On the Summation of Electrical Stimuli applied to the Skin.

By

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Part II.

Original Experiments & Observations

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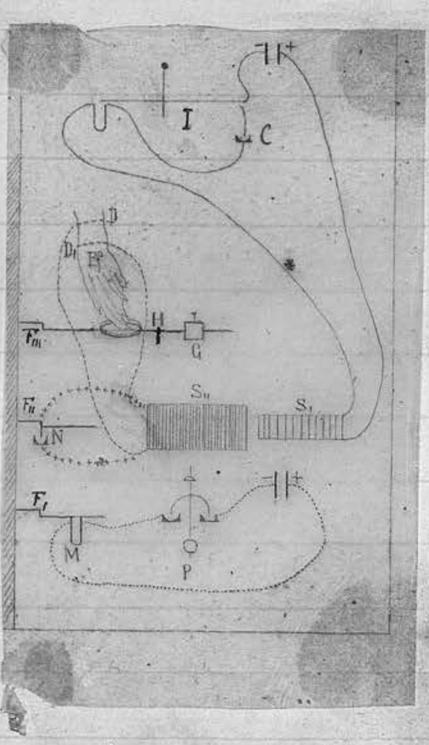
Description of the Arrangement of the Experiment and Apparatus.

The most complete arrangement of the experiment, which served for a great part of the investigation, is rendered plainly in the appended Schema. (Fig. 1)



Three pens F_I, F_{II} F_{III} write with Anilin ink upon the endless coil of paper on a kymographion whose cylinder moves with great precision. The three pens are placed directly above each other and as long as they are at rest they write horizontal parallel straight lines. The lowest pen F_I is drawn downwards a few Mm. by means of an Electro-magnet (M.) as long as the Second pendulum (P.) at the end of each vibration completes the closure of the time-marking circuit (.........).

The middle pen F_{II} is connected with a secondary closure (N') which is introduced into the induced-current (++++++)-circuit. As long as the key is depressed keeping the pen F_{II} also depressed, it conducts the current away from the preparation, which is therefore stimulated as the long as the line drawn by F_{II} is elevated.

The uppermost pen F_{III} rises up, being elevated by the counterpoise G. as soon as the foot of the frog (Pf) is withdrawn from a plate described in Bax's paper (W. Bax's Arb. aus d. physiol. Anstalt zu Leipzig p 71. /71./ The plate is attached to the lever (H.)

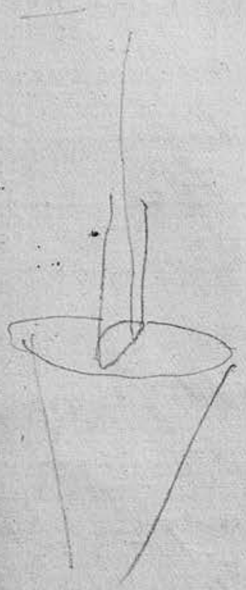
The electric stimuli, which occasioned the reflex movements of the limbs, were applied or conducted to the skin of the foot by two loops D. D_{II} of fine gold wire, which were separated from each other by a distance of about 5 Mm. These loops surrounded the ankle joint, without however constricting the skin. The wires were well isolated by sheet-caoutchouc ~~being~~ several layers, made fast to them by means of chloroform, which is an excellent solvent for this purpose. The wires ~~[illegible]~~ were connected to the poles of the secondary spiral S_{II} of a du Bois Reymond's Induction machine. The currents r metronome.

in the primary Spiral (S.) kept up by th
Grove's Elements, was broken and opened
at the mercury contact C. at regular
intervals by means of a Ruhmkorff's
Interruptor. (I.) The wires "l" and "m" (
conduct the primary current to & from
the Interruptor, whose essential parts a
here figured. The commutator at "n"
could be used for opening & closing the
current, whilst the Key "k" was not requ
for this arrangement of the apparatus.
The transverse bar "g" carrying a platinu
point reaches to the mercury contact "O"
from which it is withdrawn when the
other end of the transverse bar "p" is
attracted by the electro-magnet "i". The
contact thus severed breaks the current, &
renders the electro-magnet inactive; the
transverse bar springs back again, & thus
the vibration is commenced & continued, ju
as in the case of Wagner's hammer in th
ordinary induction machine. By mean
of the weight "h." which moves upon th
iron rod attached to the transverse bar, t
duration of each vibration of the pendu
system can be varied between the li
of 3/2" – 1/5". The small vessel "O" which
be raised or depressed, so regulates the c
that whilst the pendulum is at rest a
contact just exists; i.e an openin

induction shock would be produced as soon as the electro-magnet is set in action; after 1/4 vibrations the contact is again completed (Closing shock), after again 1/4 vibrations (whilst the style dips in & out of the mercury) an opening shock & so forth, i.e in equal intervals of half the duration of a vibration, we have alternately one opening & one closing shock. In that a good secondary closure, changeable at will, can be made or omitted (analogous to Helmholtz's arrangement in the induction-machine) by means of the vibrating bar, one may obtain the induction current in the opposite direction & of tolerably equal intensity. The spark at the opening never disappears completely.

The Washing Apparatus. Fig. 2.

This apparatus is intended to keep clean the mercury contact (C. in Fig. 1) from the isolated particles, which are formed by the unavoidable spark at the point where the primary current is broken, & which influence the constant completeness of the resistance & therewith the intensity of the current. The layer of alcohol, which following the suggestion of Poggendorff (Annalen B^{d} 94, 289.) stands above the mercury, to diminish the spark from the breaking of the current, is being constantly rendered dirty by the fine particles of oxydised mercury, & must therefore be constantly renewed. This is accomplished, by a fine stream which runs into the contact vessel „o" from a small funnel „b" filled with dilute alcohol. (& through the glass-tube a, provided with a stop-cock.) The outflow by means of the syphon „r" is so regulated, that the circulating alcohol, remains at (about) a height of 1 Ctm. above the level of the mercury. In order that the small funnel may be always filled nearly to the margin, i.e the supply for the stream may be kept constant, a small Mariotte's flask is placed above it. Through the bottom of the flask a glass tube of 5 Mm. diameter, is introduced & made watertight: This tube projects for about 2 Ctm. into the cavity of the flask. A conical pointed glass rod is placed in the tube to act as a valve (moveable). The pointed end of the rod projects below a little beyond the tube, so that it is elevated by the wall of the funnel as soon as the flask is placed on the funnel. An ascending tube of about 1 Ctm. in diameter fills the second hole in the bottom of the flask, & ends in an obliquely ground mouth about 1 Ctm.



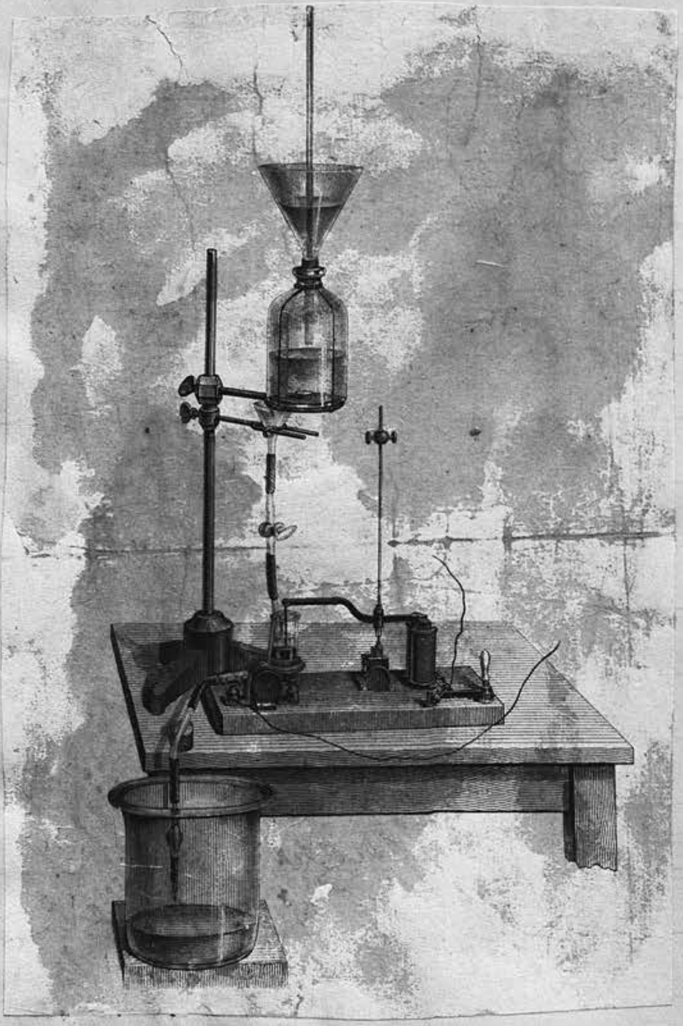
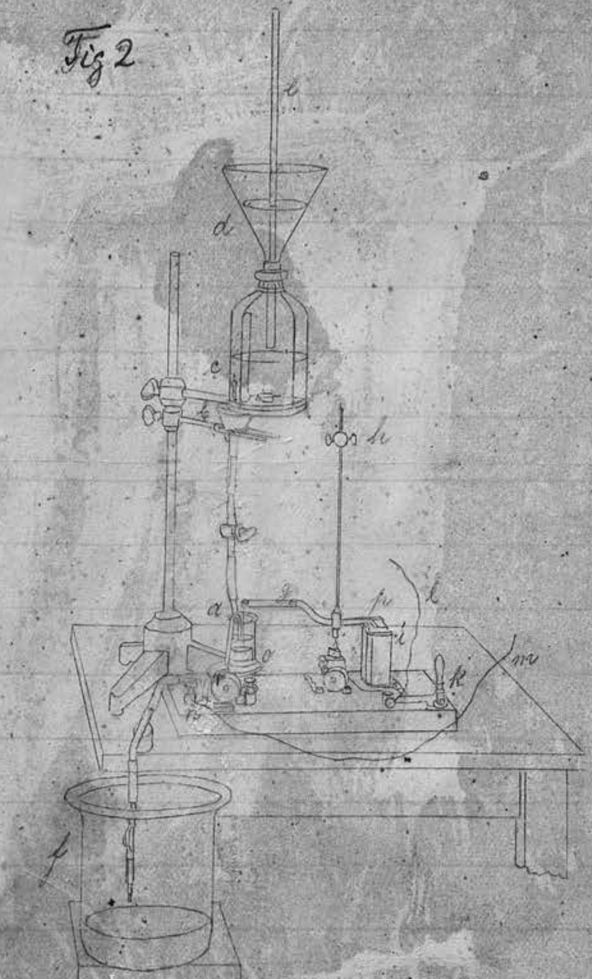


Fig 2



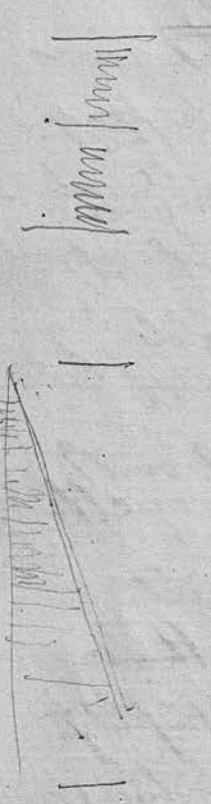
below the bottom of the flask, whilst the upper end reaches to the air space above in the Mariotte's flask. If the flask is filled to the upper opening of the ascending tube, & placed upon the funnel b, then the contents of the flask run into the funnel, until the opening (lower) of the ascending tube is closed by the level of the fluid. Then, by the pressure of the outer atmosphere, which cannot equalise that of the air contained within the flask, hinders the fluid from passing through the valve, until the level of the fluid in the funnel sinks & allows bubbles of air to ascend through the ascending tube. Thus the level of the fluid is kept constant just under the margin of the funnel.

The other parts indicated in the figure of Ruhmkorff's Interruptor will be referred to in their proper place in the text.

To imitate the chemical stimulation with the help of electrical irritation I began with applying to the limbs of ~~a~~ beheaded frogs the most frequent possible stimuli: The Wagner's hammer on the inductorium of du Bois Reymond, & later a König's tuning fork which vibrated 100 complete times in a second, & also a vibrating rod of steel (made out of an old duelling foil) were the means by which the primary current was interrupted.

i.e the greatest possible number of stimuli per second.

Minimal stimuli acted after very short latent stimulation, and soon lost their effect, if half a minute's rest was not given between the periods of stimulation. Strengthened currents produced reflex-contractions after very short latent stimulation. If such discharges of reflex activity were often produced in pauses of from 5 to 10 seconds, then the times of latent stimulation increased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to 3 seconds, & exceptionally to 5 seconds. The reflex contractions were at the same time weaker. The duration of the latent period could not be essentially changed i.e

diminished

by strengthening the frequent stimuli.

When ineffective stimuli were rapidly strengthened, then the reflex movements occurred with an intensity of the current, which remained powerless, when the currents were gradually increased to the same degree.

The often confirmed observation, that the minimal reflex contraction produced by frequent stimuli occurs after a short latent period, and that strengthened stimuli are not able essentially to short the latent period, seem to point to this, that the great differences in the duration of the latent-period, of limbs dipped in acid, are not ~~thus~~ caused, ~~that~~ by the varying ~~only the~~ intensity of the ~~very frequent~~ impulses ~~vary with the concentration~~. of similar high frequency

I therefore sought to observe the influence of changed frequence of stimulation. Slow vibrations of Wagner's hammer appeared to occasion ~~the reflex~~ elevation of the limb somewhat later, than the rapidly successive beats with high-toned spring. This result however was very doubtful, and perhaps might be caused by irregularities in the contact.

Even when I gave the limb only 48 Induction-shocks in the second, I observed little difference or no great difference in the latent period, whether the stimuli were strong or weak; only the size of the contraction increased with the strength of the current, & the latent-period first after the fatigue had made itself obvious, in that it increased the duration of the latent-period for equally strong stimuli: The following table may serve as an example of the fact cited. At the outset of the corresponding experiments, ~~seldom~~ successive ~~follow~~ stimuli of different intensities, were compared. In such, the latent-period was essentially lengthened, when the strengths of the currents were diminished.

^ applied at rare intervals

Table I.

Between each two observations, where nothing is said to the contrary, is $\frac{1}{2}$ Min. Rest.

