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The effect of strength training on the apparent inhibition of eccentric force production in voluntarily activated human quadriceps

Abstract Ten male and ten female young adults trained the knee extensors of one leg eccentrically and those of the other concentrically for 6 weeks, using a gymnastum leg-extension machine. Before and after training, both legs of each subject were tested isometrically for maximum voluntary knee-extensor force, and in both eccentric and concentric isokinetic modes at 30–250° s⁻¹. All limbs showed improvements in mean eccentric force (ranging from 18% in the concentrically trained legs of the females to 31% in the eccentrically trained legs of the males, P < 0.01–0.001). Upward trends in isometric and concentric forces were smaller and less- or non-significant. In three of the four groups, mean eccentric forces after training were significantly greater than mean isometric forces, a difference that was not evident before training. Ten further subjects of each gender, not trained but tested isometrically and isokinetically three times in 2 weeks, showed no significant improvement over the series of tests. The explanation suggested is that the increased percentage activation (“decreased inhibition”), often regarded as the main mechanism of strength gain in the early weeks of training, had been displayed particularly in the subjects’ eccentric performance. This implies that the activation-shortfall, which is reduced by the initial phase of strength training, is largely or completely the same as that responsible for the fact that untrained, voluntary eccentric force is less than that of isolated muscle.

Key words Eccentric exercise · Inhibition · Isokinetic dynamometry · Muscle · Strength training

Introduction

Isolated skeletal muscles can resist extension with forces greater than their isometric tension. A factor of ×1.8 (Katz 1939; frog and tortoise muscles, 0 °C) is widely quoted, although ×1.6–1.7 better represents Katz’s results in “warm” conditions (15–20 °C). Forces substantially higher than isometric, although never to our knowledge as much as ×1.8 higher, have been reported to be developed by human arm muscles when operating eccentrically under voluntary activation (Asmussen et al. 1965; Singh and Karpovich 1965; Komi 1973; Griffen et al. 1993 and references therein). However, thigh muscles, especially the quadriceps, present a confused picture, particularly when studied – as is now standard – by isokinetic dynamometry. Reports of forced knee flexion being resisted in a dynamometer with torque or force greater than isometric (e.g. Thorstensson et al. 1976; Collander and Tesch 1989; Griffen et al. 1993, and references therein) seem to be in the minority, and are based predominantly on studies of female subjects. More often, especially in recent work and with male subjects, eccentric torque or force has been found to equal, or even to fall a little short of isometric and, just as strikingly, to show no significant variation with angular velocity over experimental ranges from 0–360° s⁻¹ [e.g. Hageman et al. 1988; Collander and Tesch 1989 (male subjects); Westing et al. 1991; Enoka 1996, and references therein; Newham et al. 1998].

In principle, lower-than-predicted knee-extension force could be due to greater activation of antagonists during eccentric than concentric actions of the quadriceps. However, Eloranta and Komi (1980) found only slight activity in the semimembranosus during eccentric quadriceps activity. Furthermore, the semimembranosus activity did not vary with contraction velocity, so it could not explain the velocity-independence of eccentric extensor force. The recent results of Newham et al. (1998), although differing in details from Elantora and Komi’s, support the overall conclusion that antagonists
cannot be held principally responsible for the oddities of the quadriceps eccentric force/velocity relationship.

One explanation proposed for the phenomena described, is that motor unit activation in the quadriceps and other agonists is incomplete during eccentric action, although it appears that normal subjects can fully activate their muscles during concentric and isometric contractions (e.g. Rutherford et al. 1986a). This account has gained support from at least three categories of evidence. First, electromyographic (EMG) records. Although surface recording from moving muscles is fraught with problems, and perhaps for this reason the result is not universal (e.g. Newham et al. 1998), it is the case that Bigland and Lippold (1954), Eloranta and Komi (1980) and Tesch et al. (1990a) all found that integrated quadriceps EMG activity was substantially higher in maximum concentric than in maximum eccentric dynamometer efforts, although the eccentric forces measured were greater. The second line of evidence is that in the knee extensors of patients suffering from spastic paresis, a condition in which it may be assumed that normal restraining influences are absent, eccentric activation as well as force production are both dramatically higher than even their slowest concentric counterparts (Knutsson et al. 1988). Finally, and most strongly, by using direct experimental intervention Gravel et al. (1987), Hatler et al. (1989) and Westing et al. (1990) all found that transcutaneous electrical stimulation enabled the male quadriceps to develop supra-isometric tension during eccentric operation, and overall to display force/velocity curves closer to those of isolated muscles.

