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Neuromuscular responses to different resistance loading protocols using pneumatic and weight stack devices

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A B S T R A C T

The purpose of this study was to examine single repetition characteristics and acute neuromuscular responses to typical hypertrophic (HL), maximal strength (MSL), and power (PL) loadings performed with two of the most common resistance modes; pneumatic and weight stack. Acute responses were assessed by measuring maximal voluntary contraction (MVC), corresponding quadriceps-EMG and resting and superimposed twitch torques. Activation level was calculated from the twitch torques.

Decreases in MVC were greater during HL and MSL than during PL. During HL, resting twitch force decreased 8% ($P < 0.05$) more on the weight stack than on the pneumatic device. Furthermore, loading using the weight stack caused reduced resting twitch force, activation level, and EMG-amplitude after MSL and PL ($P < 0.05$–0.01).

PL on the pneumatic device decreased MVC and rapid force production, while the respective PL on the weight stack device was specific to decreased rapid force production only. However, mean angular velocities and power of the repetitions were higher on the pneumatic device when using light loads.

The present study showed that, at least in untrained subjects, the weight stack device induced greater levels of peripheral fatigue during HL. It also led to large central fatigue during MSL and PL. On the other hand, on the pneumatic device contraction velocity with low loads was higher compared to the weight stack device.

Therefore, it is recommended that the resistance mode should be chosen according to the specific training goal.

1. Introduction

The most widespread resistance modes of various training devices used in commercial gyms are pneumatic and weight stack. The resistance generated by pneumatic devices is proportional to the air pressure in the cylinder and can be modified by lever arms of the structure, whereas the device frame provides only a minimal contribution to the total resistance (see Frost et al., 2010). The resistance in the pneumatic cylinder is constant throughout the range of motion and is independent of contraction velocity. Conversely, the resistance provided by weight stack devices is composed almost entirely of mass, and is thereby influenced by inertia and momentum. As a result, the actual load (as sensed by the individual) is not maintained throughout the range of motion. With cam and lever arms of the device frame it is possible to customize the resistance and modify it to conform to the human torque-joint angle relationship. This is called variable resistance. Well designed variable resistance stresses the neuromuscular system over the entire range of movement (Graves et al., 1989). Torque production capabilities are well known to be partly dependent on the joint angle (Singh and Karpovich, 1966) and contraction velocity (Komi, 1973). However, contraction velocities and momentum affect forces exerted on the neuromuscular system, and should be considered to evaluate device properties. Häkkinen et al. (1987, 1988b) investigated weight stack devices with variable resistance and Frost et al. (2008) have studied pneumatic resistance repetitions with different velocities and loads and also muscular activities during the trials. Nevertheless, the differences between various resistance modes has not been investigated comprehensively using different strength training loading schemes (e.g. maximal strength, muscle hypertrophy and power).

Various strength training goals require specific loadings to achieve the desired adaptation. Development and adaptation progress due to fatigue, which will generate supercompensation (Zatsiorsky and Kraemer, 2006). The origin of fatigue has been classified as either central or peripheral (Bigland-Ritchie et al., 1978). In general, single session strength loading leads to acute fatigue observed as reduced force production, which is accompanied by acute neural, metabolic, and/or hormonal changes in the body if the exercise has been of sufficient intensity and duration. The exact responses relate to the specific type of loading (e.g. hypertrophic

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loading). However, if there are differences between devices in terms of how the resistance is produced throughout the range of motion, there may be differing amounts of work, muscle tension, and, therefore, muscle activity and rate of total work. Frost et al. (2010) suggested this possibility but to our knowledge no authors have directly compared these devices.

It is well known that the amount of work done plays an important role with working intensity and recovery phases in generating muscle growth (Patterson et al., 1985; Kraemer et al., 1990; Fitts and Widrick, 1996; Wernbom et al., 2007), which is the goal of hypertrophic training. On the other hand, higher movement velocities are possible when there is a difference between the resistance force and maximal force production capabilities of the muscles. Thus, this permits primarily high velocity improvements due to high velocity repetitions, for example, in ballistic or power training (Komi and Tesch, 1979; Häkkinen et al., 1985; Sale, 1988). Neural properties may also be developed through high loads, as in maximal strength training, where most or all of the motor units are required to produce large forces throughout the range of motion. Maximal strength training is based on the development of both neural properties and hypertrophy.