Observations	Interval	Strength of Stimulus in Units	Latent-Period in Seconds.	Interval	Strength of Stimulus in Units	Latent Period in Seconds.	Degree of Contraction	Observations.
	$\frac{1}{8}$"	200	0,3"	$\frac{1}{4}$"	50	0,14"	I	after 0.5" III.
	"	150	0,4"	"	25	0,5"	I	" 1,0" III.
	"	100	4,4"	"	20	0,5"	I	" 2,0" III.
	"	125	1,5"	"	15	1,3"	I	" 2,5" III.
Min. Rest.	"	125	2,3"	"	10	2,0"	I	" 3,0" III.
	"	125	2,0"	$\frac{1}{48}$"	10	0,5"	II	} 10 Mins. Rest.
	"	150	1,5"	"	30	0,3"	II	
	"	175	1,0"	"	40	0,3"	I	
	"	200	1,0"	"	40	0,3"	II	
	"	150	2,0"	"	37	0,3"	I	
	$\frac{1}{50}$"	150	1,2"	"	70	0,3"	III	
	"	100	∞	"	60	0,3"	II	
	"	125	1,2"	"	55	0,3"	I	
	"	125	1,2"	"	45	0,4"	minimal	
2 Min. Rest.	"	125	1,6"	"	45		0	
	"	150	1,25"	"	50		0	
	"	175	1,0"	"	55	0,5"	I	
	"	150	1,3"	"	60	0,5"	I	
	"	175	1,4"	"	65	0,7"	I	
	"	150	1,3"	"	70	0,7"	I	
	"	175	1,5"	"	80	1,0"	I	
	"	200	1,5"	"	90		0	
		200	∞	"	100	1,0"	I	
				"	125		0	
				"				

The second half of this table shows the same
to the first-half, but also how the size of
fraction varies with strength of
Stimulus

The different strengths or degrees of reflex contraction, I have divided into four grades, in this way, (partly also for convenience in the tabular arrangement) Grade I. means raising of the foot alone, Grade II, flexion of the leg at the knee joint. Grade III, flexion of the thigh together with the leg (proper) (at the knee & hip joints) Grade IV violent, repeated spasms of one or both lower extremities.

A 0 under the rubric "Degree of contraction" means that in the corresponding period of stimulation, no reflex action occurred. The sign ∞ under the rubric, "Latent period" shows equally that the expected contraction did not occur.

These examples are chosen, because in the one case the latent periods, in spite of moderately strong & frequent stimuli soon become large, only with long intervals between the weak stimuli becoming markedly lengthened; in the other case with rapid succession of stimuli, however they have small values until the preparation is near to death. In both series no dependence of the latent periods on the intensity of frequent stimulation is to be observed. The stimuli must be gradually increased, in order to obtain results, and also act much longer, before they produce a contraction.

Table II.

Period of Rest between the periods of stimulation	Interval of Stimulation	Strength of Stimulus in Units	Latent period in Secs.	Degree of Contraction	
30 Secunden	1/4″	50 E	0,14″	I (~~nach~~ 0,5″ III)	after
»	»	25 »	0,5″	I (~~nach~~ 1,0″ III)	"
»	»	20 »	0,5″	I (~~nach~~ 2,0″ III)	"
»	»	15 »	1,3″	I (~~nach~~ 2,5″ III)	"
»	»	10 »	2,0″	I (~~nach~~ 3,0″ III)	"
10 Minuten	1/48″	10 «	0,5″	II	
30 Secunden	»	30 »	0,3″	II	
»	»	40 »	0,3″	I	
»	»	40 »	0,3″	II	
»	»	37 »	0,3″	I	
»	»	70 »	0,3″	III	
»	»	60 »	0,3″	II	
»	»	55 »	0,3″	I	
30 Secunden	1/48″ Int.	45 E	0,4″	minimal	
»	»	45 »		0	
»	»	50 »		0	
»	»	55 »	0,5″	I	
»	»	60 »	0,5″	I	
»	»	65 »	0,7″	I	
»	»	70 »	0,7″	I	
»	»	80 »	1,0″	I	
»	»	90 »		0	
»	»	100 »	1,0″	I	
»	»	125 »		0	

N.B. This table shows how with a small interval of stimulation, the times of latent stimulation are independent of the strength of the stimulus, whilst the degree or extent of the contraction however varies.

Even before the duration of latent-stimulation has reached 2 seconds, the sensibility is generally completely extinguished. The contractions become at the same time small, i.e only the foot is still raised. This coincides with the observations of Volkmann (Müller's Arch. f. Anat. u. Phys. 1838 p 23.) "dass die Ausdehnung der Reflexbewegungen vorzüglich von der Stärke der Reize und von dem Grade der Reizbarkeit abhängig sei".

The above cited difference in the sensibility of different frogs led me to investigate the point, whether perhaps the irritability of the spinal cord changed with the altered conditions of the life of the animal. Impressed with the investigations of Leube (Reichert & du Bois Reymond's Arch. 1867.) conducted under Rosenthal's direction, & further investigated by Uspensky (Reich. & du Bois' Arch. 1868), that apnoea (produced by strong respiration) suppressed the reflex-transmission in the spinal cord, I attempted by profuse respiration or ventilation of the lungs to influence the reflex processes. Although the effect of artificial inflation of the lungs in frogs was expected to be small, on account of the very complete cutaneous respiration in these animals, compared with what is observed in mammals, still a small result might have been expected with the sensitive method for graduating the strength of the stimulus, & for estimating the period of latent stimulation. In a long series of experiments, a glass cannula was introduced through the rima glottidis, & tied in the trachea of the previously prepared frog. The lungs were rythmically inflated by a regulated current of air

In the intervals, during which, by means of a column of water the inspiratory pressure was kept constant, (by means of Bowditchs' electro-motor stop-cock (Arbeiten aus. der phys. Instit zu Leipzig 1871.) the air was admitted or cut-off from the lungs), the expanded lungs could expel their contents through the well known Rosenthals' lateral opening in the Cannula. Many comparative experiments however convinced me that artificial respiration of different depth, & of varying frequency, exercises no effect or rather I should say influence on the reflex-processes in frogs. On the contrary, most of the preparations which lasted some time, showed at the beginning an increase of excitability. (The experiment was begun in from 1/4 to 1/2 an hour after the section of the spinal cord.

Also in many cases, in fresh preparations, (Winter) it was clearly to be observed, that weak stimuli after strong ones, were more effective than before these, i.e these caused modifications in the excitability, as was observed by Wundt (Reichert & du Bois' Arch. 1859, p 537) on motor nerves, by Türk (Sitzungsb. d. Wiener Acad. d. Wissensch. 1850, Novmbr) & later by W. Baxt. (l. c. p 74) on reflex-preparations, with chemical stimuli.

Later, & in general the irritability sinks with the time, but with very different rapidity, even in frogs kept und similar external conditions. Thus, frogs with divided spinal-cord, & which had only received a few trial stimuli, might be dead even in half an hour, whilst others had preserved their irritability of the highest degree, even for 30 hours after their preparation.

Several frogs were so extraordinarily sensitive, that they, even after destruction of the brain, after section of the spinal cord below the brachial plexus, & after the section had been cauterised by a piece of iron wire, were able upon being hung up, to execute spontaneous movements. Such a reflex-frog then reacts upon very weak electrical stimuli. Sometimes it happens also, that at once, after a series of ineffective stimuli has been interrupted, that violent movements follow. These are due to the occurrence of excitations which are foreign to the experiment

Such a summation of two qualitatively different stimuli (e.g. electrical & mechanical, or chemical) may be produced artificially, & thus render the individual sub-minimal stimuli capable of producing reflex movements.

Such anomalies in the irritability however did not too often disturb the course of an experiment. The rule is, that the limb together with the part of the spinal cord from which it depends, hangs motionless, until an external stimulus of sufficient strength meets it. The oftener it is stimulated, the stronger the impulses must be to cause reflex movement. The shorter the period of rest between the individual stimulations the more rapidly is the excitability lost. The excitability can however be kept constant for a long time, when one makes the duration of the period of rest from 3 to 10 minutes.

Long periods of rest bring with them a drawback, viz that the duration of a single experiment becomes very long, & often a rapidly progressing death does not permit of the comparison of the later series in the experiment with the ~~forme~~ earlier results. In most cases, therefore, I found it useful to introduce ½ to 2 minutes between the observations, & only in exceptional cases, after very fatiguing periods of stimulation, to give longer rest. The fatigue then progresses very slowly, & its effects are easily distinguished from the other conditions of the experiment.

After having found that with rapid succession of stimuli the ~~extent or~~ strength of reflex, but not the latent time, changed with the intensity of the stimuli, I tested the effect of varying strengths of the current with moderate frequency of stimulation. By means of the Ruhmkorff's interruptor figured in 2. (Fig. 2), with the help of a vibrating blade I allowed the primary circuit of the inductorium to open & close at intervals of from 1/2″ to 1/40″ of a second. On employing moderate intervals of stimulation (1/2″ to 1/15″) the time of latent stimulation constantly diminished, when the strength of the stimulus was increased.

The follow in extenso table of a long experiment will be sufficient to show, how the times of latent stimulation varies with the intensity of the current.

In that the law which regulates the dependence of the two cited factors cannot be formulated precisely, but as the direction of the approximate extent of the change in different stages of fatigue can easily be tested by every physiologist, so I will not take up time & space by giving a repetition of many series of experiments, as occasionally the experiments to be cited later implicitly confirm the above results. Still I cannot omit to remark that in my first series of experiments, there are sometimes anomalies where with unchanged intensity of current, the time of latent stimulation varies within wide limits. On account of such marked irregularities, which can easily occur when the current closure does not take place exact equably, it is always necessary to test the results of the experiment repeatedly, as was the case in the following example.

Table III

	Intervals of Stimulation	Strength of Stimulus Units	Relation	of	Latent-period in Seconds	Degree of Contraction
			Strength of Stimulus	Latent-Periods		
1	$\frac{1}{11}$"($\frac{1}{22}$")	100E	1,0:1	1:1,0	1,0	II
2		100	1, :1,0	1,0:1.	1,0	II
3		100	1,25:1	1, :1,8	1,0	III
4		80	1,0:1	1:1,11.	1,8	I
5		80	1:1,12	1,66:1.	2,0	I
6		90	1:1,11	1,09:1.	1,2	II
7		100	1:1,25	1,1:1	1,1	II
8		125.	1,39:1	1:1,2	1,0	II
9		90	1,12:1	1:1,17	1,2	I
10		80	1,14:1	1,08:1	1,4	I
11		70	1,16:1		1,3	I
12		60	1:1,66			0
13		70	1:1,0	1,:1,05	1,8	I
14		70	1:1,14	1,27:1	1,9	I
15		80	1:1,12	1:1,0	1,5	I
16		90	1:1,11	1,25:1	1,5	I
17		100	1:1,25	1,7:1	1,2	II
18		125	1,25:1	1:1,7	0,7	IIII
19		100	1:1,25	1,5:1	1,2	IIII
20		125	1,25:1	1:2,12	0,8	III
21	Relation of Intervals 1,:1,36	100	1:1,0	1,42:1	1,7	II
22	$\frac{1}{15}$"($\frac{1}{30}$")	100	1:1,25	1,5:1	1,2	I
23		125	1,:1,20	2,66:1	0,8	I
24		150	1,20:1	1:2,66	0,3	III
25		125	1, :1,0	1,0:1	0,8	II.
26		125	1:1,20	1,14:1	0,8	II
27		150	1,20:1	1:1,14	0,7	I
28		125	1:1,20	1,14:1	0,8	I
29		150	1,0:1	1:1,28	0,7	II
30	$\frac{1}{11}$"($\frac{1}{22}$")	150	1,20:1	1:1,0	0,9	I
31		125	1:1,20	1:1,22	0,9	I
32		150	1,20:1	1:1,09	1,1	I
33		125	1:1,20	1,2:1	1,2	I
34		150	1,20:1	1:1,7	1,0	I
35	($\frac{1}{15}$")$\frac{1}{30}$"	125	1:1,20	2,12:1	1,7	I minimo.
36		150	1:1,17	3,12:1	0,8	II
37		175	1,17:1	1:3,12	0,25	III(?)
38	1,5' Rest	150	1:1,17	3,12:1	0,8	II
39		175	1,17:1	1:5,0	0,25	III
40	2' Rest	150	1:1,17	5,0:1	1,25	I
41		175	1,17:1	1:5,0	0,25	III
42		150	1:1,17	5,0:1	1,25	I
43		175	1,17:1	1:6,8	0,25	III
44		150	1,0:1	1,13:1	1,7	I
45		150	1:1,07	5,0:1	1,5	I
46		160	1:1,09	1,5:1	0,3	III
47		175	1,09:1	1:1,5	0,2	III
48		160	1:1,09	1,5:1	0,3	III
49		175	1,09:1	1:2,0	0,2	III
50		160	1:1,0	1,33:1	0,4	II
51		160	1:1,09	1,5:1	0,3	II
52		175	1,09:1	1:1,25	0,2	II
53		160	1:1,0	1:1,2	0,25	II
54		160	1:1,09	1,5:1	0,3	II

Cont^d

	Interval of Stimulation	Strength of Stimulus in units.	Relation of		Latent-period in Seconds	Degree of Contraction	
			Strength of Stimulus	Latent-period			
55		175	1,09 : 1	1 : 2,0	0,2	II	
56	2' Rest.	160	1 : 1,09	2,0 : 1	0,4	II	
57		175	1,09 : 1.	1 : 1,15	0,2	II	
58		160	1 : 1,09	1,5 : 1	0,3	II	
59		175	1,09 : 1,	1 : 3,5	0,2	II	
60		160	1 : 1,09	2,33 : 1	0,7	II	
61		175	1,09 : 1	1 : 2,33	0,3	II	
62		160	1 : 1,09	2,33 : 1	0,7	I	
63		175	1,09 : 1	1 : 2,33	0,3	II	
64		160	1 : 1,09	2,33 : 1	0,7	II	
65		175	1,09 : 1	1 : 2,33	0,3	II	
66		160	1 : 1,09	4,0 : 1	1,0	II	
67		175	1,09 : 1	1 : 2,8	0,25	II	
68		160	1 : 1,09	3,5 : 1	0,7	II	
69		175	1,09 : 1	1 : 2,0	0,2	II	
70		160	1 : 1,09	2,0 : 1	0,4	II	
71		175	1,09 : 1	1 : 4,0	0,2	II	
72		160	1 : 1,09	3,2 : 1	0,8	I	
73		175	1,09 : 1	1 : 3,2	0,25	II	
74		160	1 : 1,0		0,8	II	
75		160	1 : 1,09		[illegible]	II	
76		175	1,09 : 1	1 : 6,0	0,2	II	Tetanus.
77		160	1 : 1,0	1,09 : 1	1,2	II	
78		160			1,1	II	

End of the Experiment.

N.B. This table shows the dependence of the times of latent stimulation & the degrees of Contraction upon the intensity of the ~~stimulating~~ current stimulating at moderate intervals.

that was casually remarked in the first half of the table formerly given, is very clearly pronounced in this one (Tab. II); that the latent period diminish whilst the strengths of the stimuli increase. To make more plain the relation between the increase in the stimuli and the times of latent contraction, I have reckoned the quotients of two neighbouring intensities, & also the quotients of each two successive latent period, & placed their values between the times of the two corresponding pair data.

If one now compares the relations of the strength of the stimuli with the reciprocally proportional numbers of the latent-periods; at the same height, it is to be observed in general that the values of ~~equal~~ similar neighbouring stimuli correspond to tolerably equal amount of latent-period, or rather it would be better expressed by saying that tolerably similar latent-values correspond to the values of similar neighbouring stimuli. In a few cases deviations are to be found, which however only become considerable when the stimulating tempo is changed; a circumstance which I shall have occasion to notice further on. The obvious inconstancy of effects the results, which is sometimes to be observed, are not alone to be ascribed to my methods of experimenting, which ~~certainly~~

are certainly capable of many improve but to the variability of nervous struct Even the trunks of the motor nerves, th investigated with the most perfect met when stimulated with electrical currents o weak intensity, do not always produce the corresponding muscles, contracti of exactly equal height.

