On the rhythm of the sounds of the heart / by F. C. Donders, M.D. ; translated from the "Nederlandsch Archief voor Genees en Natuurkunde," Utrecht, 1865, by William Daniel Moore, M.D.

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On the Rhythm of the Sounds of the Heart. By F. C. Donders, M.D., F.R.S.; Professor of Physiology and Ophthalmology in the University of Utrecht. Translated from the "Nederlandsch Archief voor Genees en Natuurkunde," Utrecht, 1865. By William Daniel Moore, M.D., Dub. et Cantab., M.R.I.A., L.K.Q.C.P.I., Honorary Fellow of the Swedish Society of Physicians, of the Norwegian Medical Society, and of the Royal Medical Society of Copenhagen; Secretary for Sweden, Norway, and Denmark, to the Epidemiological Society of London.

I. *Introduction.*—The sounds of the heart are distinguished as first, I; and as second, II. The first begins nearly with the impulse and continues until the second falls in as a short stroke; hereupon follows the pause, which is terminated by the first sound of the following period.

The distance between the commencement of I and that of II we call α that between II and I, A. Thus the duration of one period is $P = \alpha + A$.

P is known by the frequency of the impulses. If we now determine α or A, we know both, and therefore at the same time $\alpha : A$ and $\alpha : P$. This includes the knowledge of the rhythm of the heart.

Respecting the rhythm, little is to be met with in literature.

Laennec[a], the founder of the science of auscultation, described the sounds very well, but said nothing directly about the rhythm. It would appear, however, that he did not consider α to be much less than A. He had, as we know, an incorrect idea of the sequence in the action of the heart, and when he says: "Sur la durée totale du temps dans lequel se suivent les contractions successives des diverses parties du cœur.......*la moitié ou à peu près* est remplie par la systole des ventricules," this means that I and II lie at little less than half a period from each other.

The only person, so far as I know, who has endeavoured experimentally to solve the question is Volkmann[b]. His method consisted in regulating the length of a pendulum, so that the duration of its vibrations was equal to α, therefore also to A. At the same time he determined the duration of the whole period, and as he thus found P about$=A+$,[c] he thought that the correctness of his results was beyond doubt. Absolute values Volkmann does not give. He merely states, that as the mean of nine

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[a] De l'auscultation médiate. Paris, 1819 (I used Andral's edition). Bruxelles, 1837.

[b] Zeitschrift f. rat. Medicin. 1842. Bd. III. p. 321.

[c] The difference stated by Volkmann is indeed rather great.

experiments, he found $\alpha : A = 96 : 100$. Now this result appears to confirm Laennec's opinion which assumes for α, "la moitié ou à peu près.

Many years ago, however,[a] in repeating Volkmann's experiments, I found that this result does not deserve credit: it appears impossible to say of a single vibration, that it is equal to α or to A; and for a series of isochronous strokes, which would be necessary for this, the opportunity, with the constantly alternating cardiac sounds, does not exist. Indeed, I thought I had satisfied myself, that the difference between α and A, in ordinary cases, is greater than Volkmann had found it; but my results also were too uncertain, to enable me to say anything more upon the subject.

Others have, from simple estimation, thought they might assume that the heart beats in a triple measure, of which α would occupy only one-third, while the second sound with the pause would amount to two-thirds[b]. Spring, the profound writer of the *Mémoire sur les mouvements du cœur*[c], thinks he has observed, that in youth and in a state of perfect rest the heart beats in a quadruple measure, of which half belongs to the diastole, the other half to the systole with the præsystole assumed by him. But so soon as the circulation is a little accelerated, even if it be only in consequence of a change in position or of mental emotion, it becomes triple, two-thirds belonging to the state of action, and only one to that of rest. In Marey[d] we find not much more than that with respect to the rhythm of the heart a great difference exists. In general, the rhythm is not independently investigated, but deduced from, or connected with, the sequence in the action of the heart, with the phases of which the sounds have at the same time been treated.

Nor could the coryphæi of physical diagnosis in Germany satisfy me. Here they stumble on a confusion between the duration of the proper pauses (stilte), which it is certainly very difficult to determine, and the distance from the beginning of the one to the beginning of the second sound, in which we are concerned. I spoke of pauses, in the plural: some writers, in fact, assume—I mean since Purkinje—two pauses, a great one between *II* and *I*, a short one between *I* and *II*, the latter especially perceptible in auscultating over the mouths of the arteries. But sometimes, according to Skoda[e], the pause between *I* and *II* is "so short, that the second sound over the ventricles appears as it were the accented end of the first sound, *and the first sound over the arteries*" (where it is less distinct)[f] "*as it were only a premonitory stroke of the second sound.* But in

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[a] Handleiding der natuurkunde van den Mensch [Guide to the Natural History of Man]. 1853. Part II. p. 44.

