

A STUDY OF THE CONDITIONED PATELLAR REFLEX

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The object of this investigation¹ was to determine the possibility of forming a conditioned knee jerk, and, if formed, to study the rate of its formation, its stability, and the effect of varying such factors in the procedure as length of training and the conditioning stimulus. Finally, it was desired to study the course of contraction in the conditioned and unconditional knee jerks and in the voluntary contraction of the quadriceps muscle-group.

The term 'conditioned reflex' was developed in Pavlov's laboratory as a name for the individually acquired connection, in an animal, between a stimulus and a response. Pavlov defines a reflex as "an inevitable reaction of an organism to an external stimulus, brought about along a definite path in the nervous system," and carefully shows that a conditioned reflex fulfills this definition. But "these new reflexes actually do depend on very many conditions, both in their formation, and in their physiological activity." Hence they are called 'conditioned' reflexes.²

The publication by Pavlov of an article entitled *Sur la sécrétion psychique des glandes salivaires*³ is usually considered to be the beginning of the study of the conditioned reflex. Since that date (1904) there has been a constantly increasing interest in the subject. Pavlov has continued his work, and built up a school of Reflexology. He and his pupils have studied for over twenty years the cortical activity of the dog by the method of conditioned reflexes. They have linked conditioning stimuli from every sense department to either of two salivary reflexes. One of these unconditional reflexes is normally aroused by food and is an alimentary reflex, whereas the other is a response to acid placed in the mouth and is a mild defensive reflex. Pavlov says that in most cases the motor actions allied with these glandular responses are not taken into consideration, but are occasionally used when the results obtained from the secretion are not sufficient. An illustration of this resort to one of the motor components of an alimentary reflex is found in an investigation of the latent time of the conditioned reflex. Bykow and Petrowa measured the interval between the sounding of a bell (the conditioned stimulus) and the movement of the head toward the usual

¹ This study was carried out in the Psychological Laboratory of Princeton University.

² I. P. Pavlov, *Conditioned reflexes; an investigation of the physiological activity of the cerebral cortex*, 1926, (G. V. Anrep, tr., 1927), 23-25.

³ *Arch. internat. de physiol.*, 1904, I, 119-135.

source of food.⁴ But Pavlov's system rests mainly on the study of conditioned salivary reflexes. He has summarized and organized the results of over twenty years of work in his book *Conditioned Reflexes*.⁵ This is the first complete discussion of the work of Pavlov's school to appear in one of the more familiar languages, although several earlier and less complete summaries have appeared.⁶

Bechterev also made an extensive study of the conditioned, or, as he called it, the 'associative motor' reflex. He and his pupils have studied the conditioned withdrawal reflex using shock as the unconditioned stimulus, in both animals and man.⁷ He differs from Pavlov in that his theories are applied to man, as well as to other higher mammals; whereas Pavlov usually confines his statements and theorizing to the acquired reactions of dogs.

In addition to the members of these two schools, there are many isolated investigators who have attacked the problem of the conditioned reflex in animals.⁸ Most of them seem to have done only occasional pieces of work, and have not attempted a systematic formulation of the results. Beritoff is perhaps the most outstanding exception to this statement. He has verified most of Pavlov's results, using the flexion reflex of dogs as the unconditioned reflex. In addition to the movements of the stimulated leg, he recorded those of the head and of one other leg, thus obtaining a somewhat better picture of what the animal was doing. The most important aspect of Beritoff's work is his attempt to explain the conditioned reflex on a modern physiological basis. As he points out, Pavlov's explanations are not in strict accord with present physiological theory. But Beritoff is himself quite careful in his explanations not to ignore the results of those physiologists who are attacking the problem of the action of the central nervous system by methods other than that of the conditioned reflex.⁹

There has been considerably less investigation of the conditioned reflex in human subjects than in animals. Conditioned emotional reactions may be easily set up in infants,¹⁰ as may feeding movements.¹¹ In adults, the iris or pupillary reflex has

⁴ K. M. Bykow & M. K. Petrowa, Die Latenzperiode des bedingten Reflexes (German summary of the Russian original). *Trudy physiol. laboratoriy akademika I. P. Pavlova*, 1927, 2, 147-149.

⁵ Pavlov, *op. cit.*

⁶ R. M. Yerkes & S. Morgulis, The method of Pawlow in animal psychology, *Psychol. Bull.*, 1909, 6, 257-273; S. Morgulis, Pawlow's theory of the function of the central nervous system, and a digest of some of the more recent contributions to the subject from Pawlow's laboratory, *J. Animal Behav.*, 1914, 4, 362-379; G. V. Anrep, The irradiation of conditioned reflexes, *Proc. Roy. Soc. Lond.*, 1923, 94B, 404-426; C. L. Evans, *Recent advances in physiology*, 1926; H. Cason, The conditioned reflex or conditioned response as a common activity of living organisms, *Psychol. Bull.*, 1925, 22, 445-472.

⁷ W. Bechterev, *La psychologie objective* (N. Kostyleff, tr.), 1913.

⁸ H. Cason, *op. cit.*

⁹ J. Beritoff, On the fundamental nervous processes in the cortex of the cerebral hemispheres, *Brain*, 1924, 47, 109-145, 358-376; Ueber die individuell-erworbene Tätigkeit des Zentralnervensystems, *J. f. Psychol. u. Neur.*, 1927, 33, 113-335.

¹⁰ J. B. Watson, *Behaviorism*, 2d ed., 1925.

¹¹ N. Krasnogorski, Ueber die Grundmechanismen der Arbeit der Grosshirnrinde bei Kindern, *Jahrb. f. Kinderh.*, 1913, 78, 373-398; F. Mateer, *Child behavior; a critical and experimental study of young children by the method of conditioned reflexes*, 1918.

been conditioned to various stimuli,¹³ as well as the eyelid reflex.¹² Bechterev, as mentioned above, has studied conditioned withdrawal from shock. Investigators in this country have established the same reflex.¹⁴ The conditioned salivary reflex in man seems a little difficult to elicit in the laboratory.¹⁵ This may be due to faulty technique, as Lashley supposes.

While studying the problem of facilitation of the knee jerk, Twitmyer¹⁶ (1902) accidentally discovered that the knee jerk had become conditioned to the bell which he used as a preparatory signal. After this accidental discovery, he established conditioned knee jerks in six subjects. Dodge,¹⁷ on the other hand, failed to establish conditioned knee jerks in several experiments. But Shevaley¹⁸ apparently set up fairly stable conditioned knee jerks in seven adults.

The history of the 'simple' or unconditioned knee jerk is long and controversial. The knee jerk is the most easily elicited of the tendon reflexes, as well as the easiest to record. Since the tendon reflexes depend so largely upon the tonic condition of the muscle groups involved at the moment of stimulation, one of them, the knee jerk, has been used constantly by the physician in general diagnosis. This same dependence on tonic conditions makes it very sensitive to all other events in the central nervous system. For this reason the knee jerk has also been considerably used by the physiologist and the psychologist, especially in the study of facilitation and inhibition. Fearing has discussed this question, and has also written a brief history of the knee jerk from this aspect.¹⁹

A complete history of the knee jerk has not been written, nor for our purposes will it be necessary to do more than to summarize briefly the three views that have been held of the mechanism of the reflex.²⁰ These three views severally maintain as follows:

¹² H. Cason, The conditioned pupillary reaction, this JOURNAL, 1922, 5, 108-146.

¹³ H. Cason, The conditioned eyelid reaction, this JOURNAL, 1922, 5, 153-196; R. Dodge, *Elementary conditions of human variability*, 1927, 68-69.

¹⁴ J. B. Watson, The place of the conditioned-reflex in psychology, *Psychol. Rev.*, 1916, 23, 89-116; I. A. Hamel, A study and analysis of the conditioned reflex, *Psychol. Monog.*, 1919, 27, (no. 118), 1-64; H. Cason, *Psychol. Bull.*, 1925, 22, 459; G. Humphrey, The effect of sequences of indifferent stimuli on a reaction of the conditioned response type, *J. Abn. & Soc. Psychol.*, 1927, 22, 194-212.

¹⁵ K. S. Lashley, The human salivary reflex, and its use in psychology, *Psychol. Rev.*, 1916, 23, 446-464.

¹⁶ E. B. Twitmyer, *A study of the knee jerk*, 1902, Univ. of Pennsylvania.

¹⁷ *Op. cit. inf.*

¹⁸ E. Shevaley, The associative-motor reflex of the knee (Russian), (Bechterev 40th anniversary commemorative volume, 1926, 105-124). [Original not available, see *Psychol. Abst.*, 1927, no. 2158.]

