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PHYSIOLOGICAL STUDIES OF THE KNEE-JERK, AND OF THE REACTIONS OF MUSCLES UNDER MECHANICAL AND OTHER EXCITANTS.

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PHYSIOLOGICAL STUDIES OF THE KNEE-JERK, AND OF THE REACTIONS OF MUSCLES UNDER MECHANICAL AND OTHER EXCITANTS.

THE phenomenon known as tendon reflex, knee-jerk, myotatic contraction, has won steady attention since Westphal pointed out its value. Indeed, as regards what we may call its natural history there seemed little of a novel nature to be learned. The discussion as to its true parentage has also been narrowed so far as to enable us to feel sure that the blow on a tendon causes motion in the related muscle, not owing to an afferent impression from the tendon, but either to a direct irritation of the muscle concerned—*i. e.*, direct muscle response, or to the pull on the muscle causing afferent sensory impressions to the cord, and efferent motor response—*i. e.*, reflex action.

At this point we leave the matter for a time to turn to our own researches on the normal history of the "knee-jerk."

We shall relate in detail all the results we have so far obtained, and shall then endeavor to show the relation some of them bear to the possible theoretic explanations of the cause of the knee-jerk.

Our point of departure was a remark of Dr. Buzzard's, in a debate before the London Medical Society, in regard to Jendrássik's discovery, now three years old, as to the power of violent volitional

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muscular acts to increase the amount of the knee-jerk.

Jendrássik, in his essay,[1] states in a too brief paragraph that if, when the patellar tendon is struck, the patient clinches his hands, or makes other violent movement, the coincident jerk is increased. His other conclusions are: that the knee-jerk is a true reflex caused by mechanical irritation of the nerves in the tendon; that the muscle must be in a condition of passive tension; that voluntary innervation of the crural nerve lessens the reflex, or prevents it altogether; and that innervation of the sciatic favors the knee-jerk.

As the word knee-jerk will, of necessity, be frequently repeated in this article, it will be hereafter spoken of as k.-j.

Our own research has led us to examine with care—

1. The circumstances which increase, and those which lessen the k.-j., and to consider the influences exerted by volition, motion, sensation, electricity, tension, etc.

2. The characteristics of direct muscular motion caused by a blow, and the effects on it of voluntary motion, sensation, electricity, tension, etc.

These portions of our work must be regarded as contributions to a branch of normal physiology. We have kept them apart from the brief speculations which follow as to the theory of tendon reactions, and of the various novel phenomena which we shall describe.

Manner of obtaining the knee-jerk, and its normal variations. The experiments which give the best

[1] Beiträge zur Lehre von den Sehnenreflexen, von Dr. Ernst Jendrássik. Deutsches Archiv für klinische Medicin, vol. xxxiii. page 175, 1883.

result are made by placing the subjects, healthy young men, on their backs on a lounge, so that they rest absolutely without muscular exertion. It is necessary or best that their hands be at rest, their eyes passive, and that they neither laugh, cough, speak, nor swallow, except when it is desired to test the effects of these acts on the phenomenon to be studied.

If the subject be seated, many of the results—indeed, all the coarser ones—can be had, but the more delicate experiments are apt to fail. The legs are allowed to hang over the foot of the lounge at varied angles with the thigh, which is itself bent at a very obtuse angle with the trunk. It is better for some of the experiments, however, to let the lower end of the thigh rest easily on two rubber pads placed at the sides of a wooden support, which is cut out below, so as to prevent pressure on the back of the thigh, and this for reasons which will appear elsewhere. Thus placed, the thigh is free from pressure, except where the tuberosities of the femur rest upon the pads, and the leg is at liberty to swing.

At the risk of being tedious, it is well to explain the modes of exciting the k.-j. so as best to get the effects of coincident and remote impressions. With a rubber percussion hammer, which should have a slightly elastic steel handle, and be not too light nor too hard, blows are struck on the tendon at intervals, or else a more or less constant excitement of the muscle is kept up by a series of quickly repeated taps. A sort of partial tetany is thus caused, and with care can be made quite equal, so that any new element of increase is easily seen. This, perhaps, is the best method for the more delicate tests. A good plan is to place across the tendon an oblong

piece of rubber, and to strike on it. Still better is it, in sensitive persons, to place one's forefinger across the tendon, and to strike on this. We get thus a double means of judging the force used, because we can feel the responsive succession of jerks of the tendon on the sensitive palmar face of the finger. A good impression is thus obtained of the briefness of the interval between the time of the blow on top of the finger and the time of the answering jerk of the tendon beneath it. Other and obvious precautions are needful at times, such as absence of constricting clothes, care to prevent swing of the pendant leg when struck.

The k.-j. varies in quality in healthy men. In some the same weight of blow causes pretty constant effects when steadily repeated at like intervals, but in others the effects are inconstant, and a series of slight motions are apt to be followed by an excessively exaggerated act. Such persons make bad subjects for experimentation.

This explosiveness is also apt to follow much excitation of the muscle.

Even in the young and healthy the k.-j. varies remarkably. On the whole, it is less good in the evening than early in the day, and possibly relaxing states of weather, as we shall show further on, may be capable of lessening these muscular responses. When familiar with the normal of one person's k.-j., it becomes easy to see that at times when he is not well or is exhausted, and especially, as we have said, toward ten at night, there may be some distinct lessening of the ease of muscular reply to the tap.

In one case of a healthy man, over fifty, there is often a good k.-j. in the morning in the left leg, and none, or almost none, later in the day; whilst, in the other leg, the jerk varies naturally from day to day,

and is sometimes singularly good in both legs. A meal and three or four glasses of wine seem in him to favor its increase. Daily repeated excitations through the knee-tap in some healthy persons enormously increase the ease and amount of muscular response. In one case we even felt some concern at the exaggeration of the symptom we finally produced. In some people the muscle soon ceases to contract if the taps be often repeated, at one sitting; in others as healthy, it is very difficult to wear out the power of reply.