[b] Conf. Beau, Traité d'auscultation, p. 229.

[c] Mémoires de l'académie royale des sciences, des lettres et des beaux arts de Belgique. Bruxelles, 1861. T. XXXIII. p. 51.

[d] Physiologie médicale de la circulation du sang. Paris, 1863, pp. 105 et seq.

[e] Abhandlung über Perkussion und Auscultation. 6te Aufl. Wien, 1864, p. 207.

[f] Conf. Rapp. Zeitschrift f. rat. Med. 1849. B. VIII. p 151.

other cases," continues Skoda, "the pause between the first and second sound is almost as long, or exactly as long as the pause between the second and the ensuing first sound." The words printed in italics would lead us to believe, that he is here speaking of α and therefore also of A, if all the rest had not evidently reference to the pauses alone. With Friedreich[a] I found the same confusion, even including the brief statement of Volkmann's results, which nevertheless referred only to α and A.

From all this it appears, that little trouble has been taken with respect to the rhythm of the sounds of the heart. And yet this rhythm is unmistakeably of great physiological importance. In a subsequent article I shall show more precisely, that α represents the active period of the heart, consequently the duration of the process, the ground of which is to be sought in the heart itself, while the period P is determined rather by the regulating nervous system external to the heart. In modification of the heart's action, under this or that influence, the altered frequency of the strokes is thus only one side of the question; and if our principal object be also to determine the modification of the active process, this can be known from the rhythm of the cardiac sounds. For this the simple statement of the existence of this or that rhythm is not sufficient; *it must be measured.*

II. *Method.*—In order to measure the rhythm, the cardiac sounds must be registered: that is, the times must be reduced to long measure. If with the slight force of the cardiac sounds it was scarcely to be conceived that they could be recorded by means of a body brought into a state of corresponding vibration, this might be effected in an indirect method. Now the latter was found in the registration of movements of the hand, practised in unison with the rhythm observed by the ear: during auscultation we follow the rhythm of the cardiac sounds by striking on the arm of a marker, and this registers the times on a revolving cylinder. In order in each experiment to ascertain also the frequency of the pulsations, the seconds of a clock are, by means of electro-magnetism, registered on the same cylinder. We thus obtain figures, as the following:

FIG. 1.

R is the tracing of the rhythm, S that of the seconds, the distance from 0 to 2 being equal to two seconds. In the tracing R the distance $I\ II = \alpha$, and $II\ I = A$, so that $I\ I'$ as well as $II\ II' = P$. At α the marker

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[a] Handb. der bijzondere pathologie en therapie, onder redactie van Virchow. D. V. Afd. 2. bl. 199.

is pushed down on hearing I, at b the finger is again taken up and the marker rises; at c it is again depressed on hearing II, it rises again at d, to begin at a', on hearing I', the second period. Such periods were registered to the number of about twenty consecutively, at which the cylinder stopped: the number of corresponding seconds showed the frequency of the pulsations, and from the a and P measured for each period the averages were calculated for the whole circuit.

Subsequently I found, that, with regular pulsations, the rhythm is capable of being imitated with more certainty and accuracy, by omitting one after each registered period. We then write, it is true, opposite a following period the rhythm of the preceding one; but where the rhythm is regular, this comes to the same thing and has no influence on the average. We thus obtain such figures as the subjoined:

Fig. 2.

In the tracing R' only A, in the tracing R only a, is alternately registered, consecutively to each other from the same heart. In R', therefore, between I' and II'', II' and I'' have been omitted, and $II\ II''$, or $I'\ I'''$ is equal to $2P$. In the tracing R, between II and I'', I' and II' have been omitted, and in this case $I\ I''$, just like $II\ II''$, is again equal to $2P$. In the tracings S' and S we again see the seconds which show the duration of the periods, and if we now measure the registered or a A, we have only to divide the ascertained value by the half of the like measured $2P$, to find a or A in percentages of P.

III. *Testing of the Method.*—In order to ascertain what degree of accuracy is attainable by the method just described, we must inquire, with what precision we can reproduce, by movement of the hand, a rhythm perceived by the ear, even when the alternating distances do not stand in simple relation to one another. Besides, I was anxious, for reasons which shall be stated hereafter, to investigate how far the strokes of the hand are isochronous with those ascertained by the ear.