¹⁹ F. Fearing, A critique of the experimental studies of cortical inhibition with special reference to the knee jerk, *J. Comp. Psychol.*, 1927, 7, 285-296; The history of the experimental study of the knee jerk, *Amer. J. Psychol.*, 1928, 40, 92-111. See also W. James, *Principles of Psychology*, 1890, Vol. 2, 379-381.

²⁰ Since most of the references may be found in Fearing's history of the knee jerk only those not mentioned in that article will be given here.

(1) The knee jerk is a simple twitch of the muscle independent of nervous connections, except in so far as these connections determine the tonus of the muscle. The reflex can be facilitated or inhibited through these changes of tonus. Westphal, Gowers and Waller held this view.

(2) The knee jerk is a true reflex, of very short latency, involving (a) the proprioceptors in the muscle, (b) an afferent nerve, (c) a synapse in the cord, (d) an efferent nerve, and finally (e) the quadriceps muscle group. The controversy between the supporters of the first and second theories continued for some time. The strongest objection to the reflex view of the knee jerk was based on its very short latent period. It was thought that this latent time was too short for a true reflex. But careful determination of the latent time and analysis of the factors involved in it (Jolly, Snyder, Dodge, Hoffman) largely overcame this objection. Since then, other evidence in support of the reflex theory has accumulated as a result of investigation of (1) the course of contraction in the muscle (Dodge), (2) coördination of flexor and extensor in the knee jerk (Sherrington), and (3) the possibility of conditioning the patellar reflex to other stimuli (Twitmyer, Shevaley²¹).

(3) At present, the position that the knee jerk is a simple reflex is being abandoned, along with other so-called simple reflexes. The work of Sherrington, Liddell and Fulton,²² and of Travis²³ especially, and the innumerable studies of the effect of facilitation and inhibition on the patellar reflex, make it apparent that the supposedly simple reflex not only involves a simple path from receptor to effector, with one synapse in the lumbar region of the cord, but also calls forth the activity of a fairly large portion of the central nervous system. The initial contraction of the quadriceps seems to be the result of a simple spinal reflex, but the curve of contraction of the muscle is soon complicated by discharges from higher centers.

It is, then, a complicated response that we are attempting to condition to antecedently irrelevant stimuli. There may be an objection to calling the result of such a conditioning a conditioned reflex; but in doing so, I am using the term in its conventional sense, with no implications in regard to the simplicity of the path of either the unconditioned or the conditioned knee jerk.

PRELIMINARY EXPERIMENTS

Preliminary experiments were made in order to explore the problem before the main part of the experimentation was attempted. Groups 1 to 6B were arranged, each planned after the completion of the preceding group, in a continued effort to obtain better conditioning.

The hammer used to elicit the knee jerk was of the usual pendulum type. The blow was delivered by the rounded edge of a wooden wedge which was mounted on a wooden block. This block served as the head of the hammer, and was mounted on a brass shaft in such a way that the striking edge of the wedge was at right angles to the patellar tendon. The shaft was a $\frac{3}{8}$ -inch brass rod, 25 inches in length. Since the

²¹ *Op. cit.*

²² J. F. Fulton, *Muscular contraction and the reflex control of movement*, 1926.

²³ L. E. Travis, W. W. Tuttle & T. A. Hunter, The tetanic nature of the knee-jerk response in man, *Amer. J. Physiol.*, 1927, 81, 670-678.

striking edge was an inch above the lower end of the rod, the hammer had an effective radius of 24 inches. The hammer was raised by hand before each blow and held in the raised position by an electromagnet. This magnet was mounted on a quadrant and could be raised or lowered as desired, thus changing the strength of the blow. It was never necessary to use more than 60 degrees to elicit a satisfactory jerk from any subject used. If this force was not sufficient, that obtained from a fall of 90 degrees also failed to elicit the knee jerk, and the subject was discarded. No attempt was made to determine the actual energy in the blow, since the sensitivity of the various subjects' knee jerks did not interest us. The weight of the shaft and head was two pounds. The quadrant, magnet, and the bearing on which the pendulum hammer swung, were all mounted on a sleeve, which was slipped over the rod of a 5-foot laboratory standard with tripod base, and held in position with two set screws, so that this whole unit could easily be adjusted for height. Adjustment in the horizontal plane was made by moving the standard. To make it possible to keep the support rod out of the way of the subject's leg when he kicked, without making it necessary to strike the tendon from one side, the quadrant, magnet and hammer bearing were mounted on the sleeve in such a way that the hammer fell in a plane 5 inches to one side of the supporting rod.

The time of fall of the hammer was carefully measured by kymographic technique (see Group 10, main series). It was found that, if the hammer was so adjusted that it hit the tendon at the bottom of its stroke, it struck .34 sec after its release. Due to unavoidable movements of the subject, and consequent slight changes of the position of his knee, this interval varied between .32 and .36 sec. No appreciable difference in this interval was caused by changing the height from which the hammer was released, since the period of the pendulum was not changed by a change in the amplitude of its vibration. This hammer was used throughout the experiments.

For the first three groups, the general set-up and procedure were as follows. The subject was comfortably seated on an elevated chair or bench, which had a broad desk-like arm attached to one side. The thighs projected several inches beyond the edge of the seat. An adjustable upholstered leg-rest was attached to the under side of the seat in such a way that it supported the stimulated leg just behind the knee. (With the exception of the last of the main groups this was the right leg.) The sides of this leg-rest prevented the leg from moving to either side. The other leg was supported by a foot-rest. A cardboard screen prevented the subject from seeing either the experimenter or the hammer. No kymographic record was made of Groups 1-3. The experimenter carefully observed whether or not the subject kicked when presented with the conditioned stimulus alone and also observed anything unusual, such as early kicks. Introspections were taken after practically every presentation of the conditioned without the unconditioned stimulus.

In Group 1, a 3-inch bell was used as the conditioning stimulus. Later it was replaced by one 6 inches in diameter, to give a louder sound. The bell was arranged in the following manner to give a single stroke when it was activated by the closing of the key. The clapper was so adjusted that it did not rest against the edge of the bell, but merely struck it once, due to the 'whip' of the clapper. This arrangement permitted the bell to reverberate until the key controlling the clapper was released, whereupon the bell was promptly deadened by a piece of sponge rubber, mounted on the clapper in such a way that the rubber rested against the edge of the bell when no current flowed through the coils of the bell. The interval between the bell and the blow was .34 sec, since the clapper, by means of a relay, was actuated by the same key that released the hammer.

The subject was seated comfortably and the hammer adjusted. He was permitted to read, or, if he preferred, to divert himself by drawing on the cardboard screen in front of him. Since all the subjects in this group, as well as the next three, were members of the faculty, graduate students, or seniors in the Psychology department, and were familiar with the conditioned reflex, no attempt was made to keep the purpose of the experiment a secret. They were instructed not to kick voluntarily at any time, but also not to attempt to inhibit a kick. The presentations of the conditioned and unconditioned stimuli were given in series of 5, with an interval of 5 sec between each double presentation, and of 15 sec between series. Fifteen such series were given the first day, making 75 double presentations in all, and 20 series on each of the succeeding sittings. Experimental periods were given to each subject once a week. The conditioned reflex was tested (presentation of the conditioned stimulus alone) once or twice toward the end of each period. It was feared that more frequent tests would wear out the conditioned reflex. Six subjects were given 9 experimental sittings each, totalling 875 double presentations.

Group 2 was designed to determine the effect of using various intervals between the conditioned and unconditioned stimuli. It differed from the preceding group in two ways. First, the double stimuli were no longer given in series but were presented at irregular intervals. The average of these intervals was 5 sec.

Secondly, the interval between the conditioned and unconditioned stimuli was not the same for all subjects. Each subject was assigned one of four intervals (.29, .34, .39, .44 sec), and this interval was used throughout all his sittings in this group. The interval was controlled by a motor-driven brass drum, with contact points that actuated relays controlling the bell and the hammer. Since the drum made one revolution in every $1\frac{1}{2}$ -sec it was necessary to insert a key in the circuit flowing through the drum, so that the relays would not be actuated every time the drum made contact. Thus the interval between presentations could be varied by omitting from 1 to 5 revolutions of the drum, while the interval between the conditioned and unconditioned stimuli remained unchanged.

Eight subjects were used, five of whom had been members of Group 1. From 2 to 5 sittings were secured from each. The group was discontinued before its completion, partly because several of the subjects were no longer available, and partly because the timing device was very irregular, due to fluctuations in the 110-volt alternating current that ran the drum.

