# ON THE RHYTHM OF MUSCULAR RESPONSE TO VOLITIONAL IMPULSES IN MAN. BY W. GRIFFITHS, B.Sc., M.R.C.S. Pl. II.

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IT has been already pointed out in a previous number of this *Journal* that it is possible to obtain myographic tracings exhibiting a series of more or less regular waves from muscles contracting in response to volitional impulses. Such myograms were obtained by Professors Horsley and Schäfer[1] from animals and by Messrs Canney and Tunstall[2] from man. And the important observation[3] made by Professors Horsley and Schäfer, that the rhythm of the muscular response in case of volitional and reflex contraction is essentially the same as that which results from electrical excitation of the nerve centres, suggests that myograms of voluntarily contracting muscles cannot be neglected in seeking to understand the nature of a voluntary muscular contraction. For if we are justified in assuming that the waves in the myograms obtained from a voluntarily contracting muscle, and from muscles contracting in response to electrical excitation of the nerve centres, are graphic representations in both cases of similar processes, we have direct evidence of the discontinuous nature of a voluntary muscular contraction. And further myograms taken from muscles contracting in response to volitional impulses afford a ready means of investigating some of the conditions of voluntary contraction.

In this paper I propose giving the results of a series of experiments carried out with the object of determining what influence, if any, strain may exert in modifying the number and character of the waves seen in the myogram of a voluntarily contracting muscle.

The apparatus used was the same as that already described by

[1] 'On the character of the muscular contractions which are evoked by excitation of the various parts of the motor tract.' By Professors Horsley and Schäfer. This *Journal*, Vol. VII.

[2] 'On the rhythm of muscular response to volitional impulses in man.' By Professor Schäfer assisted by Messrs Canney and Tunstall. This *Journal*, Vol. VII.

[3] This *Journal*, Vol. VII. page 105.

Professor Schäfer, and figured in Plate VI. fig. 1, in Volume VII, of this *Journal*, with certain modifications which will be described in the proper place.

But before we proceed to the modifying conditions it is necessary to answer more fully a question already suggested. What is the meaning of the waves seen on a myogram taken from a muscle contracting voluntarily? Are they graphic representations of contraction waves or are they merely vibrations of the muscle caused by the sudden variation in tension which occurs when the muscle contracts against resistance? Are they of Physiological or Physical import?

It is well known that a string stretched between two points is thrown into a state of vibration on having its tension more or less suddenly increased, and at least the transverse vibrations could easily be graphically represented on a revolving surface if the vibrating string were suitably connected with a receiving and recording tambour. It is found when the insertion of a muscle is divided that there is a slight retraction of the muscle, and from this it is concluded that normally the muscles are stretched to a very slight extent. May not the muscle then be looked upon as a string stretched between two points, and may not the myogram waves be merely graphic representations of the transverse vibrations following increased tension due to contraction?

Apart from other objections which might be urged there are two serious objections to our regarding the myogram waves as vibration waves.

In the first place it is found that the number of vibrations made in a given time by strings of equal densities under equal stretching forces varies inversely as the length of the string, and also inversely as twice the radius. But on comparing the results of myograms taken from the Biceps [Table I. p. 45] which is a long muscle, with those of the myograms of the thumb muscles [Table II. p. 46], for equal weights a greater number of waves per second will be found in the former, which is just the opposite of what we should expect if we were dealing merely with the physical phenomenon.

It must be remembered also that equal weights do not mean equal stretching forces in the case of the Biceps and muscles of the ball of the thumb respectively. For the weight was suspended from the first phalanx of the thumb when its muscles contracted, but was held in the outstretched hand when the Biceps was made to contract, and thus the Biceps had to lift the weight applied at the end of a comparatively long lever.

In the second place, the number of vibrations made in a given time by strings of equal densities, lengths and diameters, varies directly as the square root of the stretching weight in transverse vibrations, or of the coefficient of the modulus of elasticity in longitudinal vibrations. We should expect therefore a greater number of vibrations for a greater stretching weight in this proportion. But on consulting the myograms [see Tables] we find no such relation. There is up to a certain point some increase of the number of vibrations for an increased weight, but once this point is reached any further increase in weight is accompanied by a decrease in the number of vibrations.

