Training and Quantifying Voluntary Plantar-Flexor Movements of Rats

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***Abstract* - The present paper describes a rat preparation that was designed to produce voluntary plantar-flexor movements under precise constraints and to record various movement parameters. Sixteen rats were trained with operant conditioning techniques and food rewards to voluntarily and repeatedly enter a vertical tube, insert its head into a ring, lift the ring until its nose interrupted an infrared detector, and then lower the ring. The apparatus and training procedures were computer automated. Results demonstrate the ability of this preparation to precisely control and record the dynamics of a repetitive lifting and lowering movement of the lower limbs applicable to studies of muscle adaptation or injury.**

I. INTRODUCTION

There have been numerous attempts to model human skeletal-muscle performance with laboratory animals. Major advantages of *in vitro* [1], *in situ* [2], or *in vivo* [3] preparations include the ability to precisely control and quantify muscle function, propagate adaptation or injury, and initiate repair mechanisms.

One limitation – the use of electrical stimulation to induce involuntary muscle contractions – is common to most models. Unlike voluntary contractile activity, which in the real world is submaximal and characterized by a selective recruitment of motor units, involuntary contractile activity induced by electrical stimulation is supramaximal and involves the activation of all motor units of the target muscle [4]. Thus, comparisons between muscle responses to supramaximal electrical stimulation and voluntary submaximal contractions may be quite limited.

Operant conditioning with food rewards has been employed with some success to motivate repetitive movements [5,6,7]. Because these preparations produce voluntary contractile activity, normal neuromuscular control processes remain intact. Although these models are more representative of muscle function in the real world, they often do not precisely control or measure the resultant movement dynamics. Toward this end, the present paper describes a rat preparation that was designed to produce voluntary plantar-flexor movements under precise constraints and to record various movement parameters.

II. METHOD

Sixteen male Sprague-Dawley rats were obtained at 12 weeks of age. Rats were trained to perform the lifting and lowering movement with operant conditioning procedures and a food reward.

Four standard operant chambers were used. In each chamber, food rewards were dispensed into a food trough located on the left side of the front panel. The food trough was bisected by an infrared detector so that the retrieval of the pellet could be recorded. An opening in the center of the front panel of the operant chamber allowed the rat access to an acrylic tube that was mounted vertically. Inside the tube, a neck ring was supported by a yoke that moved along two vertical shafts via linear bearings. Weights were placed on pans attached to the yoke to increase the total load to 700 g. An infrared nose-poke response device was positioned near the top of the tube to record each lifting and lowering response. The height of the nose-poke device could be adjusted to ensure maximum plantar flexion.

A force plate, located at the bottom of the tube, depressed a load cell permitting measurement of the reaction forces during each lift. A displacement transducer attached to the yolk measured the distance over which the load was moved. Both the load cell and the displacement transducer were linear over their range. A data acquisition program recorded force, displacement, and elapsed time with a 100-Hz sampling rate.

Training the rat to perform the lifting and lowering movement occurred in stages across several sessions that were conducted 5 days per week for 1 to 2 weeks. Initially, the ring assembly and nose-poke operandum were positioned at the top of the tube, and the rat was trained to enter the tube and rear up. Gradually, the weighted ring assembly was lowered in small increments to require increasing displacement of the ring. Approximately 15 training sessions were conducted before each rat was able to lift the ring assembly reliably through its maximum displacement of 2.5 cm. In all sessions, breaking the infrared beam of the nose-poke device resulted in the immediate delivery of two food pellets. All rats were trained successfully. Approximately 30 additional sessions were conducted in which full displacement of the ring was required. Sessions lasted 1 hr or until 100 responses occurred and were conducted 5 days per week.

III. RESULTS

Several performance measures were computed for each session and plotted in Figure 1. First, the number of lifts in each session that terminated in a nose poke ("full lifts") was recorded and aggregated as the median across the rats (top panel). In addition, the median number of "partial lifts" per session is shown. In general, the number of lifts increased gradually across sessions before stabilizing, and the number of partial lifts was almost twice that of the full lifts.

