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Original research

Plyometric training improves voluntary activation and strength during isometric, concentric and eccentric contractions

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ABSTRACT

Objectives: This study investigated effects of plyometric training (6 weeks, 3 sessions/week) on maximum voluntary contraction (MVC) strength and neural activation of the knee extensors during isometric, concentric and eccentric contractions.
Design: Twenty-seven participants were randomly assigned to the intervention or control group.
Methods: Maximum voluntary torques (MVT) during the different types of contraction were measured at 110° knee flexion (180° = full extension). The interpolated twitch technique was applied at the same knee joint angle during isometric, concentric and eccentric contractions to measure voluntary activation. In addition, normalized root mean square of the EMG signal at MVT was calculated. The twitch torque signal induced by electrical nerve stimulation at rest was used to evaluate training-related changes at the muscle level. In addition, jump height in countermovement jump was measured.
Results: After training, MVT increased by 20 N m (95% CI: 5–36 N m, P = 0.012), 24 N m (95% CI: 9–40 N m, P = 0.004) and 27 N m (95% CI: 7–48 N m, P = 0.013) for isometric, concentric and eccentric MVCs compared to controls, respectively. The strength enhancements were associated with increases in voluntary activation during isometric, concentric and eccentric MVCs by 7.8% (95% CI: 1.8–13.9%, P = 0.013), 7.0% (95% CI: 0.4–13.5%, P = 0.039) and 8.6% (95% CI: 3.0–14.2%, P = 0.005), respectively. Changes in the twitch torque signal of the resting muscle, induced by supramaximal electrical stimulation of the femoral nerve, were not observed, indicating no alterations at the muscle level, whereas jump height was increased.
Conclusions: Given the fact that the training exercises consisted of eccentric muscle actions followed by concentric contractions, it is in particular relevant that the plyometric training increased MVC strength and neural activation of the quadriceps muscle regardless of the contraction mode.

1. Introduction

Several studies have shown that plyometric training has a positive effect on isometric maximum voluntary contraction (MVC) strength.[1–3] However, only few studies focused on the underlying neuromuscular adaptations.[2,4,5] Studies have revealed that increases in isometric MVC strength of the plantar flexors following plyometric training were due to an improved activation of the agonistic muscles[2,4] and in part due to muscular adaptations.[4] With regard to the effect of plyometric training on isometric MVC strength of the knee extensors, studies yielded different results. While some studies observed an increase in MVC strength after 8 weeks of training,[5,6] another experiment failed to show strength enhancements following a 15-week training period.[2] The strength gains of the knee extensors in the first studies mentioned were due to neural and muscular adaptations, i.e. an improved voluntary activation of the quadriceps, assessed with the interpolated twitch technique,[5] as well as an increased single-fiber cross-sectional area and contractile function of chemically skinned single muscle fibers.[6]

Previous research in quantifying the ability to voluntarily activate a muscle after a period of plyometric training using the interpolated twitch technique has been performed under isometric testing conditions.[4,5] Therefore, hardly anything is known about changes in MVC strength and voluntary activation of the quadriceps during concentric and eccentric contractions after a

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plyometric training regimen. Because plyometric exercises consist of eccentric contractions followed by concentric muscle actions (stretch-shortening cycle), it is of interest whether or not this kind of training influences MVC strength and voluntary activation more during dynamic contractions than during isometric contractions.

Therefore, we investigated the effects of a 6-week plyometric training on neuromuscular function of the quadriceps during isometric, concentric and eccentric MVCs. In particular, the neural drive to the knee extensors during static and dynamic MVCs was measured by using the interpolated twitch technique and the root mean square of the EMG signal normalized to the maximal M-wave (M_{max}). Putative training-related changes at the muscle level were assessed by analyzing the twitch torque signal induced by transcutaneous electrical stimulation of the femoral nerve. Furthermore, jump height in countermovement jump (CMJ) was measured.

We hypothesized that there would be a training-related increase in quadriceps MVC strength during isometric, concentric and eccentric contractions and an association between these changes and muscle activation. In view of the length of the training period, it was thought that contractile function of the knee extensors would not change. Furthermore, we expected training-related effects on the jump height in CMJ.

2. Methods

Based on the effect size for MVC strength of a previously published study,[5] a given two-sided significance level of 0.05 and a power of 0.80 sample size calculation indicated that a total of 27 persons would be required. Therefore, 27 recreational active participants without neurological disorders or injuries were recruited from our university. The participants were randomly assigned to an intervention group and a control group using randomization by a computer-generated table of random numbers. The intervention group consisted of 14 participants (10 males, 4 females, age: 24.4 ± 2.4 years, height: 180.5 ± 9.5 cm, body mass: 77.7 ± 16.4 kg), while 13 participants were assigned to the control group (10 males, 3 females, age: 25.3 ± 4.6 years, height: 182.0 ± 6.6 cm, body mass: 76.5 ± 8.0 kg). All study participants were recreational active (moderate exercise ~3 times per week, activities included running, swimming, strength training of the upper extremities and different sport games) and none of them had ever performed a systematic plyometric training program before. The participants were asked to avoid caffeine and alcohol consumption in the 24 h and strenuous exercise in the 48 h prior to the measurements. The study was approved by the university ethics committee and was in line with the declaration of Helsinki. All participants gave written informed consent prior to enrollment.