To fulfil both these requirements, sounds must be produced artificially in a rhythm, about corresponding to that of the cardiac sounds, and this rhythm must register itself, and at the same time be imitated in the manner above described. If the experiment be so arranged, that the markers of the primary rhythm and of that obtained by imitation stand directly under one another, the difference between the two tracings strike the eye immediately and may now be still more accurately measured. The primary rhythm I obtained with the aid of Maelzel's metronome. By shifting the weight on the pendulum we can regulate the number of strokes at will, and by inclining the instrument, we can make the strokes alternately unequal. These strokes themselves are not, however, to be used, for the moments of origin are not to be registered; but I attached to the pendulum a wire in a horizontal direction, bent the two extremities left and right downwards, and in the vibrations of the pendulum caused these bent extremities to dip into mercurial troughs, whereby a galvanic current was at the same time closed. To insure the regular action of the instrument, it now appeared to be even better not to incline it, but to produce the alternate difference merely by altering the length of the wire, and by placing the one mercurial trough higher than the other. Now on each closing of the current, the arm of a marker was attracted by an electro-magnet, in a distant room, where the strokes of the metronome could not be heard, and the moments of attraction, with alternately greater and shorter pauses, were here registered on the revolving cylinder of the kymographion. As we heard in the strokes of the markers upon the magnet the registered rhythm, we had only to imitate this with the hand, in the mode above described—by striking, in fact, upon a marker, which registered its movements directly above those produced by the magnet. In this manner we obtain figures like the subjoined:

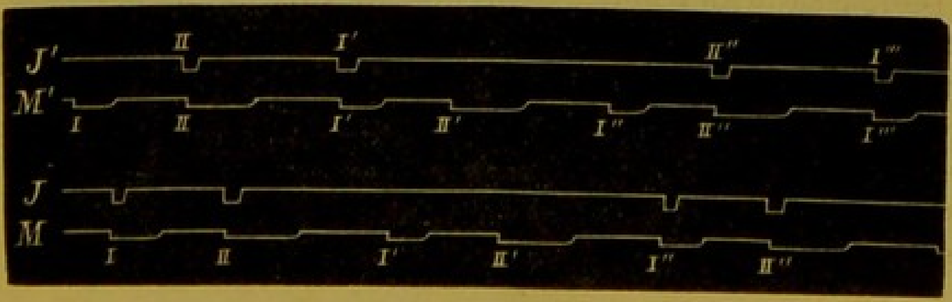
Fig. 3.

The tracing *M* is the primary rhythm, derived from the metronome; *J* is the imitated rhythm. In both tracings three whole periods are to be seen: *I II* represents α, *II I'* is *A*, &c.; at *a* the markers descend, at *b* they are set free and ascend by their elasticity, at *c* they descend anew, to rise again at *d*, and at *a'* a second period begins.

It here appears distinctly, that in the imitated rhythm *I* occurs somewhat too late and *II* often rather too early, so that α is reproduced too small and *A* too great.

The same occurs when, as in fig. 4,

Fig. 4.



a or A is alterately reproduced: in the upper tracings the A's here imitated, especially the second, are too great, because II occurs too soon, I on the contrary scarcely too soon or even too late—as in the lower tracings the a' are too small, because I occurs too late and II too early.

We have therefore here a rather considerable personal error, which with me returns each time, modified however by the values of P and of $a : P$. Of these results, I here append more than is absolutely necessary for estimating the degree of accuracy attained in registering the rhythm of the cardiac sounds. I do so because the question, what accuracy is attainable, is in a psycho-physical point of view, in itself not without importance, and moreover the method of the indirect registration of sounds will, in other cases also, find application. We should therefore know what it is capable of.

Now, in the first place, the observations, which belong to one and the same circuit of the cylinder, present a slight probable error.

Some examples may illustrate this.

No.	METRONOME		IMITATION	
	Period $P = \frac{1}{32}'$	a	Period P'	a'
1	12·9	4·4	12·6	4·5
2	18·5	6·8	18·7	7·4
3	21·	8·	21·3	8·4
4	24·2	10.	24·3	9·8
5	25·8	10·3	25·5	9·9
6	26·	10·5	25·9	11·
7	26·6	10·6	27·2	10·6
8	27·1	11·	27·3	10·6
9	27·4	11·3	26·7	10·3
10	27·6	12·	28·4	11·8
11	28·3	11·8	27·8	10·9
12	27·4	11·5	27·1	10·7
13	27·2	11·5	26·6	10·5
14	28·3	12·7	28·	10·8
15	26·5	10·7	27·8	11·1
16	26·4	11·	26·6	11·5
17	26·9	11·	24·7	9·5
18	26·4	10·4	27·2	10·7
19	26·4	10·9	26·4	10·9
20	26·8	10·9	26·8	11·2
21	27·3	10·3	27·6	11·2
22	27·4	10·9	26·3	11·
23	26·8	10·7	27·4	11·6
	536·3	220·	535·1	215·6

The first three observations, in which the cylinder had not yet nearly attained its full rapidity, are neglected: soon, as appears from the period of the metronome, its course became regular enough, and moreover, α adapted itself to P, so that, for the strokes of the metronome, the average result is very accurate.

