Why does eccentric training help prevent muscle strains?

Reading time:

By Chris Beardsley, S&C Research columnist

Although a great many studies have shown that eccentric training can help you reduce your risk of muscle strains, there is currently no clear consensus among researchers about *exactly* how it works.

This is why I think it works.

Are muscle strains really that common?

Muscle strains are a common problem, both in individual and team sports.

In international, high-level athletics, muscle injuries represent the single largest category of injury in competition, accounting for 41% of injuries overall, with a large proportion of those muscle injuries being strains (Edouard et al. 2016).

And in the football codes, lower body muscle strains account for a large proportion of injuries, where they tend to occur most often in the hamstrings, quadriceps, adductors, and calves (Hägglund et al. 2013).

One prospective cohort study in soccer athletes recorded data across 566,000 hours of exposure, and identified 4,483 injuries (Ekstrand et al. 2011). The single most common type of injury was a thigh muscle strain (hamstrings or quadriceps), and this made up 17% of all injuries. Of those thigh strains, around a third were quadriceps strains, and around two thirds were hamstrings strains.

Unsurprisingly, therefore, most research into muscle strains has been done specifically in relation to the hamstrings.

And in this respect, eccentric training seems to be very effective.

Does eccentric training *really* help prevent hamstring strains?

Not long ago, a systematic review was performed to assess the impact of eccentric training programs on hamstring strain injuries (Goode et al. 2015). The reviewers gathered studies that compared groups of players, where one group did eccentric training, and a control group did not. Then, they looked at how many hamstring strains happened in each group.

When comparing the two groups, they found that those subjects in the eccentric training groups *who actually did the eccentric training* incurred a smaller number of hamstring strains than those in the control groups. The net result was that these *compliant* athletes were only 0.35 times as likely to incur a hamstring strain.

Put the other way around, if you fail to do your eccentric training, you are 3 times more likely to pull a hamstring!

When the review by Goode et al. (2015) was actually written up, there were only four relevant studies available (Askling et al. 2003; Gabbe et al. 2006; Engebretsen et al. 2008; Petersen et al. 2011). Since then, at least one more has been published (Van der Horst et al. 2015), and this found similar results.

That seems pretty definitive, really.

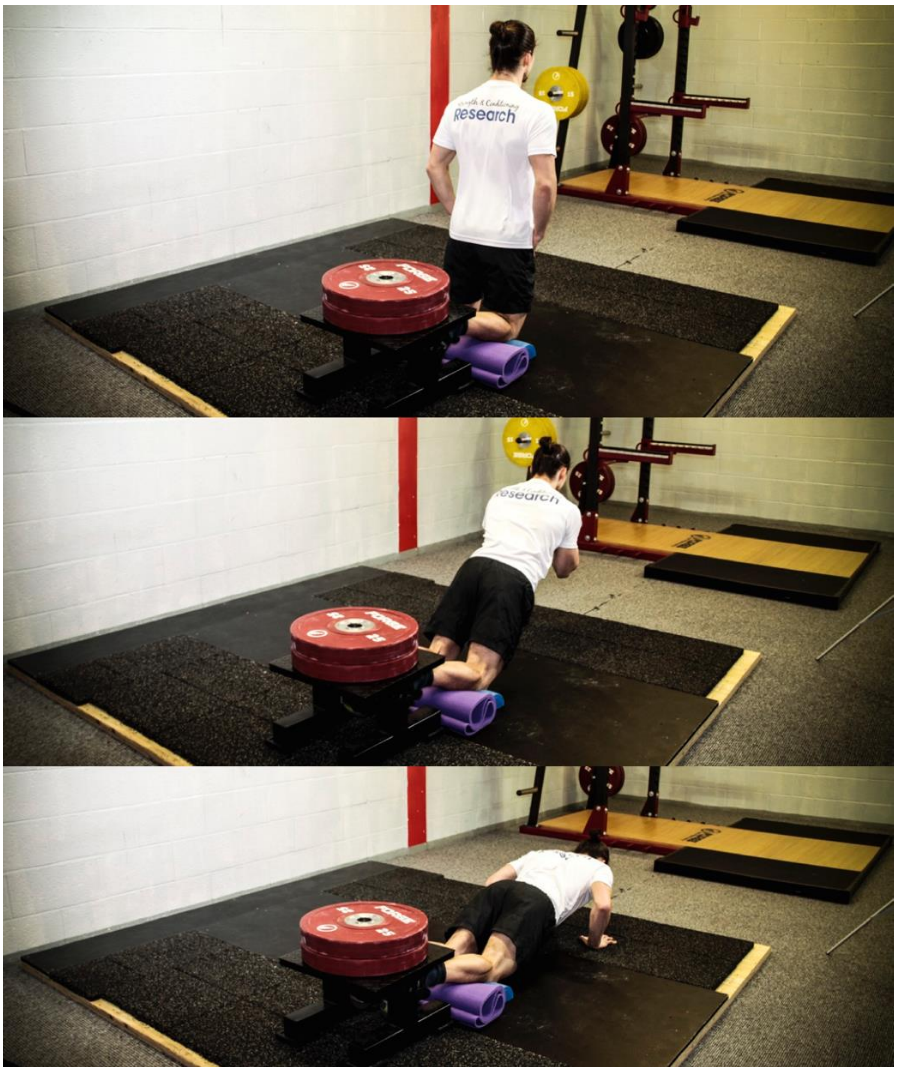
So does that mean if you already have high eccentric strength, you have a lower risk of suffering from a muscle strain?

