

# A RAT MODEL FOR CONTROLLING AND QUANTIFYING VOLUNTARY MUSCLE PERFORMANCE OF UPPER EXTREMITIES

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## Introduction

Musculoskeletal disorders (MSDs) are a major health concern of the National Institute for Occupational Safety Health (NIOSH) and a National Occupational Research Agenda (NORA) priority. Musculoskeletal disorders represent a broad category of injuries and illnesses of the upper and lower extremities. Claims of MSDs in the workplace often are associated with repetitive manual work in business and industry. It has been argued, however, that quantitative exposure-response relations between physical load factors and MSDs are largely unknown (Viikari-Juntura, 1997). Fundamental questions remain about the safe or acceptable limits of repetitive work (e.g., how many repetitions are too much?). One problem concerns the difficulty in analyzing the factors associated with muscle injury in highly controlled, laboratory studies. Existing physiological models of muscle pathomechanics and adaptation are often limited by their requirements for invasive procedures or by their focus on muscle actions that are not applicable to real-world settings.

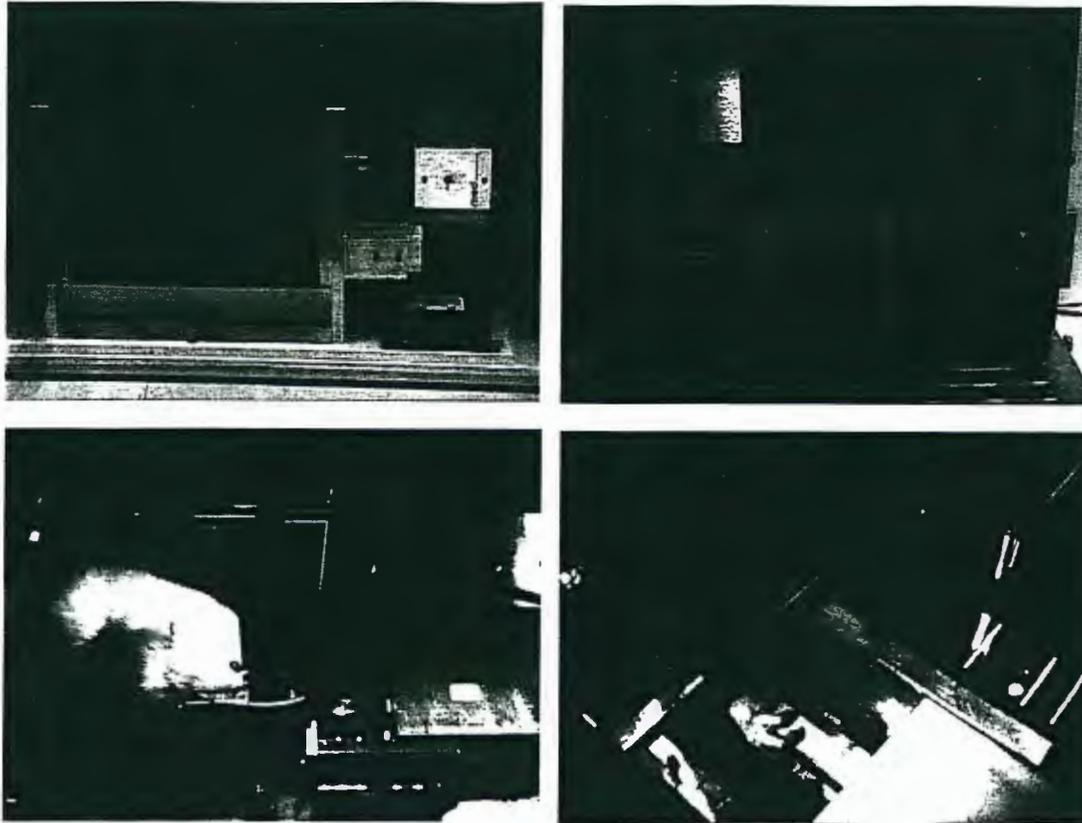
The scientific literature indicates that animal models are appropriate for the study of skeletal muscle, as the micro-architecture of rodent and human skeletal muscle are quite similar. The use of a rat model also can allow for controlled biomechanical exposures, rigorous histological and biochemical analysis of the muscle tissue, and controlled experimental conditions necessary to conduct a parametric investigations of factors associated with chronic contraction-induced injury. The present paper describes the application of operant conditioning to establish controlled voluntary movements in an animal model.

## Methods

Rats were studied using a standard operant test chamber (see Figure 1). The chamber was the size of the rat's living cage, and was enclosed within a light- and sound-attenuating, ventilated cubicle to minimize distractions. Low-wattage lamps provided light for general illumination and discriminative stimuli. Food rewards consisted of nutritionally complete 45-mg food pellets.