In the case to which the above table belongs, all strokes of the metronome were imitated, and consequently both α and A (method a' conf. fig. 3); but only P and α are taken into the Table, because $A=P-\alpha$ and is therefore ascertained by subtraction. The difference between the sum of the periods 536·8—535·1=1·7 places us in a position to judge of the accuracy of the measurement, which indeed seems to be satisfactory.

The calculation is now as follows:

Metr. $\alpha=220 \;\; : 536{\cdot}8=41^0/_0$ of P $(A=59^0/_0)$.
Imit. $\alpha'=215{\cdot}6 : 535{\cdot}1=40{\cdot}3^0/_0$ of P' $(A'=59{\cdot}7^0/_0)$.

The probable error in the 215·6 found is certainly so slight, that we may, with a safe conscience, save ourselves the trouble of the calculation (not the ascertained values of α', between which all the difference is, but $\alpha' : P'$, for each observation, should be the basis of the calculation). Yet there appears to be a personal error of 0·7 of the percentages found, and sometimes this is much greater.

A second example, in which α' alone was alternately determined (method *b*, conf. fig. 4):

No.	METRONOME		IMITATION	
	$2P=\frac{1}{31}'$	α	$2P'$	α'
3	47·2	10·8	47·2	10·9
4	47·2	10·6	46·8	11·
5	47·3	10·9	47·2	11·4
6	46·9	10·7	47·4	11·
7	45·7	10·4	45·4	10·4
8	44·	10·2	44·4	10·3
9	44·7	10·	44·2	10·6
10	45·2	10·2	45·6	10.8
11	44·4	10·	45·	11·
12	45·	10·1	45·6	10·6
	457·6	103·9	458·8	108

Here the same remarks hold good as above. The percentages of α and α' are now found by dividing by the *half* of the ascertained *double* periods. Consequently:

$$\alpha = 104{\cdot}9 : 228{\cdot}8 = 45{\cdot}4\,{}^0/_0 \text{ of } P \;\; (A = 54{\cdot}6\,{}^0/_0).$$
$$\alpha' = 108 \;\; : 229{\cdot}4 = 47{\cdot}1\,{}^0/_0 \text{ of } P' \; (A' = 52{\cdot}9\,{}^0/_0).$$

By a very small probable error, a difference of 1·7 of the percentages is here found, which again is to be ascribed to a personal error: that α' is above found too low, and here too great, is probably connected with the different values of P and $\alpha : P$ for the two cases.

Lastly, I add an example in which A' is determined (conf. fig. 4, $J'M'$), in which therefore the distance between II and I was alternately imitated (method c).

No.	METRONOME		IMITATION
	$2P = \frac{1}{43}'$	A	A'
3	37·2	10·5	10·2
4	40·2	11·8	10·4
5	42·7	12·5	12·5
6	44·3	13·5	13·2
7	43·2	13·5	12·
8	43·	12·6	12·4
9	44·	13·3	13·4
10	44·3	13·3	14·5
11	43·5	13·	13·5
12	44·7	13·6	14·5
13	43·2	13·4	13·
14	42·5	13·3	13·7
	513·4	154·3	153·3

As $A : P$ and $A' : P$ we find the percentage values of A and A', and by subtracting the quotients obtained from 100, those of α' and α, which last, even when A' had been determined, are, to facilitate inspection, taken into the Tables.[a] The calculation in this case yields:

$$A = 154{\cdot}3 : 256{\cdot}7 = 60{\cdot}1\,{}^0/_0 \text{ of } P \;\; (\alpha = 39{\cdot}9\,{}^0/_0 \text{ of } P).$$
$$A' = 153{\cdot}3 : 256{\cdot}7 = 59{\cdot}7\,{}^0/_0 \text{ of } P \;\; (\alpha' = 40{\cdot}3\,{}^0/_0 \text{ of } P).$$

These three examples are sufficient to illustrate the method of observation

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[a] All the observations and the great majority of the measurements occurring in this investigation have been made by myself. In the few series in which I intrusted the measurements to others, I had, in the equality of the sum of the periods P and P', a test of the accuracy of their work. When I myself made the measurements, it was sufficient to determine either P or P', after I had repeatedly found that with me the results did not differ.

and calculation. I now add what was found according to the three modes of observation, with different values of P and $\alpha : P$, as α'. Of the first series I communicate all the revolutions, with a statement of the number of observations in each revolution.

Series I. $P = \frac{1}{52}'$ (52 double strokes in the minute); $\alpha : P$ about equal $\frac{2}{5}$ (from 38·9 to 43·1%).