Effect of voluntary acts on knee-jerk. While the subject was at rest, as described, the tendon was struck at intervals by an assistant. An effort was made to move the scalp voluntarily, so as to make the volition coincide in time with the tendon tap. When successful, the k.-j. was increased.

The movement of one ear, an act only possible with a few subjects, reinforces the k.-j. Frowning increases k.-j. Distinct but not violent winking increases k.-j., when coincident with the tap and in good subjects. Thus if we wink and strike at different intervals an accidental synchronism reinforces k.-j. Winking forcibly with either eye gives like results, and one eye can thus reinforce k.-j. for either leg. Rolling the eyes from passive central fixation to extreme limit of motion adds to k.-j.; a sudden convergence on a very near point does the same; but these beautiful experiments failed when the subjects were seated, and succeeded when they were supine and used the knee crutch described.

Inspiratory and expiratory acts, if volitional and decided, increase k.-j., especially at the beginning of the movements; and if we suddenly fix the chest either in a full or partly empty state, there is a like result but not well marked.

A laugh or sneeze remarkably increases k.-j. Phonation gives in many people admirable results. To obtain these let the passive supine subject sound, with emphasis, the letters in turn, but so slowly that time may be allowed for a tap on the tendon to be made between each letter as well as with each act of phonation. When this is done, the exaggeration of the k.-j. can be well seen when the knee-tap coincides with the utterance, as contrasted with the lesser effect of the tap between each utterance.

Deglutition gives also very positive increments to the k.-j., but less surely than strong phonetic acts. To avoid chance of some volitional reinforcement, most of these experiments were repeated on ignorant persons to whom an assistant gave a signal to perform a certain act, or who were told to wink or to sound vowels, whilst the operator noted the results. These results are all easy enough to get if we take the precautions mentioned and select men with responsive muscles.

The following coarser muscular acts increase k.-j.:

Action of platysma myoides.

Turning the head strongly.

Drawing in the belly.

Rotation of body on pelvis.

All these acts increase the k.-j. most during the movement and least when the act is complete.

Arms and hands. These parts give, when in forcible action, great increase of k.-j. Elevation of the arms and all other strongly done acts, but especially violent clenching of the hands, are effective. The moment of greatest effort slightly precedes the maximum of reinforcement to the k.-j. Slow or gentle movements give little or no effect.

In a strong, right-handed man, violent closure of the left and much weaker hand gave less addition

to k.-j. than similar effort with the right hand. Either hand, with equal amount of action, seemed to affect alike the knee of its own or the opposite side. Motion of one finger suffices to reinforce k.-j.

Legs. Strong movements of the toes in flexion or extension in the leg struck or in the other much increases k.-j., and apparently either act gives an equal result, for its own or the other leg. Large motion of one leg in flexion and extension increases k.-j. of its fellow. The muscular acts of the leg struck were carefully studied, and the more so because our results do not precisely agree with some of the conclusions of Jendrássik.

Voluntary use of quadriceps extensor. All strong contractions of the muscles concerned in k.-j. abolish it entirely. With some care we may eliminate the synchronous activity of the opponent flexors of the leg and so get an expression of the pure voluntary action of the extensor. Thus with the leg of a sensitive subject at a good angle for k.-j. have the foot held, or stay it against some immovable obstacle. Then let him will to extend the restrained foot and with a little trial it will be found that the extensors can be called into isolated activity. If they be strongly contracted, no matter at what angle be the leg, all k.-j. ceases. Now relax them a little and then most suddenly the k.-j. returns in excessive degree. It is curious to note it coming and going with increase or decrease of contraction of the muscles concerned.

Therefore, all violent innervation of the crural nerve prohibits k.-j. All milder innervation increases it. When a movement of the quadriceps extensor is willed about equal to that produced by a tap on the tendon, and a tap is made to coincide with it, an interesting result is obtained. If the act

he timed correctly the result is a large sudden movement, which has to the observer, who is thus struck, little of the qualities of an act of will. It is abrupt, jerky, and does not seem to be moderated or passively antagonized as are our ordinary voluntary motions. It has only the peculiarities of a knee-jerk.

Action of leg flexors (opponents of the extensor group). With the patient seated, thigh on crutch, the leg is voluntarily flexed from a level with thigh whilst the k.-j. is being tested; good reactions are obtained, but in this experiment both the flexors and the moderating extensors are functionally active. To get the single influence of the flexors, with the thigh on the crutch, and the subject seated, an assistant suspends the passive leg at the ankle whilst the subject flexes the leg gently, the assistant yielding to the motion. There is then no notable extensor activity. Result, good k.-j. Next active flexion is strongly resisted. Result, great exaggeration of k.-j. up to such flexion as abolishes k.-j. by tension, as will be seen further on.

In these latter observations, if well managed, the action of the extensors is excluded. Sciatic innervation, therefore, whether gentle or strong, reinforces k.-j.

As regards all of the foregoing experiments, the reinforcement of the k.-j. lasted while muscular acts were being performed, was best when they were most intense, and continued for an appreciable time after volition had ceased. This continuation of influence was particularly noticeable with the more violent muscular acts.

Effect of continuous efforts. With the subject supine, blows were struck at intervals, and meanwhile the upper extremities, neck, and back were kept in

a state of violent muscular fixation. The k.-j., at first excessive, soon became less and less, but did not quite wear out during any length of possible effort, although it continued to be feeble for some minutes after exertion ceased. In the other leg it remained as usual.

Effect of states of tension. These experiments were made with great care, because they have some bearing on the belief expressed by Jendrássik, Tschirjew, and Gowers, that a state of passive tension due to flexion of the leg on the thigh or to other means —*i. e.*, pushing or striking downward the patella— is a needful factor in enabling the tap to cause k.-j. In other words, they help to determine whether or not anything beyond such muscular tension be requisite, as exists in a relaxed muscle.

A blow on the tendon below or just above the knee whilst the limb is passively flexed, of course most readily evolves the k.-j. We have then present two elements, muscular tension from moderate stretching and also circumstances which mechanically favor the k.-j., as the tightened tendon enables us when we strike it to influence more and more abruptly the mass of the muscle. Is the passive tension essential?