Group 3 was arranged to test the result of a less remote, and presumably more compelling, stimulus. The conditioned stimulus was a loud click in a pair of earphones. It preceded the unconditioned stimulus by .34 sec. The earphones were connected in parallel with the coils of the magnet that supported the hammer. Hence there was a rather loud click when the circuit was broken to release the hammer, and a smaller one when it was re-established. In order to cause these two clicks to fuse into one sound, the circuit was interrupted only momentarily. This effect was secured by rapidly throwing over a double-throw mercury switch, with the two terminals connected together. Mercury contacts were used to eliminate the constant crackling that would have appeared in the phones if a metallic contact had been used.

Four subjects were used in this group, none of whom had had experience in a previous group. They were given respectively 2, 5, 5, 7 sittings (300 double stimulations to the sitting).

The method for Group 4 differed considerably from that previously used. The conditioned stimulus was a buzz in the earphones, which started .6 sec before the blow

occurred, and lasted until .1 sec after it. This buzz was produced by connecting the terminals of the phones in parallel with a small high-frequency buzzer. Although the buzzer was a very good one, it was found impossible to keep it vibrating at a constant frequency because of the wearing away of the contacts. A certain constancy was obtained by inserting a rheostat in series with the coils of the buzzer, so that the voltage might be increased to compensate for the wear on the contacts; but the device left much to be desired. It was not thought necessary, however, to install a vacuum tube oscillator as a more constant source of sound, in the preliminary work, since no attempt was being made to obtain differentiation of two unlike conditioning stimuli. The time relations between the conditioned and unconditioned stimuli were controlled by a pendulum, which started the buzzer as it commenced its stroke, released the hammer at the end of its single vibration, and stopped the buzzer as it completed its double vibration. A ratchet mechanism served both as a release to start the pendulum, and as a catch to stop it on its return. Since a certain amount of energy was lost in friction, the pendulum did not return completely to its original position, and therefore had to be run further up on the ratchet before it was released again.

After four subjects had each been given several sittings in this group, it was found that they were giving conditioned knee jerks with a fair degree of regularity. It was therefore decided so to modify the group that an objective record of these conditioned reflexes might be obtained. In Professor Dodge's discussion of the various means of recording the knee jerk,²⁴ he points out that the record of the thickening of the quadriceps muscle furnishes the most accurate description of the course of contraction of the muscle. Since one of the objects of this study was to compare the conditioned knee jerk with the unconditioned or 'simple' knee jerk, on one hand, and the 'voluntary' contraction of the quadriceps, on the other, it was decided to use this method. Since certain modifications have been made in the method as described by Dodge, to permit its use with a larger number of subjects, the arrangement used in this experiment will be described completely.

The subject was seated on a chair of such a height that the foot rested on the floor, without the flexor muscle of the thigh bearing the weight of the leg. The lower leg was held in position by being strapped against a V-shaped block, placed in front of the shin. A block of wood, $2\frac{3}{4} \times \frac{3}{4} \times \frac{1}{4}$ -in was pressed against the quadriceps by the tension of two rubber bands stretched from the seat of the chair. The block was attached to a piece of copper wire .2 mm in diameter, which passed over three pulleys to a muscle lever. The light wooden pulleys had a V-shaped groove and revolved on hardened steel conical bearings. The muscle lever was of the usual type, with a cylindrical straw writing-arm and a parchment tip. As a counterpoise, a rubber band was used instead of the usual weight. The whole system was relatively free from inertia and consequent distortion of the curves. The lever wrote on a Ludwig-Baltzer kymograph, moving at a rate of 3 cm per sec. The hammer was arranged to fall so that a continuous record could be taken for 6-8 revolutions of the drum. The interval between successive double stimulations was decreased, so that it averaged 3 sec. Forty double stimulations could be recorded on each drum. During each experimental period two drums were used, the first recording presentations 1-40, the second, 200-240. Usually no tests of the conditioned reflex were made except while a record was being taken. Occasionally, however, tests were made at other times, or records were taken with no test, so that the sound of the kymograph would not acquire an inhibiting effect. In addition to the muscle lever, a signal marker was used to

²⁴Dodge, R., *Zsch. f. allg. Physiol.*, 1910, 12, 1-58.

record the occurrence and duration of the conditioning stimulus (a buzz). Since the excursion of the signal marker lasted for .7 sec, it served as a rough time-line. No greater accuracy than this was desired in the preliminary work. The actual moment of stimulation of the knee jerk was furnished by a ripple in the record of the quadriceps, caused, as Dodge pointed out, by the mechanical stretching of the muscle.

Group 4 was continued, with the changes indicated, so that the conditioned knee jerks might be recorded. Six subjects were used, all but one members of a previous group. They were given from 3 to 11 sittings.

In the remaining groups, an extension kymograph was substituted for the one described above. The belt of paper used was 60 inches in length, and as only half of the belt was used at once, each belt could be used for two revolutions. Thus 120 inches of writing space were available. The kymograph was usually operated at a speed of 1 in. to 5 sec. This speed was sufficient to record clearly the height of the kick, and to show whether or not the subject kicked before the blow. When it was desired to study the curve of contraction, the movement of a lever increased the speed to the rate of 1 in. to .2 sec. The records were fixed by spraying them before removal from the drum. A (1 : 10) solution of shellac and grain alcohol, applied with a 'G.V.' hand spray (designed for 'Duco,' etc.) was found very satisfactory. The kymograph permitted 10 min of actual recording, and as the interval between presentations averaged 3 sec, 200 double stimulations could be recorded on each belt. Since it was impractical to change the paper belt and smoke a new one while the subject waited, and since it was desired to record all presentations, it was decided to give only 200 double stimulations during each period.

In Group 5, it was planned to use a tactual stimulus as a conditioning agent. A soft iron stylus, with a felt-covered head $\frac{3}{8}$ -inch in diameter on one end, was used for the stimulus. It was 4 inches long, $\frac{1}{8}$ -inch thick, and weighed 16 grams. The stylus was placed, head down, inside a piece of copper tubing that served as the core of a coil. When current flowed through the coil, the stylus automatically took a position in the core that was a resultant of gravity and the lines of force of the magnetic field. When the circuit was broken, the stylus dropped. A finger rest was arranged at a distance beneath the coil and stylus that would allow the stylus to rest on the finger after it had fallen 2 inches. The resulting tactual stimulation of the finger was the conditioned stimulus. The circuit through the coil was interrupted simultaneously with that through the hammer magnet, so that both stylus and hammer started their fall at the same moment. Since the stylus took a trifle over .1 sec to fall 2 inches, whereas the hammer took .34 sec to reach the tendon, the tactual stimulation occurred about .2 sec before the tap on the patellar tendon. In all cases (except tests of the conditioned knee jerk) the stylus was allowed to rest on the finger until the knee jerk had occurred. It was then lifted by closing the circuit. This same set-up was used for Groups 5, 6A, 6B and 7. Unfortunately, although the stylus itself was fairly noiseless, a relay and signal marker made audible sounds, so that the so-called tactual stimulus was really a combination of tactual and auditory stimuli. Five subjects were given 5 experimental periods each, on successive days, with 200 presentations to the period. Tests were given only on the last day, to be certain that we were not setting up the phenomenon Professor Pavlov refers to as 'internal inhibition.'

Group 6A was exactly the same as Group 5, except that the subjects were instructed to lift the stylus as soon as it fell on their finger, and to hold it in that position until after the blow. Certain important differences appeared when the results of this group were compared with the results of the earlier groups, but due to the fact that

very few tests were made in this group, it was felt that the results obtained should be verified by another group. Therefore group 6B was designed. It differed from group 6A only in certain differences of procedure. Printed instructions were given to the subjects, as follows:

1. Please get comfortable, seated well back in the chair, etc., before the adjustment of the apparatus. *After that, do not change your position unless you warn me before you do so.*

2. Do not allow anything to continue that is causing discomfort, no matter how slightly. The hammer should cause no pain as it falls, and the apparatus should not hinder the circulation of blood in the leg.

3. Report, at the end of the group, any irregularities that may occur in the procedure, if you notice them, *but do not introspect regularly.*

4. Place the middle finger of the right hand under the touch stimulus, so that it falls on the first joint from the end. Lift the stylus as soon as it falls.

After the instructions had been read, any unclear points were explained. The subjects were then told that there would be 20 presentations in each series, and 10 series during each experimental period. They were then given 20 'practice' presentations, during which only the tactual stimuli were presented. This was of course done only on the first day, and served to get the subjects used to lifting the stylus. If the record obtained during these practice presentations showed that the movement involved in lifting the stylus caused a movement of the quadriceps muscle, the subject was told not to lift the stylus so vigorously. After this preliminary series on the first day and on each of the remaining days, the subjects were given 10 series, during each of which the double stimulations were given 20 times. The conditioned reflex was tested during the first and second days, on the 12th stimulation of the third series; on the 13th and 17th, fourth series; on the 3d and 5th, fifth series; on the 9th, seventh series; and on the 4th, eighth series. To prevent memorization of this schedule of testing, it was changed on the third and fourth day to 16th stimulation, second series; 4th, fourth series; 18th, fifth series; 2d, sixth series; 14th and 19th, ninth series. Five subjects were used in this group, and were given 4 experimental periods each.