In spite of the above mentioned i with similar relations, still one can observe the already cited fact, that af
periods of several stimulation, the excitability inc somewhat, so that e.g. 80 Units (E) m act 1,8–2,0", & afterwards only 1,4"–1, before they produce a reflex action that 70 E produce the effect, which previously 80 E had. Soon however times of latent stimulation again i so that the strength of stimulus 125 E, at first corresponded to a latent pe of 1,0", then to 0,7"–0,8", later, with eq interval (1") has the numbers 0,9"–1, –1,7" belonging to it.

Apart altogether from such mod of the excitability, we find, that, wh the values of the quotients of the sti deviate from 1, the quotients of the latent period also vary, & that in opposite direction, so that decrea latent periods correspond to increasing

But it is also to be observed, that by no means, as one might have expected, are the quotients of the stimuli & latent-quotients of similar series factors exactly reciprocal to ~~each~~ other. If we examine the single values (with the exception of the stimuli 4–8, which shows great anomalies) more closely, we find that with a moderate change in the intensity of the stimulus, the relations of the corresponding times do not materially depart from those expected; that when the stimulus is varied considerably, the latent periods change in a still higher degree (No. 17 to 21). A further increase of these differences between the corresponding values of the relative values in the two middle columns ~~are~~ to be found in Nos. 23 & 24. Then we observe that with progressive fatigue, nearly equal, nay sometimes smaller latent-quotients (of course always reciprocal) correspond to the large stimuli-quotients.

As induction currents of 125 E in spite of greater frequency had become ~~were~~ almost ineffective (No. 35), & now as 150 E in the series of effective stimuli were employed, [illegible] an increase of 25 E, the relative numbers of the latent periods reached much higher values than they had in earlier stage of fatigue with weaker stimuli of equal frequency & whose intensity ~~values~~ differed by 25 E. Even when the adequate

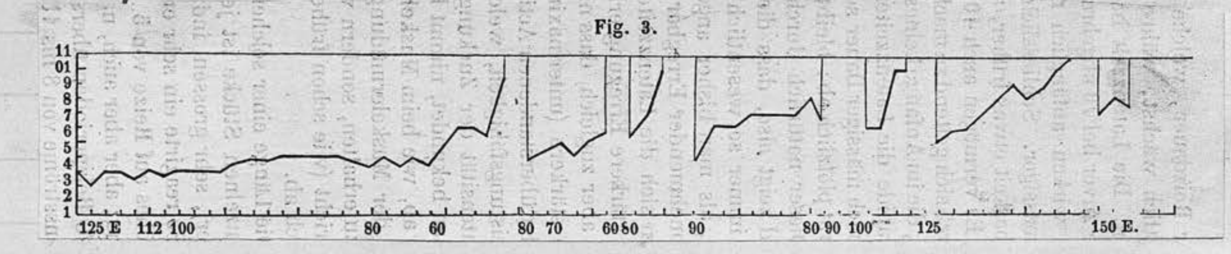
(No. 45.)

intensity of the current, (150E) was increased only 10 E, the latent period increased quite unproportionally, whilst a further increase of stimulus of 15 E only slightly shortened the latent irritation by a little. In the further course of the experiment with always similar relations of the stimuli; the relations of the latent-periods increase so that they reach the value 4:1 (No 66). & ultimately 1:6 only the latent periods of the weaker stimulus increase considerably, whilst those of the of the stronger stimuli remain tolerably unchanged. According to this then, the times of latent stimulation are by no means simple functions of the strength of the stimulus, like the height of a contraction upon the stimulation of the motor nerves, but quite different values correspond to equal increase in the stimuli under different degrees of excitability in the same reflex preparation. The result of the observation may be formulated thus; only a small limit exists between the maximal stimuli (with short latent periods) & the minimal ones (with long latent-periods). If the two stimuli which are being compared are on the other side of the limit (i.e. are both equally or nearly maximal), then they differ little from each other, no matter how different the absolute values of their intensities may be, if a stimulus remains however below the limit, or in consequence of fatigue becomes minimal or nearly so, whilst the other one compared therewith is still in the maximal area, then the effects of the two excitations are pronouncedly different, although their intensities, estimated according to their absolute value, may possible show only small differences. As I speculated upon the cause of this rare occurrence, it occurred to me, that the frequency of the stimulation exercises a great influence on the latent period, & that perhaps the frequency might vary with the intensity of the stimulus. The vibrating staff which produced the frequent interruptions (22 and 30 per second in the foregoing experimental series) gave 11 i.e. 15 closures & quite as many openings per second. In that the opening induction currents act more powerfully than the closing ones, so the former will be active with a difference between the distance of the primary from the secondary spiral, by which the latter will be quite without effect. If the approximation of the spirals however is carried so far that the closures also become adequate stimuli, then the frequency of the effective stimulations will be doubled.

To test this view I arranged the interrupter so that instead of making & opening the primary circuit, it closed & opened a good secondary closure. (Analogous to the arrangement of Helmholtz on the inductorium) Although I did not succeed in making both shocks completely equal, still the differences between the two were very greatly diminished. This arrangement did not permit of very rapid vibration of the staff.

The following Curve (Fig. 3) gives the results of an experiment obtained in this way.

Fig. 3.



Curve of latent-stimulation from a reflex preparation of a frog. One foot was stimulated at intervals of 1/4" by alternating currents whose two directions had attained nearly equal intensities. The stimulus strength of the varied between between 150 & 60 E of the graduated induction-machine, & is noted where the change was made. After each stimulus there was a period of rest of 1 min. The units in the ordinate, indicate seconds of latent time; the abscissa-units periods of stimulation.

The curve is constructed in this way that each unit in the abscissa corresponds to the duration of each period of stimulation together with the time for rest (1 Minute), the corresponding latent periods are drawn as ordinates, each of which are indicated in seconds upon the ordinate placed at the beginning of the curve. The connecting lines between the end-points of the ordinates gives the curve of latent stimulation. The vertical thin lines, which reach from the broken ends of the latent-period curve to the upper limiting line, show that that stimulus acting at that time did not produce any reflex movement, i.e that the latent period can here be marked as indefinitely great.

This curve shows that the duration of latent stimulation in a fresh reflex preparation is not essentially changed when the strength of the stimulus is diminished, 125E, 112E & 100E act after a duration of the stimulus of nearly equal length, whilst after the tenth period of stimulation with unchanged strength of stimulus, the latent period gradually lengthened from 3'' to 4'' i.e 1'' But it also remained at this height even with 80E. Then after diminution of the intensity by 20E, the latent period increases considerably, & soon however becomes quite ineffective (Latent period ∞). The limb reacts ~~with~~ 80E after short duration of stimulation, which does not essentially increase with 70E, whilst 60E remain without effect. With 80E the latent time again occurs, where it has formerly broken off with 70E. & soon becomes ∞. 90E act at first with a relatively short latent period, then after a moderate period. Lastly the excitability seems to increase; but 80E remain without effect & so do 90E. 100E can only produce effects for a few periods of stimulation. Under the influence of 125E, wh. at first certainly had no deleterious effect; the latent times increased rapidly to ∞. 150E, produce (still) after moderate duration weak reflex actions, then the preparation died suddenly; & gave no result with 1000E.

This result confirmed of course by many series of experiments shows, that the duration of the latent stimulation is by no means always so essentially dependent on the intensity of the stimulation, as was formerly supposed. When moderate stimuli, with diminishing irritability, become nearly minimal, the latent periods become considerably longer and can again be diminished by strong stimulation. We see however at the same time that stronger (sub-maximal) stimuli are not able to compensate the

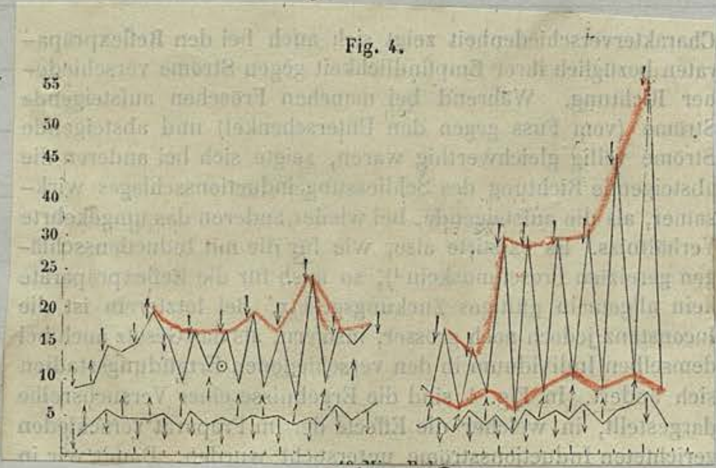
the weakening influence of the resulting actions, as in nerve-muscle preparations. The capability of energising, shown by the reflex-frog, in the rapidity of its reaction, apart from the intensity of the contractions, diminishes in a much more irregular manner than in a muscle; its course is not to be obtained very flat by long periods of rest as in the fatigue of a muscle, but becomes always steeper towards the end, & then breaks (as formerly shown) frequently quite suddenly.

The length of such a fatigue curve, & the increase or rise of its individual parts ~~is~~ however, even at the same time of the year, (winter) are subject to very large individual variations. Thus a very irritable preparation at the beginning of the experiment reacts to stimuli of 5 units after 5 secs. latent-stimulation, but after it has endured 75 periods of stimulation (in the course of 1½ hours) induction currents of 8 to 15 E acting at ½" interval suffice to produce reflex movements after 1" latent stimulation. Such differences in character are shown also by reflex preparations with regard to their sensibility to currents of different directions. Whilst in some frogs ascending currents (from the foot towards the leg) & descending ones were completely alike, in others the descending direction of the closing induction shock was more effective than the ascending one, whilst in others the this relation was reversed. No general law of contraction exists for reflex preparations, just as there is none for the frog's muscle stimulated with induction shocks. (H. Kronecker, Monatsb. d. Akad. d. Wissensch. zu Berlin 1870, p.640). In the former the inconstancy however is greater, in as far as the reaction varies in the same individual in the different ~~degrees~~ stages of fatigue. In Fig. 4. the results of an experiment are shown, where the the effects of differently directed currents in the preparation were investigated. In order that in every period of stimulation only equal similar induction shocks would be obtained, for this expt. I arranged the interruptor so that the anchor (like Wagner's hammer for Pflüger's blending) (E. Pflüger, Untersuchungen über die Phys. d. Electrotonus Berlin 1858 p.130). as soon as the magnet had attracted it, lowered a stirrup arch of copper wire into vessels with Hg. wh. were connected with the poles of the secondary spiral of the inductorium. Thus the opening shocks were conducted away from the preparation. — This arrangement, if it acts properly does not permit of any very rapid vibration of the anchor. The equal directed closing induction shocks were reversed after each period of stimulation so that the part was alternately traversed by ascending (↑) & descending (↓) currents. In the next figure, I beg, that you will at first attend only to the upper curve; the lower one will be considered later.

At the beginning of the upper curve we see that the latent period gradually increases independently of the direction of the current. From the 8th period of stimulation onwards the currents in the ascending (↑) direction begin to distinguish themselves by short periods of latent stimulation, whilst the descending (↓) induction-shocks, require a little longer time of stimulation than formerly, once (17th period) even to 24" to produce strong reflex actions.

Fig 4.

Fig. 4.



18 Min Rest:

Closing induction shocks, of 20 E intensity in 1/2" interval stimulate the reflex preparation. ~~They~~ follow each other after pauses of 3 mins. (Alternating ascending ↑ & descending ↓ direction of the current) The marks on the abscissa indicate periods of stimulation. The ordinates marks, each 5" latent stimulation. The upper curve indicates the time of strong reflex contraction.

The longer latent-period for the descending induction-shock-stimulation may be referred to the sixth law of contraction formulated by Rosenthal (l.c) that "die Reflexzeit für die vom Rückenmarke entferntere Stelle grösser ist als für die nähere".

After a longer pause (13 minutes) whilst the mercury of the secondary closure was being cleaned, very great regular differences in the action of the currents in both directions set in, so that after four periods the teeth of the latent-curve become very large: It appears that the latent-period only increase very considerably for currents in one direction (till over 51" latent-stim.), a peculiarity analogous to that cited in Table III. There we remark that the latent-periods increase only a little with the fatigue for strong stimulations, but increase considerably for weak stimuli; so that the quotients of the latent periods always considerably exceed the reciprocal proportions of the times of stimulation. — The later periods of the Expt. wh. are not given in the graphic representation of the results also point to remarkable changes in the irritability. The curve sinks again, & the differences in the actions of the ascending & descending currents disappear, just as was the case at the beginning of the Expt. Later, the latent times increase with the fatigue for ~~both~~ both directions of the current. With currents of high intensity contractions with very short latent-periods can however be again obtained.

In this series the individual shocks follow each other at intervals of $\frac{1}{2}$".

The times of latent stimulation ~~only~~ reach the considerable values of 1 minute & more, only ~~with~~ seldom stu
Only in these cases therefore do we observe great diffe
in the latent-time with change of the intensity of the stu

It was to be expected that the duration of the late
stimulation would be essentially influenced by the
stimulating tempo. The three tables wh. serve a
examples of the action of varying strength of stu
is afforded an opportunity of observing the influence
the varying frequency of stimulation.

In Table I (p 9a.) in the last-line, wh. conta
the interval of stimulating $\frac{1}{4}$", the latent-time 2,0
is noted, wh. corresponds to the strength of stimu
150 Units, whilst in the next period of stimulation
of equal intensity with an interval of $\frac{1}{50}$" only
1,2" elapses before a contraction occurs. Much
more pronounced however is the difference betw
the two neighbouring latent=values 2,0" and 0,5
In both cases the induction shocks, were of equa
intensity (10E); but in the first case the inte
of stimulation was $\frac{1}{4}$", in the second $\frac{1}{48}$". In
Table III (p 17.) there are smaller changes in t
interval of stimulation; ($\frac{1}{11}$" & $\frac{1}{15}$"). But here a
the time of the latent period clearly varies with t
change in the interval.

pplied to the
rogs foot-

1) 11 stimuli: (100E) per sec. act after 1,7" Latent p.
15 " (100E) " " " 1,2" " "
2) 15 " (150E) 0,7" " "
11 " (150E) " " " 0,9" " "

3.) {11 stimuli (150 E) per sec. act after 1,0" Lat. pd.
{15 " (150 E) " " " " 0,8" "

A glance at this table might be apt to lead us to the hypothesis, that a certain number of stimuli of a certain intensity were necessary in each stage of the excitability of the preparation, in order to produce a reflex action.

In the two first parallel cases 18,7, & 18,0 stimuli respectively were applied to the limbs before it was raised; in the second pair 10,5 & 9,9 shocks were effective. In the third pair the limbs reacted at the 11th & 12th induction shock. Such an assumption however is only true in seldom cases. We find deviation toward both sides.

A tabular view of some numbers of beats which were necessary to produce reflex actions in neighbouring periods of stimulation of equal intensity but varying intervals, will not only serve to enfeeble the just mentioned hypothesis, but also to give other useful indications.

The following trials are taken from suitable expts. where all the conditions of the expt. were ~~as~~ similar. Each of the running numbers in the table indicates a series of the expt. Several pairs from one expt. carry similar figures with different letters.