In some sensitive but healthy subjects the following experiment succeeds at times:

The subject is seated on the floor, passive, with the back supported. The leg is in full extension on the thigh, and the body at a right angle with the latter. Complete relaxation is thus attained. Then the stiff rubber cushion is placed above the knee, and a blow is struck so as to fall on it at right angles with the line of the muscle, or the pad is so placed as that the force is rather directed a little upward. The position of the tendon above the knee is such

that it has under it a cushion of areolar tissue. The blow evolves a distinct jerk of the muscle. The infrapatellar tendon under like circumstances does not give a response, because the blow must take up its slack and that of the suprapatellar tendon before the pull reaches the muscle, but in this position of the leg there is not space enough beneath the slack tendon below the knee to allow this to occur. In the experiment stated, there is no preparatory tension from knee flexion, and we have only ordinary muscular tone as a preparation. That the result is comparable to that obtained when we tap below the knee with a mechanically tense tendon, is shown by the fact that the motion caused by a blow above the knee, managed so as not to push the patella downward, is reinforced by motion elsewhere. They who hold with Gowers that preliminary passive tension is needed to enable a pull on the muscle to excite it, will plead that every blow on the tendon above the knee placed as described acts at one and the same moment to pull on the muscle and to excite it, and this may be true, nor do we see how entirely to eliminate this element of doubt.

If with the leg relaxed, a blow on the suprapatellar tendon, either at a right angle with the thigh or even in a slightly downward direction, so as to depress the patella, causes a muscle response, the time should be that of a reflex and not the shorter time of a direct muscle act, because these methods do at one and the same moment involve and cause muscle tension (reflex preparation, Jendrássik, Tschirjew, and Gowers), and also muscle excitation. This has not been shown as yet to be the case, and until it has been, there seems no reason to seek beyond the existence of common muscular tone to explain the k.-j. If the time should be found to be

that of a reflex act, it would favor the idea that the k.-j. should be so considered.

Effect of extreme tension. It is possible to abolish the knee-jerk even in spastic paralysis by increasing the tension of the muscle. I. P., æt. thirty, case of spastic paralysis. The reactions are excessive. He was placed on his face so that the body and pelvis lay on an upward slope. This brought tension on the upper part of the quadriceps extensor. Then the leg was bent slowly, and at a certain angle the k.-j. rather abruptly failed, as it always does under like circumstances in the normal subject.

As *strong* flexion of the leg upon the thigh has the effect of greatly diminishing or even abolishing the k.-j., the question arose whether this was caused, in part at least, by the great mechanical disadvantage at which the patellar tendon then was placed, as a blow upon it in this position would have the minimum effect upon the muscle. To investigate this point, the subject was placed upon the floor on his side with the underneath hip and knee each at a right angle; in this position a marked k.-j. was obtainable; now, by slowly extending the trunk upon the thigh, keeping the thigh and leg perfectly quiet, an increased tension was made at the *upper end* of the muscle, while the mechanical arrangement at the knee remained unchanged, except as concerned the increased tension: this procedure had the effect of gradually diminishing and at last even abolishing the k.-j. When the subject was placed upon his side, with the body at a right angle to the thigh, and the leg almost perfectly straight, a very slight k.-j. was obtainable; now if the trunk, as before, was slowly extended upon the thigh, the k.-j. increased markedly with the increasing tension, as now the slack in muscle and tendon was taken up

by the pull from above, so that the tap on the tendon could make itself felt upon the muscle more markedly; a further flexion of the leg on the thigh now increased the tension too much and diminished the k.-j.

It might be considered by some that extreme tension by pulling on the fibrous sheath of the muscle makes the sheath so tense that any external blow is mechanically hindered from impressing the muscle beneath; but the following very interesting and novel experiment appears to make it possible that there is also present a physiological element, although the mechanical arrangement may have some influence. The poles of the secondary coil are placed, for instance, on the belly of the flexor sublimis digitorum with a current that is sufficient to flex powerfully and very painfully the ring and middle fingers into the palm, so as to put them entirely beyond the control of the will. Then an assistant forcibly extends the flexed fingers and wrist; this procedure at first increases the pain, but by the time the wrist and fingers are fairly extended the contraction and the pain begin to diminish until at full extension pain is almost entirely gone, only a sense of discomfort remaining, and the fingers are again under full control of the will. If now we release the wrist, the fingers return to their powerfully flexed condition and the pain becomes as great as before.

It seems probable, on the whole, that moderate tension is mechanically of use in enabling us to get the fullest k.-j., but is certainly not essential to the evolution of lesser manifestations of the phenomenon. Extreme tension, of course, may make it mechanically difficult to get k.-j., and also to observe it, but it seems likely that there is also involved in this apparent inhibition some physiological obstacle due

to stretching of the muscle. The problem is one of great obscurity, and needs laboratory study.

Effect of acts of volition on organs functionally inert or on lost parts. When one of us willed to move his ear, over which he had no control, a considerable increase of k.-j. followed. Persons who have lost limbs often retain the power to will a motion of the absent member, and have then in their consciousness a sensory representation of such motion. It is very remarkable that these patients can never seem to themselves to make sudden, quick, or very complete movements of absent parts. It was needful to be sure that the stump was not moved. With proper precautions, the effort to move by will a non-existent part reinforced k.-j. distinctly in a case of loss of left arm at shoulder, and in a knee amputation. These results have value as proving that the reinforcement is not due to the muscular movement which, in the unmutilated, follows an act of will.

Elbow-, ankle-, and jaw-jerks. These obey as to increase from remote voluntary muscular acts the same law as do the motions due to knee-tap. The elbow-jerk is hard to obtain, but in one or two of our subjects was very good and was reinforced easily by willed toe movements, as also by those of the other hand.

