Proceedings of the Iowa Academy of Science

Volume 29 | Annual Issue Article 48

1922

Simultaneous Fast and Slow Drum Records of Fatigue

Francis Marsh Baldwin
Iowa State College

SIMULTANEOUS FAST AND SLOW DRUM RECORDS OF FATIGUE

INTRODUCTION

FRANCIS MARSH BALDWIN

The essential details of fatigue processes as they develop in a properly prepared protoplasmic system like that of a frog muscle, are conveniently transcribed by the writing lever either upon a kymograph drum revolving comparatively rapidly, or one going very slowly and these records furnish data for subsequent analysis. In each procedure some facts are obtained as to amplitude, enhancing and diminution of responses under a given rate of stimulation and under certain physical and physiological conditions, but unfortunately neither method alone suffices for the proper analysis of the whole process. Although details of mechanical devices differ somewhat in the two methods the muscle is usually mounted in a moist chamber in such a way as to move at each response a counter-poised muscle lever which in turn transcribes its movement upon the surface of the drum.

In using the slow drum method, an interrupter of some sort, which is set for a definite rhythm, usually about one stimulus per second, is placed in the primary circuit and a record is obtained under given conditions. Upon analysis by this method records usually give interesting curves whereby the comparative amplitude of successive contraction and relaxation phases of the developing fatigue process are secured. The curves also give evidence of increased contraction in the initial successive excursions with formation of the so-called "treppe" phenomenon and the accompanying production of the so-called primary contracture phase followed almost immediately by the primary relaxation phase merging more or less directly into the secondary contracture. Obviously, however, this method fails to record such comparative duration intervals as are concerned with latency, increments and decrements of irritability, as evidenced by more and more rapid contraction at the outset, followed by a corresponding decrement in the recovery velocity as evidenced in the succeeding relaxation phases. Records involving this method are commonly illustrated and analyzed in some of the many standard texts.[1]

In the rapid drum method several mechanical devices have been used by various investigators, but the one found easily adapted to this end consists of a Harvard type moist chamber in which the muscle is mounted in such a way as to move a light writing lever. The primary circuit is automatically "made" and "broken" by the rapidly revolving drum. This is done by cams rotating upon the drum spindle coming into contact with a circuit breaker (Zimmermann type) mounted upon the clock housing. Obviously upon analysis, records obtained by this method have some advantages over those obtained by the other in that they give valuable data as to the relative amplitudes of responses, and in addition the accompanying rate and duration of various phases of the oncoming process can be found especially when correlated with time intervals as recorded by a chronometer. They have some disadvantages, however, for since the stimuli fall at the same point as the drum rotates, the transcribed lines representing successive responses are more or less superimposed upon one another with consequent masking, especially in the contraction phase. In some cases this masking of individual responses is more serious than in others, due no doubt to differences in rate of metabolic reorganization, and when this is true it renders the record by this method difficult to analyze. Another objection is that the crest and trough representing any one cycle of responses are so far removed from one another, due to the rapid rotation of the drum, that indexes of such important phases as primary contracture or relaxation are impossible to accurately ascertain. Curves illustrating this mode of procedure are found quite generally, especially in the English texts.[2]