DISCUSSION OF PRELIMINARY RESULTS

Under Table I the results obtained from Groups 1 to 6B have been tabulated. Each subject in the preliminary

TABLE I

PRELIMINARY GROUPS, 1-6B; PERCENTAGES (BY SUBJECTS) OF TESTS RESULTING
IN CONDITIONED KNEE JERES

	Subject.....	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Ave.	
Group 1	8	0	25	50	35	0									20	
"	2.....	9	50		14	0	0	0	59	0						17	
"	3.....										55	13	21	17		27	
"	4.....				11		0				33		9	25	0	13	
	Subject.....	O	P	Q	R	S	T	U	V	W	X	Y	Z	A'	B'	C'	
Group 5	0	40	0	0	12											10
"	6A.....						16	67	0	100	67						50
"	6B.....											75	40	75	80	45	63

groups is designated by a letter, which he keeps throughout the experiment. Thus it may be seen, for example, that Subject D participated in three groups. The figures show the percentage of tests on which each subject kicked in response to the conditioned stimulus alone.

It may readily be seen from this table that, if some previously indifferent stimulus is repeatedly presented just before the knee jerk is elicited, eventually the presentation of this stimulus alone will call out the knee jerk. Twenty-one out of twenty-nine subjects kicked at one time or another when presented with the conditioning stimulus alone. This conditioned reflex was, however, extremely unstable. Only four subjects kicked on more than 67 per cent. of the tests, and only one reached a percentage of 100. Furthermore, these kicks varied in height from the smallest observable movement of the leg to a kick of approximately the height of the subject's unconditioned knee jerk. Examination of the records of the conditioned knee jerk showed that they differed considerably from the unconditioned reflex. Since no time line was used in the introductory groups, these differences cannot here be stated accurately, and will not be discussed until later.

In Table I the percentages of trials on which each subject showed a conditioned knee jerk have been averaged. These averages appear at the right of the table and furnish a means of roughly evaluating the efficiency of the conditions in each group in forming a conditioned knee jerk. It will be noted that the averages of Groups 1-5 vary between 10 and 27 per cent. (For the present, the results of Groups 6A and 6B will be omitted from the discussion.) Since there are so few subjects in these groups, none but the most pronounced differences may be considered significant. Therefore, any conclusions drawn from these results must be considered only as suggestions for future experimentation.

In the first place, it would seem that the interval between successive double stimulations does not make much difference in the rate of formation of the conditional knee jerk. Group 1, in which this interval was 5 sec, shows about the same conditioning as Groups 2, 4, and 5, in which the interval between presentations of the double stimulation was only 3 sec. Furthermore, variation of interval between the conditioned and unconditioned stimuli seems to make no great difference within the limits tested. Group 5 is about as effective as Group 4, although the interval in the former group was .2 sec and in the latter, .6 sec. These two groups in turn are about as effective as Group 1, in which the interval between bell and blow was .34 sec. Furthermore, in Group 2, where several intervals were used for the various subjects, no pronounced difference in favor of any of the intervals was seen.

Consideration of the original records by successive days (not included in the table) makes it apparent that the number of repetitions has a limited effect. The frequency

with which any one subject gives conditioned reflexes does not always increase from day to day. One subject (A), for example, who gave a strong conditioned knee jerk during the first sitting, gave none after that. It was decided to plan the experiments in the main group so that they might throw light on the effects of frequency in the formation of the conditioned knee jerk.

No decisive difference was noted in favor of any of the first five groups, with the possible exception of 3. Only four subjects were used in this group, and the average was raised from 17 per cent to 27 per cent by one exceptionally good subject, so this difference is not particularly significant. It also seemed that the conditioning was about as effective when the leg was prevented from moving (Groups 4, 5) as when it was allowed to swing freely (Groups 1, 2, 3).

By referring to the results of Group 6A, it may be seen that the percentage of conditioned reflexes obtained in this group was about twice as great as that of any of the earlier groups. It will be noted that this group differed from 5 only in that the subjects always responded to the conditioning stimulus in the former group by lifting the tactual stylus, whereas they did not make any voluntary response to the conditioning stimulus in Group 5. Yet Group 5 was somewhat less effective than the other preliminary groups. Since very few tests were made of the conditioned knee jerk in either of these two groups, little significance could be attached to this difference. Yet in view of the fact that Group 5 gave about the same results as the other groups in which no voluntary response was used, it was felt that the results for this group were fairly valid. To give the results of Group 6A an equal validity, Group 6B was arranged, as noted above. It may be seen from the results of this group (Table I) that the percentage of conditioned knee jerks obtained was again twice that obtained from any of the non-facilitated groups; that is, those in which no voluntary response was used. Thus the results obtained from Group 6A were verified, and it seemed quite likely that the increased effectiveness of conditioning in these groups was due to the effect of facilitation. It was thought best, therefore, to plan the main groups so that they would show the effects of facilitation by a voluntary response to the conditioning stimulus.

MAIN EXPERIMENTAL GROUPS

The results obtained from the preliminary groups cannot be considered of great validity, owing to too large a number of uncontrolled factors, and to too few subjects. Indeed, it must be remembered that these groups were merely exploratory and were not expected to yield more than suggestions for further study. The main groups were planned to furnish more conclusive data, so that fairly reliable conclusions might be drawn. To make the groups comparable, they were all built on the same pattern. Since the pattern used in Group 6B was found quite satisfactory as regards frequency and number of double presentations, instructions, frequency of tests of the conditioned reflex, etc., this pattern was adopted for the main groups. Nine or ten subjects were used in each group, and no subject was a member of more than one group,

nor had had previous training in a conditioned reflex experiment.

The first of the main groups (Group 7) involved facilitation of the reflex by a voluntary lifting of the stylus, as had 6A and 6B. Instead of lifting the stylus every time it touched his finger, as in the previous groups, the subject lifted it only 50 per cent of the time. The instructions were changed to read "Lift stylus only on trials 1, 3, 5, 6, 8, 12, 13, 15, 17, 18" for the first two sittings; but for the third and fourth this was changed to 1, 2, 4, 7, 10, 11, 15, 16, 17, 19 to prevent memorization of the order. The subject was allowed, of course, to keep the list before him during the experimental period. He was required to make the count himself, and was instructed to report if he lost it, whereupon the correct count would be given him. Nine subjects participated in the group, each of whom had four sittings, with the exception of two subjects who had only three. In all other details, the group was just like group 6B.

In Group 8 the conditioning stimulus was a bell, arranged as in Group 1, so that it gave a single stroke .34 sec before the blow. In place of lifting the tactual stylus, the subjects were instructed as follows: "As soon as the bell rings do the following.—On trial 1, clench both fists. On trial 2, do nothing. On 3, say 'ah'; 4, nothing; 5, 'ah'; 6, fists; 7, nothing; 8, 'ah'; 9, nothing; 10, nothing; 11, nothing; 12, fists; 13, 'ah'; 14, nothing; 15, nothing; 16, nothing; 17, fists; 18, 'ah'; 19, nothing; 20, nothing," and on the third and fourth days this order was changed to "Trial 1, clench both fists; 2, clench left fist; 3, do nothing; 4, left; 5, nothing; 6, nothing; 7, nothing; 8, nothing; 9, nothing; 10, left; 11, left; 12, nothing; 13, nothing; 14, nothing; 15, right; 16, left; 17, right; 18, nothing; 19, left; 20, nothing." There were nine subjects, each of whom had 4 experimental periods. Except for the above differences, the procedure in this group was the same as that used in Group 7.

Group 9 was designed to determine the minimal latent period of the conditioned knee jerk. It was feared that the intervals between the conditioned and unconditioned stimuli used in all the previous groups were too long to permit the formation of a conditioned reflex of a very short latency. Therefore the conditioned and unconditioned stimuli were made more nearly simultaneous, by decreasing the interval between bell and blow to .04–.11 sec. The bell was mounted on the head of the hammer and swung with it, to determine whether the subjects would then identify the bell more closely with the blow. A contact on the hammer brushed another contact on the support thus sounding the bell just before the hammer reached the tendon. The contact was adjusted for each subject so that he reported that the bell preceded the blow. The interval between bell and blow was then determined by the kymographic record. The hammer was always operated by hand to eliminate any noises that might be made by the depression of a key. These noises would always have preceded the blow by several tenths-of-a-second, so that the effective interval would have been that between the release of the hammer and the blow, rather than that between bell and blow. To insure a blow of constant strength, the hammer was always raised to the (now-inactive) magnet as a stop. When it was desired to make a test of the conditioned reflex, the hammer was moved rapidly past the contact by hand, but was not permitted to touch the patellar tendon.