Table IV

Running Numb. of the Expts.	Strength of Stimulus Units	Interval of Stimulation Seconds	Duration of Stimulus in Secs necessary for Reflex action	Number of beats
1	150 150	$\frac{1}{8}$ $\frac{1}{50}$	2,0 1,2	16,0 60,0
2	10 10	$\frac{1}{4}$ $\frac{1}{48}$	2,0 0,5	8,0 24,0
3a	100 100	$\frac{1}{8}$ $\frac{1}{21}$	2,2 0,3	17,6 19.2
3b	100 100	$\frac{1}{21}$ $\frac{1}{8}$	0,7 2,4	18,4 14,7
4	100 100	$\frac{1}{8}$ $\frac{1}{21}$	2,3 0,7	13,6 14,7
5a	100 100	$\frac{1}{21}$ $\frac{1}{8}$	1,7 0,7	10,5 10,4
5b	175 175	$\frac{1}{21}$ $\frac{1}{8}$	0,5 1,3	30,0 16,0
6	20 20	$\frac{1}{4}$ $\frac{1}{8}$	7,5 2,0	20,0 8,0
7	15 15	$\frac{1}{4}$ $\frac{1}{8}$	5,0 1,0	16 16.
8a	11 11	$\frac{1}{4}$ $\frac{1}{4}$	4,0 2,0	4 4
8b	30 30	$\frac{1}{4}$ $\frac{1}{8}$	1,0 0,5	4 4
9	8 8	$\frac{1}{4}$ $\frac{1}{8}$	7,0 3,0	28 24
10	10 10	$\frac{1}{8}$ $\frac{1}{4}$	5,0 15,0	40 60
11	15 15	$\frac{1}{8}$ $\frac{1}{4}$	1,5 4,0	12 × 16
12a	12 12	$\frac{1}{5}$ $\frac{2}{5}$	2,5 7,0	12,5 15,5
12b	20 20	$\frac{2}{5}$ $\frac{1}{5}$	30,0 5,0	75,0 25,0
12c	20 20	$\frac{1}{5}$ $\frac{2}{5}$	10,0 45,0	50,0 112,5
13a	10 10	$\frac{1}{2}$ $\frac{1}{4}$	6,0 2,5	12,0 10,0
13b	10 10	$\frac{1}{2}$ $\frac{1}{1}$	4,0 15,0	8,0 15,0
13c	10 10	$\frac{1}{1}$ $\frac{3}{2}$	19,0 50,0	19,0 33,0
14	15 15	$\frac{1}{2}$ $\frac{1}{4}$	5,0 3,0	10,0 12,0
15	8 8	$\frac{1}{4}$ $\frac{1}{2}$	1,0 2,5	4,0 5,0
16a	500 500	$\frac{1}{4}$ $\frac{1}{2}$	1,0 3,0	4,0 6,0
16b	400 400	$\frac{1}{4}$ $\frac{1}{2}$	13,0 30,0	52,0 60,0
17	15 15	$\frac{1}{2}$ $\frac{1}{4}$	46,0 5,0	92,0 20,0
18	900 900	$\frac{1}{2}$ $\frac{1}{4}$	25,0 5,0	50,0 20,0

This table shows the dependence of the latent stimulation of the eye of the contraction upon the intensity of the stimulating current applied at moderate intervals

N. B. Continuation of this table on back of folded leaf marked ×.

A cursory glance at the foregoing table shows, that in the same preparation in the same stage of the excitability, with unchanged intensity of stimulus, the shorter latent period belongs to the smaller intervals of stimulation.

At the same time it is to be observed that it is quite unfair to compare the results of several series of expts together each other; for with the same intervals of stimulation there are very varying latent periods: e.g. with $\frac{1}{8}$" interval, variations between 0,5" & 5" latent p^d, with $\frac{1}{4}$" interval, latent stimulation from 1" to 30" & so on. —

The irritability of the different preparations is so various, that for each of the stimulating currents, one must give another intensity. Of course the cited units of the stimuli do not serve as absolute measures, because the Groves' Elements employed for the production of the currents, were not filled each time with fresh acid. During the same expts however, the combination remained obviously constant.

Through all individual & experimental differences however, it is to be remarked that frequent stimuli (to about 1/8" interval), even under unfavourable circumstances, (~~Al~~diminished excitability & weak strength of current) do not reach the long latency, ~~wh~~ which belong to them with seldom stimuli (1/2 to 2" Interval).

The greater the difference of the corresponding interval of stimulation, the greater also is generally the difference in the times of latent stimulation

The interval-difference $\frac{1}{8} - \frac{1}{21} = 0,07$ corresponds to 1,89" as mean difference of the times of latent stimulus reckoned from the cited expts.; the interval-difference $\frac{1}{4} - \frac{1}{8} = 0,125$ coincides with the mean latency-value of 4·07", & to the difference of the intervals $\frac{1}{2} - \frac{1}{4} = 0,25$ there belongs the mean of latency difference 12,4".

The three pairs of periods with the interval-difference $\frac{2}{5} - \frac{1}{5} = 0,2$ cannot be used for the estimation of the mean values, because the two last groups correspond to to stages of greater fatigue.

For the interval-difference 0,5 the corresponding mean value of the difference in the latent period is 23,3" ~~2[illegible].5~~. When we however exclude the results of the groups 13b & 22 = 9,0 & 3,5, then we arrived at the mean value 30,1. It is of course probable that a diff^t value belongs to the great-difference 0,5, according as it arises from $1 - \frac{1}{2}$ or from $\frac{3}{2} - 1$, or from $2 - \frac{3}{2}$. The induction-shocks following each other at intervals of 2" or 3" must for most frogs be chosen very strong, & be often repeated to produce an effect; whilst the shocks wh. follow each other at intervals of 1" without their having very great intensity are sufficient to produce reflex action in many preparations, in some however (where $\frac{3}{2}$" interval is quite ineffectual) first after frequent repetition.

If instead of the differences of stimuli & latency we regard the relations of the same, then we find that this is most easily expressed in the number of beats necessary for the reflex act, wh. are given in the 5th column.

From these numbers it is obvious that we cannot assume that in order to produce a reflex act, with unchanged excitability of the limb, a certain amount of stimulus is necessary, which with a varying interval of equally intense shocks require a corresponding number of shocks. The bracketed shocks of pairs of 4 pts vary most considerably from each other. Only in ~~some~~ groups, apparently by accidence, are there equal values. (No 5b, 8a, & ~~11~~). In by far the most cases large numbers of beats belong to the great intervals i.e the duration of latent stimulation with seldom stimuli is not only absolutely longer, than with frequent ones, but more than is necessary to permit of the completion of an equal number of stimuli. Not infrequently the number of beats of the seldom stimuli must exceed by a multiple those of the frequent ones before the limb is raised. This phenomenon has a ~~considerable~~ certain analogy to the results of W. Baxt's investigations (p) who showed that the time of latent action increase more rapidly than the strength of the stimulating acid diminished. Only the two first groups cited in the table deviate from the relations of the others. Relatively very many stimuli of short interval are applied to the limb, before it is raised. To discover

The cause of this peculiar phenomenon with the aid of completely instrumental methods I have not found time. ~~for~~.

7a,b, +8a,b)

Further, from the same table, is to be noted how with great intensity of stimulation the time of latency diminishes somewhat.

Fatigue acts as was shown already (p.23 Fig 3.) in an opposite manner. In the 3rd group wh. has the same intensity of stimulus as the 2nd the latency for $\frac{1}{8}$" is indeed smaller; but the degree of the reflex action was at the same time in this case a very low one. I will soon return to the relation between the degree of contraction & the latent time. The lengthening influence of the fatigue on the latency can be compensated, by increasing the stimulus; but this is not valid in an equal degree for all intervals. Whilst with medium intervals the fatigue can be overcompensated (5a. b. 8a, b) this can no longer be done with the larger ones (12a, b. c.). With such the duration of the latent stimulation soon reaches a very high degree. The increase of the latency with stimulation of different intervals will be more plain by the following curve. (Fig. 5) constructed from the data of a series of expts.

This series of expts. shows how the fresh preparation reacts equally rapidly to stimuli of tolerably different intensity (20E. & 12E.) & different intervals ($\frac{1}{5}$ & $\frac{2}{5}$). The extent of the two first contractions is somewhat greater, than that of the next following, wh. only reach degree II. In the 6th period a reflex act. of degree II after 10" latent stimulation is obtained under the same external conditions. With an interval $\frac{1}{5}$ however after 2". The process can be repeatedly observed, interval $\frac{1}{5}$ requires only the fifth part of the time of stimulation of the interval $\frac{2}{5}$.

In the 12th period of the expt. the reflex after seldom stimulus was somewhat anomalous but in the following periods the latency increased rapidly & soon

(35a)

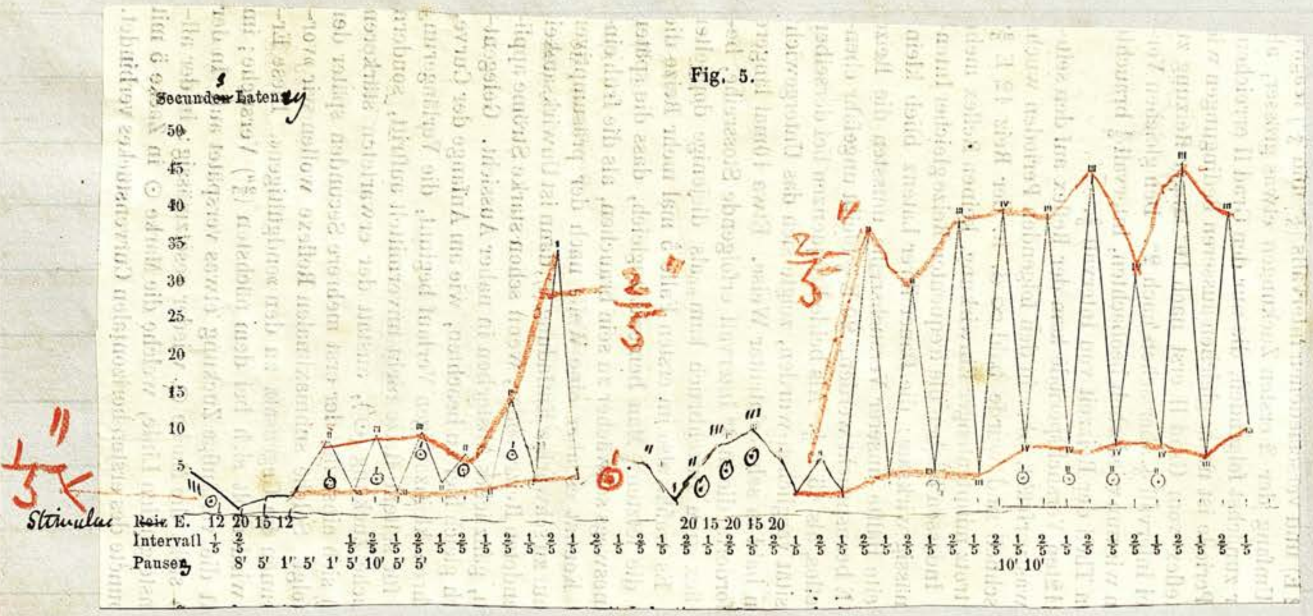


Fig. 5.

Curve of the times of latent-stimulation. Reflex preparation stimulated with induction currents of varying intensity (12-20 E) & varying intervals (1/5" & 2/5"). The units of the abscissa indicate periods of the exp't. wh. follow each other in the undernoted pauses of 1 to 10 minutes; each unit of the ordinate corresponds to 1" latency. The strength of each reflex is noted by the signs I. II & III as already indicated. The ⊙ indicates the time where the continually stimulated limbs contracts __before__ reflex indicated as final. Where nothing otherwise is noted the last noted number is valid.

36.

became ∞ i.e the stimulus 12 E $\frac{2}{5}''$ was unable in spite of ~~the~~ application for several minutes, to produce a reflex action. In the mean time the frequent stimuli of equal intensity remained still moderate, the duration of their latency remained small. For the second half of the experimental series the stimuli 15 E to 20 E must be employed 20 E $\frac{2}{5}$ remains nearly as long ineffective as 15 E $\frac{1}{5}$. When both frequencies with the same intensity of current were compared, the inferiority of the seldom ones is shown in a very striking manner. The series of shocks following each other at intervals of $\frac{2}{5}''$ require nearly ten times longer stimulation before a reflex action appears, than those of double the frequency. In the first case five times more stimuli were applied to the nerve than in the latter. It is to be observed at the same time, that the late reflex actions do not by any means require to be weaker, than those occurring early. If ~~it~~ occurs a time after the presumptive latent time, then we must look to inaction of the stimulus employed, or if strong currents have been employed, death will soon take place. In passing I beg here to remark ~~that~~ how at the ~~beginning~~ commencement of the curve, where it begins its small toothed course, the increase of the latency for seldom stimuli does not occur directly, but a weak contraction ⊙, instead of the wh. was to be expected (strong one) (II or III) occurs, the definite one occurring several seconds later. Such sub-maximal reflex actions, I will call

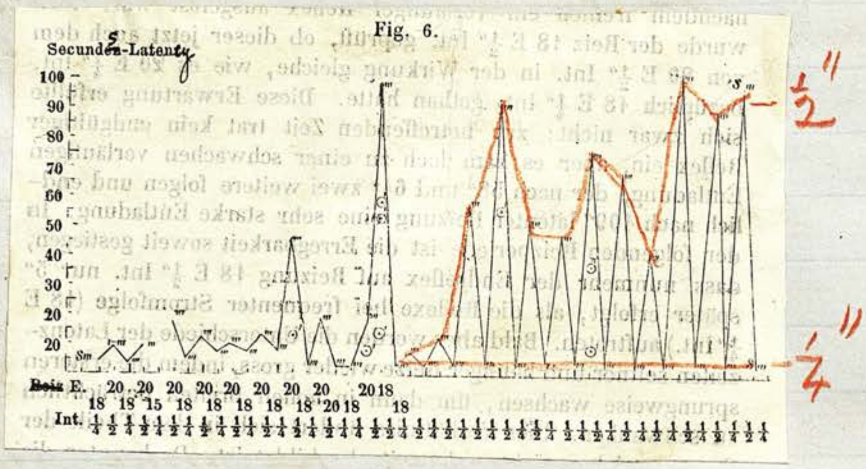
ly a weak dis-
charge (I.)

"preliminary" in opposition to the 'final contr
This phenomenon is repeated in the next ($\frac{2}{5}$") expt.;
in the third the preliminary contraction occurs somewh
late. In the 4th tooth the mark ⊙ occurs regularly;
the gradually ascending line wh. connects the mar
⊙ in the 5th tooth with the end of the first horizonta
part of the curve. In the 6th tooth, the point of
preliminary discharge is completely ~~#~~ wanting;
final one is ~~a~~ minimal. Indications of simi
relations are also to be found in the second pa
part of the same curve; specially in the parts w
belong to expts. with frequent stimuli.

The next figure (6) presents interest on accoun
the instructive distribution of the "preliminary refle
whose indications ~~We~~ will consider later in connect
with similar phenomena. This curve is worthy
being communicated on account of the uncomm
large variations in the heights, & because it sh
the temporary modification of the excitability of a
slightly fatigued preparation, such as I have
considered in Table III.