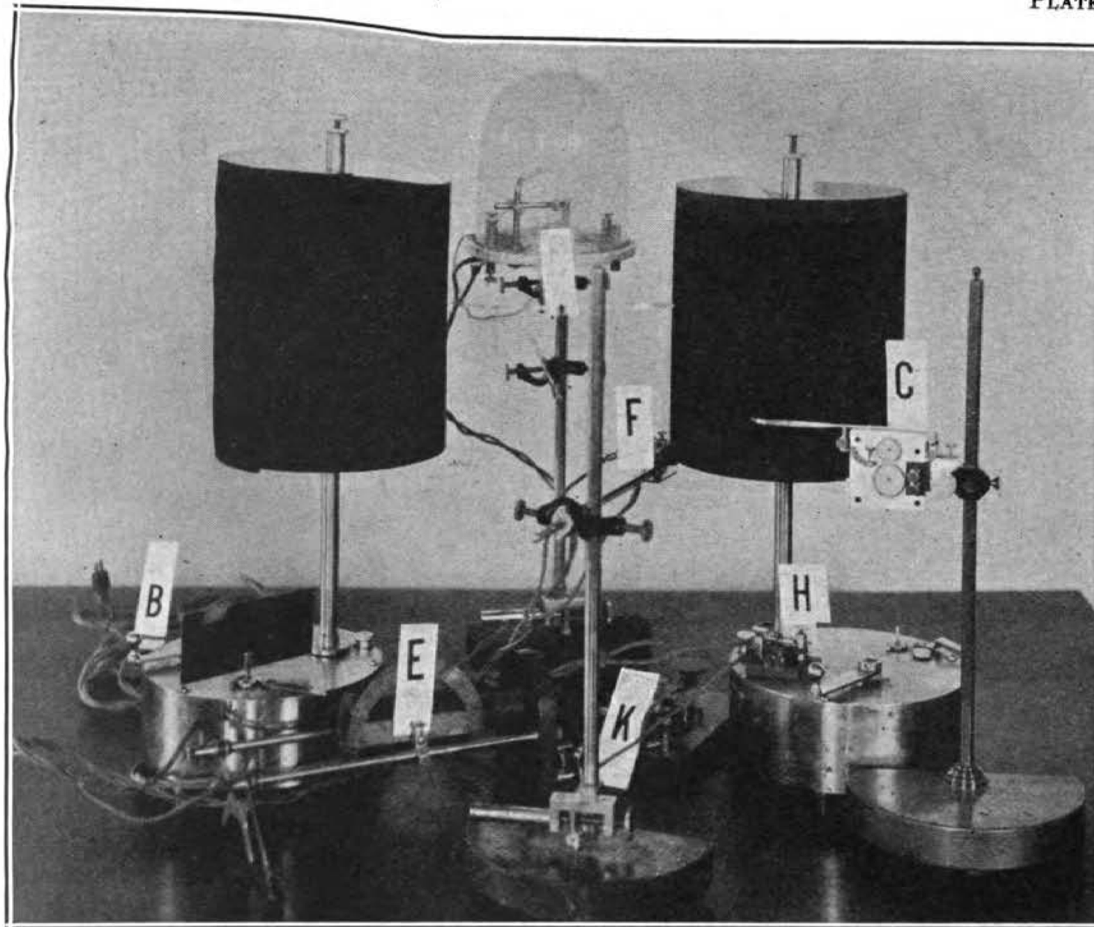
With such considerations in mind it seems desirable to combine the two classical procedures and obtain simultaneously records by both methods using the same irritable tissue. Especially such a procedure is of value in demonstration where by careful observation and notation the details in one can be made to supplement the other at critical points. By such a method also difficulties from the comparative analysis of the various phases are obviated since the same muscle produces them simultaneously in both.

---

[1] See Howell, Textbook of Physiology, 7th ed., pp. 33-34, 1919; also Brubaker, Textbook of Physiology, 4th ed., pp. 70-71, 1912.

[2] See especially Schafer, Textbook of Physiology, V. 2, 1900, p. 388; fig. 216; Starling, Principles of Human Physiology, 1912, p. 234; Halliburton, Handbook of Physiology, 1920, p. 98.

PLATE I



Details of the mechanism adapted for making simultaneous fast and slow drum records of fatigue. The muscle is mounted in the moist chamber and stimulated by interrupted current from wire B through contact breaker H.

