Work done in contracting is proportional to the weight of the muscles.

Haughton about the heart which works harder all day & night than a boat crew

444. Law of constancy of work. — men his curves, (greatest work) does not coincide with Jevons results. By the latter, more useful work is done by throwing a lb 28 weight than a lb 56. 103.4 in the former 103.04 in the latter it is obvious that there is a minimum of useful work when weight is too heavy to be moved, which occurs without the weight being infinite.

450. Law of fatigue Total work done × rate of work is constant. If so, a

~~man who can walk 8 miles ... [illegible]~~ it is the same as 8 miles

man who can walk 8 miles a day without fatigue at the rate of 3 miles per hour would with equal ease walk 24 miles in 24 hours

28 walk for ever. which beats Barclay of Ury's 1000 miles in 1000 hours all [illegible]

478. Law of refreshment.