On the other hand, there is no necessary antagonism between the indications of the myograms and any vital process; indeed, as will be pointed out, there is a very remarkable coincidence between the character of the variation in the number of vibrations and some important physiological processes, such as the production of heat in the muscle and the effect of work. Further, the observation already referred to of Professors Horsley and Schäfer that the rhythm of muscular response in case of volitional contraction is essentially the same as that which results from electrical stimulation of the nerve centres is strong evidence of the Physiological nature of the myogram waves obtained from a voluntarily contracting muscle.

Assuming then that the waves of a myogram obtained from a muscle contracting in response to volitional impulses are graphic representations of an incomplete tetanic state, we have now to answer the following questions:

What is the number and character of the waves in a myogram obtained from a voluntarily contracting unweighted muscle?

What are the conditions, if any, which modify the number and amplitude of these waves?

1. *The number of muscular responses per second in a voluntarily contracting unweighted muscle.*

The generally accepted idea is that when a muscle contracts voluntarily, i.e. through the will, it makes 19·5 vibrations per second[1]; this idea is based on the note heard on listening to a contracting muscle. That this note cannot be regarded as a true indication of the number of oscillations in a contracting muscle has been pointed out by Helmholtz, who has shown that this sound coincides with the fundamental note of the ear.

[1] Landois and Stirling. *Text-book of Human Physiology*, Vol. II. page 666. First edition.

Professor Schäfer in the paper[1] already referred to has urged weighty arguments against our regarding the note heard on listening to a contracting muscle as a true indication of the number of muscular responses, or even as a proof of the discontinuous nature of a voluntary contraction.

Horsley and Schäfer found in their experiments on animals that the voluntarily contracting muscle made a number of responses varying from 8 to 12, or 13 per second[2], giving an average of about 10 per second.

Canney and Tunstall in their experiments on man also found the number of muscular responses to vary from 8 to 13 per second[3], giving an average of about 10 per second.

And from a very large number of tracings taken from myself and other individuals I have come to the same conclusion.

But from a large number of tracings taken chiefly from my own muscles I have strong reasons for believing that the range of variation stated above is too wide, and that the higher numbers are too high for the 'unweighted' muscle. By 'unweighted muscle' I mean not only that the muscle is liberated from the influence of any force external to the body during contraction, but that it is also liberated as far as possible from the influence of the simultaneous contraction of antagonistic muscles. For example, if the extensors of the thumb are contracted at the time when we are taking a myogram from the muscles of the ball of the thumb, it is evident that the latter muscles have during contraction to overcome a force as real as if they were made to draw up a weight by means of a string over a pulley. It is important to keep this in mind and to guard as far as possible against contraction of antagonistic muscles when taking a myogram from any given muscle, otherwise we shall have results from whose variable and uncertain character we may prove any theory which we have at heart, but from whose regularity we can prove nothing.

In animals the influence of the simultaneous contraction of antagonistic muscles might be eliminated by dividing the motor nerves of these muscles, and it was also eliminated in some of the experiments of Professors Horsley and Schäfer by cutting through the insertion of the muscle and attaching the tendon by string to the recording lever. In man complete elimination is almost impossible, but partial elimina-

[1] This *Journal*, Vol. VII. pages 111—112.
[2] *Ibid.* page 101.
[3] *Ibid.* page 114.

tion can be effected by fixing the limb and by practice in myogram taking. When I first began taking myograms from my own muscles contracting in response to volitional impulses I found no difficulty in getting good myograms, having from 12 to 13 waves per second for the muscles of the ball of the thumb [Table I.], and 13 to 14 per second for the Biceps [Table II.] when these muscles were made to contract without having to overcome any force external to the body. After taking tracings for several months from the muscles of the ball of the thumb voluntarily contracting under different weights, I one day tried again to take tracings from these muscles when they were not made to lift any weight but found that the waves in the tracings were so indistinct that it was almost impossible to count them, but so far as I could count them they were fewer in number than those of the tracings taken from the same muscle contracting under no external force some three months before. I could still however obtain good tracings having 10 to 13 distinct waves per second without making the contracting muscles lift any weight; but when this happened, I was distinctly conscious now of the simultaneous contraction of antagonistic muscles. The more thoroughly I eliminated this antagonistic action the more indistinct my tracings became. On two occasions I obtained short tracings with fairly distinct waves when the muscles were fatigued, although as far as my consciousness went there was no resistance offered by the antagonistic muscles. In this latter case the waves per second were fewer, 8 to 10 per second.