EXPERIMENTAL

The mechanism to this end (Plate I), aside from the customary relative adjustments and positions of the various parts, is in its essential details rather simple and is adapted to any laboratory with little trouble. A muscle lever of the Harvard type is provided with two aluminum rods instead of one. These are curved away from their support in such a way that their distal ends each form an arc of a quadrant. Thus their writing tips may be brought into contact with their respective drums. By slight adjustments both points can be made to rub lightly upon the drums which by previous preliminary trials have been fixed to rotate at definite relative speeds. The fast type, in records soon to be discussed, was set for one revolution in four seconds, while the slow type was made to revolve once in an hour. The muscle received its successive stimuli by the automatic contact interrupter mounted upon the fast drum housing. By the use of this mechanism, comparable records are obtained in which it is possible to follow excursion after excursion of the writing points throughout the entire fatigue process. By mounting signal magnets and chronometer in proper position checks on time of stimulation and relative duration of any phase or groups of phases can be made and subsequently analyzed. By count of actual excursions of the lever or by interposing simple signal devices any response can be located at will, thus, for example, in typical records B and B′, the one, two or three hundredth responses are located definitely on each curve.

In attempting to analyze fatigue curves by either method, one is forcefully impressed with the fact that there are characteristically at least two types to be found, and possibly inter-gradations which when analyzed resemble in certain of their features one or the other of these. One of these extremes is illustrated by curve G and the other curve by A′ in Plate II. Among the chief points of difference in these, obviously, are differences in first and secondary contracture, and primary relaxation, the former exhibiting all three phases to a marked degree, the latter comparatively lacking them all. Why this should be is a matter of interesting speculation. From the physiological standpoint the phenomenon of contracture, when compared with that of a simple contraction indicates the possibility that two different contraction processes may take place in an irritable muscle, one involving the so-called state of tone and therefore the length and hardness of the muscle at all times, the other concerned with the actual production of work. Such suggestion has been made by several workers (Uexkull, Guenther, et al.)[3] on various grounds. Indeed it seems reasonable to believe as has been suggested by some, that there are two different contractile substances in muscle, one giving the usual quick "twitch," the other the slower contraction, which exhibits itself as tone or contracture.[4] Assuming that there are two different contractile substances in the muscle it seems logical to infer that when the stimuli actively or excessively irritate the tonic substance at the same time with the activation of the contractile substance, the successive responses would be accompanied by gradual shortening, as indicated by the first type of curve, and on the other hand when the reverse condition prevails, that is to say when the stimuli affect slightly or not at all this peculiar tonic substance, the second type of curve would result. Doubtless between these two extremes, there are ranges of specific irritability in each substance so that when compounded in various ratios under a given rate of stimulation and possibly under differences in metabolic condition prevailing in the muscle they would combine in responses to produce fatigue curves intermediate between the two that have been considered extremely typical. Indeed, during the course of this and previous investigations[5] such intermediate or gradation curves have not been lacking. Just what condition or conditions combine to bring about relative proportional responses in the two substances, or what conditions must be fulfilled in order to predict just what type of fatigue curve will result upon stimulation are as yet questions that need more light thrown upon them. In the light of recent investigations by Loeb, Osterhout and especially Lillie,[6] it seems probable that muscular contraction is only one of the many phases of the general problems in physiology, such as irritability, conductility, stimulation, etc., awaiting solution, and like them is dependent in the ultimate analysis upon an understanding of fundamental physical and chemical changes in membrane permeability.