A custom-designed lever served as the response operandum and allowed for continuous, real-time recording of isometric force exerted on the lever (cf. Fowler, 1978; Notterman & Mintz, 1965). The lever consisted of a 0.6 cm by 0.6 cm aluminum bar attached to a strain gage to measure the isometric force exerted between 0.1 N and 5.0 N. The bar initially protruded approximately 1.75 cm into a small opening on the far right side of the front panel. The lever was mounted to a bracket that allows the lever to be retracted manually to a maximum distance of 3 cm outside the chamber during training. The retracted position required the rat to reach through the small opening and extend its right fore limb to contact the lever. All experimental events, such as the presentation of visual or auditory stimuli, were controlled and monitored by computer throughout the test session.

The rat initially was magazine trained to reliably retrieve food pellets as soon as they were delivered. The rat then was trained to press the lever for food with the lever protruding into the chamber. A food pellet was delivered for every successful response in which the



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*figure 1.* The panel on the **top left** shows a side view of the operant test chamber with the isometric force lever mounted in the foreground; the pellet dispenser appears on the right behind the lever. The panel on the **top right** shows the front panel as seen by the rat. The isometric force lever appears on the far right protruding through a small opening in the panel. A stimulus light is mounted above the lever and a trough through which pellets are delivered appears in the center. The panel of the **bottom left** shows a rat reaching through the opening on the front panel and pressing the lever, which has been retracted 2.5 cm from the opening. The panel on the **bottom right** shows the fore paw of the rat as it contacts the retracted lever.

force exerted on the lever reached a predetermined criterion (0.25 N during training). A stimulus light turned on whenever the force lever was active, and turned off when a pellet was delivered.

Once reliable responding was established, training continued as the lever was gradually retracted until the bar was positioned approximately 2.5 cm behind the chamber panel. The final position of the lever required that the rat reach through the opening to contact the lever (see Figure 1). Placement of the lever against the far right side of the chamber also facilitated the acquisition of an isometric lever press that is isolated to the right fore limb, allowing the contra-lateral limb to be used as a control. Occasionally, it was necessary to bait the lever with a food pellet to encourage reaching through the opening.

Once responses occurred reliably, the number of responses required for each pellet was increased gradually up to 15, and then delivered intermittently (on average every 30 s after successful responses). An intermittent schedule of reinforcement was used because it produces a rapid and steady rate of responses. Total training took approximately four days, with sessions lasting one hour on each day.

Further requirements on the topography of the response were imposed after training. For example, the apparatus and control software allowed reinforcement to depend on such factors as the number, rate, force, duration, or temporal pattern of lever presses.

## Discussion

Conventional techniques used to study the contractile properties of skeletal muscles are highly invasive. In most cases, the procedures separate muscles or muscle groups from connecting soft tissue such as tendon and bone. Less invasive models such as *in vivo* rodent dynamometry leave the muscle-tendon complex and neural and vascular supply intact; however, these models still require anaesthesia making chronic study difficult.

Although noninvasive, the present model still allows for control over the movement topography. Biomechanical parameters such as the force, duration, and rate of responding can be precisely controlled by manipulations of the reinforcement contingencies and, within some limits, the rat's behavior will conform to those contingencies. Treadmill exercise models are relatively noninvasive and allow for chronic study; however, they are total body physical activities in which it is difficult to assess the damage to the muscle because the biomechanics of the movement are not controlled. Forces exerted by the muscles using these techniques cannot be measured accurately.

Like *in vitro* and *in situ* preparations, *in vivo* models such as dynamometry produce involuntary muscle contractions via electrical stimulation to produce supramaximal contractions of muscles. Stimulation in which all muscle fibers are activated limits direct comparisons to the submaximal contractions of voluntary movements. Furthermore, because the present model produces voluntary responding through operant contingencies, some nonphysical factors may be investigated experimentally. These include work organization factors (e.g., workload, repetitiveness, job control, mental demands, etc.), temporal aspects of the work and task (e.g., cycle time and shift work), economic aspects (e.g., pay and benefits), and individual characteristics (e.g., size and level of conditioning).

## Conclusions

The application of operant conditioning to the development of an animal model expands the armamentarium of techniques that can be used for the study of muscle pathomechanics. The model produces voluntary movements by the animal that more closely approximate the movement topographies encountered in work settings. The training procedures also take advantage of the animal's behavioral repertoire, thereby minimizing training requirements and allows for chronic study of repetitive loadings. When combined with biomechanical, biochemical, and histological analyses, this model can provide a comprehensive and externally valid model for studying muscle pathomechanics and work-rest cycles that will broaden the scope of musculoskeletal research.

## References

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**International Society of  
Biomechanics  
XVIII<sup>th</sup> Congress  
July 8-13, 2001, Zurich, Switzerland**

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