The foregoing observations may possibly explain how it is that Cadiat[1] failed to get evidence of discontinuity except in fatigued muscle. They may also partly explain the range of variation in the number of the waves in the myograms obtained by Horsley and Schäfer from animals and by Canney and Tunstall as well as by myself from man. It is quite possible that the different muscles from which the records were taken had to overcome different resistances, and that the same muscle at different times contracted under variable opposing forces, and was in different states.

The only conclusion we seem justified in arriving at from a consideration of the results so far obtained is that the generally accepted idea that normally there are 19·5 muscular responses per second when the muscle is voluntarily contracted is erroneous. That the exact number is uncertain, but that the average number of muscular responses per second is not more than 10 for the unweighted muscle.

[1] Quoted by Professor Schäfer in this *Journal*, Vol. VII. page 112.

2. *Conditions modifying the number of muscular responses per second in a voluntarily contracting muscle.*

It is generally assumed as seen in the passage already quoted from Landois and Stirling, that when a muscle contracts voluntarily it makes 19·5 vibrations per second.

The experiments of Professors Horsley and Schäfer on animals, and those of Messrs. Canney and Tunstall on man, show that there is no such constant number of muscular responses when a muscle contracts voluntarily, but that the number of vibrations varies from 8 to 13 per second.

In my own experiments I find that the number of muscular responses varies from 8 to 19, or even 20 or 21 in some cases.

With the object of ascertaining some of the conditions associated with these variations I have carried out a series of experiments specially bearing on the effect of weight and continued action upon the myogram. The muscles were made to lift weights at the time that the tracings were taken from them. In the case of the thumb the weight was suspended by means of a fine flexible string passing freely over a pulley and brought to bear on the thumb by means of a collar into which the second phalanx was inserted. In order to eliminate the effect and prevent the contraction of the other muscles of the hand and forearm the fingers and the wrist were made immovable by means of a wooden stock. In the case of the biceps muscle, the weight was held in the hand, the forearm being freely stretched out and free to move while the arm rested on a wooden box. The receiving tambour in each case was fixed in an adjustable support so arranged that the button of the tambour was brought into contact with the muscle during contraction.

I started by taking a series of tracings—about fifty—with different weights from the muscles of the ball of my thumb contracting in response to volitional impulses. I began with 50 grammes, and increased the weight by 50 grammes until the total of 5000 grammes was reached. On taking the average of the number of waves per second for each weight and comparing the different averages I found that with the increase of weight there was an increase in the number of waves per second. But as the number of seconds from which the averages were taken was necessarily small, and as I had not observed all the conditions which suggested themselves to me when making the calculations I discarded all these tracings and started afresh.

The results of the above myograms seemed clearly to point to a relationship between the variation in the number of vibrations and the amount of weight lifted. Several points in the tracings also suggested to me that the variation in the number of waves could be brought about by a variation in the load only, or a variation in the time during which the muscle was made to contract, the load remaining the same.

## I. *Effect of combined load and action on the number of waves in a myogram of a voluntarily contracting muscle.*

In the series of tracings, the results of which are seen in Tables I. and II., no attempt was made to separate the influence of an increase in load from the influence of an increase in the time during which the muscle was made to contract. The individual tracings of a group for any given weight were for the greater part taken in rapid succession, as three or four tracings were taken on the same sheet and only a couple of minutes were allowed to elapse between the several sheets. All the tracings except those for 'no weight' presented distinct and remarkably regular waves. Specimens of the tracings are given in the accompanying plates. The number of waves per second for a given weight was very constant, not presenting a deviation of more than one or one and a half from the average number per second when the tracings were short, i.e. not extending over more than 8 or 9 seconds. Most of the tracings whose results are given in Tables I. and II. were of this length.

Table I.

Presenting Analysis of series of Myograms taken from the Biceps Muscle contracting in response to volitional impulses.

| Weight in grammes | Number of tracing | Number of seconds from which the average has been taken | Average number of waves per second |
|---|---|---|---|
| 0 | 9 | 33 | 14 |
| 1000 | 12 | 110 | 15½ |
| 2000 | 9 | 125 | 16 |
| 3000 | 7 | 78 | 17 |
| 4000 | 7 | 80 | 17½ |
| 5000 | 12 | 100 | 18 |
| 6150 | 5 | 70 | 15 |
| 8500 (dead strain) | 9 | 58 | 15 |
| Tremor of whole arm with 6150 | 6 | 24 | 14½ |

Table II.