The same remarks apply to the jaw-jerk[1] (chin-reflex), although this movement is not so readily shown in some subjects. This jerk is most easily obtained by allowing the jaw to hang passively, or by gently supporting it with one hand while with

[1] "The Chin-reflex: A New Clinical Observation," by Morris J. Lewis, M.D. Philadelphia Medical and Surgical Reporter, May 9, 1885, p. 591. Read before the Philadelphia Neurological Society, March 23, 1885.

the other a blow is struck on the teeth or chin in a downward direction with the rubber hammer.

Effect of one tendon tap on another. Numberless experiments were made to learn if the one k.-j. reinforces the other. Thus we keep the right quadriceps extensor moderately excited by a series of quickly repeated blows on the tendon, and call out the most extreme k.-j. possible in the left leg. We do not add to k.-j. of its temperately excited fellow member.

The normal knee-jerk, ankle-jerk, and arm-jerk do not react on one another. All of these experiments as between the arm- and leg-jerks are difficult to manage, but easy enough as concerns the various leg motions.

The experiment of Jendrássik naturally led us to carry out, in regard to volitional movements, the investigations we have detailed; but we were quite unprepared for some of the phenomena which presented themselves, when we tested the effect of sensory stimulation on the k.-j.

Influence of sensations upon the knee jerk and other phenomena of like nature.

Touch. Mere touch or rough but painless contacts, which call out the well-known subcutaneous reflexes, do not influence k.-j.

Pain. This is a fertile means of reinforcement, as the following experiments show:

The subject being at rest, supine, with the right leg on the crutch, a series of equal blows, at regular intervals, is struck on the tendon. A second assistant takes hold of a hair on the thigh and twitches it so as to cause pain at the moment of one of the blows on the tendon. Nearly always this gives rise to a notable increase of the k.-j. If rapid blows,

which keep the foot slightly extended, be used, the pull on the hair exaggerates the k.-j.

A needle-prick on the thigh or anywhere else on the surface of the body or limbs, below the neck, has a like influence, and is better seen when the hands are pained than the arms or trunk. Like hurts to the neck and face, and even more decisive hurts, such as a pull on the moustache, give little result. Needle pricks are most efficient on the thigh of either side; but all of these phenomena vary with the individual; the efficiency of all such influences wears out after much repetition.

Sudden, sharp pain seems to act best. Chloroform burning is not available; but a sharp pinch of the skin of either leg or arm reinforces k.-j.

Heat. When heat is great enough to cause sudden pain it increases the k.-j., whenever used on arm, leg, or trunk, but as regards the face and neck in some persons it is efficient, and in others causes no response. The touch of a hot knife-blade on the thigh struck gives excellent results. If the heat used cover a large sensitive surface and is not great enough to cause pain, as when an assistant drops the passive hand of the subject into rather hot water, a good increase of k.-j. is observed.

Cold. Mild impressions of cold over limited surfaces cause no visible effect. The sudden application of water at 32° F. to the entire hand often strongly reinforces the k.-j., or a cold spray on leg, widely used. More remarkable are the effects of a jet of rhigolene spray on the skin of the thigh struck. At the moment of chill there is little effect; but when abruptly the part grows white and frozen, there is a momentary sharp painful sensation, and the k.-j. increases, and is exaggerated until the entire part thaws, after which, for a time, the k.-j. is

below the normal of excitability. The same results may be had with rhigolene on the other leg, or either arm or hand. In one person, freezing of the neck or face, cheek, or temple, gave remarkable additions to the k.-j. In another, rhigolene freezing of the neck caused no obvious result.

Taste. Our experiments in this direction were limited to the effects of red pepper, salt, and vinegar on the k.-j. ; the results were entirely negative.

Hearing and smell. No experiments were tried by exciting these senses.

Sight. When a magnesium wire is burned, and a succession of abrupt exposures of the eyes is made by moving a screen quickly to and fro, the first effects are not notable, but at the third or fourth, as the light becomes painful, there is a reinforcement of k.-j.

Effect on the knee-jerk of pressure on, and stimulation of the sciatic nerve. For some time we have noticed that if the thigh of the side to be investigated was supported by a staff, or by the arm being placed under it, so that the pressure came upon its middle third, the k.-j. was obtained with difficulty, or not at all. To investigate the cause of this, pressure was made upon the sciatic nerve in the middle third of the thigh with a tourniquet, for the period of fifteen minutes; this caused pain in the spot pressed upon, tingling, and, finally, numbness of the leg and foot.

During this experiment the k.-j. of the side experimented on rapidly diminished, until it could scarcely be obtained; while the k.-j. on the opposite leg remained unchanged. On several occasions, when the leg had gone to sleep from sitting in a cramped position, the k.-j. was tested, and always found to be less than that of the opposite leg.

These facts are curious, and rather at variance with some of our other experiments.

Even the encircling band produced by rolling up the pantaloons above the knee sometimes makes enough pressure to interfere materially with the k.-j.

To test the effect of direct stimulation of the sciatic nerve on the k.-j. a full-grown male rabbit was etherized, and the k.-j. found to be good; the sciatic of the opposite side was now carefully dissected out and severed from its muscular connections. Tetany of the extensor muscles of the untouched leg was now caused by taps on the tendon, and then the sciatic was stimulated by a current from a Du Bois-Reymond coil. With the coil as far out as thirty or twenty centimetres there was no appreciable effect on the k.-j., but with the coil at fifteen or ten centimetres there was a very marked reinforcement of k.j. This was verified over and over again, and the effect of the application was to make the k.j. more easily obtainable for some time afterward. The cord was then cut in the upper dorsal region, and the experiment was repeated with the same result. With the coil at five centimetres distance, the k.-j. was now evoked when the tap on the tendon was made with a thin piece of whalebone, so lightly as to cause not the slightest visible movement in the muscle.

Nitrite of amyl. The inhalation of nitrite of amyl carried to full flushing of the face appeared in no way to influence the k.-j.

Ether. Our experiments in this line were but few, and confined to animals. In dogs the k.-j. was not materially affected by light etherization after the first excitement stage was over, but full etherization entirely abolished it, and it was curious to witness the

k.-j. come and go with the varying stages of anæsthesia. This was not so apparent in the rabbit.