The frog wh. yielded this series of results
(Fig. 6 p. 37a.) gave even in the first testings with
stimuli of intervals $\frac{1}{2}$" & $\frac{1}{4}$", obvious differences i
the latency. The initial part of the above curve
wh. was preceded by 11 equally effective periods
stimulation shows that the latency of seldo
stimuli ($\frac{1}{2}$" Int.) are longer than those of
frequent ($\frac{1}{4}$" Interval), even when the intens
of the first (20E) somewhat exceeds that of

Fig. 6.



Curve of the times of latent stimulation. Reflex-preparation stimulated with varying intensities (18&20E). & varying intervals (½" & ¼"). The units of the abscissa mark periods of the 4pt, wh. follow each other at intervals of 3 Mins. The ordinates mark each five secs.; the Marks I. II. III. degree of contraction, the (☉) ring preliminary reflex actions.

of the latter (18 E.) On attempting to length
the latency of frequent stimuli by diminishing
the intensity of the current (to 15 E.) the reflex
did not occur. Alternate stimulation with
20E ½" Int. & 18E ¼" produced latent periods wh
graphic representation are given by the flat top
piece of curve. Thereupon a preliminary contr
⊙ occurs at the time when the final one c
be expected, & this is postponed till 45" after th
beginning of the period of stimulation. The next
definite point of contraction for 20E ½" int. sta
at the right place. The curve now remains
for two periods, although in the second instead
the stimuli 20E only 18E were employed. The frog appear
have become more excitable; nevertheless the late
for 20E ½" int. only again reaches the former valu
after a preliminary reflex has produced. The
18E ½" int. was next tested, whether it resembl
its effect 20E ½ int. as was done by 20E ¼" int
relation to 18E ¼" int. This expectation was
fulfilled; at the corresponding time no pr
contraction occurred, but there was a weak pre
discharge succeeded by two others after 58" & 6
& at last after 109" of latent stimulation a ve
strong discharge. In the following period
stimulation the excitability has fallen s
that the last reflex on stimulation by
½" int. follows only 5" later, than the ref
with frequent succession of currents (18E
Soon however the differences in the late

period of the seldom & frequent stimuli become great,
that the former increase by strides, their varying cond
within wide bounds. This relation changes in the p
of curve wh. is not figured. The seldom stim
of intensity 18 E could no longer produce a reflex. o
be supplanted by the intensity 20 E wh. also mu
act for a long time. In the mean time the tim
latent stimulation for the frequent stimuli remain a
unchanged at relatively low values 3"–4". As the p
-paration became very fatigued the stimuli of ¼" in
also summed themselves up, sometimes to 40", to p
a visible contraction.

Whilst the two former in extenso described & expti
of series of expts. serve for the comparison of the effec
seldom & frequent stimuli, presented absolutely lo
latency, the following expt. curve (Fig. 7) presents
experimental series in wh. the seldom stimuli (⅓")
at the maximum require only to act ~~at~~ seconds to produce
reflex, whilst on the contrary the frequent ones (⅛") ac
even after 0,5 seconds, & in the series of expts. neve
require more than 2,5" to produce the same resu
In the first place the cause of this relationship li
in the tolerably high frequency of both stimuli, but
in the individual differences in excitability as ha
been shown by the precise expts. of Kronecker on the
muscles. (Compare H. Kronecker, Arb. aus d. phys
Anstalt zu Leipzig, 1871, p 204.) I have als
experimental series where with ¼" interval & hig
intensity of current latent times of 7" & 20" & mor
were necessary to produce a reflex action, & al

others (June 1873) in wh. 0,25–0,5'' (i.e. 1 or 2 shocks) were sufficient to produce the result, witho the intensity of the current employed being uncom high (27E & 200E.). In the mean however the latent times wh. correspond to the interval of stimula ¼'' remain within the limits 2'' & 10'', & those of the in ⅛ between 0,5'' & 4''.

In order that the smaller variations in the latent pe may be made plain, in the construction of the follow curve, I have given the ordinates a 5 times smalle value (in time) than in the former curves, so that occupies the space between two lines.

Fig. 7.

Strength of Stimulus
Intensity of Current.

Curve of the times of latent stimulation. Reflex frog's preparat Stimulated with induction-currents whose intensity remai constant in each half of the series of the 4 pt. (first 30 E then 35 E. The intervals (1/3'' & 1/8'') alternate. The units of the abscissa ar minutes, those of the ordinates seconds. The degree of contra is indicated by the marks I. II. III. Where these are omit it is of the normal final strength (III).

In the small proportions we find again the preva of the variations in the latency with seldom success of stimuli, as is expressed in the previous curves The latency of the fresh preparation varies only wi with a change in the interval of stimulat

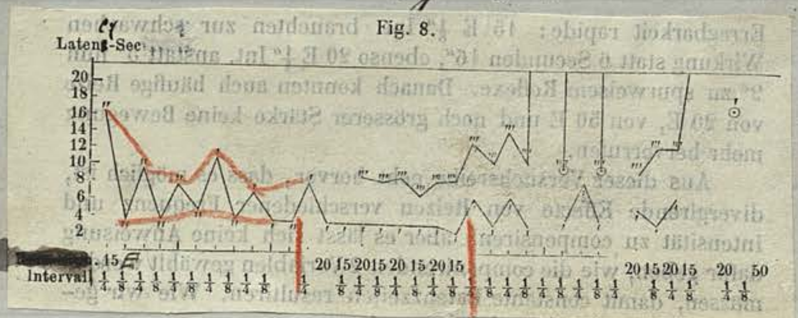
Suddenly however the times of latent stimulati rise to a high values for seldom shocks, whils for frequent ones the small latent times remain The third point of the great-teeth remains muc deeper than the two foregoing ones, but the refle is characterised as weak & ~~that~~ the next stimulation with interval $\frac{1}{3}$ no reflex is produc This shows that the previous reflex action wa only a preliminary one, but the final one cou not take place. Even with a somewhat lengthened pause the stimulus 30 E $1/3''$ ints. did not ai the action. The current of 35 units however after a longer time produce a result after moderately long latency.

In this series of 4 pts only the <u>first</u> refle-act wh. occurs is noticed. The stimulus was interrupted ~~as~~ as soon as the prepara had responded to it. Preliminary reflex act are always therefore noted as final ones. Thus is partly explained the relatively larg variations in the latency, when one takes into count the degree of contraction. I shal soon go more deeply into this point.

Up to this time we have considered the changes when the duration of the latent stimu when the intensity of the exciting current is changed, & when the interval varies. But occasionally have the resulting effecting of simultaneous change in the amount of the two variables.

The next curve (Fig. 8) shows how the reflex times change when stimulating-tempo & strength of stimulus are changed in the opposite direction. As we have seen from a former series of expts (Fig 5.) that a fresh preparation can react tolerably rapidly to considerably different stimuli; so I have begun the curve here represented, where the decreasing interval of stimulation in the 4 pt. permitted tolerable variations in the latency.

Fig 8.



Curve of the times of latent stimulation; reflex prep. stimulat with induction currents whose intensity were at first kept equal, whilst the interval of stimulation varied but later were varied in an opposite direction. Then ~~the~~ alternately once more the intervals with constant strength of stimulus; lastly both variable. The abscissae mark periods of stimulation, separated by pauses of 3 minutes from each other. R. indicates rest for 10 mins. Each unit of the ordinates corresponds to 2 seconds. The signs I, II & III indicate the degree of contraction.

The absolute values of the latent-times are also in this expt 'small', remaining within the limits 1" to 8". Only in a single case the stimuli remain latent for 16 secs. Here however we have to do with tolerably frequent shocks. Nevertheless the relations of the small amounts present us with the already known picture. The first toothed part of the curve presents again the varying amount of latency with equal strength of stimulus, with the intervals ($\frac{1}{4}$" & $\frac{1}{8}$".) During two periods ~~while~~ the same interval was employed the latent-time remained unchanged. The latency however could be kept at the same level by combining a diminished strength of current with ~~with~~ smaller interval; induction shocks of 20 E at an interval of $\frac{1}{4}$" remain equivalent to currents of 15 E & with the tempo $\frac{1}{8}$". Upon again employing the strength of stimulus 15 E. the different effects of the varied frequency became apparent. Soon however 15 E $\frac{1}{4}$" int. ceased to have an effect, & that completely, after having ~~produc~~ caused a weak discharge from the reflex centre; whilst in the reflexes wh. were produced by 15 E $\frac{1}{8}$" int. no change was to be observed either in degree of latency. The compensation between the frequency & the intensity of the stimuli could be again reached in higher limits of the latent time but suddenly the excitability sank rapidly; Instead of 6" 15 E 1/8" required 16 seconds for a

weak action, & 20.E ¼″ int. required of a
of 5.4″ for a trace of a reflex. Afterwards
stimuli of 20E, of 50E & even greater the
could not produce more movement.

From this series of 4 pts, it is obvious
it is possible to compensate diverging
of stimuli of different frequency & intensi
one cannot give any indications how
two component-variables must be chosen,
that constant-latent-times may result. A
in different stages of fatigue have seen (in Table III) ~~Similar~~ differe
or proportions of stimulus correspond to
differences or proportions of latency. With the
of different frequent-stimuli the laten
times with disappearing excitability incr
stimuli in quite different proportions; with se
stimuli more rapidly & more in strides than with f
stimuli. The increase of stimulus wh.
a fresh preparation is sufficient to give
distinct stimuli at ~~seldom~~ intervals the power of freq
weak stimuli are not sufficient with a
fatigued preparation, a circumstance
appears clearly in Fig. 5. & is also to be
noticed in Fig. 6.

Of course with varying moderate frequ
of stimulus we can certainly obtain latent times
constant size, by making the stimuli
-moderately strong; but then there also
occurs the minimum of latency. In
a case of course nothing is to be lea

regarding the relation of the stimulating force to the strength & number of the shocks. The following is deduced from our 4 pts.

By variation of the intensity of the individual shocks the latent-time can only be changed within narrow limits; on the contrary the graduation of the interval of stimulation affords us a means of obtaining extraordinarily large variations in the duration of the latent stimulation. Hence small differences in the latency caused by change in the tempo can be compensated by changes in the intensity of the current; but not great differences ~~however~~.

Further the time of latency cannot be varied indefinitely by changes in the tempo. The intensities of the current wh. are sufficient for frequent stimuli don't remain so for seldom ones. This may be seen by observation of Figs. 5 & 7. The more seldom stimuli (at first very active intensity) soon became completely ineffective, without maximal latency having previously been obtained. We must strengthen the intensity of the current to produce effects from the seldom shocks. The more the interval of stimulation is increased the more powerful strengths of currents are necessary to produce reflex.

Table V.

shows how the times of latent-stimulation increase with the interval of stimulation! seldom stimuli soon require strong currents to produce an effect, & the excitability is soon to be finished.

Rest between the periods of Stimulation	Interval of Stimulation Secs.	Strength of Stimulus in Units	Latent-time Secs.	Degree of contraction.
24 Minutes	$\frac{1}{2}$	10	6	II
11 »	$\frac{1}{4}$	10	2,5	II
5 »	$\frac{1}{2}$	10	5,0 6	I II
5 »	$\frac{1}{4}$	10	2,5	II
5 »	$\frac{1}{2}$	10	3 4	I II
9 »	1	10	8	II
5 »	1	10	9 15	I II
5 »	1	10	7 14	I II
5 »	1	10	8 19	II II
5 »	$\frac{3}{2}$	10	50	II
5 »	$\frac{3}{2}$	10	63	II
7 »	$\frac{3}{2}$	10	63	II
5 »	$\frac{3}{2}$	10	∞	
5 »	$\frac{3}{2}$	15	30 90	II 0
5 »	$\frac{3}{2}$	15	∞	
5 »	$\frac{3}{2}$	15	∞	
5 »	$\frac{1}{4}$	10	40	I
5 »	$\frac{3}{2}$	30	45	III
5 »	$\frac{1}{4}$	15	14	II
5 »	$\frac{3}{2}$	30	∞	
5 »	$\frac{1}{4}$	30	6	II
7 »	$\frac{3}{2}$	40	∞	

In this table the bracketed numbers indicate the latent-times of reflex contractions following each other ('preliminary' & 'final') in a period of stimulation.

It is worthy of notice that here the latent-times for small intervals (0,25") wh. are at first normally short become uncommonly long after the periods of strong stimulation in large intervals, with similar intensity of stimulus! & [illegible] first diminished by relatively strong currents to the ordinary amount), whilst we have generally seen that in spite of greater latency, they generally remain at nearly the same level.

with little change in the intensity of the current

The more distant the stimuli are chosen

the earlier

they become inactive in the stages of fatigue. Induction-shocks (closing & opening) following each other at intervals of 2,5") I have only seen active several times, when employing very high strength of stimulus with fresh preparations. In such a case the duration of the latent stimulation were as is shown in the following Table VI, very short, as strong shocks were applied to the foot immediately at the beginning of the 4 pl. Soon however the susceptibility was lost for the seldom stimuli; then gradation for the always more frequent ones with almost dead preparations ~~with~~ extraordinary intense shocks had no long latent times. Suddenly, after a double period of rest (2") had rendered possible a contraction with short latency to stimuli of interval 0,5" the excitability was completely & for finished! even to the at other times infallible pinching.

Table VI.

Shows how ~~long at doses~~ stimuli (or seldom intervals applied at rare) only produce reflex actions ~~with~~ when they have an + an advancing intensity ~~of stimuli~~ owing being applied to the fresh preparation, soon become ineffective! & how both sinking & irritability do not respond to always smaller intervals of stimulation.

Periods of Rest in Minutes	Interval of Stimulation Secs.	Strength of Stimulus Units	Latent time Seconds	Degree of Contr.
38	2,5	1000	5,0	III
1	2,5	1000	∞	
1	2,0	1000	∞	
2	2,0	1000	25,5 48 58	I I II
1	1,5	1000	10,0	III
1	1,5	1000	36,0	II
1	1,5	1000	12,0	III
1	1,5	1000	18,0	III
1	2,0	1000	46,0 66,0	I II
1	2,0	1000	35,5	I
1	1,5	1000	7,5	III
1	1,5	1000	18,0	II
1	1,5	1000	16,5	III
1	2,0	1000	64	III
1	2,0	1000	42,5	III
1	2,0	1000	49	III
3	1,5	1000	19	III
1	1,5	1000	18,75	III
1	1,5	1000	21	III
1	1,5	1000	36,0	II
1	1,5	1000	40,5	II
1	1,5	1000	26,0	III
1	1,5	1000	53,75	I
1	1,5	1000	∞	
3	1,5	1000	∞	
1	1,0	1000	10	II
1	1,0	1000	11	II
1	1,0	1000	14	I
1	1,0	1000	16	II
1		1000	∞	
10		1000	8,5	II
1	1,0	1000	8	II
1	0,5	1000	8,5	II
1	0,5	1000	9	I
1	0,5	1000	10	I
1	0,5	1000	∞	
	0,5	[redacted]	—	II
2	0,5	1000	11,5	
1	0,5	1000	∞	
	0,5	[redacted]		0

Pinching

~~Kneifen~~ = pinching

In another case where the shocks of intensity 900 E had been applied without effect for a minute to the limb of a fresh preparation ~~without effect~~, 1000 E produced after 40 seconds a weak reflex, & then with the direction of the current reversed a weak contraction after 17,15" of latency. Hereafter the interval 2,0" itself was almost completely without effect; it required stimuli following each other every second to produce promptly reflexes after short latency. After several periods of stimulation shocks of interval 0,5" were no more to be trusted & then the preparation died.