Presenting Analysis of series of Myograms taken from Muscles of ball of Thumb contracting in response to volitional impulses.

| Weight in grammes | Number of tracings | Number of seconds from which the average has been taken | Average number of waves per second |
|---|---|---|---|
| 0 | 12 | 43 | 12 ? |
| 1000 | 18 | 45 | 14½ |
| 2000 | 17 | 90 | 14½ |
| 3000 | 17 | 87 | 14½ |
| 4000 | 11 | 95 | 15 |
| 5000 | 11 | 102 | 15½ |
| 6000 | 10 | 103 | 14½ |
| Dead strain | | | 10 |

Two points of considerable interest are noticeable on examining Tables I. and II.

Firstly. The number of waves per second in the myograms taken from the biceps muscle is higher than that of the myograms taken from the thumb muscles contracting against the same stretching forces. This is just the opposite of what we should expect if these waves were merely of physical import.

Secondly. As the weight is increased there is an accompanying increase in the number of waves per second up to a certain point. Once this point is reached any further marked increase in the weight is accompanied not by an increase but by a decrease in the number of vibrations. For equal increments of weight the phase of decrease is more rapid than the phase of increase.

This peculiar relationship between the variation in the stretching weight and the variation in the number of waves per second is not so prominent in the case of the thumb as in the biceps myograms. The explanation is, I believe, to be found in the following facts, the full meaning of which will be better understood after the results of the experiments on the effect of increase in weight, and the effect of activity respectively on the number of waves per second have been given. Firstly, in the case of the biceps myograms, the group of myograms for a higher weight was commenced soon after the group for a lower weight had been finished. When this did not take place and a considerable interval necessarily intervened the muscle was submitted to some exercise, but not fatigued, before commencing the new group of tracings. In this way a certain uniform state of the muscle was secured before commencing each group of tracings. No such precautions however were taken in the case of the thumb myograms.

For example, the muscles of the thumb were greatly fatigued before beginning the group of myograms for 3000 grammes. On the other hand, an interval of several days had elapsed before I took the group of myograms for 4000 grammes, and the muscles were not submitted to any exercise before I began. In the second place, I was distinctly conscious on three occasions of a peculiar thrill in the interior of the forearm during the time the myograms for 5000 and 6000 grammes were taken from the muscles of the ball of the thumb. Was this thrilling sensation in the interior of the forearm due to the contraction of the *flexor longus pollicis* muscle? If so the waves in the myograms taken from the thumb muscles contracting against weights of 5000 and 6000 grammes respectively are graphic representations, at least in part, of the responses of the *flexor longus pollicis* muscle, while the waves in the myograms for the lower weights are due to the responses of the muscles of the ball of the thumb.

It is further worthy of note that the lowest number of waves per second are found in tracings taken from the muscles (1) when made to contract voluntarily against no external force, and (2) under a force which is too great to be overcome. For the unweighted Biceps I found 14 to 15 waves per second; when the Biceps was made to contract against a force which it could not overcome—dead strain—the myograms presented an average of 15 waves per second,—see Table I. In the case of the thumb muscles, when the unweighted muscles were made to contract, the myograms presented an average of 10⅓ waves per second, —see Table IV.; when the muscles were in a state of dead strain the myogram presented 10 waves per second,—see Table II. I have already given my reasons for regarding the average of 12 waves per second (Table II.) for the unweighted thumb muscles as being too high, no precautions having been taken to eliminate the influence of the simultaneous contractions of antagonistic muscles when the myograms (those obtained by Messrs Canney and Tunstall) which gave this result were produced.

There is also an interesting fact seen when the whole arm trembles. This occurs when the Biceps muscle is contracted voluntarily against a powerful force for any length of time. When the Biceps became too fatigued to sustain by itself the weight held in the outstretched hand, the muscles connecting the arm with the trunk came to its aid, and arm, forearm and weighted hand were slightly raised from the support on which the arm had hitherto rested and the slight trembling of the whole arm was distinctly felt. It was noticed that the character of the myogram now changed. The waves which were before regular and of small amplitude now exhibited considerable depth, but still remained regular as regards shape. The number of waves per second obtained in myograms from trembling of the whole arm was about 14½, and this number was very constant. The change in the character of the myogram when the contraction of the Biceps passed into a trembling of the whole arm is well shown in Figs. 6 and 7. This fact may also serve to explain the true nature of some of the large waves which occasionally present themselves in a myogram which upon the whole presents a series of small waves. Professor Schäfer[1], who calls attention to these larger waves, is inclined to regard some of them as summation waves. In my own tracings some of the larger waves undoubtedly present the character of summation waves; but I am inclined to regard at least some of them as being due to the vibration of the whole limb or to some sudden increase or decrease of the force opposing contraction, whether due to change in the resistance offered by antagonistic muscles or to a change in the external force. I found where precautions were taken to steady the limb and to eliminate the influence of the simultaneous contraction of antagonistic muscles as far as possible that the number of these larger waves became fewer.