No.	α (Metronome)	α', obtained by			$\alpha - \alpha'$	Number of Observations
		method a (imit. of $\alpha + A$)	method b (imit. of α)	method c (imit. of A)		
1	39·9	39·			0·9	13
2	38·9	38·2			0·7	14
3	41·8	39·5			2·3	18
4	41·5	39·2			2·3	20
5	43·1	42·7			0·4	21
6	42·2	39·2			3·	19
7	41·	34·8			6·2	24
8	41·2	36·8			4·4	20
9	41·4	40·7			0·7	20
10	41·	40·3			0·7	20
11	40·7		38·8		1·9	11
12	40·9		40·1		0·8	12
13	41·		38·9		2·1	8
14	40·8		38·7		2·1	12
15	41·5		39·		2·5	12
16	41·4			39·	2·4	12
17	41·6			41·5	0·1	11
18	41·3			40·6	0·7	12
a	41·2	39·1			2·1	189
b	41·		39·1		1·9	55
c	41·4			40·4	1·	35

The calculated final averages for each of the three modes of observation are here introduced as *a*, *b*, and *c*: α' here appears in all the observations, and consequently also in the final averages, to be less than α. I have chosen the series in which P is greatest, although the deviations in this prove to be much greater than in most others. By the method α we can imagine the accent on either the sound *I* or *II*, at pleasure; in making the experiments this was distinguished, but it yielded no constant differences, so that to simplify the Table I have comprised all the observations, performed according to the method *a*, in the same column.

Series of observations, similar to that here communicated, were now made also with other values of P and $\alpha : P$. In general they appear much better than the above. But for the sake of conciseness, we must confine ourselves to a statement of the final averages, which are collected in the subjoined table:

Series	$P=1'$:	Method	α Metronome	α' Imitation	$\alpha-\alpha'$	Number of Observations
I.	52	*a*	41·2	39·1	2·1	189
	52	*b*	41·	39·1	1·9	55
	52	*c*	41·4	40·4	1·	35
II.	66	*b*	44·1	44·2	−0·1	8
	66	*c*	44·9	41·	3·9	11
III.	65	*a*	46·5	45·5	1.	44
	64	*b*	46.	45·6	0·4	60
	64	*c*	46·9	45·1	1·8	61
IV.	72	*a*	41·4	39·2	2·2	95
	72	*b*	40·	39·8	0·2	35
	72	*c*	38·8	37·7	1·1	34
V.	73	*b*	41·8	41·5	0·3	18
	72	*c*	39·2	39·3	−0·1	9
VI.	73	*b*	46·4	46·8	−0·4	9
	73	*c*	45·7	45·6	−0·1	9
VII.	82	*b*	46·3	45·6	0·7	9
	82	*c*	47·2	48·9	−1·7	10
VIII.	83	*b*	42·3	41·8	0·5	9
IX.	85	*b*	34·2	38·5	−4·3	31
	85	*c*	33·7	35·1	−1·4	31
X.	86	*a*	39·	36·6	2·4	53
	86	*b*	39·3	41·8	−2·5	54
	86	*c*	39·9	38·7	1·2	43
XI.	84	*b*	43·9	44·8	−0·9	35
	84	*c*	43·6	42·6	1·	33
XII.	94	*c*	44·4	43·5	0·9	11
XIII.	98	*b*	38·2	37·2	1·	13
XIV.	97	*b*	40·3	40·7	−0·4	11
	97	*c*	42·5	42·5	0·	7

This table, deduced from not less than 1,022 observations, exhibits the degree of accuracy I attained to in imitating the rhythm. On an average the error amounts to 1·25 in the percentages. At first, experimenting with slight frequency of the strokes, I usually reproduced α too low, A, too high. Subsequently I found that not unfrequently the reverse takes place: in three examples α' is twice too low and once too high, with about the same average error of 1·25. The greatest deviations occur when α is comparatively little or else very great and nearly equal to A. No regularity is, however, to be traced in this matter. In order with every value of P and of $\alpha : P$ to determine the personal error, it would be necessary to experiment and measure for many months. For our object it is sufficient to know, that on an average a personal error of 1·25 of the percentages attaches to our observations of the rhythm of the pulsations of the heart hereto appended, and that this error will not easily increase to 2.5°/₀. Moreover, when the P' and $\alpha : P'$ found for the heart correspond to one of the series, occurring in the above table, we shall be able to take into calculation the personal error found in this particular case.

IV. *Results obtained.*—The rhythm of the sounds of the heart was registered by different persons, almost without exception in the sitting position, sometimes in the state of rest, sometimes after previous bodily exercise. I made use of König's stethoscope, which I found particularly well adapted for hearing the sounds of the heart[a].

