Welcome to the January 2018 edition! This edition includes the first major round of formatting changes to the new-style edition, thanks to everyone who has given feedback to date. You will find this edition even easier to read than the previous ones, but it also packs much more information about strength training, athletic performance, and muscular hypertrophy into the same space.

As always, this edition is divided into three parts. It starts with reviews of studies of general strength training, moves onto sprinting and athletic performance, and finishes with a section on hypertrophy.

The most important study in this edition assessed the effects of training a two-joint muscle at each joint. Surprisingly, both hip flexion and knee extension strength training caused voluntary activation to increase during a knee extension maximum voluntary isometric contraction. This suggests that a substantial element of the neural adaptations that happen after strength training are independent of the joint action used to train the muscle. Although the study involved the rectus femoris, it seems likely that the same results would be observed for the hamstrings, suggesting that knee flexion strength training would enhance hamstrings voluntary activation in a hip extension movement. This obviously has important implications for programming strength training exercises for sports!

Hypertrophy enthusiasts will find plenty of practical tips this month, with discussions ranging from the relative benefits of multi-joint and single-joint exercises, to the use of post-workout protein for recovery after sustaining muscle damage, and the potentially negative effects of training a muscle group *too frequently* on proxy markers for long-term muscle growth. I hope you enjoy reading this edition. See you next month!
## Strength training

1. Effects of training a two-joint muscle at each joint on strength at each joint
2. How can training adaptations be monitored in Olympic weightlifters?
3. Do tendons act as a mechanical buffer to the muscles during step landings?

## Sprinting

4. Why does competitive soccer cause long-lasting muscular fatigue?
5. How are ground reaction forces related to sprinting performance?
6. Can lowering a weight more slowly enhance change of direction ability?

## Hypertrophy

7. Which are better for hypertrophy: multi-joint or single-joint exercises?
8. Can training more than once per day be counter-productive for hypertrophy?
9. Can protein supplementation help accelerate post-workout recovery?
10. Can muscle size increase even without the contribution of satellite cells?
This sample only includes one study review. To read the full edition with 10 study reviews, click HERE and create a subscription.
Effects of training a two-joint muscle at each joint on strength at each joint

Proponents of (visual frameworks) of functional training often recommend that we should load movements and not muscles in order to maximize the neural adaptations to strength training. However, it is not clear whether neural drive to a two-joint muscle increases when tested in a given joint action, after it has been trained at the other joint. While the hamstrings are perhaps the most well-known two-joint muscle group, the rectus femoris is both a knee extensor and also a hip flexor.

Key findings
After short-term training of either the hip flexors or the knee extensors, maximum knee extension strength was increased. This increase was partly mediated by gains in voluntary activation. Yet, strength gains were still somewhat specific to the joint trained. This specificity likely arose due to both neural adaptations and differences in (regional) hypertropy.

Practical implications
Two-joint muscles can be trained at either joint to increase strength tested at both joints, although optimal results in athletes will be attained by focusing on the joint that is loaded in the sporting movement being improved. Bodybuilders may wish to use exercises that load the muscle at both joints, to maximize gains in muscle size in all regions.

Why is there so much confusion about “functional training”?

There are lots of approaches to “functional training” now being used. Many (but not all) of them fall into one of the following two frameworks, which are very different from each other.

**Visual framework**
“what does the exercise look like?”

- Classifies *exercises* as functional or non-functional.
- Exercises identified as functional if they *look similar* to a range of other common movements.

**Outcome framework**
“what effect does the training program have?”

- Classifies *training programs* as functional or non-functional.
- Training program identified as functional if it produces an increase in performance on a single athletic movement.
- Exercises that overload certain aspects of a muscle contraction (such as load in the eccentric phase) can be very effective for ↑ performance.
- Exercises that look nothing like sporting movements can still ↑ performance in those tasks.

**PRACTICAL IMPLICATIONS**
Functional training approaches can be categorized into two types: (1) analyzing what an exercise looks like, and (2) identifying training programs that ↑ an outcome. Since an exercise does not need to look like a sporting movement to ↑ performance, the visual framework is not reliable. The outcome framework avoids this pitfall, and allows us to focus on other aspects that affect performance, like eccentric loading.

**OBJECTIVE**

To compare the effects of isometric knee extension and isometric hip flexion strength training on changes in muscle size, strength, rate of force development, and voluntary activation in untrained males.