If one takes a step further back, and asks why activation is incomplete, it has been suggested (Young and Stokes 1986; Westing et al. 1990) that inhibitory mechanisms, central or peripheral, are at work. A further speculation is that the adaptive advantage of these mechanisms is to protect soft-tissue structures in the vicinity of the knee from overload. Since this joint is one of the most complex and highly loaded in the biped body, and is notably injury-prone, such a speculation has appeal.

Independently of the foregoing topic, it is widely acknowledged that the first 2–3 months of strength training produce performance gains that are out of all proportion to any increase of muscle bulk (e.g. Moritani and de Vries 1979; Jones and Rutherford 1987). In one widely-quoted study no bulk increase at all, and no significant intracellular enzyme or myofibril changes, could be demonstrated for 10–12 weeks (Tesch et al. 1990b). Accordingly, the early period has been termed the “neural phase” of strength training, in contrast to the later “hypertrophic phase”. One proposal to explain this is that inhibition, initially preventing full activation of the untrained muscles under high-load conditions, is being gradually overcome during the period (Moritani and de Vries 1979; Sale 1988). As before, it has been speculated that the adaptive advantage underlying the inhibition of the untrained muscle is the protection of unconditioned structures.

In neither case described (eccentric action and strength training) has the mechanism of the putative inhibition been elucidated, and critics consider that the concept of inhibition itself goes beyond the evidence. The difference of view may be terminological. We ourselves feel it appropriate to regard any mechanism that results in activation being less than complete when maximal voluntary effort is undertaken as being, by definition, inhibitory. No claim about the nature or level of the inhibitory mechanism is implied.

Thinking in these terms leads to an otherwise-improbable but readily testable hypothesis. This hypothesis is that the form of inhibition (or mechanism of activation-shortfall) that commonly stands in the way of supra-isometric force development in the eccentrically active quadriceps is largely or wholly the same as that which is suppressed during the first 3 months of strength training. If so, male as well as female subjects, strength trained in either mode, should be able to produce knee-extensor torques that are not only greater in all modes of action than could be produced before training, but greater in the eccentric mode than the isometric, and increased more in eccentric than concentric actions.

Our results, which have previously been reported in abstract form (Spurway et al. 1999), are in agreement with the above predictions.

**Methods**

**Experimental subjects**

The training experiments were completed by ten male subjects (aged 20–28 years) and ten females (19–30 years). All were physically active, but not recently involved in weight training. None had any history of knee pathology and all preferred to kick with the right leg. They were all requested to maintain their normal exercise and sporting activities throughout the experimental programme. Each gave their informed consent to perform the protocol described below, which had been approved by the University Ethics Committee.

**Dynamometry**

To minimise improvements in performance arising only from familiarisation with the dynamometry itself, subjects in the experimental groups were asked to attend the isokinetic laboratory only once before, and once after, their strength-training programmes. At the first laboratory session, each subject was allowed as long a period as (s)he wished for familiarisation. When each individual felt fully acquainted with what was required, the following routine was initiated, and was repeated at the second visit.

First came a standardised, 10-min, pre-test warm-up and stretch routine. The subject was then seated erect on the isokinetic dynamometer, a hydraulically driven, microcomputer-controlled Kinetic Communicator (“Kin-Com II”), Chattanooga, Chattanooga, TN 37405, USA). The machine’s maximum force limit was set at 2000 N, and the force required to activate movement was set at 50 N. The Kin-Com read-out is of force applied by the limb against the moving lever, not of resulting torque at the fulcrum. The leg to be tested was secured to the dynamometer chair with a Velcro strap just above the knee, and a seat belt was used to prevent significant utilisation of trunk muscles in the test action. Then the axis of rotation of the dynamometer lever arm was aligned with the lateral