Ah, well. It is not that simple.

Does high eccentric strength prevent muscle strains?

Neither concentric hamstring strength nor eccentric hamstring strength are *unambiguously* clear risk factors for hamstring strains, at least when the tests are done isokinetically (Opar et al. 2012; Freckleton & Pizzari, 2013; Van Dyk et al. 2016).

And although more recent studies do suggest that eccentric knee flexion strength in a Nordic curl exercise might yet be a good predictor of hamstring strain injury (Opar et al. 2015; Timmins et al. 2015a), not all studies have reported *exactly* the same result (Bourne et al. 2015).



The Nordic curl (exercise variation without partner)

Similarly, for the quadriceps, neither concentric nor eccentric knee extension strength are clear and unambiguous risk factors for quadriceps strain injury (Fousekis et al. 2010). And while adductor weakness is a risk factor for groin strains (Ryan et al. 2014; Whittaker et al. 2015), whether reviewers will continue to tell the same story once there are more trials, is less clear.

So if strength (even eccentric strength) is not a *perfectly* reliable risk factor, but eccentric training reduces the risk of incurring a muscle strain injury, what it going on?

I suspect that it is because *eccentric training* reduces the risk, not just having high levels of eccentric strength.

An athlete might be strong in the eccentric phase for many reasons, including just being strong overall. But that does not mean that they have enjoyed all of the other adaptations that occur after eccentric training. While these adaptations do increase eccentric force production, they have other effects as well.

So we might *expect* conflicting results, as sometimes an athlete will have high levels of eccentric strength because they are just strong, and sometimes they have high levels of eccentric strength because they have done eccentric training.

Indeed, Goossens et al. (2015) found that a higher isometric-to-eccentric hamstring strength ratio was prospectively associated with an increased risk of hamstring muscle strain injury. Even when the subjects were strong overall, this was not *necessarily* a protective factor. Rather, it was the extent to which they were able to display force eccentrically, compared to how much force they could produce isometrically that was key. To achieve *this kind of ratio* requires exposure to eccentric training.

So eccentric training is helpful for preventing muscle strains, but this may be partly because of various specific changes that happen after eccentric training, including specific gains in eccentric strength (relative to isometric or concentric strength) and not just because of overall strength gains.

Having settled that, we can now look at why muscle strains happen.

But what does "strain" mean anyway?

What does "strain" mean anyway?

Understanding the theories of what causes muscle strains requires a quick primer on some basic engineering terms, as follows:

Stress is the force per unit area, which in this context is easiest to think of as just force applied. This force is usually applied on the body by the ground, when absorbing an impact during running or jumping.