**INTERVENTION**

Subjects in the two training groups trained 3 times per week for 4 weeks. Each workout = 4 sets of 10 single-leg isometric hip flexion or knee extension maximal voluntary isometric contractions (MVICs) in a dynamometer with the knee joint at 90° and the hip joint at 80° (full extension = 0°). Each MVIC was done as fast and forcefully as possible, and contractions were sustained for 3 seconds each, with a 17-second rest between contractions and a 2-minute rest between sets. The non-training group did no training.

**POPULATION**

37 subjects: a hip flexion group (14 males, aged 22 ± 2 years), a knee extension group (12 males, aged 22 ± 3 years), and a non-training group (11 males, aged 22 ± 4 years)

**MEASUREMENTS**

**Maximum strength, voluntary activation (VA), and rate of torque development (RTD):** Maximum voluntary strength by hip flexion and knee extension MVICs; involuntary knee extension torque by supramaximal electrical stimulation (single twitch) at rest; VA by the interpolated twitch method with electrical stimulation (triplet) in a knee extension MVIC; RTD in 0-50, 50-100, and 100-150ms in explosive knee extension and hip flexion contractions.

**RESULTS**

Knee extension MVIC torque increased in both training groups (the increase was greater after knee extension training); hip flexion MVIC torque increased only after hip flexion training. Involuntary knee extension torque did not change. Both training groups increased knee extension RTD in 0-50 and 50-100ms. Hip flexion RTD in 50-100ms increased only after hip flexion training. Both training groups increased VA; this increase was associated with the increase in knee extension MVIC torque (r = 0.54 – 0.77).

**Muscle activation:** Electromyography (EMG) amplitudes were recorded from the rectus femoris (both middle and proximal regions) and vastus lateralis (normalized to the M wave recorded in the involuntary contractions) and the biceps femoris long head (normalized to levels in a knee flexor MVIC).

In the knee extension MVIC, rectus femoris EMG increased in both training groups, but vastus lateralis EMG increased only after knee extension training, and biceps femoris EMG did not change in either group. In the hip flexion MVIC, rectus femoris EMG increased only after hip flexion training.

**Muscle thickness and pennation angle:** By ultrasound of the (proximal and distal) rectus femoris and vastus lateralis.

Both training groups increased muscle thickness of both regions of the rectus femoris. Knee extension training increased muscle thickness in the distal region by more than in the proximal region. Only knee extension training increased vastus lateralis muscle thickness.

**SUMMARY**

After short-term training of either the hip flexors or the knee extensors, maximum knee extension strength was increased. This increase was partly mediated by gains in voluntary activation. Yet, strength gains were still somewhat specific to the joint trained. This specificity likely arose due to both neural adaptations and differences in (regional) hypertrophy.
This study discovered that both short-term periods of hip flexion and knee extension isometric training can bring about an increase in maximum voluntary knee extension strength, and that these strength gains were strongly associated with the increases in voluntary activation. This is a ground-breaking finding, because it shows that the neural adaptations that contribute to increased strength after training do not depend on which joint is used to train a two-joint muscle. While previous studies have shown that high-force isometric training can increase voluntary activation (1), these have tested strength and voluntary activation using the same joint action as used during strength training. In contrast, this study demonstrated that voluntary activation during a maximal knee extension effort can be increased by a hip flexion strength training program.

This discovery is likely to upset advocates of visual frameworks of functional training, who maintain that the functional (i.e. specific) effects of training are mediated by the way that the exercise looks, rather than by the adaptations it causes. Indeed, since the hamstrings are also two-joint muscles, these findings remove a key argument against using leg curl (knee flexion) variations for improving hamstrings strength to contribute to hip extension. Yet, this study did still observe specific strength gains according to the joint used in training, as shown in the chart below. Hip flexion training increased hip flexion MVIC torque more, and knee extension training increased knee extension MVIC torque more. This likely arose partly from differences in regional hypertrophy, and partly from the involvement of other muscles like the iliopsoas (2) and vastus lateralis that only contribute to one joint action.