It was found that when several tracings were taken in rapid succession a sensation of fatigue was experienced in the muscle sooner or later. And the myograms taken after the time that this sensation of fatigue was first experienced were found to present a less number of waves per second than the myograms which had been previously taken from the same muscle contracting voluntarily against the same force. The sense of fatigue made itself evident sooner with a great weight than with a small weight. With the heavier weights the sensation of

[1] This *Journal*, Vol. VII. page 214.

fatigue passed into a sensation of pain, which often became intense when the muscle had been made to contract for some time.

Several attempts were made to procure a series of tracings from different persons; but in no case was I very successful, owing to the fact that the necessary time could not be spared by these individuals. In Table III. will be found the results of myograms taken from two of my friends compared with the results obtained from my own muscles. So far as they go I believe they agree with my own: but it ought to be added that the myograms for the different weights were taken under very different conditions, and that the averages are in most cases taken from only two or three seconds.

TABLE III.

Comparison of number of Waves per second found on Myograms taken from the Thumb and Biceps muscles of Messrs S. and F. with results already presented in Tables I. and II.

| Weight in grammes | | | 0 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 |
|---|---|---|---|---|---|---|---|---|---|
| Results given in Tables I. and II. | Thumb | vibrations per second | 12 | 14½ | 14½ | 14½ | 15 | 15½ | 14½ |
| | Biceps | ,, | 14 | 15½ | 16 | 17 | 17½ | 18 | 15 |
| E. G. S. | Thumb | ,, | 9 | 10 | 10 | 11 | 10½ | 10 | 9½ |
| | Biceps | ,, | | | | 12 | 12½ | 13¼ | 13¼ |
| W. F. | Thumb | ,, | 8 | 8½ | 8½ | 10 | 10½ | | 9 |
| | Biceps | ,, | | | | | | 11½ | 12½ |

## II. *Effect of Weight on the number of Waves in a Myogram of a voluntarily contracting Muscle.*

In the myograms already considered no attempt was made to separate the effect of weight from that of continued action, long tracings were taken, and often several of these in rapid succession. In order to eliminate the effect of action as far as possible I took a number of short tracings, allowing about half-an-hour to intervene between each tracing. The results are shown in Table IV.

### Table IV.

Analysis of a series of short Myograms taken from the Muscles of the Ball of the Thumb voluntarily contracting.

| Weight in grammes | Number of tracings | Number of seconds from which the average has been taken | Average number of waves per second |
|---|---|---|---|
| 0 | 7 | 13 | $10\frac{1}{3}$ |
| 1000 | 3 | 17 | $12\frac{1}{2}$ |
| 2000 | 4 | 6 | 13 |
| 3000 | 4 | 17 | 14 |
| 4000 | 10 | 41 | $14\frac{1}{10}$ |
| 5000 | 6 | 41 | $14\frac{1}{2}$ |

The gradual increase in the number of waves per second as the weight increases is well marked in this series. No tracings were taken with a higher weight than 5000 grammes. It will be noticed that the average number of waves per second for the respective weights are lower than those for the same weights in Table II. This is just what we should expect, if as I believe the results of the next series of tracings—Table V.—show, that increased action as well as increased weight up to a certain maximum point causes an increase in the number of waves. The myograms whose results are given in Table II. represent the combined effect of weight and action, while the myograms whose results are given in Table IV. represent the effect of weight only, the effect of action being eliminated as far as possible, so in this latter case we get a less number of waves per second for a given weight.

### III. *Effect of Action on the number of Waves in a Myogram of a voluntarily contracting Muscle.*

With the object of ascertaining to what extent the variation in the number of waves was due to action and fatigue a series of tracings were taken, in which series, instead of a number of short tracings for each weight, there is one long tracing extending over $2\frac{1}{2}$ minutes.