It had been planned to put the subjects through the usual four sittings, as in Group 8, and then if any of them developed fairly stable conditioned reflexes, careful records were to be taken of the unconditioned and conditioned knee jerks, as well as of the voluntary contraction of the quadriceps. These records were to be taken with

the kymograph moving at the rate of 1 inch in .2 seconds. The single electric marker was replaced by a triple marker. One of these markers was connected in parallel with the coils of the bell, another was connected to improvised keys around which the subjects were instructed to clench their fists, and the third was wired in parallel with the coil of a 50 d.v. electrically maintained tuning fork. Thus there was available a record of the moment of occurrence of the conditioned stimulus, the unconditioned stimulus, the movement of the quadriceps, the clenching of the fists, and finally, a time line.

Since none of the subjects in this group showed more than an occasional conditioned reflex, the desired records were not obtained. Therefore several subjects that had been members of previous groups, and had developed very stable conditioned reflexes, were given several sittings in this group. One of them developed a stable conditioned reflex after 200 double stimulations, and records were obtained of the conditioned reflex, the unconditioned reflex and the voluntary contraction of the quadriceps.

Group 10 was designed primarily to test the effect of stimulating both legs simultaneously, instead of only one, and of permitting them to swing freely, instead of holding them rigid. With the exception of certain modifications in the apparatus made necessary by these two changes, this group was similar in all details to 8, so that the results of the two groups are strictly comparable. One other minor difference in Group 10 was the use of the 'fist keys' described in Group 9, so that a record of the clenching of the fists might be obtained if desired.

The subject was seated in the chair used in Groups 1, 2, and 3, modified by the addition of another leg rest, so that both legs could be simultaneously stimulated. Another hammer was mounted on the sleeve of the stimulating apparatus, opposite the original hammer. The magnet support was lengthened and another magnet added, to hold the new hammer in the raised position. The new hammer head could be moved a short distance on its shaft and was held in place with a thumb screw, so that it could be adjusted to small differences in height between the two legs. The stimulating unit was placed in front of the subject, with the supporting rod in such a position that the subject's legs swung on either side of it when he kicked. Since both hammers had to be caught and cocked by hand, it was necessary to mount the telegraph key which released them on the floor where it could be operated by the foot of the experimenter. The addition of a heavy spring made a standard telegrapher's key sufficiently stiff to be worked satisfactorily with the foot. Recording was still done by the method of muscle thickening, as before. The response of the right leg alone was recorded. The first part of the curve resembled that obtained with the leg held rigid, but the last portion was distorted by movements of the lower leg. This movement of the leg usually started before the muscle had reached its maximal thickening.

Three out of the nine subjects used in this group developed stable conditioned reflexes by the end of the fourth sitting. A new smoked belt was then put on the kymograph, and several conditioned and unconditioned knee jerks were recorded, using the technique described in Group 9.

RESULTS AND DISCUSSION OF THE MAIN EXPERIMENTAL GROUPS

The results of the main experiments, as summarized in Table II, are as follows.

TABLE II

MAIN GROUPS 7, 8, 10; PERCENTAGES OF TESTS RESULTING IN CONDITIONED KNEE JERKS (SUBJECTS 70-98)

<i>Group 7. Recorded by muscle thickening</i>										
<i>Facilitation Employed</i>	<i>Subjects</i>									
	70	71	72	73	74	75	76	77	78	Ave.
Lift Stylus.....	58	56	46	35	13	71	39	15	58	43
None.....	50	30	14	14	15	10	11	11	0	17

<i>Group 8. Recorded by muscle thickening</i>										
	<i>Subjects</i>									
	80	81	82	83	84	85	86	87	88	Ave.
Clench Fists.....	17	80	100	75	75	50	75	100	100	75
Say "Ah".....	20	60	56	20	71	33	50	83	83	53
None.....	50	0	25	11	33	13	80	33	0	27
Clench R. Fist.....	60	50	0	33	33	100	50	100	50	53
Clench L. Fist.....	67	11	33	83	20	100	100	83	0	55

<i>Group 10. Recorded by muscle thickening</i>										
	<i>Subjects</i>									
	90	91	92	93	94	95	96	97	98	Ave.
Clench Fists.....	75	75	40	100	100	0	100	25	50	63
Say "Ah".....	83	67	40	100	20	17	33	50	17	47
None.....	0	38	63	100	38	22	38	12	25	37
Clench R. Fist.....	0	67	50	100	50	100	50	0	50	52
Clench L. Fist.....	16	80	100	100	67	71	50	50	33	61

<i>Group 10. Observed movement of lower leg</i>										
	<i>Subjects</i>									
	90	91	92	93	94	95	96	97	98	Ave.
Clench Fists.....	25	0	60	100	50	0	100	50	25	46
Say "Ah".....	0	0	20	100	0	0	17	33	0	19
None.....	0	0	50	100	38	22	25	0	13	28
Clench R. Fist.....	0	33	50	100	50	100	50	0	0	43
Clench L. Fist.....	0	0	83	100	67	71	33	33	0	43

(1) In several groups or sub-groups,²⁵ the subjects gave conditioned knee jerks in over 50 per cent. (average) of the tests. All of the subjects in Groups 7, 8, and 10 gave conditioned knee jerks at one time or another when they were presented with the conditioning stimulus alone. The results of Group 9 are not presented in the table, for reasons that will be explained later. The results of this experiment, therefore, are in agreement with those of Twitmyer,²⁶ who was able to set up a conditioned knee jerk in all six of his subjects,

²⁵ By sub-group is meant those double stimulations which are followed by a given facilitating response, as 'clench fists' or 'ah,' e.g., in Group 8.

²⁶ E. B. Twitmyer, *A study of the knee jerk*, 1902.

and with those of Shevaley,²⁷ who was successful in conditioning the reflex in seven subjects. Dodge²⁸ reports that he failed to get a "reconfiguration of the mechanism of the knee jerk" in several situations that might have been expected to produce a 'conditioned knee jerk' (although he does not use the term). The situations in Dodge's experiment were somewhat different from the present, a fact which may explain the difference.

Unlike Twitmyer's, however, our subjects failed to get stable conditioned reflexes. One-third of the subjects in Groups 7, 8, and 10 showed complete conditioning in one or more sub-groups, *i.e.*, gave a conditioned knee jerk on every test. From an examination of the daily records of each subject (not included in this report), it was found that only three of the twenty-seven subjects used in the main groups kicked on every test in any sitting, if we consider all sub-groups instead of just one. Furthermore, most of the conditioned reflexes were very small in extent. In fact, in Groups 7 and 8 most of them measured under 1 mm on the record. Explanations of this instability will be suggested later.

Introspections²⁹ as to the nature of the knee jerk varied considerably. Although several of the subjects felt that it was partly or completely voluntary, the vast majority were quite certain of its involuntary nature. Many of the subjects, especially in the groups in which the leg was allowed to swing freely, expressed surprise when they felt the leg move without the usual blow. One subject (No. 93) was unable to inhibit the conditioned knee jerk, after he had asked permission to do so, even when warned before the test that the blow would not be given. This evidence of the involuntary nature of the conditioned knee jerk is given, not because of its intrinsic value—indeed, the term 'voluntary' might well be kept out of a discussion of the conditioned reflex—but because this evidence shows that the subjects were not consciously motivated to kick when the conditioned stimulus was presented. Additional proof of this lack of motivation is given by the fact that almost all the subjects in the main groups had no idea of what a conditioned reflex was, and were kept in complete ignorance of the nature of the experiment until after it was completed.

In addition to the actual knee jerk, there were many other indications of con-

²⁷ E. Shevaley, *Bechterev 40th anniversary commemorative volume*, 1926. (See footnote 18.)

²⁸ R. Dodge, *Elementary conditions of human variability*, 1927, 68, 69.

²⁹ The subjects in Groups 1-4 had had some training in introspection, whereas most of those in later groups were untrained. The introspections given by the former class of subjects differed chiefly from those of the latter in their completeness.

ditioning. Chief among these was the tendency to kick before the blow occurred. This happened fairly frequently. Several other subjects showed a slight withdrawal of the knee just before each blow, although they reported that the tap on the tendon was not at all uncomfortable. Finally, those subjects who were practiced in introspection (members of the preliminary groups) reported 'tension,' 'kinæsthesia,' 'tingling,' and similar phenomena, all located in the stimulated leg, when the conditioned reflex was tested by the presentation of the conditioning stimulus without the blow. Several other subjects reported that they had kicked, after a test, even though the leg had not actually moved at all. All these reports suggest that something was happening in the muscles of the leg. Unfortunately no records of the quadriceps thickening are available for these subjects, since the preliminary groups in which they participated were not recorded on the kymograph. The only similar phenomena reported in the main groups was a 'desire to kick.' This seemed uncorrelated with any movements of the recording lever, therefore any associated muscular responses must have been of the nature of tonic changes.