The middle panel of Fig. 1 shows the number of concentric

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movements per lifting and lowering response (i.e., any positive change in displacement of the ring). The number of eccentric movements (i.e., negative displacements) per session was the same (not shown). These measures represent plantar-flexor muscle actions while shortening (concentric phase) and lengthening (eccentric phase). Compared to the number of lifts per session, more concentric (and eccentric) movements occurred, suggesting that each lifting and lowering response consisted of several oscillations between concentric and eccentric movements.

The bottom panel of Fig. 1 shows the *total* work performed (in J) in each session. Using the trapezoidal rule, work was computed for concentric and eccentric movements separately. In general, the absolute magnitude of work performed increased gradually across sessions before stabilizing. In addition, work during concentric movements (work performed) was somewhat greater than that during eccentric movements (work absorbed).

Other measures such as the median peak force (N), velocity of concentric and eccentric movements (cm/s), work (J), and power (W) *per lift* were computed for each rat in each session. Table 1 shows the mean of these measures for concentric and eccentric movements over the last six stable sessions, along with the average interquartile ranges that depict the extent of within-subject variability. Differences in peak force, velocity, and work were found between concentric and eccentric movements.

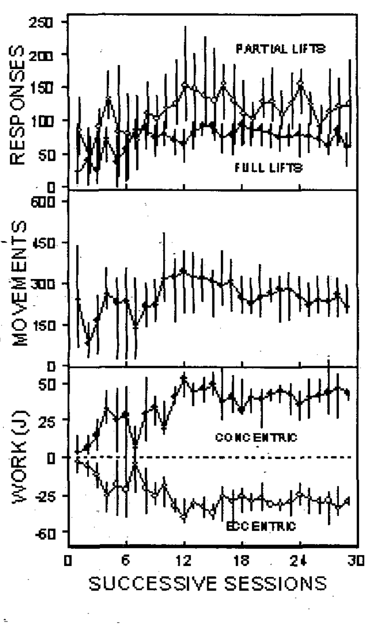

Fig. 1. Group performance across sessions (medians and interquartile ranges).

TABLE 1.

GROUP PERFORMANCE MEASURES FOR INDIVIDUAL CONCENTRIC AND ECCENTRIC MOVEMENTS ACROSS THE TERMINAL SESSIONS

	Peak Force (N)	Velocity (cm/s)	Work (J)	Power (W)
Concentric (n = 1480)	12.3** (11.1-13.2)	9.5* (5.4-13.5)	0.14 (0.04-0.26)	1.0 (0.5-1.4)
Eccentric (n = 1472)	9.5 (7.7-11.3)	-13.0 (-6.0- -21.4)	-0.09 (-0.05- -0.15)	-1.0 (-0.5- -1.7)

Note: Asterisks indicate significant differences from eccentric; *$p < .05$; **$p < .001$.

IV. DISCUSSION

Existing physiological models of muscle pathomechanics and adaptation often are limited by their requirements for invasive procedures or by their focus on muscle actions that are not applicable to real-world settings. The presented model is volitional, noninvasive, and well suited for chronic studies. Furthermore, the ability to control and record biomechanical parameters of the lowering and lifting movement is a significant advantage over other *in vivo* weight-lifting models. Further research is needed to determine how manipulations of various work and biomechanical factors (e.g., load, number or rate of repetitions, and work-rest cycles) affect the response dynamics. Despite the intersubject variability found in the performances, several parameters of the movement dynamics are quantifiable allowing comprehensive dose-response assessments of exercise intensity or volume. When combined with biochemical and histological analyses, this model can provide a comprehensive and externally valid model for studying muscle adaptation and pathomechanics that will broaden the scope of musculoskeletal research.

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