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High-Speed Cinematography of Muscle Contraction

Abstract. Motion pictures of the "twitch" of an excised frog gastrocnemius muscle taken at rates of 6000 frames per second provide a means of very accurately timing the phases. The extreme "slow motion" reveals surface phenomena not observable by other techniques. Evidence of "active relaxation" is suggested by results of frame-by-frame analysis.

High-speed cinematography (frame rates in excess of 500 per second) has had wide application in researches in the fields of engineering and technology. Very limited application has been made to the study of rapid biological phenomena. Farnsworth *et al.* (*1*), Prinzmetal *et al.* (*2*), and Zorgniotti *et al.* (*3*) have strikingly demonstrated the value of the technique in the analysis of various motion phenomena in human subjects.

The phases of a simple muscle twitch (latency, contraction, relaxation) have been accurately timed by various electronic and photographic techniques. None of these, however, has provided the experimenter with a continuous pictorial representation of the muscle during the events.

The excised muscle preparation, illuminated with incandescent light (24,000 ft-ca) was photographed with a "Fastax" camera operating at 6000 frames per second (*4*). The motion pictures were studied by projection at normal (24 frames per second) speed and were also subjected to frame-by-frame analysis. The muscle was stimulated to contract by a single shock from an electronic stimulator, and an electromagnetic signal marker was included in the camera field to indicate the instant of stimulation. The muscle was loaded with a shortened Harvard-type muscle lever and a 10-g weight. The muscle was marked by a "tattooing" technique. This consisted of placing a series of black dots at intervals on the surface of the muscle to provide distinct reference points in the frame-by-frame analysis. The muscle preparation was photographed against a grid background.

Direct observation of the projected motion pictures reveals several interesting features. It may be easily seen and proved that the mass inertia of the lever system causes the lever movement to lag considerably behind the movement of the dots on the muscle except during the latter portion of the relaxation phase. Frame-by-frame analysis of a typical twitch provides data regarding the duration of the phases as indicated by the movement of the muscle dots and by the movement of the lever system (Table 1).

Careful observation of the projected film shows certain expected changes in the diameter of the muscle during contraction and relaxation. These are not, however, as simple in form as one might have expected. They appear as bulges traveling downward during contraction and upward during relaxation. Their movement is extremely rapid. Attempts to ascertain the velocity of these contraction and relaxation waves by frame-by-frame analysis were not considered valid because of the difficulty of exactly tracing and measuring the muscle image from projected single frames. This difficulty is due to an inherent lack of image definition in many high-speed motion pictures.

Both by simple viewing of the projected film and by the frame-by-frame analysis it is readily shown that the initial portion of the relaxation phase is extremely rapid. A plot of the movement of the tattoo marks on the muscle shows this part of the relaxation phase to be as rapid as, if not more rapid than, any portion of the contraction phase. No definite physiological conclusions are drawn from this, but it suggests an "active" type of relaxation. Later portions of the relaxation phase were slow by comparison, and the muscle did not return to its fully relaxed state until the lever system had caught up with it in time. Exact true relaxation time, therefore, could not be determined.

Table 1. Duration of phases of a simple muscle twitch of an excised frog gastrocnemius as shown by frame-by-frame analysis of high-speed (6000 frames per second) motion pictures.

Latency (sec)	Contraction (sec)	Relaxation (sec)
	Movement of dots (true time)	
0.003	0.037	?
	Movement of lever (apparent time)	
0.007	0.044	0.052

Extreme slow-motion projection of the film suggests one further phenomena which is noteworthy but unsubstantiated by concrete evidence. There appears to be an undulatory movement over the surface of the muscle during both its contraction and its relaxation. This phenomenon, if it actually occurs, is extremely rapid and not at all distinct. It is suggested that it could be a high-frequency surface vibratory movement and, if this is the case, might be a purely physical result of tension developed in an elastic system rather than anything of physiological significance.

The data giving accurate time relationships in the simple muscle twitch, as well as the surface phenomena observed when action is slowed by a factor of 250, clearly indicate the applicability of high-speed cinematography to the study of muscle activity. Further experiments of this type should not only improve the techniques but provide data of important physiological significance (*5*).

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References and Notes

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