TABLE V.

Presenting Analysis of a series of long Myograms taken fr m the Muscles of the Ball of the Thumb voluntarily contracting, the weight remaining constant for each tracing.

| Weight in grammes | Duration of each tracing in seconds | Average number of waves per second about beginning of tracing | Average number of waves per second towards end of the 1st minute | Average number of waves per second towards end of the 2nd minute |
|---|---|---|---|---|
| 1000 | 186 | 11 | 12 | 13 |
| 2000 | 154 | 12 | 13·5 | 13·5 |
| 3000 | 160 | 13·5 | 14 | 13 |
| 5000 | 110 | 14·5 | 13 | 12 |

In these tracings we see that the number of waves varies with the time during which the muscle is voluntarily contracted, the weight remaining constant during this time.

With 1000 grammes we find a gradual increase in the number of waves per second, from 11 at the beginning of the first minute to 13 at the end of the second minute. In this tracing the optimum effect of action and weight has not been reached. In the myogram for 3000 grammes, which it is important to note was taken immediately on finishing the myogram for 2000 grammes, we find 13½ waves per second at the beginning of the first minute; the optimum effect is attained by the end of the first minute, then there is a gradual diminution in the number of waves per second. In the myogram for 5000 grammes, which it will be found on reference to Table II. is the optimum weight (i.e. the weight accompanied by the highest number of waves per second); we find a gradual decrease in the number of waves per second, from 14½ at the beginning of the first minute to 12 at the end of the second minute. 5000 grammes being the "optimum weight" for the thumb, we are not surprised to find that protracted action has the same effect as an increase in weight would have.

We conclude then that the variation in the number of the waves seen in the myogram of a voluntarily contracting muscle is partly dependant on the weight and partly on the time during which the.

muscle is kept in a state of contraction, and that with an increase in weight as well as with an increase in the time during which the muscle voluntarily contracts we get an increase in the number of waves per second up to a certain point, and then a decrease.


### *Summary.*

1. The waves seen in a myogram taken from a voluntarily contracting muscle are graphic representations of contraction, and not of vibration waves. For

*a.* With a given weight there is a greater number of waves in a myogram obtained from a long muscle like the Biceps than in short muscles like those of the ball of the thumb.

*β.* In a given muscle though there is an increase of the number of waves with an increase of the stretching weight up to a certain point, beyond this point any increase in the stretching weight is accompanied by a decrease in the number of waves.

*γ.* Such increase in the number of waves which is found to obtain up to a certain point with increased weight is different from that which would be produced in a laterally vibrating elastic string by a corresponding increase of tension.

2. The number of waves per second in a myogram of a voluntarily contracting muscle varies in different individuals.

3. The average number of waves per second in a myogram of the Biceps muscle is greater than that of the muscles of the ball of the thumb contracting voluntarily in the same individual. The weight in the former case being held in the outstretched hand, in the latter case suspended from the first phalanx of the thumb.

4. The number of muscular responses per second in a voluntarily contracting muscle has been found to vary from 8 to 13 when the muscle is not made to overcome any force external to the body. This range of variation is probably too wide, the higher numbers being due to resistance offered by the simultaneous contraction of antagonistic muscles.

5. The average number of muscular responses per second in a voluntarily contracting muscle varies with the weight lifted. There is a gradual increase in the number of muscular responses per second as the weight is increased up to a certain maximum number; any increase in the stretching weight beyond this point is accompanied by a decrease in the number of the muscular responses per second.

6. The average number of muscular responses per second in a voluntarily contracting muscle varies with the time during which the muscle is made to contract. Increased activity producing an increase in the number of muscular responses up to a certain point, then a decrease. The phase of decrease is in most cases accompanied by a consciousness of fatigue.

7. The number of muscular responses per second presented by an *unweighted* muscle, and the same muscle in a state of *dead strain* contracting voluntarily, is fairly constant, and is the lowest number of muscular responses obtained from a voluntarily contracting muscle. In the muscles of the ball of the thumb the number is 10, in the case of the Biceps the number is about 14.

8. The myogram-waves become more extensive as the muscle becomes fatigued.

## DESCRIPTION OF PLATE II.

In each figure the base line represents the time and presents a notch every one or two seconds according as the time was marked every one or two seconds. The wavy lines are the myograms of the voluntarily contracting muscle. The vertical lines were drawn after the tracings had been taken in order to enable the number of waves corresponding to the time represented on the base line to be counted. The tracings all read from right to left.