Faradic electricity. A moderate current (short circuit, poles four to five inches apart), sufficient to move muscles, without pain, was used on the thigh, feet, arm, or hand, with the result of increasing k.-j. A current violent enough to give rise to pain and muscle-cramp sensations, or the abrupt use of a wire-brush on dry skin increased the k.-j. powerfully. The latter experiment—*i. e.*, the application of the wire-brush—produced almost as marked an effect on the k.-j. as anything that we tried, and left the skin so sensitive that a light touch at once increased k.-j.

Galvanism. This gave far more interesting results. Ten or twelve cells of an active zinc and copper battery caused slight but distinct burning sensations when placed on the skin three inches apart. Thus used anywhere on the leg struck, the opposite limb, the arms, hands, back, or flanks, they increased the k.-j., or, when they did not, the addition of five or six cells insured this result. In these short circuits the direction of the current seemed of no moment; but it was of importance to make and break the circuit to get the most marked result. This was effected by applying the two poles at once to the skin.

Galvanism to head, back, etc. The startling results obtained by the coincident use of knee-tap and currents through the head appear to open new paths of investigation. A great number of these experiments have been made by the authors, with the aid of Drs. J. M. Taylor, S. C. Wood, T. R. Neilson, W. J. Taylor, and G. Hinsdale. As they involved the passing of powerful currents through the brain, every neurologist will understand the risks and the discomforts to the physicians who subjected them-

selves to these experiments. We may add, that persons are sometimes met with who feel very little vertigo or distress from powerful currents through the head, and who yet give good reactions as regards the influence these currents exert on the k.-j.

It will be, of course, needless to state all of our observations; of necessity, there were many failures, and the whole investigation should lead to laboratory study on animals, from which more accurate and more clearly explanatory results may be looked for. Their influence on the therapeutics of electricity seems also to be promising.

The subject being placed at rest on a lounge, with one leg on the crutch-rest, or held up in a loop, one pole of an open circuit of twelve cells is placed on each temple. An assistant has on the floor an apparatus enabling him to change the direction of the current, and to make or break circuit abruptly. A second assistant taps the tendon at intervals of three or four seconds. The assistant who controls the current watches his chance, and, without notice, makes and breaks circuit. Under these circumstances making circuit causes, of course, subjective sensation of light, some muscle movement of the temporals and occipito-frontalis, and more or less vertigo (fifteen cells or fewer), with notable increase of k.-j. This experiment always succeeds, but, in some subjects, a larger number of cells must be used. The effect wears out after a few repetitions. Breaking circuit causes little or no increase of k.-j.

The same experiments were made with the poles over the leg centres, or with one on the temple and one behind either ear, or with both behind the ears; but although the latter caused most vertigo, and all gave increase of k.-j., none gave as remarkable a result as when the two temples were within

the circuit. This may perhaps be due to the thinness of the temporal bones or may await some more satisfactory physiological explanation.

Polar effects of galvanic current. To test this, the subject, as before, was placed on the lounge and the positive pole was held on the temple, while the negative was placed on some indifferent spot, on the clavicle or on the hand. With ten cells, but little sensation was produced at the positive pole, and on making and breaking the circuit no effect was produced on the k.-j. When a greater number of cells were used, the sensations of burning and pricking became much more marked under the positive pole, and the k.-j. was reinforced. On moving this pole about the temple certain regions were found which gave more scalp pain than others, and making the current at these points gave the most reinforcement to the k.-j.

A very different result was found to follow the placing of the negative pole on the temple. In this case a marked increase of k.-j. was seen, even with currents that gave no results with the poles reversed, and when thirty or thirty-five cells were used the effect was proportionally greater.

The sensations experienced were entirely different with the two poles; the first gave the most scalp pain, while the second gave an indescribable sensation within the head. These results were obtained whether the tendon on the same side or on the other was struck. Not so marked a result was obtained when the positive or negative pole was placed over the leg centres, as on the temple.

The effect of galvanism to the head is so decisive that it is difficult to explain it as being merely the result of a combination of influences, and yet it may be that it is so active because it affects at one

and the same time, taste, sight, and general sensibility, and also gives rise to motion.

Galvanism and muscular effort combined. The same observations were made with the addition of violent and abrupt muscular effort. In this case as passivity is needless, the subject himself makes circuit either with the free foot or hand, while he strongly closes both hands. Of course, he watches the fall of the hammer, or, in case of constant excitations by frequent knee-taps, may neglect to do so. In either case coincidence of patellar blow, making circuit, and muscular effort gives the largest amount of increase of k.-j. in any way obtainable.

As to the next observation, it must be said that it is often difficult. It succeeds best with a fresh man in the morning, and has been made on the ignorant and unprepared as well as on ourselves. It succeeds to-day and fails to-morrow. In one instance it failed with four persons at nine P.M. of a warm, moist relaxing day, having succeeded before and since with at least two of them. As it demands the most powerful current a man can bear, it is needless to say that we hesitated to repeat it often. Indeed, in one or two cases, headache and vertigo, lasting an hour or two, followed it.

With the individual seated or supine (thirty to seventy cells) current through temples. Violent synchronous closure of both hands. Knee-tap. Very great increase.

Same conditions. A blow on the *tibia alone*, quite below the tendon, coincident with making current, caused distinct k.-j. Then the leg was steadied by a hand on the calf, to prevent swing, and the same phenomenon was seen. Next the muscles in front of the leg were tapped sharply, and a k.-j. obtained. These effects were absolute,

and were verified over and over. They can be had only three or four times, and then not again for some time.

It seems clear that a combination of strong galvanization of the brain with violent voluntary action is capable of making the muscles as sensitive as they sometimes are in disease, and that under these circumstances we get response to such milder forms of stimulation as a tap on the tibia.