(2) *A*. In determining the latent period of a conditioned reflex, two possibilities present themselves. We may obtain the average of several measurements, as Cason did³⁰ in his work with the wink reflex, or we may take the shortest latent time obtained. Bykow and Petrowa³¹ favor the latter method, on the ground that repetition of the conditioned stimulus without reinforcement by the presentation of the unconditioned stimulus increases the latent time. Since each measure has something in its favor, both will be given here.

Subject B', who was the only one to form a stable conditioned knee jerk after training with the short bell-blow period used in Group 9, developed a conditioned knee jerk with an average latency of .47 sec. When he was told to kick voluntarily as soon as the bell rang, the period was the same; i.e. he kicked .47 sec after the bell rang. The latent time of his unconditioned knee jerk was about .04 sec. One could not expect the latent period of the conditioned reflex to be less than .1 sec, since during his training period the knee jerk had always followed the bell after an interval of .1 sec. The shortest latent period, however, was .32 sec. This was longer than the shortest reaction time of voluntary quadriceps contraction recorded for this subject, which was .26 sec.

Latent periods of the conditioned knee jerk and of the voluntary contraction of the quadriceps muscle are available for three subjects from Group 10. Here the period between bell and kick during the training period had been .35 sec. The latent periods are as follows:

³⁰ H. Cason, The conditioned eyelid reaction, this JOURNAL, 1922, 5, 153-196.

³¹ K. M. Bykow & M. K. Petrowa, Die Latenzperiode des bedingten Reflexes (German summary; see footnote 4).

Subject 92. Latent period of conditioned knee jerk, average of two determinations, .40 sec. Minimum .40 sec. Voluntary contraction of quadriceps, .40 sec.

Subject 93. Latent period, conditioned knee jerk, average of 11 determinations, .34 sec; minimum, .20 sec. Voluntary contraction of quadriceps, average of 5 readings, .46 sec. Minimum, .22 sec.

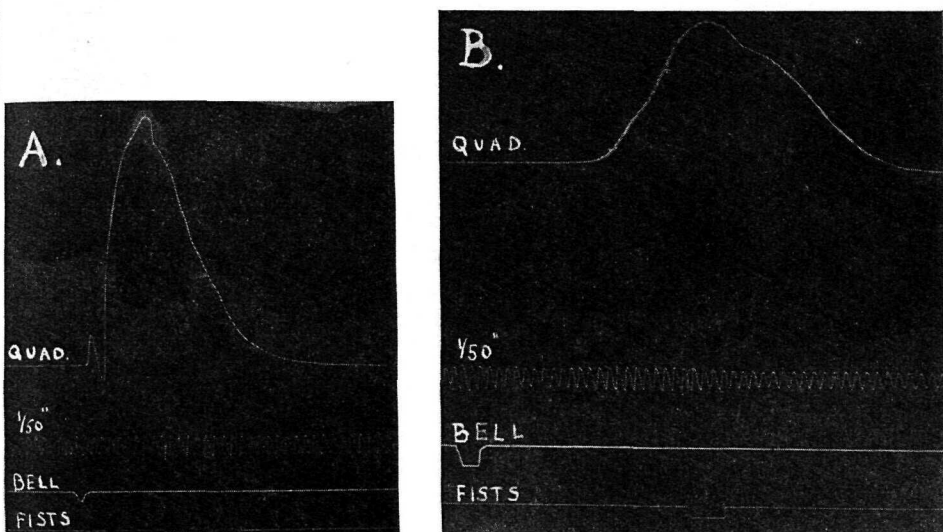
Subject 95. Latent period, conditioned knee jerk, average of 7 determinations, .28 sec; minimum, .16 sec. No voluntary contractions recorded.

It may be seen from these figures that the latent time of the conditioned knee jerk in four subjects averaged between .28 sec. and .47 sec. This latent period was about the same as that required for a voluntary kick, and about ten times the latent period of the unconditioned knee jerk. This result is in agreement with those of Humphrey,³² who finds the latent period of the conditioned withdrawal of the hand from shock to be .3-.4 sec. The latent periods obtained in this experiment are longer than those obtained by Dodge and Cason for the conditioned eyelid reflex, or by Bykow and Petrowa for the flexion reflex of the dog.

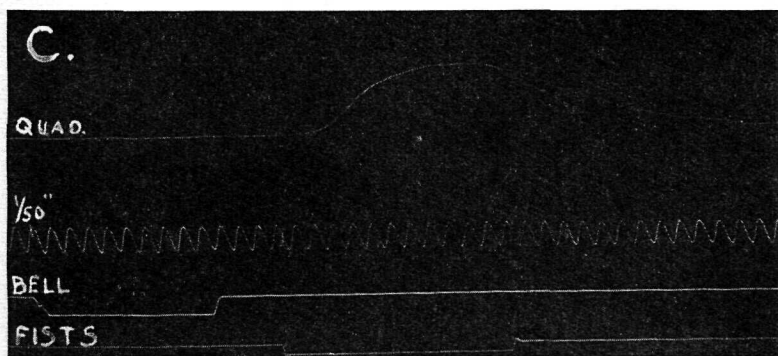
B. The drum record below (Fig. 1) represents an unconditioned knee jerk, a voluntary contraction of the quadriceps, and a conditioned knee jerk. These were all obtained during one experimental period from subject B' who had developed a stable conditioned reflex. It may be seen from these records that the curve obtained from the conditioned reflex is very similar to that obtained during voluntary contraction of the quadriceps and quite different from the record of the unconditioned jerk.^{32a} The most striking difference between these two curves and that of the unconditioned knee jerk is the sharp initial rise seen in the latter. This difference is found in all the records of the conditioned and unconditioned knee jerks

³² G. Humphrey, The effect of sequences of indifferent stimuli on a reaction of the conditioned response type, *J. Abn. & Soc. Psychol.*, 1927, 22, 194-212.

^{32a} The initial movement of the recording lever that shows on the record of the unconditioned knee jerk as a ripple is not due to an actual contraction of the muscle but to the purely mechanical stretching of the muscle by the depression of the tendon. It marks the actual moment of stimulation of the end organs in the muscle.



A. The Unconditioned Knee Jerk
B. Voluntary Contraction of the Quadriiceps



C. The Conditioned Knee Jerk

Quad. = Thickening of the Quadriiceps

1/50'' = Time line (50 d.v. fork)

Bell = Moment of completing circuit through electric bell

Fists = Voluntary clenching of the fists

FIG. 1

that I have obtained. A second difference shown in the records is the greater rapidity of fall in the case of the curve of the unconditioned knee jerk, when compared with the other two records. This rapid fall, although very frequently found, is not always seen in the records of the unconditioned knee jerk, for occasionally the return to the base line is quite as slow as it is in records of the conditioned reflex.

After noting the apparent similarity between the conditioned and the unconditioned knee jerks, Twitmyer³³ said that "if differences really exist, a much more rapid recording device will be needed to detect them." He recorded the knee jerk by attaching a pen, its carriage and a weight, to the heel of the subject by means of a string, and then permitting the pen to write on a moving paper. This method of recording, owing to its inertia, would obviously fail to show the rapidity of the first initial rise that is so characteristic of the unconditioned knee jerk, and so notably lacking in records of the conditioned knee jerk.

As noted in the introduction, Fulton has discussed at great length³⁴ the effect of the higher centers on the later phases of the unconditioned knee jerk; and the work of Travis and his associates³⁵ shows that the action currents of the quadriceps found during the later phases of the knee jerk resemble very closely those obtained from the same muscle during a voluntary kick.

These findings support the conclusion drawn by Dodge³⁶ from his work with reflexes that a simple reflex usually initiates movements; but that these movements are promptly taken over and modified by 'voluntary' or cortical control. If we apply Dodge's view to the unconditioned knee jerk, it would seem, then, that the resemblance between it, on the one hand, and the conditioned reflex and the voluntary contraction of the quadriceps muscle, on the other, is due to the presence of impulses from higher centers, whereas the difference between them is caused by the short reflex through the lumbar region of the spine, which occurs in the unconditioned knee jerk, but not in the conditioned reflex or in the voluntary contraction. Thus a consideration of the curve of the conditioned reflex and of its latent time supports the widely prevalent view that conditioned reflexes involve higher centers.