The purpose of this study was to examine acute neuromuscular fatigue after hypertrophic, maximal strength, and power loadings performed with pneumatic versus weight stack devices. Single repetition loading characteristics were also studied in order to reveal possible differences between the loading devices, which could then explain, at least, partly the differences between the acute responses.

2. Methods

2.1. Subjects

Fifteen healthy young men (20–35 years) volunteered as subjects. None of the subjects had regular strength training background but they were all physically active. Full details about possible risks or discomfort were given to the subjects and they signed the informed consent. The study was performed in accordance with the Declaration of Helsinki 1975, and protocol was accepted by the Ethics Committee of the University of Jyväskylä.

2.2. Experimental design and loading devices

The experimental design comprised a familiarization session with single repetitions and six different loading sessions: (1) maximum strength loading, (2) hypertrophic loading, and (3) power loading using both weight stack and pneumatic devices. After the familiarization session subjects rested at least 4 d before the first testing session. The loadings and the order of the devices were randomized and recovery times between the different loadings were at least 1 week. However, the power and hypertrophic loadings were performed on the same day and the hypertrophic loading was done one hour after the end of the power loading.

Subjects performed single explosive repetitions with different loads and performed three different resistance training sessions using bilateral pneumatic (P) (Hur 3350, Hur Ltd., Finland) and weight stack (WS) resistance (D200, David Sports Ltd., Finland) knee extensor devices in a seated position. Although the inertial characteristics of the resistance differ between the devices, they both provide variable resistance; the pneumatic system included lever arms and the weight stack system utilized a cam wheel in the mechanism. The range of the knee extension was 60–180° of knee joint angles and the hip joint angle was fixed, secured by a belt, to 110° throughout the movement. The knee extension exercise was chosen in the interests of using muscle stimulation and limiting the complexity of the model being examined, because this single joint movement isolated the quadriceps muscles. Also, different knee extension devices are very popular in commercial gyms.

2.3. Familiarization and single repetitions

The first session was partly a familiarization visit. In this session subjects practiced all the devices and each device was set up according to the above mentioned anatomical dimensions of the subject. Subsequently, one repetition maximum (RM) load was determined on both devices and subjects performed explosive single repetitions using 20%, 40%, 60% and 80% 1 RM loads in a randomized order. The 1 RM load was the highest load that each subject could use to complete a single repetition using an acceptable lifting technique. It was determined separately on both devices. Surface EMG, force and angle data were measured during all single repetitions. When analyzing the measurements of the familiarization session, all single repetitions were divided into six 20° sectors, from 60° to full extension (180°) of the knee joint angle. EMG activity of the vastus lateralis, vastus medialis and rectus femoris of the right leg were combined and averaged during analysis of single repetitions.

2.4. Loadings

In every loading session subjects performed a warm-up, which consisted of 6 reps on 40% 1 RM on the loading device. The maximum strength loading protocol consisted of 15 sets of one repetition at 100% 1 RM, with a 3-min rest period between the sets. The hypertrophic protocol was $5 \times 10 \times 80\%$ 1 RM, with a 2-min recovery. During these loadings the subject was just able to finish the required repetition of each set and the knee extension was done using a self-selected velocity. The power loading protocol consisted of 5 sets of 5 repetitions at 40% 1 RM load, with a 3-min recovery and each repetition was performed as fast as possible. All protocols were modified from Fleck and Kraemer (2004). All intensities were based on the device-specific maximum (1 RM).

2.5. Measurements

The measurements (pre- and post-loading) consisted of fingertip blood samples for lactate analysis, unilateral maximal isometric torque (MVC), resting twitch torque, and superimposed twitch torque during MVC at 107° knee angle (SMVC). Superimposed twitches (the protocol included also resting twitch), MVCs and blood lactate were measured immediately after the loadings (Fig. 1). Subjects were instructed to perform MVCs (without superimposed twitch) as fast as possible against the immovable load.

2.6. Force and angle

Both loading devices were equipped with in–built knee extension force and knee angle sensors allowing evaluation of concentric actions. The other torque measurements (pre- and post-loading) were performed on a separate isometric knee extension dynamometer (Department of Biology of Physical Activity, University of Jyväskylä). Consequently, the effects of both resistance modes on isometric contraction capability could be directly compared. In addition, a separate knee goniometer was attached to the leg around the knee joint and recorded knee joint angles during all dynamic repetitions. Calibration of all equipment was accomplished before the beginning of each test.

All torque (concentric and isometric) and angle signals were sampled at 2000 Hz and signals were low pass filtered (torque 20 Hz, and angle 75 Hz). From these parameters, mean angular