Strain is the relative length change, which is how much the muscle fascicle is stretched in comparison with its starting length. It is not to be confused with the muscle "strain" injury, which is something else. Strain is normally best thought of in percentage terms, where the percentage refers to the increase in length, relative to the resting length. Active strain refers to strain while the muscle is exerting force, and resisting the length change.

Elastic strain energy absorbed is the area under the stress-strain curve. So greater stress (force) or greater strain (length change) both cause increases in the amount of energy absorbed.

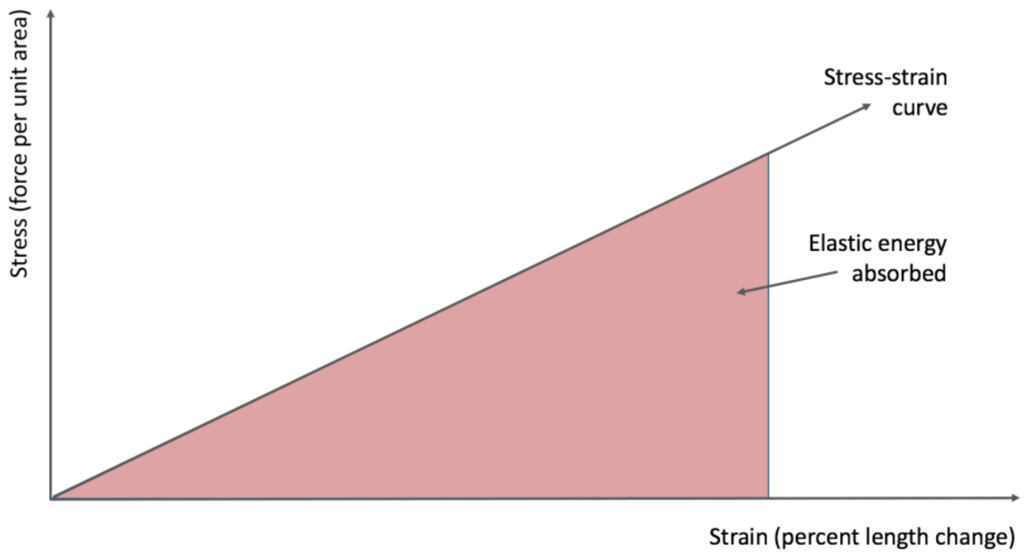
So how do these terms relate to muscle strain injuries?

Why do muscle strains happen?

Muscle strains almost always happen during lengthening contractions, when the muscle is active (Liu et al. 2012). Strain injury seems to be caused *either* by the amount of active strain (i.e. relative length change) *or* the energy absorbed, although there is currently no consensus on which is more important.

In any event, the two concepts are closely related. They are both features of lengthening contractions (Asmussen & Bonde-Petersen, 1974), and the energy absorbed is the area under the curve of the stress-strain relationship. Incidentally, the gradient of this stress-strain relationship is called the *stiffness* of the material, which is how much it changes in length for each unit of force that is applied.

The stress strain relationship is shown below:



The stress-strain relationship

Much of the research into the mechanisms of muscle strain injury has been done in single fibers, with force being artificially stimulated, and many of these studies have reported conflicting results.

Most show that active strain is the most important factor (Garrett et al. 1987; Lieber & Friden, 1993; Talbot & Morgan, 1998; Brooks & Faulkner, 2001; Butterfield & Herzog, 2006), while others show it is cannot be solely responsible (Tsuang et al. 2007). Others show that force is a key driver (McCully & Faulkner, 1986; Warren et al. 1993; Hasselman et al. 1995), and others show that energy absorbed (also called negative work done) is the best predictor (Brooks et al. 1995; Macpherson et al. 1996; Mair et al. 1996).

Added to this, at the whole muscle level, muscle architecture seems important for muscle strain injury risk, although exactly *how* it affects strain risk is unclear (Timmins et al. 2016). For example, individuals who have shorter and more pennated fascicles are at greater risk of hamstring strain injury (Silder et al. 2010; Timmins et al. 2015a; Timmins et al. 2015c).