It was applied in the region of the stomach, while two elastic tubes proceeding from it reached to the external auditory passages and had their ivory extremities fitted in the same. The fingers of the right hand were joined to one another, just above the marker, while the wrist rested at a suitable height. The rhythm of the cardiac sounds was now imitated by movements of the hand, before the cylinder came into motion, and so soon as it appeared that the rhythm continued regular, and that I had taken it up correctly, the signal was given by a slight movement of the head, whereupon the cylinder was set free, to stop after one circuit. The first observations, in which the cylinder had not acquired sufficient rapidity, were neglected. The heart's action is extremely rarely quite regular. It is therefore not possible to register all the sounds, and I soon confined myself to the alternate registration of α or A, according to method *b* or *c*, which methods in testing the accuracy attainable by them, as appears from the above table, were then employed by preference.

To give an idea of the results obtained, I here append the observation of one circuit:

Series I. Mr. A., aged 21, short and stout.

	α	$2\,P$.	α in per Centages of P.
	9·8	48·2	40·7
	9·6	47·8	40·2
	9·2	46·5	39·6
	9·1	44·3	41·1
	9·1	45·	40·4
	7·9	43·6	36·2
	7·3	40·	36·5
Forward,	62·0	315·4	

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[a] In a subsequent communication, treating of the cardiac sounds with reference to the action of the heart, this stethoscope is described.

	α	$2\,P$	α in per Centages of P.
Over,	62·0	315·4	
	8·3	41·3	40·2
	7·6	41·2	36·9
	7·8	42·	37·1
	8·	40·8	39·2
	7·7	40·3	38·2
	101·4	521·0	consequently $\alpha = 38{\cdot}9\,^0/_0$ of P.

From the seconds registered at the same time I found that 62 pulsations occurred in the minute, consequently $P = \frac{1}{62}'$. In the above series the numbers diminish downwards, which is to be ascribed partly to increasing frequency of the pulsations, partly to retardation of the movement of the cylinder: this too the seconds simultaneously registered shewed us. In the following table we now combine with the first, the results obtained with the subsequent revolutions of the cylinder in Mr. A., in the state of rest (to the modifications produced by movement we shall afterwards revert):

No.	$P=1$:	Method	α'		Number of Observations	Remarks
			in percentages of P	in seconds		
1	62	*b*	38·9	0·376	12	(See preceding page).
2	63	*b*	40·8	0·395	9	
3	61	*b*	38·8	0·382	6	
4	63	*b*	40·2	0·383	6	
5	65	*c*	43·5	0·402	7	
6	66	*c*	38·6	0·351	8	frequency increased by a swallowing movement.
7	64	*c*	42·3	0·397	8	

We now combine the average of this Series, obtained in Mr. A., with the averages of the Series found in other persons with greater frequency of the pulse.

Name and age	Series	$P=1$:	α' in percentages of P	α' in seconds	Number of Observations
A. 22	I.	63·4	40·4	0·382	56
Br. 28	II.	74·4	40·6	0·327	59
Jac. 22	III.	77·	41·6	0·324	98
Kw.	IV.	78·	42·6	0·328	53
„	V.	79·7	42·3	0·318	31
Pan.	VI.	81·	44·4	0·329	75
„	VII.	81·5	42·6	0·313	75
St. 2	VIII.	87·7	42·8	0·293	28
L. 22	IX.	89·7	45·1	0·302	29
K. 23	X.	91·	45·6	0·301	61
H. 15	XI.	93·7	41·2	0·309	32

These series lead to the important result that, in the state of rest, α is relatively greater the shorter the period. Hence it appears, that in different persons there is less difference in the duration of the active part of the period, than in the period in its integrity. It seemed to us sufficiently important to calculate the absolute duration of the active part of the period, and we see from the above table that, with the considerable difference in frequency of the pulsations from 74·4 to 93·7, the absolute value of α' continues between 0·327 and 0·301. Only in the first series where 63·4 pulsations occurred in the minute, does α increase more considerably and indeed to 0·382 second.

We had occasion to determine P and α' in a case of very slow pulse, occurring in John Vroomans, shoemaker, aged 57. Six months ago he had a fit, which he described as a sudden shock in the brain; he had fallen and had got a slight wound in the head, which however had been attended with no further serious consequence. The same day he got two slighter attacks, and subsequently also he continued not quite free from similar seizures. At the same time he suffered habitually from pain in the occiput, was asthmatic, and experienced difficulty in going up stairs. On the first examination he had, when sitting, 32 pulsations in the minute. In the subsequent investigations in which the seconds were at the same time registered, I found at first a still lower figure. We have put the results together in the subjoined Table.