Strong stimuli therefore act very rapidly deleteriously, even without producing any visible reflex. We will soon see that sub-maximal shocks also, i.e. those with a moderate interval of stimulation just suffice to produce a reflex [with greater intervals] do not diminish the excitability pronouncedly. There is, here an essential difference from the condition of the transversely striped muscles, in wh. Kronecker remarked the peculiar condition "dass schwächere Reize, wenn sie keinen erheblichen Effect mehr haben, nicht ermüden wie es maximale Reize thun auch ohne mechanische Wirkung zu äussern, dass der mit unwirksamen Reizen behandelte Muskel

Note¹) The deviation observed by Funke (Pflüger's Archiv 1871. p 261.) is only apparently so. The closing induction shocks wh. were regarded a of equal maximal value with the corresponding opening-shocks, were not maximal, as is shown by this, that they became sooner effective than the opening-shocks, & even at the beginning showed small differences i heights. The heights of the pair of closing & the corresponding opening induction shocks given a an example in Fig 22 (a) Plate III are relatively more different than the contrac designated by Kronecker (l.c. p 260 Fig 30) as maximal & sub-maximal.

sich fast wie ein Ermüdender verhalte".(1) (Arb. aus d. phys. Anstalt zu Leipzig 1871. p 264.)

We therefore see that successive stimuli ‸tend to produce two opposite results in the preparation, viz to produce movement & to diminish life. This injurious influence seems to belong in the highest degree only to the most intense stimuli; movement on the contrary as we have seen is better assisted by repetition of the shocks, than by strengthening them. With ~~seldom~~ stimuli applied at rare intervals, which require strong ~~stimuli~~ currents to be effective at all, the injurious influence is therefore more obvious than with frequent succession of shocks.

How can we conceive this summation of movements?

By observation of the already cited 'prolonged reflex' scheme we shall be able to gain much important information.

Türck in his already cited paper(2) remarks that "Sehr häufig erfolgt eine kräftige Streck- und Beugbewegung der in der Säure getauchten Extremität (des Frosches) nicht plötzlich sondern es gehen ihr erst geringe langsame Bewegungen voraus" Es wurden dadurch für jede Hinterextremität zwei Ziffern erhalten, z. B. 12–17 Secunden Latenz an der Normalen, 7–12 an der hyperästhetischen.

(2) l.c. Separat-abz. p. 3.

Sanders-Ezn (Arbeiten aus d. phys. Anstalt zu Leipzig 1867 p 29). in a special chapter discusses "Die Wiederholung derselben Bewegung bei anhaltender (chemischer) Reizung." He finds an appreciable pause always elapses between the first & second appearance of the second muscular movement, the pause being the shorter the greater the excitability "Dieses abwechselnde Verschwinden und Erscheinen einer Bewegung zeigt an, dass der Reiz, obwohl er continuirlich besteht, dennoch nur periodisch seine auslösende Wirkung äussert." He observed often, that when two similar weak stimuli were applied shortly after each other, the movement following the latter stimulus was more energetic than that which occurs after the first one. As the most probable explanation of this he holds "dass die vom Ersteren Reiz disponibel gemachten Kräfte bei der darauf folgenden Bewegung nur theilweise ausgelöst wurden, während der restirende Theil sich zu denjenigen Kräften summirte, welche durch den zweiten Reiz disponibel wurden."

An analogous phenomenon was observed by Eduard Weber (Art. Muskelbewegung Wagner's Handwörterbuch d. Physiologie Bd III. Abth II. 1846 p 19.) as he sent the alternating currents from an electro-magnetic apparatus through the limb of a frog,

× also by Nothnagel, (Zur Lehre vom
klonischen Krampf. Virch. Arch. B^{d} 49,
p 276.)

wh. was only connected to the trunk by the ischiadicus. Weber observed (as is referred at the beginning of this paper) that a considerable time elapsed before the movement followed: "dass ferner, ungeachtet die Einwirkung des Rotationsapparates ununterbrochen fortdauerte, die Muskelbewegungen vorübergingen, Pausen zwischen sich liessen, und wieder kamen, als ob das Thier wirkliche Anstrengungen machte, dass endlich auch nicht immer dieselben Muskeln in Bewegung geriethen".

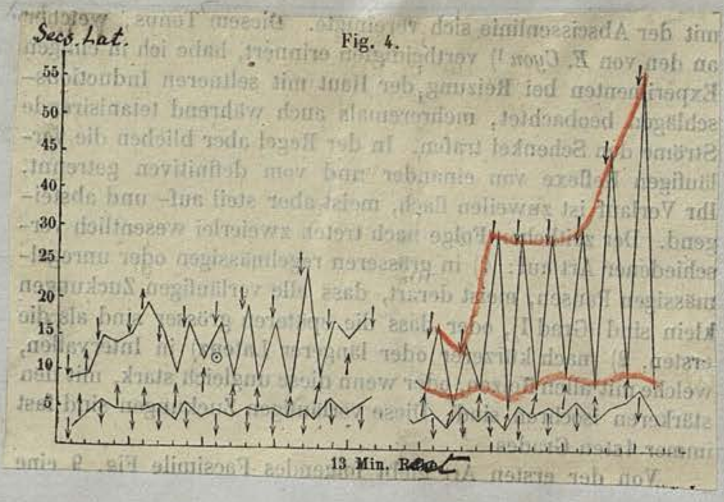
Similar peculiarities were observed by Setschenow× in electrical stimulation of the central end of the ischiadicus. With weak stimulation with tetanising currents of the induction machine, he observed at once at the beginning of the stimulation, only a single evanescent movement of the anterior extremities; or following this still a series of quivering contractions lasting for several seconds; then rest. Moderately strong stimulation caused at once strong movement in both anterior extremities, wh. then assumed a tetanic character, to make room in a few seconds as in the former case for absolute rest. Nevertheless if the stimulation is continued after the elapse of some time (sometimes 1–2 minutes) a tetanic wave is observed to pass over the body of the frog, wh. generally begins in the femoral muscles of the stimulated side, & is propagated from here to the abdominal muscles & the anterior 4tremities & ends in the form of a strong continuing tetanus. Later there follows malcoordinated movements. "Bei starker Reizung wird die erste Bewegungspause ubergangen. Anstatt ihrer sieht man höchst unbedeutende Bewegung in den 4tremitäten mit nachfolgender Ruhe von einigen Secunden, oder ein sofortiges Auftreten der zweiten Bewegungsphase in Form einer tetanischen Hebung der 4tremitäten mit nachfolgendem Strecktetanus." Setschenow 4plains the rest after the first attack as an "inhibitory phenomenon" produced by the strong stimulus; for when the stimulation of the nerve is interrupted at the beginning of period of rest, one always obtains as an after-effect a (sometimes very strong) tetanic ~~Stellung~~in of the arms.

Setschenow made progress in the analysis of the process of summation by stimulation of the central end of the ischiadicus with single electrical shocks. He says (l. c p 11) "Unterbricht man constante galvanische Ströme (welche zu schwach sind, als dass Schliessung und Oeffnung derselben einzeln zu wirken vermochte) beispielsweise 60 mal in 1 Min. so tritt nach einigen Unterbrechung die erste Zuckung noch schwach und in einer beschränkten Anzahl von Muskel ein, die zweite, dritte u.s.w. werden immer stärker und ausgebreiteter, bis endlich eine Bewegung der ganzen Extremität zu Stande kommt, aber auch jetzt sieht man dennoch oft eine jede Stromesschwankung durch eine Zuckung der in der Bewegung begriffenen Extremität beantworten.

In none of the above cited papers are there to be found nine exact results regarding the relations of time by wh. the reflexes produced at different parts of a period of stimulation, stand to each other.

Table II in this paper gives some values, wh. show with moderate frequency of stimulat. (1/4") a moderately rapid increase of the latent times of the preliminary as well as of the final reflexes. A series of 4 pts. is presented in Fig. 4 where the preliminary reflex has occurred in every period of stimulation. The characteristic curve of these times of latency wh. I have indicated of where this curve was first introduced, I have again introduced here.

Fig. 4.



Closing induction shocks of 20 E in ½" int. stimulate the preparation. The periods of stimulation follow each other after intervals of 3 min., alternated in a descending (↓) & ascending (↑) direction of the current. The lines on the abscissa indicate periods of stimulation, those of the ordinates each 5 secs. of latent stimulation. The lower curve indicates the latency of preliminary (weak) reflex contraction the upper indicates the points of final (strong) excitation.

The course of the lower curve deviates from that of the upper ones in a marked manner. Whilst the latter ~~is characterised~~ shows by its large teeth that the latent-times for the descending currents rapidly increase to very great values, the latencies of the preliminary reflex remain within narrow limits (3"–8"). Although here a less action of the of the descending current is also obvious. Further the preliminary reflexes in this series had a peculiar form. They were not rapid evanescent contractions but gentle & continuing elevation of the foot, which gradually increased, to wh. were then added weak movements of the knee till suddenly the flexors of the foot, leg & thigh became strongly contracted, after wh. the succession of stimuli was generally interrupted & the limb sank suddenly to its position of rest. ~~In many expts of this series where the stimulation had to last very long before it produced a final contraction~~

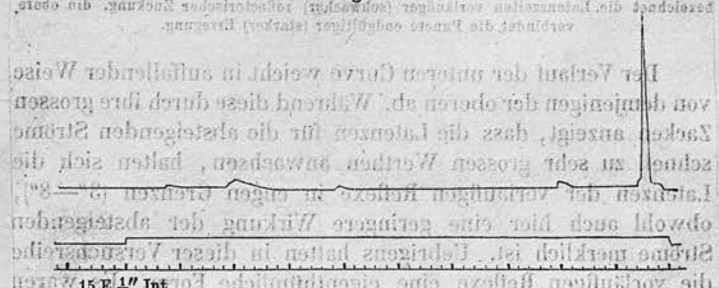
~~the weak tonic contraction of single small contractions following in long irregular pauses (whose latency is not indicated in Fig 4.) between wh. the curve drawn by the plate for the frog's foot again became united with the abscissa.~~ I have observed this tonus wh. remembers one of that supported by E. Cyon (Pflügers Arch. Bd VIII 1874 p 348) in several expts in stimulating the skin with seldom induction-shocks, several times also whilst tetanising shocks were applied to the ~~sk~~ limbs. As a rule however the preliminary reflexes remained separated from each other & from the definite one. Their course is sometimes flat, generally however steeply ascending & descending. According to their temporary course there are two essentially different sorts: 1) in great, regular or irregular pauses.

mostly of this sort, that all preliminary contractions are small (degree I), or that the later ones are larger than the first ones, 2) (after shorter or longer latency) in intervals, wh. are isochronous with all stimuli, or when there are unequally strong, with the stronger. The preliminary contractions are almost always of the 1st degree.

The following facsimile Fig. 9 gives an example of the first sort.

Fig. 9.

Fig. 9.



The limb of a reflex frog preparation weighted with 5 grms. fixed to the writing-lever, stimulated with alternating induction currents of 15 E intensity at intervals of ½", the elevations being written on the upper line of the endless paper. The middle line drawn by a ~~secondary~~ accessory key is notched upward as soon as the stimulation is applied to the limb, & downward when they cease. Seconds are marked on the lowest line.

The first small elevation of the post. begins after 3,5" after the beginning of the stimulation, after this, one a little stronger after 6", & then after ~~2~~" individual weak pauses of 9" & 20"

Hastily after 48" latency a strong elevation of the whole limb (Degree of contraction III.)

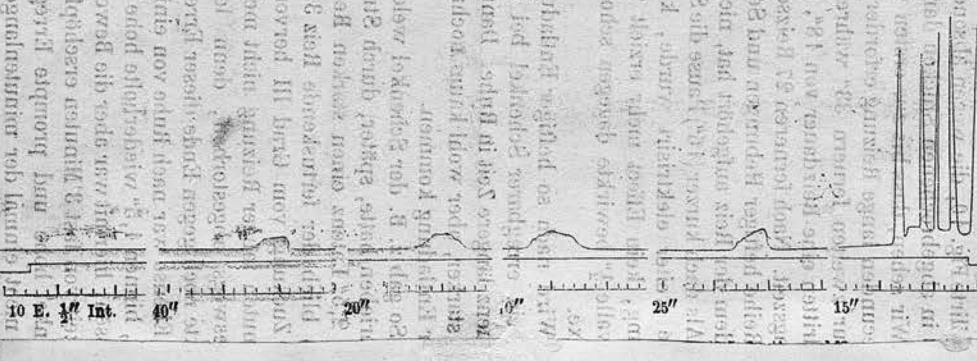
After a short pause this limb replies to frequent stimuli, ¼" interval, of the same strength after 4" latency, with a high contraction, but even with continued stimulation no other contraction followed.

~~If a limb is weakly excited, whether it is that weak stimuli are applied to it, or that its excitability has diminished, not only does its excitation remain longer latent; but it is now no longer propagated to the other limbs. Sometimes this peculiarity becomes obvious where to a preliminary initial contraction there succeeds a second. When the second is stronger, the other limbs then begins the strong movement with the first. If longer stimulation has no effect for the first, the second one also remains quiet.~~

N.B. Introduced later

Fig 11

Fig. 10.



Limb of reflex preparation prepared as in Fig 9. Stimulation with induction-shocks of 10E ½ int. The middle & lower (time) lines have the same significance as in the last figure. The number of seconds wh. correspond to the excised pieces are placed each time at the corresponding spot.

If the fatigue proceeds, the other limb does not participate in the second (strong) contraction. But even in advanced stage of fatigue a strong repeated contraction may take place in both limbs after longer latency //

// After this of both limbs the nervous centres have lost either temporarily or forever their excitability to a greater extent.

To what degree however a seldom succession of weak stimuli may increase in an excitable limb is shown in Fig. 10 (facsimile) wh. on account of the great length of the original must here be given in shortened pieces.

We see that 57 seconds of stimulation are necessary till the first preliminary contraction (degree I) appears; from this 33" more till the second, & till the third twice a duration of the stimulation of 18", & then till the fourth 43" time of stimulation. After 27 other seconds of stimulation the limb makes a series of violent elevations & depressions, & does not come to rest at once after the stimulus has ceased.

After a short pause (10") the skin of the limb was stimulated further in exactly the same way, but even in spite of stimulation for several minutes no more effect could be obtained. The same stimulus at an interval of ½" however produced powerful reflex even after 15" latency.

If after such a violent discharge further stimulation is carried out, an irritable limb with moderate intensity of stimulus and frequency remains a long time at rest. Then it can be made to produce anew, perhaps even a strong, but scarcely ever a spasmodic repeated discharge.

= Here should come the paragraphs scored out on p. 58 & 59.

Thus, the original limb wh. note Fig 11, stimulated with 10E 1/4 int. gave later a strong reflex spasm after 2,5" latency of 8,5" duration, then the continually acting stimulus remained 35" latent, & now produced a contraction of degree III, & then nothing more even after stimulation for two minutes. The limb was however by no means dead, for gentle mechanical stimulation produced toward the end of this period of stimulation a strong reflex.