And yet, in vitro studies show that pennate muscle can endure more strain than fusiform muscle (Garrett et al. 1988), and muscle pennation angle actually rotates during lengthening contractions in a protective mechanism that enables greater strains to occur

(Azizi & Roberts, 2014). Reconciling these conflicting results, to achieve an understanding of the mechanism, is difficult.

Whatever the exact underlying causes, from this general research we can deduce that muscle strain injury is caused during actively lengthening muscle actions, and is caused either by the energy absorbed or the size of the strain.

Maybe looking more closely at hamstring strain research will help clarify things.

When do hamstring strains happen?

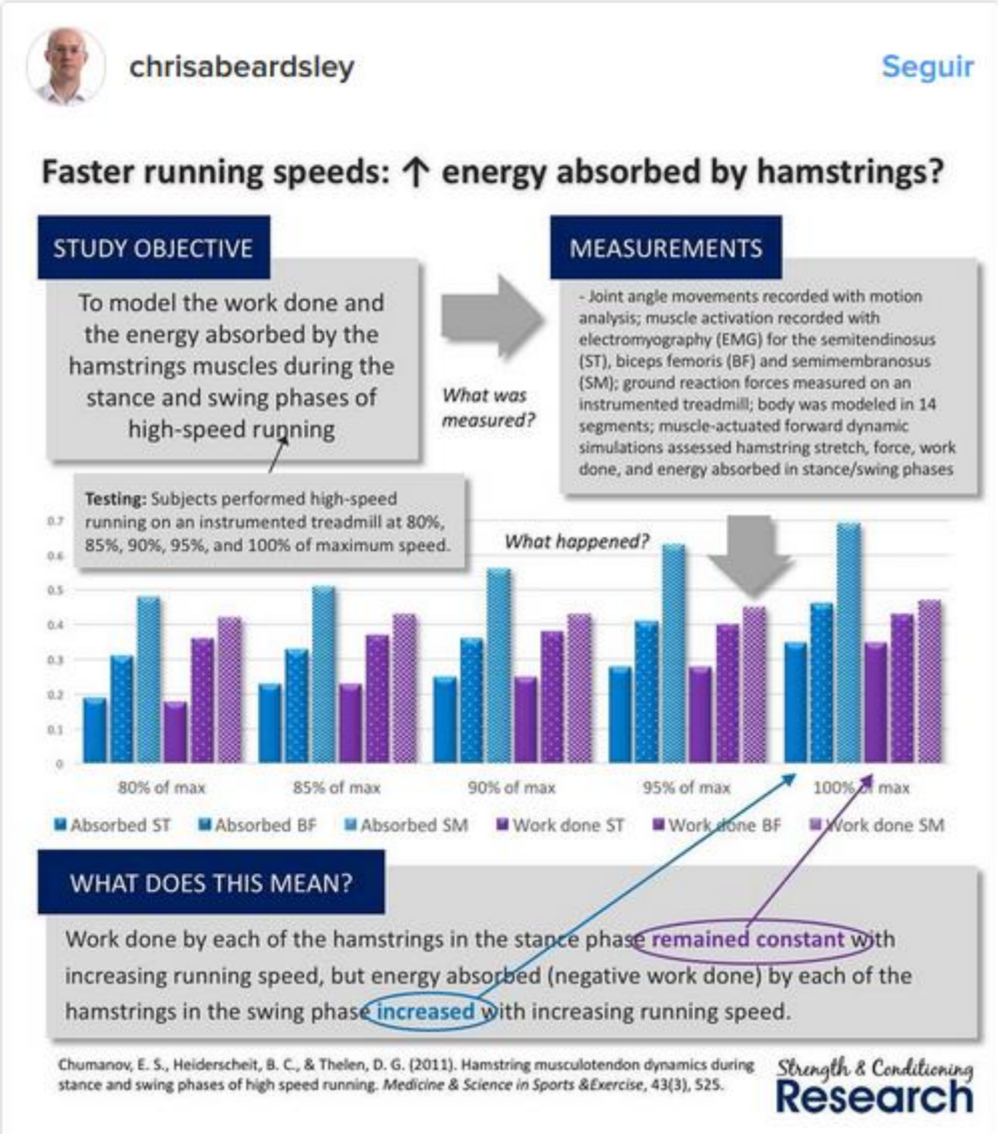
Hamstring injuries seem to happen *either* just at the end of the swing phase (as the hamstrings are actively lengthening at the hip and knee) *or* at the start of the stance phase (as the hamstrings absorb large forces at touchdown).