Fig. 1. Myogram of Biceps voluntarily contracting against no external force. Space of time between the upright lines, one second. Taken from a tracing extending over about 10 seconds.

Fig. 2. Myogram of Biceps contracting voluntarily. 1000 grammes were held in the outstretched hand. Space of time between the two uprights 2 seconds. Taken from a tracing extending over 10 seconds.

Fig. 3. Myogram of Biceps contracting voluntarily. 2000 grammes were held in the outstretched hand. Time between two uprights 2 seconds. Taken from a tracing extending over 12 seconds.

Fig. 4. Myogram of Biceps contracting voluntarily. 3000 grammes were held in the outstretched hand. Time between two uprights 2 seconds. Taken from a tracing extending over 10 seconds.

Fig. 5. Myogram of Biceps contracting voluntarily. 5000 grammes were held in the outstretched hand. Time between two uprights 1 second. Taken from tracing extending over 8 seconds.

Fig. 6. Myogram of Biceps contracting voluntarily. Time between two uprights 1 second. Taken from tracing extending over 9 seconds. 6150 grammes were held in the outstretched hand. Towards the left of the tracing the waves are seen to increase in amplitude, at this moment the muscles connecting the arm with the trunk were called into play and the whole arm vibrated. This same effect is well seen in the next figure.

Fig. 7. Taken from same tracing as fig. 6. The muscles connecting the arm with the trunk were called into play. The arm was very slightly raised from the block on which it previously rested: but there was still consciousness of contact with the block at some points. I was conscious of the vibration of the arm but did not see the vibration during the time this tracing was taken. The vibration of the whole arm was seen also when other tracings were taken under similar circumstances.

Fig. 8. Myogram of Biceps contracting voluntarily against a force which it could not overcome. Time between the uprights 1 second. Taken from a tracing extending over 8 seconds.

Fig. 9. Myogram of muscles of ball of thumb contracting voluntarily against no external force. Time 2 seconds. Taken from a tracing extending over 6 seconds from Mr S.

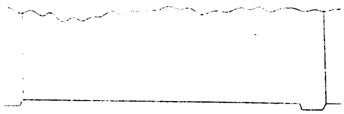
Fig. 10. Myogram of muscles of ball of thumb contracting voluntarily against no external force. Time between the two uprights 2 seconds. Taken from tracing extending over 8 seconds.

Fig. 11. Myogram of muscles of ball of thumb contracting voluntarily. 3000 grammes were raised by means of a string passing over a pulley and attached to the first phalanx of the thumb. Taken from a tracing extending over 8 seconds. Time between the two uprights 1 second.

Fig. 12. Myogram of muscles of ball of thumb contracting voluntarily. Weight 4000 grammes. Time in seconds. Taken from a tracing extending over 10 seconds.

Fig. 13. Myogram of muscles of ball of thumb contracting voluntarily. Weight 5000 grammes. Time in seconds. Taken from a tracing extending over 9 seconds.

Fig. 14. Myogram of muscles of ball of thumb contracting voluntarily. Weight 6000 grammes. Time in seconds. Taken from a tracing extending over 9 seconds.



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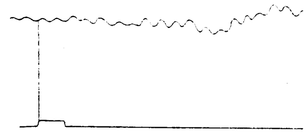

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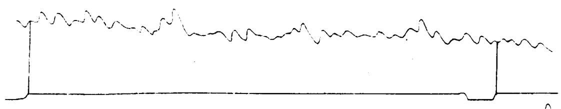

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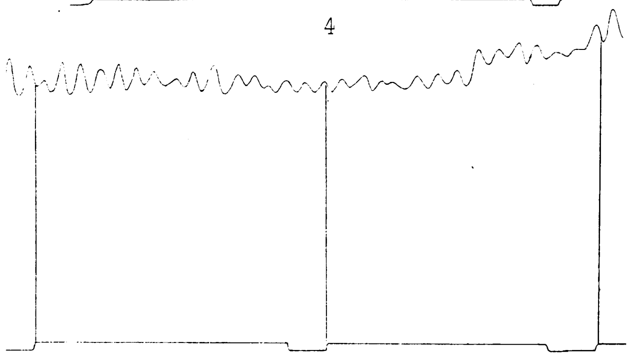