The most probable explanation of this remarkable phenomenon is that it is due to the imperceptible stretching of the quadriceps muscle by the blow on the tibia. In cases of spastic paralysis where it is obtainable with the greatest ease by the slightest percussion of the tibia without the aid of combined muscular movements elsewhere, or electricity through the head, if an assistant slowly extends the leg while the operator steadily taps the tibia, the k.-j. is not observable unless the blows are delivered with a considerable increase of force, because the forward movement of the leg neutralizes the influence of the backward impetus given by the blow; a blow forward on the internal border of the shaft of the tibia does not produce the k.-j. This experiment could not be verified on a healthy subject, as this form of k.-j., the product of voluntary motion and galvanism, is slight and disappears so soon. The observation shows, however, how enormously the k.-j. is increased by the combined influences mentioned.

The "front tap contraction" described by Gowers, may also be explained in the same manner. To elicit this symptom the foot is pressed up until the calf muscles are tense, the leg being extended on the thigh with the calf resting on the operator's knee; a tap is now delivered upon the anterior

group of muscles, or on the tibia, an imperceptible pull is thus made on the tendo Achillis as the result of the slight downward movement of the leg which is followed by an answering jerk of the calf muscles.

This phenomenon has heretofore only been observed in disease, but we have succeeded perfectly in producing it in health, by the conjoint use of galvanism through the head and violent voluntary movements of the arms, and also by the latter conjoined with the electric wire brush. We attempted to produce an ankle clonus in the same manner, but failed.

Galvanic currents to head with sensory stimulation to skin elsewhere. The use of head currents with pinching or freezing of the skin gave a larger addition to the k.-j. than did either alone.

Galvanism to spine. With subject at rest in a reclining chair, or lying on his side on a lounge, or seated, one pole was placed on the first cervical vertebra, and the other on the last lumbar; descending current thirty to seventy cells, caused moderate increase of coincident k.-j.

Ascending current gave great increase of k.-j. The best results were had with interruptions which were not very abrupt. As there are pain, flash, taste in the mouth, both here and in the case of the head muscle movements, it is difficult to be sure as to the mode in which the current acts; certainly neither direction of current lessens the jerk, and the phenomenon of increased k.-j. seems to have relation rather to the making than to the rupture of the galvanic circle. It were also as well to add that the effect of these long circuits demands for its full expression subjects of unusual sensitiveness. It frequently fails entirely. Continuous moderate currents up or down the spine do not add to k.-j.

The time element. In these experiments it soon became evident that in order to obtain the best effects, and occasionally to obtain any at all, a certain relation in time must be observed between the muscular act, or making of the circuit, and the tapping of the tendon. In the foregoing pages the expression, coincident tendon tap, is often used, and the method of completing the circuit was by a pedal or by an electric button which was pressed by the thumb, and coincided with the tendon tap as nearly as was possible with such a coarse movement. In order to make the circuit practically coincident, an electric hammer was made, so that the lightest tap with this upon the tendon sufficed to close the circuit. In repeating the experiments with this, it was found that double the number of cells could be borne, through the head or up and down the spine, as the circuit was very abruptly made and broken, and the interesting point is, that with this we failed to reinforce the k.-j. It therefore seems that the muscular action, or circuit-closing, must precede the tap, in order to reinforce it, by a period which is, as yet, undetermined, and which needs for its determination careful work in the laboratory. When a series of very quick taps, ten or twelve per second, on a tendon were employed, thus constantly exciting the muscle, it was possible at times for the subject to appreciate the interval mentioned. When the experiment of increasing the k.-j. by the application of the secondary current and the wire brush before mentioned was employed, a large portion of a second elapsed between the application of the brush to the forearm, and the reinforcement of the k.-j. This was perfectly patent to all observers, and particularly so to the subject experimented upon. It is also entirely clear, that the effect

of volitional reinforcement lasts some little time, certainly in some people quite a second.

Skin reflexes. These being unquestioned reflexes, it became desirable to know if they obeyed the laws of reinforcement. Among them the cremaster reflex is the most available, and, as regards this, we think it clear that it is not increased by distant muscular acts, nor by sensations, as of pain.

Direct muscle reactions. In examining the k.-j. we were naturally led on to a remarkable series of discoveries in regard to the behavior of muscles when mechanically stimulated by a blow. The capacity of the muscle to respond to a blow varies with the muscle and the subject. It will, we think, be found that in health those persons give the best muscular response in whom the k.-j. is best. In some men a painful blow is needed to move the muscle; in others, the least tap of the hammer calls out motion. Usually the rounded conical end of our rubber percussion hammer gets the best response; but whatever is used, we make a local depression in the muscle as we strike and stretch the fibres abruptly over a limited area. What we thus do has some resemblance to the universal pull on the muscle fibres made by a blow on a tendon, but the direct muscular blow is far more rough and violent, and is a coarser and more local stimulation. The stretched muscles contract as the hammer leaves the part.

Relation to voluntary motion elsewhere. Place the bare, prone arm of a sensitive young person at rest on a cushion, with the hand dependent; strike the muscles on the back of the arm or the long supinator, so as just to get motion of the hand or of the muscle without the hand; then cause the subject to flex the other hand strongly: the muscle reaction will be at once reinforced notably. If we repeat this experi-

ment by striking the extensors of the leg, and use violent effort in closing both hands, we shall get, in good subjects, a distinct k.-j.

All the motions which reinforce k.-j. can be shown to increase the mechanically evolved muscular reaction.

To swallow, cough, laugh, count aloud, or strongly act with the limbs, hands, or feet, reinforces the effect of a tap on the muscle. Even the slight act of winking decisively is competent to do this.

Tension behaves somewhat as it does with the tendon-jerk. With the muscle in full relaxation we get fair results. With slight passive tension the blow acts better, and over a larger area, for obvious mechanical reasons. With extreme tension we utterly fail to be able to cause movement.

Effect of one direct muscle reaction on another. As one k.-j. does not increase another, so neither does one muscular reaction from a direct blow increase another produced at the same time; neither does the k.-j. increase the direct muscular reaction, nor *vice versâ*.