No.	$P=1$:	Method	α' in percentages of P	α' in seconds	Number of Observations
1	29	*b*	15·7	0·325	6
2	38	*b*	20·4	0·322	9
3	37	*b*	19·4	0·315	10
4	35	*b*	17·4	0·307	10
5	35	*b*	18·3	0·314	10

It is remarkable that α', that is the active part of the period, does not in this case last longer than in a pulse nearly three times as quick. A stronger proof of the independence of the duration of the contraction from that of the period could not be adduced. The registration of the sounds of the heart was attended with no difficulty. In the sitting position at rest the heart's action was very regular, and spontaneously the observer was inclined, between each pair of sounds to imagine a second pair, which was not heard: the imitation might take place from the sounds heard just before, as in the ordinary method *b*, with this difference only, that during the imitation the second pair of sounds was absent, whose existence is properly speaking rather prejudicial than advantageous to the observation. The regularity of the heart's action was in this case so great, that, as shall be communicated in a subsequent paper, I even succeeded in making some strokes consecutively coincide precisely with the cardiac sounds.

It is well known that in a standing position the pulse is quicker. In the annexed we find the results in the same person in a sitting and in a standing position compared.

Name and age	Position	$P=1'$:	α'	α' in seconds	Number of Observations	Remarks
Br. 28	sitting	63·4	40·6	0·327	59	
	standing	83·6	41·5	0·298	85	

Evidently with the increased frequency of the periods, in consequence of a standing position, the relative value of α only slightly increases, the absolute on the contrary strongly diminishes. Such observations must, however, be performed on a greater number of persons, in order to be able thence to deduce a general rule.

The results obtained with the altered frequency in consequence of bodily exercise are very remarkable. The individuals were examined in a sitting position after having gone a few times quickly up and down stairs.

In Mr. A., to whom the first series above communicated refers, we found the following:

No.	State	$P=1$:	Method	α'		Number of Observations	Remarks
				in percentages of P	in seconds		
Average	In rest	63·4		40·4	0·382	56	(See above)
1	After exercise	74	*b*	36·5	0·296	9	Some minutes' rest had preceded.
2	1 minute later	68	*b*	33·3	0·294	8	
1′	After repeated exercise	124	*b*	41·2	0·199	15	Immediately.
2′	½ minute later	80	*b*	39·2	0·294	9	Rapid breathing.
3′	1 minute later	70	*b*	34·8	0·298	7	Rapid breathing.
4′	½ minute later	68	*b*	38·1	0·336	7	
5′	2 minutes later	72	*b*	40·1	0·334	7	Breathing much less rapid.
6′	1 minute later	71	*b*	41·4	0·35	9	
7′	½ minute later	67	*c*	39·8	0·356	8	
8′	½ minute later	68	*c*	40·9	0·361	6	

It is remarkable that, while with greatly increased frequency, immediately after exercise (compare 1′), α has become relatively greater, a few minutes later the frequency diminishes considerably (1 and 2, as well as 2′ and 3′), and that at the same time α' becomes relatively much less. Subsequently the pulse becomes again somewhat quicker and still the relative value of α' approaches more and more to the state of rest. It occurred to me that the diminished frequency of the pulse, shortly after exercise with quick breathing, might indeed be connected solely with the need of quick breathing. The result of a remarkable experiment which I am unable to refer to its author, but which I first saw with Pflüger, and yearly repeat in my lectures, is pretty generally known. It is this: that in a rabbit whose chest is opened, so long as artificial respiration is kept up, the pulsations of the heart proceed regularly, but that, when the artificial respiration is no longer continued, with the efforts at respiration then setting in, before asphyxia is yet imminent, the heart nearly stops, or rather exhibits very long periods of rest between its contractions. Now the retardation of the pulse, shortly after great exertion, likewise suggests the idea of imperfect respiration and irritation of the nervus vagus. It is, however, possible that the mechanism of respiration itself, with the accompanying alteration of pressure in the thorax, gives rise to the peculiar retardation. However this may be, the fact is established. The latter acquires still higher signification, when we see how little the absolute duration of a is affected by it : this still continues short, when the pulse is only slightly quickened (No. 2 and No. 3′,) and increases from 0·294 to 0·361, without any perceptible retardation of the pulse. The independence of a is thus again exhibited.

I have proved much the same in other persons. The retardation of the pulse becomes shortly after exercise, sometimes so considerable, that with the subsequent increase, a, although it has become absolutely greater, remains relatively less. We see this in the following example (compare 1, 2, 3) :

No.	State	$P=1$:	a	a in seconds	Number of Observations	Remarks
P. average.	Rest	81	44·4	0·329	31	General Table See page 234
1	After exercise	78	36·7	0·282	7	Not immediately.
2	1½ minutes later	107	40·9	0·229	13	
3	2 minutes later	94	44·7	0·285	6	
1′	After repeated exercise	126	39·7	0·189	15	Immediately.
2′	1½ minutes later	105	39·4	0·225	15	
3′	1½ minutes later	98	40.9	0·250	8	

On repeating the exercise 1′, 2′, 3′) the retardation of the pulse did not again occur, but we see the value of a relatively and especially absolutely diminish and gradually approach to that of the state of rest.