³³ E. B. Twitmyer, *A study of the knee jerk*, 1902.

³⁴ J. F. Fulton, *Muscular contraction and the reflex control of movement*, 1926.

³⁵ L. E. Travis, W. W. Tuttle & T. A. Hunter, The tetanic nature of the knee jerk response in man, *Amer. J. Physiol.*, 1927, 81, 670-678.

³⁶ R. Dodge, Protopractic and epicritic stratification of human adjustments, *Amer. J. Psychol.*, 1927, 39, 145-157.

(3) The results of Group 9 have not been presented in the tables in percentage form, as have the other groups, because of a certain difficulty that developed in scoring them. There were very few movements of the muscle that could clearly be ascribed to the presentation of the conditioning stimulus. In seven of the ten subjects, whenever the period between one double stimulation and the next was more than the average (3 sec), the muscle would thicken in little jumps. The record looked very much like a flight of steps. It seemed as if the subject were anticipating the blow and contracted the quadriceps before it arrived. This thickening usually occurred at a more rapid rate and reached a higher level when the conditioned stimulus was presented without the unconditioned during the thickening. This step-like rise had been noticed occasionally in three subjects in earlier groups, but had occurred only when several tests were presented in succession. It seems probable that, in this series, the subjects were becoming conditioned to the interval between double stimulations, as well as to the bell. It is likely that this change in conditioning was caused by the extreme shortness of the interval between the bell and the blow. In this group the interval bell-blow was never more than .11 sec. This is less than the shortest latent time obtained for the conditioned knee jerk. It may be that reducing the interval between the conditioned and the unconditioned stimulus to a value below that of the latent period of the conditioned knee jerk has an effect somewhat similar to that produced by reversing the order of stimulation.

(4) Table III gives the percentage of conditioning from day to day. All the facilitated sub-groups of Groups 7, 8

TABLE III

THE EFFECT OF FREQUENCY

Sitting.....	I	2	3	4
Facilitated.....	54	60	50	50
Unfacilitated.....	11	23	38	38

The figures indicate the average percentage of conditioned knee jerks obtained in the facilitated and unfacilitated sub-groups, respectively, computed for each sitting.

and 10 are averaged to obtain the upper row of percentages; while the unfacilitated sub-groups of these groups are averaged to furnish the lower row. It may be seen from these averages that the conditioning in the facilitated sub-groups very rapidly reaches a maximum for given conditions; whereas the maximal conditioning is delayed until the third experimental period in the unfacilitated sub-groups. The decrease in the percentages for the third and fourth days of the facilitated sub-groups may have been due to the change from facilitation by clenching both fists, or by saying 'ah,' to clenching the right or left fist (Groups 8 and 10); but the fact that a similar decrease in percentage of conditioned reflexes is seen where the same facilitation is continued throughout (Group 7), is rather against this hypothesis. It is possible that the decrease is due to a diminishing effectiveness of the facilitation, through a gradual automatization of the voluntary facilitating response.

(5) From the results and from the previous discussion it may be seen that the conditioned knee jerk in man, as obtained in these experiments, is very instable. The cause of this instability is not known, but several theories may be suggested.

A. In the first place, most conditioned reflexes in man are somewhat unstable. Humphrey³⁷ reports some difficulty in setting up a conditioned withdrawal of the hand from shock, and Watson³⁸ had trouble in forming a similar withdrawal of the foot. Cason³⁹ found it difficult to establish a conditioned lid reflex in certain subjects; although the conditioned stimulus was a sound just too weak to call out the lid reflex before the training had taken place. Several investigators found no conditioned salivary reflex in man, but Lashley⁴⁰ reports that they may be set up quite easily in the laboratory, if conditions are properly controlled. Various investigators have suggested that the reason conditioned reflexes are hard to establish in man is that he is less easily deceived than animals. Lashley, in discussing the failure of others to elicit a conditioned salivary reflex from man, states this objection in more objective terms. He says that "the stimuli to conditioned secretion in man are complex situations which are not duplicated under laboratory conditions" (459). It will be noted that difficulties arising from lack of control of the conditions were carefully eliminated

³⁷ G. Humphrey, *J. Abn. & Soc. Psychol.*, 1927, 22, 194-212.

³⁸ J. B. Watson, The place of the conditioned-reflex in psychology, *Psychol. Rev.*, 1916, 23, 89-116.

³⁹ H. Cason, The conditioned eyelid reaction, this JOURNAL, 1922, 5, 153-196.

⁴⁰ K. S. Lashley, The human salivary reflex and its use in psychology, *Psychol. Rev.*, 1916, 23, 446-464.

from the present experiment. Since the subject could not see the experimenter, and since the slight movement of the experimenter's hand in holding the hammer gave the subject no auditory cues, he had no means of telling beforehand when the blow was to be omitted, or, in objective terms, there was no stimulus that could set up conditioned inhibition.

B. Another possible explanation of the instability is found in the fact that the unconditioned knee jerk undergoes great variations in strength, so that one knee jerk may be quite vigorous and the next one almost lacking. Pavlov has pointed out⁴¹ that the strength of a conditioned reflex varies with the strength of the unconditioned reflex on which it is based. This is probably one of the factors involved in the instability of the conditioned knee jerk. For if the condition of the organism at a given moment were such that the unconditioned knee jerk would have been weak, the conditioned reflex, if tested at that moment, might be so weak that it would not objectively show. It is likely that this factor is not the only one, for some subjects either kicked vigorously or not at all when presented with the conditioning stimulus alone. If the variations in the strength of the unconditioned reflex were the sole explanation of the instability of the conditioned reflex, we should not expect to find subjects who either kicked vigorously or not at all, but only those whose conditioned responses varied by small steps between zero and a maximum in extent.

C. There was one very obvious inhibition present in this experiment which may have been partly responsible for this instability, namely, the withdrawal from the blow. Every effort was made to prevent any discomfort from this source, and all subjects reported that the blow was not uncomfortable. It was noticed, however, that several subjects, especially those who had weak patellar reflexes, and consequently needed a stronger blow to elicit the reflex, developed a tendency to withdraw the knee slightly before each blow. Several of the more candid subjects reported that although the blow was not painful, it was still somewhat of a shock, and that they might have been withdrawing from it. One subject (F) who regularly moved his leg to the left, instead of kicking, when the reflex was tested, felt that this movement was a resultant of tendencies to kick forward and to withdraw from the blow. It seems quite probable, therefore, that the instability of the conditioned knee jerk may have been partly due to an inhibition arising from the shock of the blow. There is a possibility that the fact that the leg was held rigid may have been another inhibitory factor. This will be discussed under 7.

D. Reflexes, in addition to their objective strength, show another quality that has been called 'prepotency,' 'physiological strength,' etc., referring to the ability of that reflex to inhibit other opposed reflexes when both are stimulated at the same time. Thus, in the decerebrate dog, the flexion reflex will inhibit the scratch reflex. This quality of a reflex is said to correlate with its 'biological utility.' The physiological basis of this prepotency is not known, for its explanation apparently involves a knowledge of the mechanism of inhibition. But as a generalization obtained from the observation of reflex behavior, this 'prepotency' seems valid.

Pavlov has pointed out⁴² that this physiological strength or biological importance (to use his terms) determines the ease with which a reflex may be conditioned. The apparent lack of this 'biological importance' in the knee jerk is quite apparent. Indeed, Dodge has referred to it as 'an apparently imbecilic reflex.'⁴³ Furthermore,

⁴¹ Pavlov, *Conditioned reflexes*, etc.

⁴² *Op. cit.*, 30, 31.

⁴³ R. Dodge, Problems of human variability, *Science*, 1924, 59, 269.

the ease with which the knee jerk is facilitated or inhibited shows how little prepotency it possesses. Accepting Pavlov's generalization, then, it is possible that this lack of physiological strength, whatever its physiological mechanism may be, is one of the factors causing difficulty in establishing a stable conditioned knee jerk.

Too little is known about the mechanism of the central nervous system to make a further attempt at explaining this instability of the conditioned patellar reflex of any value. All of the factors mentioned above, and perhaps others, may be involved. But enough has been said to show that the conditioned reflex is not always the simple product of simultaneity of stimulation and frequency of repetition that so many assume it to be.

(6) When we compare the sub-groups in which facilitation was used with the unfacilitated, in Groups 7, 8, and 10, with regard to the percentage of tests in which the subjects showed conditioned knee jerks, an interesting fact may be observed. If we consider the records of these groups as obtained by recording muscle thickening, we find that no one of the unfacilitated sub-groups is as effective as the poorest of the facilitated. This difference is especially significant, since there were 3 unfacilitated and 9 facilitated sub-groups. Furthermore, the unfacilitated sub-groups involved 4 times as many double stimulations as did any one of 8 of the facilitated, and the same number as the ninth. Any practice-effect, therefore, would favor the unfacilitated sub-groups. In spite of this, the average percentage of conditioning for the 9 facilitated sub-groups is 56 per cent.; whereas that for the unfacilitated is only 27 per cent. If the preliminary groups are included in this average, the difference becomes more striking, namely 57 per cent. compared to 21 per cent.