The intervention group trained 3 times a week for 6 weeks. The plyometric training consisted of CMJs in different variants, e.g. vertical CMJs, jump and reach tasks, standing long jumps, CMJs over different obstacles. The jump and reach tasks were performed next to a whiteboard where the individual jump heights were marked. These marks served as minimum target for the next jump and should motivate the participants. During long jumping, subjects jumped as far as they could and the distance was marked on the ground to motivate the subjects for the next jump. In order to adjust training intensity for each participant during the CMJs over obstacles, boxes of varying heights were used. In addition, Airex® balance pads, consisting of foam material, were used to enhance the height of the obstacles without increasing injury risk. During the first week, participants had to perform 4 sets of different CMJ exercises with 10 repetitions per set. In the following 3 weeks participants performed 12 repetitions per set. After 4 weeks of training, participants had to perform 5 sets with 15 repetitions per set. The rest interval between the CMJs was 10 s so that the participants could concentrate on every single jump and the rest interval between sets was 3 min. The participants were instructed to perform the CMJs with maximal effort in order to achieve explosive force production and maximal jump performance. In every training session, the individual jump height was measured during 1 set of the different exercises using a force plate (9290AD, Kistler, Winterthur, Switzerland) or a light barrier system (OptoGait, Microgate, Bolzano-Bozen, Italy). The results were immediately transmitted to the participants. The control group was asked to maintain their individual level of physical activities.

Neuromuscular function of the knee extensors of the right leg and jump height in CMJ were assessed prior to and after the 6-week plyometric training. Throughout the testing sessions, participants were comfortably seated in a standardized position on a CYBEX NORM dynamometer (Computer Sports Medicine®, Inc., Stoughton, MA). Neuromuscular tests consisted of supramaximal electrical stimulations of the femoral nerve at rest and during isometric, concentric and eccentric MVCs (Fig. 1). The contraction sequences were randomized. In addition, jump height was estimated on a separate day. All participants underwent a standardized warm-up on a cycle ergometer for 5 min at 60 W prior to the jump tests.

Transcutaneous electrical stimulation of the femoral nerve in the femoral triangle was used to assess neuromuscular function of the quadriceps as described previously.[7] Briefly, the femoral nerve was stimulated using a cathode ball electrode. The anode was a self-adhesive electrode (35 mm × 45 mm, Spes Medica, Genova, Italy) fixed over the greater trochanter. The electrical stimuli were single and paired rectangular pulses (1 ms duration and 1 ms duration, 10 ms apart, 400 V, respectively) delivered by a Digitimer® stimulator (DS7A, Hertfordshire, UK). The inter stimulus intervals (ISI) were provided by a LABVIEW® based program (Stimuli, Pfitec, Endingen, Germany). The testing procedure included electrical stimulation (ISI was randomized between 6 and 7 s) with increasing current intensity until identification of M_{max} of the vastus medialis (VM) muscle. M_{max} responses were elicited with supramaximal stimulation intensity (140%).[8,9] Resting twitch torques were evoked prior to the MVCs using supramaximal single and doublet stimuli.

Voluntary activation during isometric, concentric and eccentric MVCs was assessed by using the interpolated twitch technique.[10] All measurements were performed at 110° knee flexion (180° = full extension). For the isometric condition, the supramaximal electrical stimuli (doublet) were delivered to the femoral nerve 2 s after torque onset, during the plateau phase, and 2 s after MVC. Concentric and eccentric MVC testing was done at a velocity of 25°/s.[11,12] During dynamic contractions, the supramaximal doublet was triggered automatically and delivered at a knee angle of 110°. After every single contraction, participants had to relax their knee extensors immediately and the lever arm moved again through the same range of motion with the same velocity. During this passive trial, supramaximal electrical stimuli were applied at 110° knee flexion as well. The time between the active trial (concentric or eccentric MVC) and the electrical stimulation during the passive trial was 6 s. The stimuli were triggered by a LABVIEW® based software program (Stimuli, Pfitec, Endingen, Germany).

Surface EMG electrodes (EMG Ambu® Blue Sensor N) were used to record muscle activity of VM, rectus femoris (RF) and vastus lateralis (VL) muscles of the right leg as described previously.[5,7,13] Signals were amplified (2500×), band-pass filtered (10–450 Hz) and digitized with a sampling frequency of 3 kHz through an analog-to-digital converter (NI PCI-6229, National Instruments, Austin, USA). Both, the EMG and torque signals were sampled at 3 kHz and stored on a hard drive for later analysis with a custom built LABVIEW® based program (Imago, Pfitec, Endingen, Germany).

Torque signals were measured using a CYBEX NORM dynamometer (Computer Sports Medicine®, Inc., Stoughton, MA). The participants were seated with a hip joint angle of 80°. The