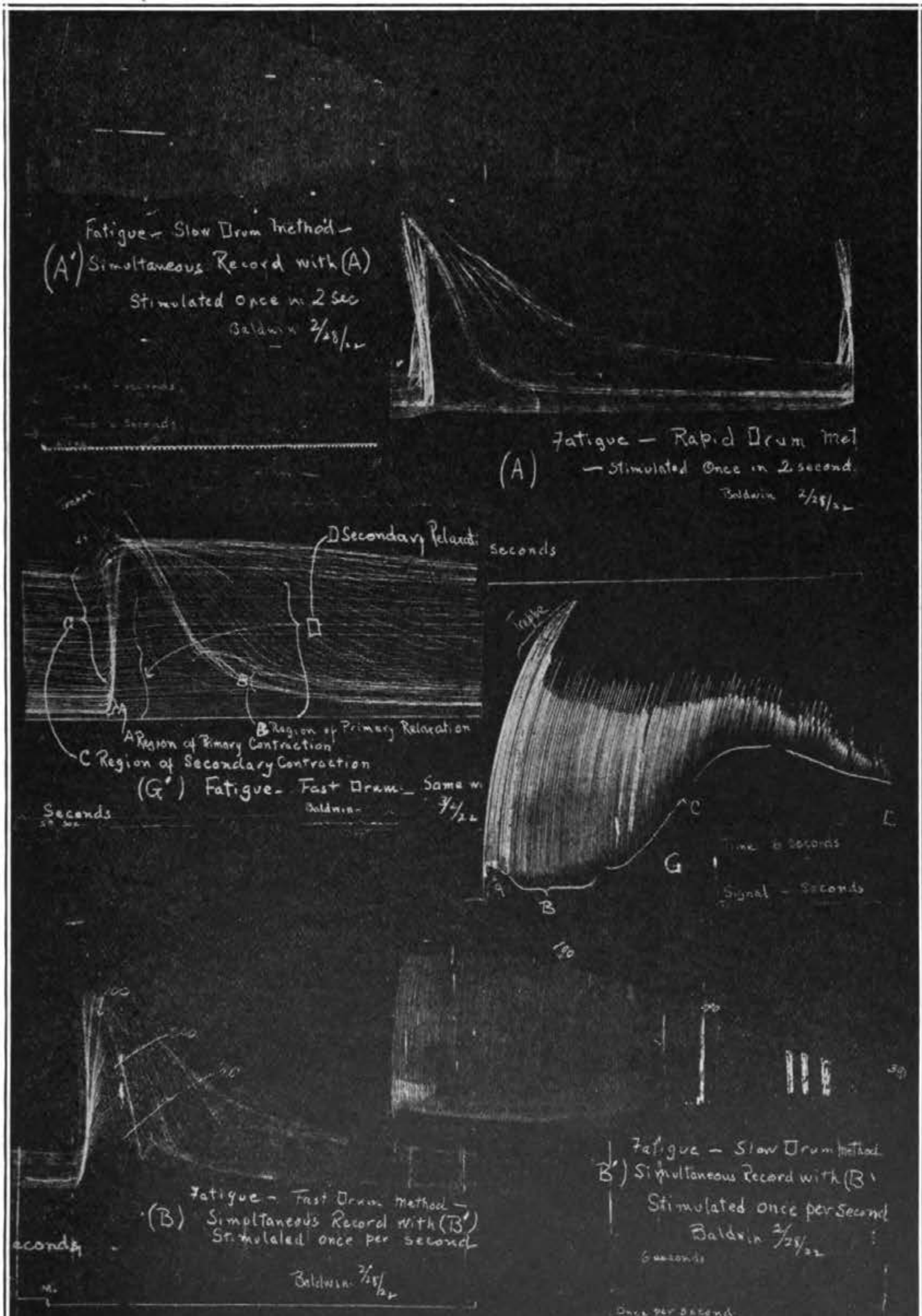
On referring to the simultaneous records B and B′, which represent one of the extreme types of fatigue curves, a number of points are evident by comparison. Upon being stimulated once per second the muscle made in the course of seven minutes about

3 Uexkall, Zentralblatt d. Physiologie, V. 22, p. 33, 1908, also Guenther, Am. Jr. Physiol., V. 14, p. 73, 1905.

4 Iotekyo, Travaux du laboratoire de Physiologie, Institut Salvay, 5, 25.

5 Baldwin, F. M., Am. Jr. Physiol., Vol. LVI, pp. 127-139, 1921.

6 Lillie, Physiol. Rev., Vol. II, No. 2, p. 1, 1922.



Typical simultaneous curves of fatigue obtained by the use of apparatus shown in Plate I. The significant differences in these curves are discussed elsewhere in this paper