Sensation and galvanism. Rhigolene freezing and remote or near sensations (pain) reinforce direct muscle reactions (m.-j.), but not nearly so well as they do the muscle reactions from a blow on the tendon (k.-j.). Galvanism through the head increases the direct muscle act as it does the k.-j.

Points of resemblance between the direct muscle acts (muscle-jerk) and the knee-jerk.

These phenomena have many points in common, the differences are chiefly of degree, and are partly due to the fact that in the k.-j. we have a whole muscle in movement and in the muscle-jerk but a small fraction of it.

The knee-jerk seems to depend for its existence on the presence of muscular tone due to the connection

of the muscle with the spinal cord, while the direct muscle reaction depends upon the presence of the muscular irritability which exists independently of any immediate connection with the spinal cord, but may be increased by toning influences coming from it.

The tap on the tendon is a distinct generalized sharp pull on the whole muscle, and is a somewhat delicate excitation easily affected by neural changes. The direct muscle blow is a strong, positive local stimulus. It may be left in existence after the knee-jerk is lessened or lost by disease. Usually what increases the one adds to the other, as we see in spastic palsy. In a case examined lately, a young man in absolute health, without a trace of disease, athletic and a good dancer, there is absolutely no knee-jerk and also no muscle act under hammer in the thigh, neither can these be called into action by any coincident act, electricity, rhigolene, etc., although in the arms the muscle-jerk is perfect for all tests.

It seems difficult to escape the conclusion that the two sets of phenomena are but varied forms of expression of one normal muscular property, dependent for its integrity upon various nutritive conditions, and for its grades of excitability upon certain relations of the muscle to normal spinal centres.

Inability to reinforce electrical contractions of muscles by the means which add to knee-jerk and muscle-jerk. It was natural to presume that if k.-j., and the muscle response to a tap, could be increased by remote movements, and sensations, and galvanism, that electricity, the third means of exciting motion, would follow the same law. This is not so; no form or degree of muscular movement obtained through galvanism or faradism could be increased by anything we could do; heat, cold, galvanism to head

with volitional movements, all alike failed. It is hardly needful to detail these observations; they were varied, and made on several persons in whom it was easy to get the reinforcement of k.-j. by volitional acts or pain. The cause of this exception is not clear. It seemed possible that electric currents might interfere with the passage of the more delicate tone waves. This we tested as follows: a strong or moderate faradic primary current being allowed to traverse the supinator longus, the muscle was struck lightly with the flat end of a percussion hammer, so as to get a slight direct response; then, violent contraction of the other hand was still found able to reinforce the muscle-jerk. There are obvious fallacies in this too promising experiment, for it is impossible to be sure that all of the muscle is, so to speak, electrically occupied, unless we use an excessive current, and that interferes with the experiment, by causing too much contraction. There is, however, an interesting observation which anyone may easily repeat, and which gives one a distinct impression that electrical possession of a muscle makes its volitional acts fatiguing or difficult. Let the arm rest on a cushion, prone, faradize the extensors, so as to contract them only partially, now will to extend the hand; there is at once felt to be some unusual need for effort, some mysterious impediment. It takes an extra effort of will to use the muscle through which runs a faradic current.

It may be, therefore, that nerve and muscle texture, when under the coarse influence of electric stimulation, are less accessible to gentler tone waves.

Reinforcement of volitional acts by other volitions. If muscular movement, caused by a blow or a tap on a tendon, be capable of increase by willed motion in another part of the body, it seemed to us that one act of will should thus increase the effects of

another act of will. This has been stated to be the case by Quetelet,[1] and denied by G. Stanley Hall and E. M. Hartwell.[2] Our own experiments incline us to believe with Quetelet. Muscles already fatigued by previous efforts seemed to show the most reinforcement. We hope to investigate this subject further.

Résumé and conclusions. The k.-j. varies in health, it may be exhausted by too much use, and may increase from frequent excitation.

All volitional acts, if strong enough, may increase the k.-j. of either leg, and even such small acts as winking, etc., are competent to do so under favoring circumstances.

Weak innervation of the crural nerve increases, and strong innervation of the same, prohibits k.-j.

All sciatic innervation increases k.-j.

Volitional reinforcement lasts for an appreciable time after volition ceases.

Continued violent muscular acts, as of both arms and hands, at last enfeeble the k.-j., and this enfeeblement lasts for an appreciable time.

Passive tension is not essential for the production of k.-j.

Moderate tension mechanically favors it.

Extreme tension destroys it, even in spastic cases, and this is probably mechanical in part, but also, and to a large degree, physiological.

An act of will directed to a part which is functionally inert, or to amputated parts, reinforces k.-j. Hence it is not the muscular motion which is the essential factor.

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[1] Sur l'homme et le dévelopement de ses facultés, par A. Quetelet, Bruxelles, 1836, vol. ii, pp. 79, 80.

[2] Bilateral Asymmetry of Function, Mind, No. xxxiii.

Strong or weak stimulation of one sciatic in an etherized animal, intensifies the k.-j. of the other leg; pressure upon the sciatic in man, causing pain and numbness, diminishes the k.-j. of that leg.

Elbow-, ankle-, and jaw-jerks obey the same laws as the k.-j.

One k.-j. does not reinforce the other.

Mere touch has no effect on k.-j. All abrupt impressions, as of pain, heat or cold, anywhere on the skin, increase k.-j.

Gustation has no effect on k. j.

Violent optical impressions, in sensitive cases, increase k.-j.

Nitrite of amyl has no effect on k.-j.

Etherization, if profound, abolishes the k.-j. in dogs, has less effect in rabbits.

All short faradic currents, anywhere, if strong enough to move muscles, increase k.-j.

The wire-brush, with faradism on the dry skin, is one of the most effectual of all means of addition to k.-j.

Short galvanic currents, not strong enough to move muscles, give, under certain conditions, marked increase of k.-j.

Galvanism to temples especially, but also to other regions of the head, gives large reinforcements to k.-j.

Making circuit is more effectual than breaking, and these effects soon wear out.