After rest for several minutes the same stimulus was capable within 1,5" of producing repeated high contractions (degree IV.); hereafter however, the motility was exhausted for the whole remainder of the time of stimulation - about three minutes. - Rest of 6 mins. restored to the limb high & prompt excitability. But once it did not even require the minutes' rest. Even 10" restored to the preparation a greater part of the reflex capability. Thus is proved what I have already indicated (p.), that even sub-maximal stimuli fatigue the reflex preparation. For recovery however only a very short time is required.

// Can one however so apply the stimulus that its motor effects may sum themselves up, but not its injurious effect? This postulate seems to involve a contradictio in adjecto. Then if the movement is heaped up from stimulus to stimulus, & only the resulting movement, not the producing ~~movement~~ factor fatigues, then just as the internal activity increases, must the exhaustion increase. If on the contrary one regards the reflex-discharge as the resulting effect of independent opposite forces, accelerating & inhibitory, there is nothing in the way of conceiving that with a certain succession of stimuli the inhibitory factors are only able to sum themselves up in an evanescent form, whilst the impulses to movement last longer than the intervals; that by appropriately arranged pauses the small time for recovery is preserved to the excitory nerves, wh. is not sufficient for the inhibitory ones. After the previous discussions one may doubt the existence of a succession of stimuli, with wh. the after-effect of the shocks last above a short time. The greatest possible interval of stimulation I have characterised as 2,5", & have shown at the same time, that stimuli of so seldom frequency in order not to lose their after-effect must be very strong, & in consequence soon exhaust the excitability. But we have seen from the results of other experimenters & from my own that violent reflex-spasms last longer than the stimulus, sometimes in a pronounced degree. It therefore appears that internal movements increased to a considerable intensity act for a longer time afterwards, than ~~the~~ the individual shocks.

It must ∴ be possible to a certain extent for sums to heap themselves up; such must bear large intervals of stimulation. In fact I have succeeded in making the after-effect of the reflex excitation visible for longer than 12 secs' time of rest. The sluggish preparation required strong stimuli; 1000 units with interval $\frac{1}{2}$". The small series of 4 pts. is be arranged in a tabular form.

	Duration of				
Period of Rest.	of latent stimulation	period of stimulation	of whole contraction	of contraction remaining after end of stimulation	Maximal height of curve in millim.
	1,0"	10,5"	12,0"	2,5"	12,0 mm.
12,5"	2,0"	8,0"	8,0"	2,0"	9,0
11,0"	2,2"	6,0"	6,2"	2,4"	5,0
11,0"	2,3"	6,0"	6,0"	2,7"	6,0
12,5"	2,5"	6,0"	6,0"	2,5"	5,5
10,3"	2,0"	7,0"	4,2"	0,	57,0
12,0"	3,0'	13,5"	10	0,	2,0.

The excitations heap themselves up from period to period, without the height of the preliminary contractions increasing, or ~~that~~ the length of the visible after-effect beginning considerably increased. After the strong discharge however only appears small reflexes were to be obtained. One can scarcely assume that in this case the excitation was not increased but only the excitability. It is scarcely to be believed that so extra-ordinarily strong stimuli, wh. are able quickly to kill the preparation should previously have increased the excitability. The most probable view is that neighbouring part are set in commotion or rather co-vibration from the nearest stimulated central parts, & this movement, when the external stimulus continues, always goes further (hence the reflexes extend themselves.) When a large mass is already in vibration, the primary impulse may be dispensed with for a short time without the whole coming to a stand still. The powerful new impulses wh. after a few seconds of rest meet the somewhat recovered fatigues are able to give the previously reached amplitude to the whole system, & then to increase it. In regular long intervals (2" to 2'5") single strong shocks follow, on the contrary they lose their force. The vibrations awakened by the single impulses do not long preserve their intensity & remain local. Hence the difficulty of increasing the small remainder of seldom shocks, ~~whol~~that they come to produce extensive movements, whilst with rapid stimuli (1/4" l.s.) of only moderate strength the preparation can be brought to manifest the most complicated apparently purposive washing-movements, which are so pronounced with chemical stimuli.

The strong stimuli fatigue especially the peripheral nerves, & so the impulse proceeding from them becomes weaker. Therefore it is that preliminary reflexes are often absent at times where from analogy with previous & following periods of stimulation they ought to occur (Compare Fig 5 & 6. p35a & 37a.) A small weakening of the induction current or of the sensibility of the nerves is sufficient to ~~retain~~ prevent the stimulus from the generally causing a discharge of

"reflex, activity. On the contrary often a quite weak assistance sometimes slight touch (with brush or finger).

is able during the Electrical stimulation, to produce a reflex. The sometimes apparently spontaneous reflex movements I have already tried to indicate as summation contractions (p.).

Of the second category of preliminary reflexes I have cited the regular contractions isorhythmical with the strong stimuli. They occur very often, sometimes when the skin is stimulated with moderately frequent & intense shocks. Their size is generally very small, some-times however very considerable. It makes the impression generally as if the foot was moved by direct stimulation of its muscles, but one can easily satisfy himself by correct observation noting that the contractions also are reflex; for with fatigued preparations they first occur after obvious, sometimes after long latency, & often change their strength periodically: a phenomenon that I shall discuss more nearly presently.

The supposition of Meihuizen (p Part I.) that with electrical stimulation of the uninjured skin direct & reflex contractions could not be distinguished is also unnecessary for this case of rythmical preliminary reflexes. Very strong stimuli of course also act on the deeper muscles. When the reflex-excitability is nearly extinguished I often observed that the strong currents were replied to by an extension of the foot. In several cases this movement was undoubtedly to be regarded as reflex, for they occurred after longer latency & could also be produced by pinching the toe of the same or of the opposite foot. But even after complete exhaustion of reflex phenomena the foot stimulated by strong currents extended itself the toes being spread out: undoubtedly in consequence of direct stimulation of the muscles. The preliminary rhythmical reflexes ~~we~~ have observed with the already described apparatus (p.) as also on the kymographion cylinder on account of the better view obtained. Here it was possible to write series of over 100 reflex-expts. upon one piece of paper. But in order to spare room the writing lever was inhibited in its motion, so that it only made a small excursion. The movements of the foot were here distinguished from those of the leg eventually by their evanescence. The degree of contraction was noted at the corresponding pt. of the curve during the expt. The following figures IIa & IIb wh. on acct. of space is divided into two parts gives an example of curve so registered.

The small proportions of the contraction curves require exact observation in order to detect the details, but by a cursory glance at the two figures it is to be observed that after latent stimulation of 0,2 to 0,6 sec. the rhythmical reflexes began & after a total latency of 1,3"–1,8" passed into the final elevation of the ~~limb~~, so that now the released lever could mark its line of rest at a little higher level.

Fig. 11a.

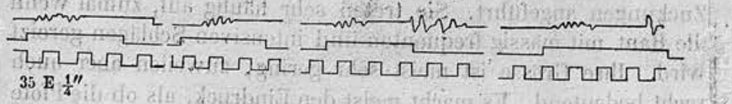
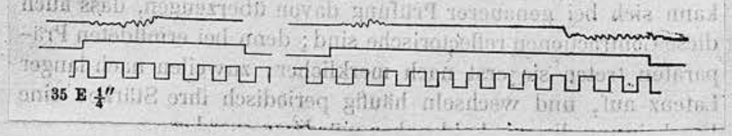


Fig. 11b.



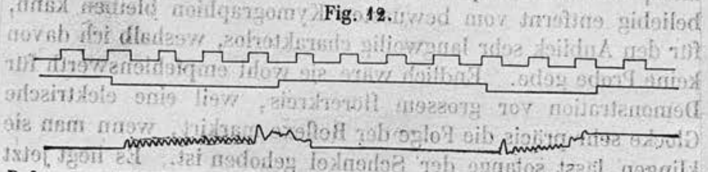
The foot of the suspended reflex frog preparation rests upon the writing-lever moveable only within narrow limits. This writes the upper line (read from left to right) straight as long as it is at rest, in waves when it is rhythmically depressed & elevated by the foot & the counterpoise. The middle line by its high course indicates that the skin was stimulated with induction shocks of 35 E ¼″ interval; by lower course that the stimuli were interrupted. The lowest line marks seconds, divided into halves. Fig. ' gives neighbouring parts of the curve wh. belong to the early stages of fatigue, Fig. the same from somewhat later stages.

When the reflex-tetanus was resolved & the limb fell rapidly back upon the lever it ~~thrust~~ stretched the check (made out of a string Elastic band) somewhat downwards, & returned to its equilibrium after one, even after several after-vibrations, as is to be observed in the 3rd & 4th period of Fig. 11a. Thus the beginning & end of the reflex-tetanus is most precisely indicated. Only when the contraction is very flat & descending, subjective observation must control the apparatus. In the curves of Fig 11. we observe, that the latent times of the preliminary reflexes have tolerably equal (0,2"–0,4"), that the spinal reflexes however in general require longer latent-times (1,9" to 2,2"). At the same time the second Expt. shows that with long continued stimulation of the spinal reflex-tetanus yields & now rythmical contractions of the foot again occur.

The limits of the latent-times estimated throughout the Expt. show very great differences. The spinal reflexes of the fresh preparation occurred after strong stimuli (70E) after so short a time, that the rapidity of the cylinder of the Kymographion was not rapid enough for their measurement whilst in the highest stage of fatigue 12 seconds latent-stimulation were noted. The preliminary reflexes also sometimes became obvious first after latency of several seconds.

The next Fig. (12) gives an example of a very irregular dancing movement of the foot.

Fig. 12.



18) Reflex preparation stimulated by induction-shocks of 100 E & 125E in 1/10" int. with the aid of a vibrating blade. Apparatus as in the foregoing figure. Only the stimulating-line & the line marking the time are drawn above the contraction curve & the middle line indicates by its descent the beginning of the stimulation.

(1) Bowditch. Arb. aus d. Phy. Anstalt zu Leipzig 1871. p142.

In this case the foot replies to only every second stimulus (Opening-shock) & reacts to the closing-shock invisibly, exactly like a weakly stimulated over-weighted or a fatigued muscle. The reflex nature of the contraction is also proved here by the length of the latent stimulation. Beyond this further reflex periods of the preparation shows an increase of the at-first-invisible rythmical contractions, what I have never observed by stimulation of smaller frequency applied to muscles. In the above figure also the long series of vibrations of the foot before the production of the high reflex contraction are also noticeable. The neighbouring curve wh. was produced by strength of stimulus 125 E contains a much shorter stage of preliminary reflexes i.e the latency till the final reflexes is shorter than with more strong stimulation.

I also employed another exceedingly sensitive method for registering the results of the most feeble reflex contractions. On the beam of a "Schottmann's relais" a thin cork plate was fixed, so as to touch the toes of the preparation. The platinum stilette at the other end of the anchor beam dipped into a small vessel of Hg. As soon as the foot removed the weight from the double lever.

The closed current permitted the anchor beam, provided with a writing-style, to note the

a small electro-magnet

the moment of elevation then with the rhythmical succession of contractions a fine toothed curve is obtained, with the longer contractions of a reflex of high degree a long mark &c. The curves are very convenient for measurement on account of the sharpness of the moment noted. This arrangement also permits of every manipulation during the course of the expt., because one may stay as far removed from the smoked kymograph as he will. Lastly this method is to be commended for a large circle of hearers for an electric bell marks very precisely the succession of reflexes, by allowing it to sound as long as the limb is raised. The question is at hand: Are these rhythmical reflexes fundamentally different from the formerly observed individual single preliminary contractions?

Later on I shall support the view that every stimulus adds an increase to the movement of the reflex centres, that several single-shocks sum themselves up till the threshold of stimulation is overcome or passed, & a preliminary contraction occurs, that then the summation goes further, till a final contraction or an spasmodic attack closes the reactions. The further movement is therefore not caused to cease by every small contraction, but only by strong discharges.

Why should not every stimulus after the threshold has been once reached of the summation of others, increase the remainder of their effect to an end reflex just as ~~in~~ in Table VI we have seen the primary & small reflex forms heap themselves up to greater secondary ones.

Great regularity or equability of the stimuli & excitability are necessary thereto. Such a process is only a special case of the general. To found this view I then present several forms of discharges which show the passage of the single reflexes into the periodical ones.

Fig. 13.

The originals of this contraction curves had after each the two reflex-preparations whose ankle joint was united with the writing lever, & wh. wrote upon endless paper. The one preparation was stimulated with induction currents of intensity 30 (E) at intervals of ½", the other with strength of current 20 E at ½" int. The middle line shows by an elevation the time of stimulation. The lowest line marks seconds.

The first curve shows a complete reflex-period with synrhythmical moderately strong reflexes.

wh. appear after short latency (almost 1") & increase after 5" (always to a spasm, in which curve the compensating impulses it as still to be recognised.

The second curve represents a group of reflex contractions wh. were produced by induction-shocks of interval ½" after 5" latent stimulat. The preliminary ones follow each other at intervals of about 1" & increase rapidly to a final contraction. The third group lastly, gives the last piece of a longer period of stimulation (20 E) ½" int. in wh. before this discharge single preliminary ones follow thus. after 13" (degree I) 14" (degree II) 20" (II) 28" (II) 31" (II), then there occurred the first small elevation of the leg of this group. After 38" total latent-time & at intervals of 1–1,5" a complete discharge was produced, (wh. exceeded the former ones more than can be given in the limited amt. of space)

Here there are Elevations of the leg wh. ~~precede~~ singly or in rythmical succession precede ~~the~~ true reflexes. Even the latter are with relatively weak stimuli so great, that one can scarcely imagine that secondary loops of currents wh. ~~distributing~~ to the flexors of the leg act as direct muscular stimuli.

Fig. 14 wh. serves to illustrated an allied question gives an example of a rythmical succession of small reflexes wh. were also written by the leg. In my curves of 4 pts.

there are also a number of pictures, wh. would serve as intermediate stages to the above. I have series of large reflexes following in half rythm of the stimulus, wh. alternate with single ones del. In Fig 8 an example is given in wh. from the middle of the series onward in every 4 pt. a weak (I) initial reflex occurs, to wh. after a pause the sharp reflex III) succeeds; also in the latency-curve Fig 6 several preliminary reflexes are indicated by rings (⊙) wh. follow each other at very unequal distances, & place near to those where only simple discharge was to be obtained. On comparing these modifications, ~~the key~~ is to be found between the simple, final discharges to the isolated reflexes of Figs 9 & 10, from there to the rythmical ones of Fig 11 & 12, & come to the conclusion that between the complexity of the units a distinct number of combinations is possible through the number of stimuli. When however one takes into count the continually variable height of the contraction, an endless number.

Up to this time on account of simplicity I have generally termed the first strong reflex "preliminary". With great right too; for we have already remarked, that with moderate excitability & moderate or weak stimuli that ×no reflex ×generally follows the first strong simple or spasmodic attack of reflexes in the same period of stimulation

It is quite different however with susceptible preparations or those treated with intense stimuli. Here many very often high contractions ~~often~~ frequently follow at short or long intervals. After a time the discharges become smaller, seldomer, irregular & disappear completely. The stage before the last requires our special consideration. If the preparation is only capable of moderately strong or weak reflexes, wh. contraction have we to regard as preliminary, when can we interrupt the stimulation as not likely to give us a result? Rosenthal (l.c. p2). in the estimation of the 'Reflexzeit' excludes entirely "solchen Reizen welche nicht das Maximum der Reflexwirkung geben, und vergleicht nur solche Reize, welche grade ausreichen dieses Maximum zu bewirken ("ausreichende Reize") mit stärkeren ("über-maximalen". In my expts. I could not follow this system without losing many valuable data, Had I omitted the points marked in Figs I & II. then numerous disturbing imperfections would have been left. Examine e.g. Fig. 5. How often there, exactly at the expected spots, instead of the maximum contractions (III) those of degree II. or even I & on the other hand more strong spasmodic ones (IV).