In the two following young persons too the retardation of the pulse scarcely occurred after exercise, but the relative, and, much more still, the absolute diminution of the value of a, which regularly approaches that of the state in rest, is in each instance evident.

No.	State	$P=1$:	Method	a'		Number of Observations	Remarks
				in percentages of P	in seconds		
K average	In rest	91		45·6	0·301	61	(above X.)
1	After exercise	137	*b*	44·1	0·193	8	
2	0·5 minute later	114	*b*	42·7	0·224	12	
3	After exercise	103	*c*	48·2	0·28	13	
U. average	In rest	937		48·2	0·309	32	(above XI.)
1	After exercise	131	*b*	42·5	0·195	9	29 Oct.
2	0·5 minute later	107	*c*	45·1	0·252	10	
3	1 minute later	110	*b*	48·1	0·262	15	
1′	After exercise	127	*b*	43·8	0·207	9	2 Dec.
2′	0·5 – 1 min. later	126	*b*	44·1	0·21	9	
3′	0·5 min. later	122	*b*	48·5	0·239	8	
4′	1 min. later	108	*b*	46·5	0·258	12	

On the other hand, the retardation of pulse in an asthmatic boy, which, because he was sickly, was not included in the General Table (p. 234) of the averages, but of which, nevertheless, I here communicate, for the sake of comparison, the average in the state of rest, was remarkable. All the observations were made according to method *b*, which, in the end, affords the best results.

No.	State	$P=1$:	a'		Number of Observations
			in percentages of P.	in seconds	
H. average	In rest	79·3	47·1	0·356	39
1	2 minutes after exercise	81	37·8	0·287	7
2	0·5 minute later	63	38·6	0·367	

Immediately after the exercise, before registration was possible, the pulse was quick, and at the same time *a* was nearly equal to *A*. It was only subsequently that the periods became much greater, with panting and irregular respiration, and α' was found relatively much less, as is to be seen in 1 and 2. It would be desirable in such cases at the same time to register the respiration, which I shall hereafter not neglect, now that Marey[a] has placed at our command so simple a method of doing so.

Much remains still to be investigated, with respect to the modifications which the rhythm of the sounds of the heart experiences under different circumstances. In particular I have laid out to study in man the influence of digitalis and in animals that of irritation of the vagus. I also hope to present some contributions in the field of pathology. By continued practice I have gradually attained greater accuracy in registering; perhaps also the study of music, which I began early, and have never wholly given up, is not without influence thereupon. The profession has therefore some right to expect that I should proceed with the application of the method to particular cases. Meanwhile I hope in a subsequent communication to show the connexion between the sounds and action of the heart, which has become feasible by simultaneous registration of the impulse and sounds of that organ.

V. *Corollaries.*

1. The cardiac sounds are distinguished as *I* and *II*. The distance from the commencement of *I* to that of *II* is α, that from *II* to *I* is *A*. The period $P = \alpha + A$.

2. The frequency of the pulse being given, the rhythm of the sounds of the heart teaches us α and $\alpha : P$, that is the absolute and the relative duration of the active part of the cardiac period.

3. The rhythm of the sounds of the heart can be imitated by movement of the hand and so be registered.

4. The accuracy of this method, tested by the imitation of a self-registering rhythm, has been shown to be satisfactory. The probable error is very slight; the personal error is variable with the values of *P* and $\alpha : P$.

5. In the state of rest α amounts usually to from 0·309 to 0·327 of a second, and continues tolerably equal, with different values of *P*.

6. In this we have a proof, that α, the duration of the active working of the heart, has a certain independence.

7. $\alpha : P$ is, in the state of rest, the greater, the shorter the periods are; in young persons $\alpha : P = 0{\cdot}404$ to 0·482, average 0·428.

8. With increased frequency of the pulsations in consequence of work (rapid ascent of stairs), α on the contrary often diminishes more quickly than *P*, and $\alpha : P$ therefore becomes less, the less *P* is.

9. A few minutes after work is performed, the cardiac periods usually become, with strong and quick respiration, temporarily very long, but α

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[a] Journal de l'anatomie et de la physiologie de l'homme et des animaux. Juillet, 1865.

continues in general short, so that then $\alpha : P$ is less than ever. The independence of α is thus again demonstrated.

10. In the standing posture α becomes perhaps relatively somewhat greater, but absolutely considerably less than in the sitting.