The negative pole to temple gives greater and more constant increase of k.-j. than the positive in same postion.

There is more effect on k.-j. from pole on temple than over leg-centres. Effect the same for either k.-j.

Galvanism to temples, with violent synchronous muscle acts, very greatly reinforces k.-j.

Long ascending spinal galvanic currents give good increase of k.-j. ; descending, far less.

Moderate constant currents to spine do not reinforce k.-j.

The skin-reflexes (cremaster, abdominal) are not reinforced by muscle acts or by pain.

When the belly of a muscle is struck, the resulting contraction obeys all the laws of reinforcement which apply to the k.-j. Tension has upon it much the same influence as on k.-j. One muscle-jerk does not reinforce another.

The movement caused by electricity seems incapable of reinforcement.

Tension lessens the effect of even quite strong faradic currents as to pain and motion.

Well-known facts and the researches here stated, lead us to believe that the knee-jerk and other like responses to tendon taps are direct muscular acts; they cannot exist without that spinal contribution known as tone, which is capable of increase from a variety of causes. These muscle responses to a pull on the tendon cannot be reflexes, for the latter are inhibited by violent sensory stimulations, which are here shown to increase the k.-j. The true skin-reflexes are incapable of being reinforced by distant volitional muscular acts like the k.-j., and have a time far greater than that of the k.-j. The two groups of muscular replies to forms of irritation, therefore, differ radically. There is no reason to believe that the aid given by moderate tension to the knee-, ankle-, elbow-, and jaw-jerks, is other than mechanical; besides, it is not essential. As regards the k. j., tension has previously been shown to be unessential. The jaw-jerk can be had when the part is without tension

and is being supported by the hand. A tap on a tendon mechanically affects the tissues lying within the whole of the muscle case, but whether through the nerve ends, or more directly, is difficult to say.

The tendon tap is a more delicate mode of stimulating the muscle to act than is the mechanical blow upon its body, it is also more competent to influence the entire muscle.

The direct blow on a muscle abisrupt, violent, and local, and has two results. By abruptly depressing the muscle it makes on the muscle fibres a pull, which is limited, and to which they respond by contractions, and at the spot directly hit the immediate violence of the blow has the effect of causing an abrupt mounding of the fibres, which rise rather slowly as the longer primary fibrillar contraction ceases. This small firm elevation is not easily observed in firm muscles or in health, except in thin subjects or over bones; it lasts for some seconds and slowly disappears.

It is seen from these researches that the muscle responds to various excitations by virtue of its intrinsic irritability and its tone. Both of these vary, and their sum, when the health is highest and the body at its best, represents capacity to shorten under nerve influence, and other less natural excitations. The muscular irritability depends for its character and existence on nutritive influences. The tone is merely what might not inaptly be called tuning of the muscle. It is a final preparation for volitional excitation. We have already said that efferent spinal excitations sustain its constancy, and from our own observations it seems clear that incessantly tone waves are flowing from the spine, set in motion by

every sensation, and by all muscular volitions however remote.

Hence it is that when by section of nerves, disease, or other cause, we cut off the efferent influences, tone is lost and the most delicate of muscle tests, the response to tendon taps, is synchronously abolished. Clearly something in the muscle itself is the most potent excitor of tone waves, as is shown by the fact that section of the sensitive roots so affects them as to put an end to the k.-j.

After cutting the crural nerve, although tone is lost, the muscle still competently replies to the violent excitation of a blow in the peculiar manner described. If now the animal be killed, circulation ceases, and with this nutritive damage come lessened response to a blow and greater humping up of the fibres at the point struck. This latter phenomenon seems to increase for a time as the muscle gets weaker, and we are thus reminded of the fact that in the feeble muscles of thin, phthisical people it shows so remarkably well.

Next the long contraction from a direct blow becomes less, and soon only the shorter is seen. Then this too is lost. At this stage of enfeeblement, induction currents still powerfully affect the fibres which all other excitants fail to impress.

The application of the facts we have discovered to clinical research remains to be made, but assuredly they widen the field of useful possibilities in the domain of symptomatology.

It is very difficult to explain the fact that electricity, sensory impressions, and distant voluntary muscle acts increase the knee-jerk and the response to the muscle blow. If we conceive of a series of inhibitory centres extending from the mesocephalon all the way down the cord, and infer that all the agents

mentioned are capable, by more or less paralyzing these centres, of releasing the active reflex groups below them, we shall be able to comprehend that the centres thus set free may, by increasing tone, give to the muscle a suddenly enlarged capacity to respond to the tendon taps or the muscle blow.

Nearly all of the facts with which we are concerned may be explained by inhibition organs and the effects produced upon them. On the other hand, it is equally conceivable that whenever a sensation reaches the cord or brain, or both, an overflow may occur which shall, by increasing the excitation of the centres, be felt throughout the body and reinforce any organs chancing to be synchronously otherwise excited from without. Under this view we conceive of the nervous force as not confined entirely to the direct paths between the centres and the muscle to be moved, but as overflowing so as to pass through numerous ganglia, adding a certain small increment to their effects when in a state of such activity as the spinal toning centres must be at all times. The tone centres thus stimulated send out a higher wave of excitability to all the muscles, and if at the time this reaches a muscle that muscle is being excited by a tap, there is an increased response.

Several facts tend to support this theory of overflow. The awkward movements of young children, and the associated movements accompanying many of our everyday acts which require great effort, may be thus explained. In excitable conditions of the spinal cord associated movements are common. Writer's and telegrapher's cramp are examples in point.

Lauder Brunton's theory of the coincidence and interference of nerve waves, as increasing or diminishing the resulting motions, as waves of light and sound are known to be influenced, may in the light

of further knowledge be competent to explain more precisely the manner in which overflow acts as a reinforcing agency.

Our discoveries as to the various influences which affect the direct and indirect muscle reactions should, we think, be regarded as distinct additions to physiological knowledge. The brief speculations founded upon them may be more or less correct, and until we have examined their relations to the domain of pathology it will be difficult to decide more positively on their causes.

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