three hundred and fifty responses in undergoing fatigue. Both curves show that up to about the one hundredth response, the amplitude in terms of height is not greatly affected and although the first few responses are accompanied by primary contracture subsequent relaxation is remarkably gradual as is shown in the slightly declined margin of B′ and the slight overlapping of relaxing lines in B near the base. One of the most valuable facts in comparison is brought out in connection with relative duration of the different phases. From the curve B′ one would be led to believe that successive responses following the one hundredth were being executed in about the same interval of time as those immediately preceding. On comparison with B, however, such is found not to be the case. Successive contractions here are shown to be more and more slowly produced, and in addition a very marked slowing of the successive relaxation phases. Although, of course, it is difficult to be exact because of comparative differences in various muscles it seems reasonable to assert that comparatively speaking the successive contraction responses vary from one another by intervals of .001 second in this range between the 100th to the 200th response, while the relaxation phase certainly is retarded by as much as .01 second. Beyond this up to perhaps the 300th response, the contraction response time increases until it takes a total of at least 0.2 second, while the relaxation phase is retarded so that at the end of this interval it consumes at least .08 second. Secondary contracture can best be recorded by the slow drum method, as also can secondary relaxation. These two phases develop in the record under consideration between the 100th and the 200th responses, and between the 200th and the 300th responses, respectively. In the fast drum record B and the comparable slow record B′ these phases make themselves evident as a respective rise and fall of the curves near the stimulation take-off of contraction, and as can be seen, neither are clearly defined. On the other hand, latency is not evidenced by the slow drum. By the fast method under favorable conditions and care of mechanical adjustments latency can easily be calculated as ranging in the initial responses between .004 to .005 second, and gradually this interval increases as fatigue develops so that toward the end it may be as much as 0.02 to 0.04 second, depending upon temperature, load and osmotic conditions.

Curves G and G′ represent another extreme type characterized by marked secondary contracture with equally marked secondary relaxation. The muscle is stimulated at the same rate as before (once per second) and is practically fatigued in about the same time (seven minutes). Primary contracture is certainly accompanied by treppe in both methods during the first few responses as indicated at A. That relaxation is increased in its rate immediately following the first five or six strokes is evident by the overlapping of tracing lines G′ and B. The fact that this is true expresses itself in G by the successive dropping of the lower contour of successive tracing at B. Both curves give index to the rapid onset of secondary contracture during the progress of the interval labeled C, and this is soon followed by a reversal, indicated in both curves by D. On comparing curves B and G′ it is seen that they are as characteristically different in form and content, as are their simultaneous counterparts B′ and G.

The effect of varying the rate of stimulation on the development of fatigue has of course been known for a long time. Somewhat rapid stimulation results in the production of tetanus, while stimulation at a slower rate than once in four or five seconds postpones indefinitely the onset of typical fatigue phenomena. With this in mind curves A and A′ were obtained where the stimulation was set at once in two seconds. It is seen that under this rate curves result which are fairly comparable to B and B′, which were produced by a slightly faster rate (see B and B′). The treppe phenomenon is possibly more marked, primary relaxation is perhaps less so. The total time interval is perhaps a little prolonged, consuming about nine minutes to complete, but in other respects no great differences are noted.

SUMMARY

By making simple adaptations of laboratory apparatus a method is described whereby both fast and slow drum types of fatigue records can be produced simultaneously. Such a procedure is of especial value in demonstrations before classes of students who in their general physiological course are expected to obtain records of fatigue and make proper interpretations of such records, together with a reasonable amount of the theoretical implications of such phenomena.

By the use of one muscle to transcribe both records comparable stages in the progress of fatigue processes are located on each, thus amplitude and duration of responses as well as phases of latency, contracture and relaxation are obtainable.

Different extreme types of fatigue records are noted, with

possible gradations between the extremes, and these may possibly be explained upon the basis of differences of irritability and responsiveness of the "tonic" and "contractile" substances in the muscle.

By the use of the chronometer relative duration times of the various phases are easily calculated in terms of the fast drum method. From data taken, for example, latency, contracture and relaxation lie roughly between 0.005 and 0.02; 0.04 and 0.2; and 0.02 and 1.0 second, respectively.

By proper signal device count can be kept and any response can be located at will, on curves by either method.

DEPARTMENT OF ZOOLOGY,
IOWA STATE COLLEGE.