It was felt that this difference might be due to the inclusion within the percentages of the facilitated sub-groups of many small movements of the record that were actually caused by movements of the whole body, rather than by contractions of the quadriceps. The subjects were all requested not to make the voluntary response so energetically that it caused a twitch or vibration of the whole body. As noted under Group 7B, all subjects were watched for this movement during the 'practice series' that preceded the regular series on the first day. Furthermore, if any subjects were suspected of making such movements during the course of one of the sittings, they were requested to clench the fists and the like, in response to the command of the experimenter, while he watched the record for such movements. One subject was discarded because he did not seem able to eliminate these movements. To test the question further,

however, all the records of Groups 7 and 8 were re-examined, and scored for those movements only that showed over 1 mm on the record. The increased effectiveness of the facilitated sub-groups showed just as clearly, even under these conditions; although practically all of these small bodily movements would have been eliminated by this method of scoring. The average for the facilitated sub-groups, when scored in this way, was 27 per cent., whereas that for the unfacilitated was only 6 per cent.

As another check on the existence of this difference, Group 10 was reconsidered. It will be remembered that the leg was allowed to swing freely in this group. In addition to the kymographic records of muscle thickening, there was available a set of notes, taken by the experimenter during the sittings, as to whether or not the subject actually kicked on each test. These data have been tabulated in Table II (Group 10). It may be seen that only one facilitated sub-group; namely, that in which the subject said 'ah,' is exceeded by the unfacilitated sub-group. This reversal is caused by the fact that this type of facilitation was used only on the first two days. This sub-group did not benefit, therefore, as much from practice as did the unfacilitated sub-group. The percentage obtained from the 'ah' sub-group is half again as large as that obtained from the unfacilitated sub-group on these two days.

We may safely conclude, therefore, that the occurrence of a voluntary response, made to the conditioning stimulus during the conditioning period, increases the effectiveness of the conditioning. It may be seen from Table III that this facilitation effects the conditioned response in two ways; namely, by decreasing the number of double stimulations needed to produce the maximal conditioning for the given situation (the maximum is reached on the second day in the facilitation sub-tests, and on the third in the unfacilitated) and by increasing the extent to which the knee jerk may be conditioned. Although the complete explanation for this increased effectiveness is not known, several hypotheses present themselves.

A. The effect of 'attention.' The preparation to give a voluntary response, such as clenching the fists, as soon as the conditioning stimulus is received, directs the attention toward this stimulus. This would probably give the stimulus a greater effectiveness, and therefore better and more rapid conditioning might be expected.

Furthermore, attending to the stimulus and the voluntary response would take the attention from the unconditioned stimulus and response. Certain subjects reported that they gave the highest and most frequent conditioned reflexes when their attention was directed toward their reading matter, or when they were 'lost in thought.' Stated in

physiological terms, this may be the removal of the inhibitions mentioned above.

This explanation has many points in its favor. Pavlov found that excitable dogs formed conditioned reflexes most rapidly.⁴⁴ He also found that, under certain conditions which made the dogs more excitable, all inhibitions vanished. These two observations seem to be borne out to some extent by the results of this experiment. In addition to the attentional effects noted above, it was noticed that the subjects who gave the best conditioning were of the quick 'nervous' type. Furthermore, several subjects who normally gave no trace of a conditioned knee jerk gave frequent large reflexes upon becoming emotionally disturbed during the course of an experimental period. This disturbance took the form of amusement at some humorous idea that occurred to them or of embarrassment at being late for the sitting or disturbing the recording apparatus by a careless movement. Since no objective measurement of 'nervousness' or of emotional disturbance was at hand, only the observations of the experimenter can be offered as evidence. It is hoped that further work can be done to investigate this matter, both in the conditioned knee jerk and in other problems of the conditioned reflex type.

B. Another possibility is that the voluntary response facilitated (in the physiological sense) the conditioned knee jerk. This facilitation may be directly effective on the conditioned reflex, or indirectly through increasing the strength of the unconditioned reflex. The tonus of the whole body would be increased by the 'set' of the subject to clench his fists, etc., as soon as the bell was heard. This increased tonus might well be accompanied by a lowered resistance in the nerves supplying the quadriceps. There would thus be a greater likelihood that a weak excitation would cause the muscle to contract.

C. There is the further possibility that the facilitating response acts as an additional unit in the constellation of stimuli that becomes the conditioned stimulus situation for the conditioned knee jerk. The voluntary response almost always occurred during or just before the contraction of the quadriceps. The fact that the effects of the voluntary response were so marked, whereas other changes in the conditioning stimulus seemed to have little effect, makes this possibility somewhat unlikely. Another point against it is the fact that those subjects who developed the most stable conditioned reflexes usually made the movement of the quadriceps and the voluntary response at the same instant. It has been noted that it is very difficult to set up a condi-

⁴⁴ *Conditioned reflexes, etc.*

tioned knee jerk when the interval between the conditioned and unconditioned stimuli is very short. Hence the facilitating response probably occurs too late to act as a conditioning stimulus.

(7) The effects of permitting the leg to move freely, as in Group 10, rather than holding it in a rigid support (as in the earlier groups) were somewhat unexpected. As may be seen from Table II (Group 10), this technique had no great effect on the percentage of conditioned reflexes when the group is considered as a whole. It did tend slightly to decrease the differences between the sub-groups; although this result may have been obtained by chance, since it is based on nine subjects only. The most pronounced effect, however, was a very great increase in the height of the conditioned contraction. Whereas most of the conditioned reflexes obtained in the earlier groups were under 2 mm, as measured on the record, more than half of the conditioned knee jerks obtained in Group 10 were over 2 mm. When the leg is permitted to swing freely during the knee jerk, there is a large mass of stimuli caused by this movement, coming from muscle, tendon, joint and skin. These stimuli, and the reflexes that they excite, apparently account for part of the contraction of the quadriceps muscle, particularly in the later phase of contraction. When the leg is kept from moving, stimuli from the skin and joints are lost, together with their reflexes. Without these components, one would expect the conditioned knee jerk to be smaller than it would have been had they been retained by permitting the leg to swing freely as in Group 10. It is probable, then, that the increased height of the conditioned knee jerks obtained with the leg swinging freely is due to the proprioceptive reflexes, which are not present when the leg is prevented from moving.

Another possible factor presents itself, namely, that inhibitions are set up when the leg is kept from swinging. This factor probably does not play an important part; for, if it did, the frequency of the conditioned knee jerks would increase, as well as their height, when this inhibition was eliminated. As noted above, there is apparently little, if any, increase in the frequency of conditioned reflexes obtained in Group 10. This same objection may be raised against the possibility that the increased height obtained in this group is caused by the fact that both legs were stimulated, and that the simultaneous contraction of the muscles of both legs acted as mutual facilitation.

SUMMARY

1. Conditioned patellar reflexes have been formed, using a bell, a click, a buzz, and a tactual pressure as the conditioning stimuli.

2. These conditioned knee jerks have been formed in 44 out of 49 subjects.

3. When the interval between conditioned and unconditioned stimuli was varied between .20 and .44 seconds there was no significant difference in the ease of conditioning; but when this interval was decreased below .11 seconds it was more difficult to form a conditioned reflex.

4. The conditioned knee jerks formed were very unstable, varying considerably in both height and frequency of appearance, even within one experimental period.

5. Subjects varied considerably, both in their rate of conditioning and in their ability to form a conditioned knee jerk.

6. Computed by groups or sub-groups the percentage of trials on which conditioned knee jerks appeared varied between 10 and 75.

7. When facilitation, in the form of a voluntary response to the conditioning stimulus, was used, conditioned knee jerks were obtained more than twice as frequently as when no facilitating response was made.

8. The records of the conditioned knee jerk resemble those of the voluntary contraction of the quadriceps group, and they both differ from those of the unconditioned knee jerk, chiefly in that the sudden initial rise seen in the latter is not found in the former.

9. The latent period of the conditioned knee jerk varies between .2 and .5 sec, being about the same as that of the voluntary contraction of the quadriceps group, and 5 or 10 times that of the unconditioned knee jerk.

10. When the lower leg is allowed to swing freely, conditioned reflexes are obtained about as frequently as when the leg is not permitted to swing; but the conditioned reflexes obtained in the former situation are much bigger than those obtained in the latter.

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