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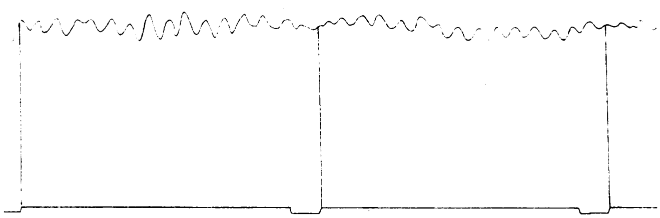

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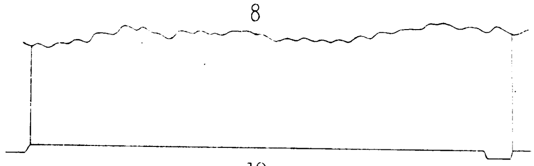

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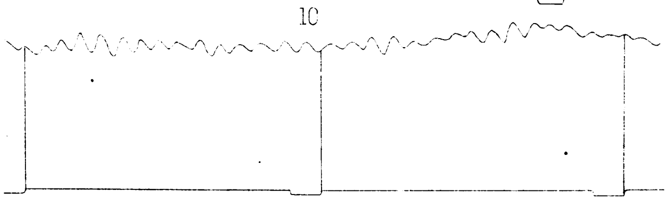

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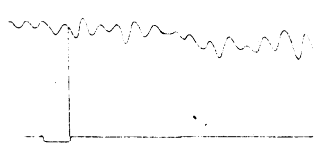

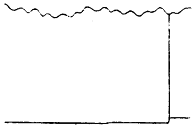

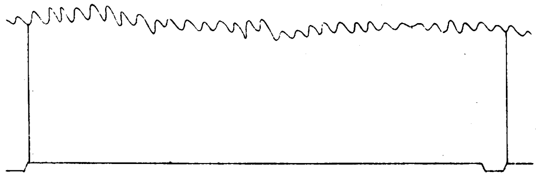

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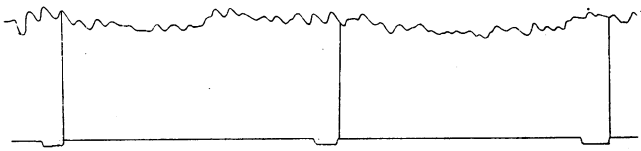

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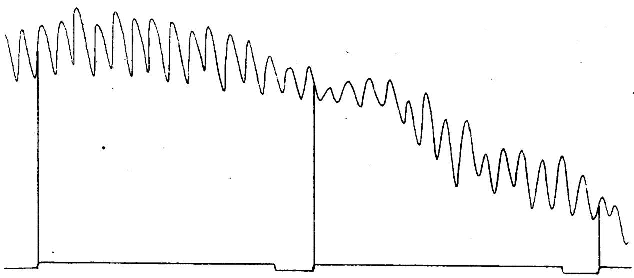

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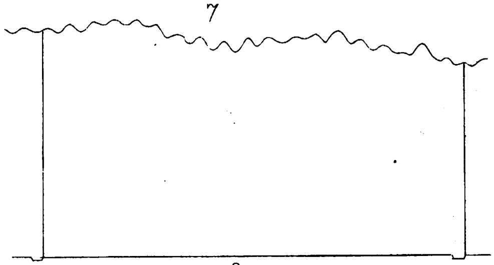

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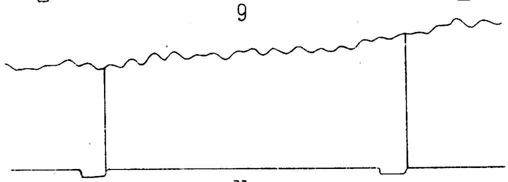

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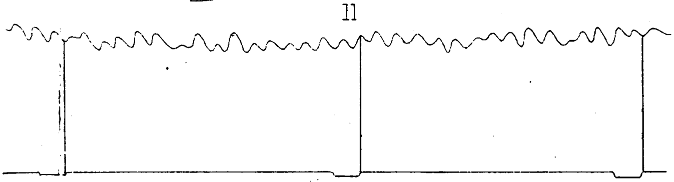

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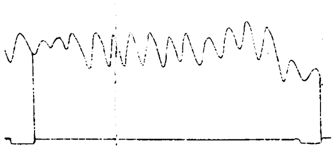

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