Similar results are found in other examples. From this it appears that it is not the

Sitzungsb. d. phys. med. Societ. zu Erlangen 1873. p13.

strength wk

strength or extent of the reflex-contraction wh. is of fundamental importance, but the circumstance whether a complete discharge has taken place or not.

What process however can we characterize as a complete discharge? This is the most important question wh. we have all now come upon in the course of this investigation.

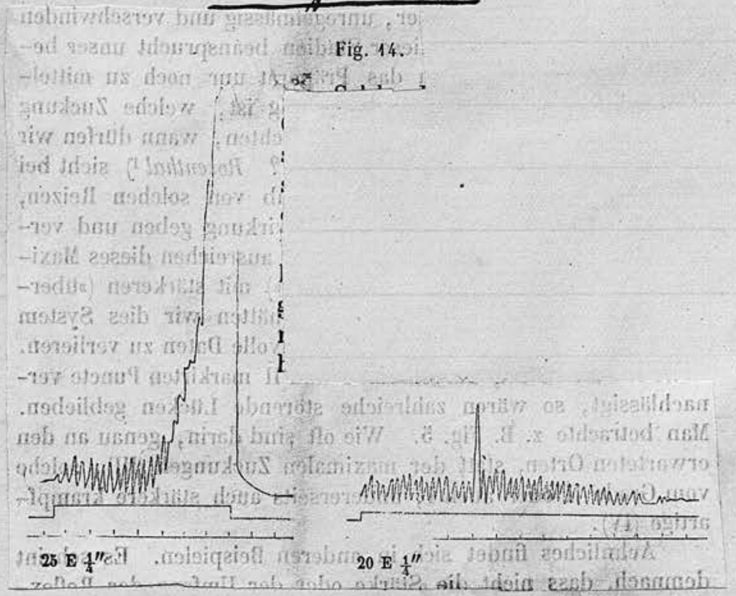
When we observe a reflex preparation wh. requires moderately strong electrical cutaneous stimuli to set it in motion & treat it with moderately frequent shocks we frequently observe that the foot after a short time exhibits rythmical movement. This beating of the foot as it were, in whole or half tempo of the stimuli gradually becomes stronger, till a great reflex results.

When the preparation is still more rusty the leg begins at once to beat & write curves like the first of the following facsimiles Fig 14. If the excitation is weaker (because stimulus or excitability have diminished) then there is no longer a great reflex (Obs. III) but the vibrations of the foot or small ones of the leg only increase to weak movements of the leg.

Such a condition is presented by the second curve of Fig 14. Or lastly one observes that only the rythmical beats of the foot periodically diminish or increase, with-

– out the leg being moved also. ~~[illegible]~~ the preliminary contraction groups of beats often occur several times during a period of stimulation & it frequently happens that the first group does not cause elevation of the leg, but after several, often many minutes of complete rest the movements of the foot reappear & increase to movements of the leg, or even to those of the thigh.

Fig. 14



Reflex frog ~~[illegible]~~ preparation stimulated at intervals of 1/4" with 25 E & 20 E (intensity) & writing its contractions upon an endless coil of paper on a kymographion by lever attached to the ankle joint. The middle line indicates the duration of the stimulation, the lower one seconds.

The elevations are often repeated several times in a period. If one has some experience in such observations, ~~[illegible]~~ on observing the limb during a longer period of stimulation

it is possible to predict
whether a reflex may be expected or not

As Eduard Weber compared the intermittent movements of the reflexly excited limbs with an animal "das wirkliche Anstrengungen macht" so (might I) call the process described a "Sisyphus-task". Near to the result (the production of a powerful reflex) the force weakens & the work done becomes in vain, or useless, & must be done again from the beginning. This appears to me to indicate the moment of production. A simple or complex production exhausts the store present.

In fresh preparations this can be rapidly recovered. The energy becomes disposable by the stimuli; & independent of the regenerating metamorphosis. Even minimal excitations wh. produce even the most localised reflexes in the foot, appear to fatigue, for there when alone we have seen to increase rhythmically, to decrease, & to disappear, but this diminution of excitability appears to be very evanescent, & such vibrations often last for minutes. The process may be made clear by a simple comparison. A pendulum requires only minimal impulses to be raised a little from the position of equilibrium; returning it can only overcome very small resistances. When raised higher it gains in the return greater velocity & with a corresponding mass it is able to convey greater amount of kinetic energy to a resisting body. If the hinderance is not great, the pendulum spends the remainder of its force in rising in the opposite direction; on returning it can again overcome resistance & so on until its energy is used up, until its vibrations round ~~f~~ from its position of equilibrium become invisible, & it at last stands still. Imagine further a second pendulum, of the same length, placed with regard to the other one, so that both planes of vibration are parallel. An easily moveable process (e.g. a piece of watch-spring of small elasticity) is fixed to the second pendulum, so that the first pendulum in passing it touches the position of equilibrium — With small impulses the spring will be only slightly compressed, not sufficiently however to be bent. The process conveys the shock to the second pendulum, wh. moves more weakly than the first, wh. is hindered by the resistance, but not brought to a stand-still. With greater elongation the first pendulum falls with great rapidity against the spring process, presses it aside & completes the other quarter of its vibration. In the mean time however the second pendulum has also taken up the part of the force for wh. the spring was still unbent. It makes a small vibration but as its duration of vibration is equal to that of the first it is also a quarter vibration, & arrives in the position of equilibrium simultaneously with the strongly moved one. Here it receives from the rapidly falling one a new impulse wh. is again partly conveyed to the spring. The impulses of the first pendulum sum themselves up in their action upon the second, & at last it may reach the full amplitude of the first.

The employment of this picture for the reflex-process is obvious. We only require to conceive that the force of the motor nerves is applied to the first pendulum, that the next sensory nerve receives an impulse from the pendulum, as soon as this passes the position of equilibrium on its return. The ends of other nerves are set in motion by the second secondarily moved pendulum, as soon as the kinetic energy of the shocks has exceeded a certain limit. A third similarly coupled pendulum would represent a vibrating complex of the third order. To explain the consumption of material with secondary & tertiary productions we must introduce into our picture a complication, that at the moment, where the forces of the secondary or when the tertiary pendulum become sufficiently increased, to introduce a motor process in the ends of the nerves, where a sort of explosion takes place, wh. sends the motor impulse towards the periphery, but also reacts upon the centre.

The production of heat & the production of acid may be partly the cause of the deadening of the central excitability. By frequent discharges the whole system becomes moveable with greater difficulty. So therefore the conveyance from one vibrating system to the other lasts very long, until force sufficient for the production of a reflex act reaches the second or third system. But the exhaustion of the central parts does not require to bear the blame of the inactivity of cutaneous stimuli. The peripheral nerves may also refuse to act, & ∴ render the passage to the centrum impassable.

This is easily known, by testing the reflex excitability of the observed limb from the other limb. Frequently, when very when very strong cutaneous stimuli in large intervals have acted without much effect, we find the central excitability retained. My exps. are not sufficient to decide the very interesting question, whether the non-excitable cutaneous nerves no longer influence the centre. There still remains ~~to be~~ explained another point of fundamental importance for the principle of summation.

Up to this time we have regarded ~~the~~ reflex-actions in as far as they are the effects of summated electrical cutaneous stimuli, we have related the operators, wh. render possible, or favour, or disfavour the effect sought. It has now to be asked whether a reflex act can occur without the summation of stimuli. This seems unquestionable. A prick is sufficient to cause an animal to fly away, pressure on the foot of a reflex-frog to occasion brisk contraction. The very short-continuing discharge of a Leyden jar have been found by Cavendish & Volta (du Bois Reymond. Untersuch. über thierische Electricität, 1848. Bd. I, p290) to act on the sensory nerves of man & fishes. Setschenow, Fick, & Rosenthal have in the cited papers, investigated the effects of single electrical discharges (Interruption of the current, & induction-shocks). I have already occasionally remarked that with very strong, seldom stimuli applied to fresh preparations, the reflex occurs earlier than the second shock. All experimentors agree in this that for reflex-excitation with single induction-currents, quite incomparably greater strengths of the current are reqd. than for stimulation of motor nerves, whilst for summation-reflexes comparatively weak stimuli are sufficient.

To find out the cause of this remarkable differen

I have tried the effect of single induction-shocks in several ways, & compared them with the effects of repeated stimuli. The following is the result of my 4 pts. with single induction-shocks.

Reflexes were only produced by simple single (always applied to the skin of the leg) induction-shocks when they were very strong. In most cases the limb replied only a few times to the stimulus, even when longer rest was given between the beats. Only very lasting preparations could hold out 50 such stimuli. These must however at last be increased to enormous heights. The latency may increase to 3", & even higher. The increase of the latent-time will be better made plain by the following fac-simile curve, than by numbers. (Fig 15 a & b.).

We observe at all parts of the curve, with the exception of the first (P_1) two or three differently formed parts; a pointed, short elevation & a variously formed (between or behind) a small simple or double tooth. The meaning is clear. The first point represents the composite curve of contraction, wh. follows direct stimulation of the motor elements of the limb without obvious latency. In the first period (P_1.) this remains invisible, because it is united to the long reflex-curve wh. rose with little latency before the first one could sink from the maximum. In the other represented periods wh. on the original paper almost continually follow each other we see the curve of contraction always further removed from the one directly excited. They have always a tetanic character. Sometimes with indications of clonic spasms. The rapid fall of the writing pen between the curves or contractions proves that the contractions are not due to sluggish movement of the lever. The reflex-

Fig. 15a.

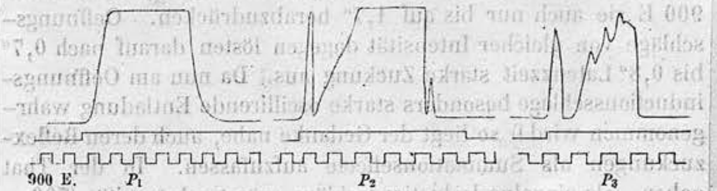


Fig. 15b.

The left foot of a large frog rested on the already described writing lever. An induction shock (opening) stimulates it in each of the 6 periods (P_1 to P_6) of 900 E. After each stimulation there is a minute's rest. The stimulating pen makes a notch upward when the primary current is opened. The time marker notes seconds (½" below ½" above)

The reflex latent time in P_6 reaches the value of 1,7". The increase of the latency with the fatigue is also a common phenomenon in the reflexes produced by single contractions. The dependency of the duration of latent stimulation upon the intensity of the current is not easily proved, because the strength must be rapidly increased, in order to obtain a longer series of reflexes. In some cases, where it was possible to compare increasing & decreasing strength of current, the intensity appears to be without influence on the latent-time.

The closing induction-shocks are only in seldom cases capable of inducing reflexes, they are always surpassed in their action by the action of the opening shocks, As closing-shocks of 800 E. produced reflex contractions

+ Helmholtz. Verhandl. des naturhist. med. Vereins zu Heidelberg 1869.

Both papers are referred to in Wiedemanns "Lehre vom Galvanismus und Electro-magnetismus" 2. Auflage. Braunschweig, Bd. II. Abth 2. p. 360. §128.

with latencies from 1,25" to 1,75", 900E analogous depressed it to 1,7". Opening shocks of equal intensity on the contrary produced strong contraction after 0,7" to 0,8" latency. Now ~~was~~ in opening shocks induction & generally strong oscillating discharge has been proved (Donders, Process verbaal van de Akademie zu Amsterdam 1868, 30 Mai)ˣ so the thought readily strikes me that these reflex contractions are also to be regarded as summation effects. In fact as single induction shocks of the greatest intensity (700E to 900E.) acted first after longer latency (1,7") & then had no more effect, tetanising stimuli of moderate strength (100E) gave reflex-contractions after invisibly short latency. This result was in the highest degree striking because according to the usual views it is difficult to understand, how one strong stimulus requires a greater rapidity of propagation than many weak ones. To explain this result, experiments were made, in wh. the resulting effect of as single shocks was compared with that of three following each other in different intervals.

At first a closing shock acted like an opening shock, (~~after~~ 600–700E after latent time of 0,7–0,6") Successive shocks following each other at an interval of 1" were able to sum up their effects to a stronger (reflex) than the simple reflex. With employing the ordinary opening & closing shocks this was still possible at intervals of 3". If however two stimuli followed each other at an interval wh. was shorter than the ~~duration~~ of the duration of the latent stimulation of a simple shock (0,2"), then the reflex followed directly after the second stimulus, i.e. after much shorter latent time, than after equally strong induction-shocks. Herewith is shown, that the observed time of latent stimulation does not give the time of the rapidity of the propagation of the excitation from peripheral sensory nerves to peripheral motor ones, for it would not be possible to see how a second stimulus should arrive earlier, than an equally strong first one, but that the estimation of the latent stimulation also includes the time wh. is required to bring the movement in the spinal cord to the threshold. This view would accord with that of S. Exner who defines the "reducirte Reflexzeit" as the time "welche die nervösen Centren gebrauchen, um den sensiblen Eindruck in einen motorischen zu verwandeln". (Pflügers Arch. f. Physiol. Bd VIII, p. 530).

Regarding the question how it comes that simple stimuli can cause summation-effects is indicated by Englemann; (Pflüg. Arch. 1872. Bd V p 37) very strong induction-shocks act by changing the nerves thermally (& chemically). In fact in my experiments I have observed that a sensitive limb treated with single shocks of the strongest sort pass directly into a tetanus, wh. must be produced from the motor structures. Many observers have long ago proved that applied to the sciatic nerve, (a single strong induction shock) is able to produce tetanus in the gastrocnemius.

Then I would have shown that the apparent single stimuli could also be brought into the category of the summated ones, & we can say! Reflexes can only be produced by repeated ~~by~~ repeated impulses to the nervous centres.

The results of the above experiments find their conformation in many experiments, wh. we can make on ourselves; a prick of the mucous membrane of the nose is painful, tickling produces sneezing. Coughing yields a splendid example of reflex discharge from summated stimuli. We feel a particle or film wh. is contact with the mucous membrane of the larynx. The slight sensation increases without a new cause till it becomes ~~a~~ stimulus, gradually we feel that it is necessary to get rid of it, then the follows a seldom short coughs. If this is not capable of removing the offending body, the violent expiratory ~~out~~explosions increase to violent spasms. A stage of fatigue follows the violent discharges, the fatigue giving rest, in spite of the continuation of the stimulus, until the excitation again becomes active. But even when the offending body has been expelled the feeling still remains for a time & expresses itself in mild coughs, wh. gives a certain amount of satisfaction, just like the after swallowing.

The sensation without reflex conveyance can also be increased by gentle stimuli; Intermittent gentle touching of the skin produces tickling feeling wh. when long continued becomes quite unendurable. The untiring, pertinacious fly can by its seldom weak pricks ~~place~~ throw nervous men into a great state of excitement: A strong blow, or pressure or cut can easily be borne.

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Edinburgh University
M 1875.