Effects of hip flexion or knee extension strength training on strength and voluntary activation

![Chart showing changes in knee extension and hip flexion MVIC torque and voluntary activation after training](chart.png)

- Hip flexion training caused a larger ↑ in hip flexion MVIC torque, while knee extension training caused a larger ↑ in knee extension MVIC torque.
Previous studies have shown that the strength gains in an exercise are associated with changes in regional muscle size, and not just increases in the size of the muscle overall. For example, increases in one repetition-maximum (1RM) back squat are associated with increases in muscle thickness of the central, but not medial, region of the vastus lateralis (3). As shown in the chart below, knee extension training increased rectus femoris muscle thickness to a greater extent in the distal region (near the knee) than in the proximal region (near the hip). Hip flexion training caused similar increases in both distal and proximal regions. In general, it seems that exercises involving two-joint muscles do place more load on the region of the muscle that is closest to the joint producing force.

For example, when training the hamstrings, knee flexion exercises activate the lower region (near the knee) more than hip extension exercises (4). The same thing has been observed in hip flexion and knee extension exercises. Hip flexion exercise tends to activate the proximal region more than the distal region of the rectus femoris, while knee extension tends to activate the distal region more (5,6). Long-term muscle growth in specific regions is often related to the regions that are most activated in an exercise (at least when using MRI) (7). It therefore makes sense that regional hypertrophy will arise after either hip flexion or knee extension strength training, and that this will contribute to specific strength gains at each joint.
There is so much going on in this study that it is very easy to miss a number of smaller findings.

Firstly, the neural adaptations contributing to increased knee extension MVIC were not *identical* between the training groups, even though there was clear evidence of a large contribution after both types of training. The association between the relative changes in voluntary activation and the relative changes in MVIC knee extension torque was stronger in the knee extension training group (r = 0.77) than in the hip flexion training group (r = 0.54). Moreover, in the knee extension MVIC, rectus femoris EMG amplitude increased in both training groups, but in the hip flexion MVIC, rectus femoris EMG amplitude increased only after hip flexion training. Together, this suggests that small differences in neural adaptations likely contributed to the specific strength gains after training, in addition to the differences in regional hypertrophy.

Secondly, biceps femoris muscle activation relative to knee flexion MVIC during the knee extension MVIC did not change, even though knee extensor muscle activation increased. In other words, antagonist activation remained constant, while agonist activation increased, so coactivation reduced. This is largely in accordance with the findings of previous short-term isometric strength training programs (1,8,9).

A reduction in coactivation, particularly if the antagonist muscle does not increase activation at all, could contribute to increased strength gains. However, we should be cautious about extrapolating from short-term isometric training to conventional, dynamic strength training. While dynamic strength training programs can also reduce antagonist activation (10) as an adaptation to unstable conditions, programs with shorter durations tend to display increases (11), perhaps because of an increased need for joint stability as strength increases very rapidly in the first few weeks.

Thirdly, when considering the large increases in muscle thickness after training in this group of previously-untrained individuals, it is worth recalling that the duration of the study was only 4 weeks in length. This is yet more evidence that meaningful muscle growth occurs very quickly after starting strength training (12), alongside large increases in neural drive as measured by voluntary activation and EMG amplitudes. It seems that we must finally leave behind the old idea that early strength gains are *first* caused by neural adaptations and *then* caused by changes in muscle size. The fast strength gains that occur after starting a strength training program are produced by both neural adaptations and hypertrophy (and almost certainly by other changes inside the muscle as well).
**Conclusions**
When two-joint muscles are trained at one joint, this also increases their ability to produce force at the other joint as well, albeit to a lesser extent. This study showed that strength gains over 4 weeks were caused by both neural and muscular adaptations. Increases in voluntary activation contributed (largely) similarly to strength gains at both joints. Even so, there was some evidence of specific strength gains at each joint. This specificity likely arose partly from differences in regional hypertrophy, and partly from the development of other muscles like the iliopsoas (a hip flexor) and the single-joint quadriceps, which only contribute to one or other joint action (hip flexion or knee extension).

**Practical implications**
When writing training programs to develop two-joint muscles in athletes we should not assume that we *always* need to load the muscle at the joint used in the sporting movement we are trying to improve. Rather, we can simply add this factor to our existing list of ways in which strength gains are specific to the type of training performed (muscle action, velocity, load, range of motion, amount of stability, external load type, force vector, and muscle group). Depending on the athlete and the specific goal of the training program, one or more of these factors may be more important than the others. In contrast, when writing training programs for bodybuilding, we will want to incorporate exercises that load the muscle at both joints, in order to maximize gains in muscle size in all regions.


To keep reading this edition, click **HERE** to visit our online store and create a subscription.