Early work identified that high forces at touchdown that might be the cause of injury (Mann, 1980; Mann & Sprague, 1980), although it seems likely that the hamstrings do not lengthen in the early part of the stance phase (Yu et al. 2008; Chumanov et al. 2011; Nagano et al. 2014), which makes the idea of incurring a “strain” injury in the stance phase quite difficult to accept.

Later studies found that the maximum hamstring muscle-tendon lengths are reached in the late swing phase (Heiderscheit et al. 2005; Thelen et al. 2005a; Thelen et al. 2005b; Yu et al. 2008; Schache et al. 2012; Schache et al. 2013). This high degree of strain is accompanied by high levels of muscle force (Chumanov et al. 2007; Schache et al. 2010; Nagano et al. 2014), and this leads to the absorption of a large amount of energy.

Importantly, strain itself does not seem to increase very much with increasing running speed, particularly at higher velocities. In fact, many studies have found that strain does not increase with running speed (Thelen et al. 2005a; Thelen et al. 2005b; Chumanov et al. 2007; 2011; Schache et al. 2013).

On the other hand, it seems that the eccentric forces continue to grow with increasing running speed. This in turn causes large increases in the amount of energy that must be absorbed (Chumanov et al. 2007; 2011), which suggests that increasing running speed causes a particular need for greater energy absorption.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Faster running speeds: ↑ energy absorbed by hamstrings?
STUDY OBJECTIVE
To model the work done and the energy absorbed by the hamstrings muscles during the stance and swing phases of high-speed running
What was measured?
MEASUREMENTS
- Joint angle movements recorded with motion analysis; muscle activation recorded with electromyography (EMG) for the semitendinosus (ST), biceps femoris (BF) and semimembranosus (SM); ground reaction forces measured on an instrumented treadmill; body was modeled in 14 segments; muscle-actuated forward dynamic simulations assessed hamstring stretch, force, work done, and energy absorbed in stance/swing phases
Testing: Subjects performed high-speed running on an instrumented treadmill at 80%, 85%, 90%, 95%, and 100% of maximum speed.
What happened?
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
80% of max
85% of max
90% of max
95% of max
100% of max
Absorbed ST
Absorbed BF
Absorbed SM
Work done ST
Work done BF
Work done SM
WHAT DOES THIS MEAN?
Work done by each of the hamstrings in the stance phase remained constant with increasing running speed, but energy absorbed (negative work done) by each of the hamstrings in the swing phase increased with increasing running speed.
Chumanov, E. S., Heiderscheit, B. C., & Thelen, D. G. (2011). Hamstring musculotendon dynamics during stance and swing phases of high speed running. Medicine & Science in Sports &Exercise, 43(3), 525.
Strength & Conditioning
Research

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For many years, researchers and coaches have thought of the sprinting movement as like a bouncing ball. Athletes first absorb and then release kinetic energy in each ground contact phase, supplementing it only to make up for the losses of energy to friction and for any inefficiency in the system. This energy is stored and returned either by the passive elements of the same muscles, or from other muscles, through proximal-to-distal sequencing. As this study shows, this has one very interesting implication. As running speeds increase, the hamstrings have to absorb more energy during the swing phase with every stride. In contrast, the amount of positive work done during each stance phase does not increase very much at all. This may be why eccentric training is so effective for helping reduce muscle strains in sprinting, because it allows the athlete to continually absorb these large forces with every stride. Eccentric training allows athletes to increase their eccentric strength (and therefore their ability to absorb force) more than their concentric strength (and therefore their ability to produce force). Indeed, sprinting seems to require a greater ability to absorb force than to produce it, at least when considering the hamstrings, which are essential for sprinting performance.

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So on balance, by analyzing the muscle-tendon length changes in the hamstring strain injury research specifically, it seems more likely that *energy absorbed* is the key driver of a muscle strain injury, rather than the size of the strain.

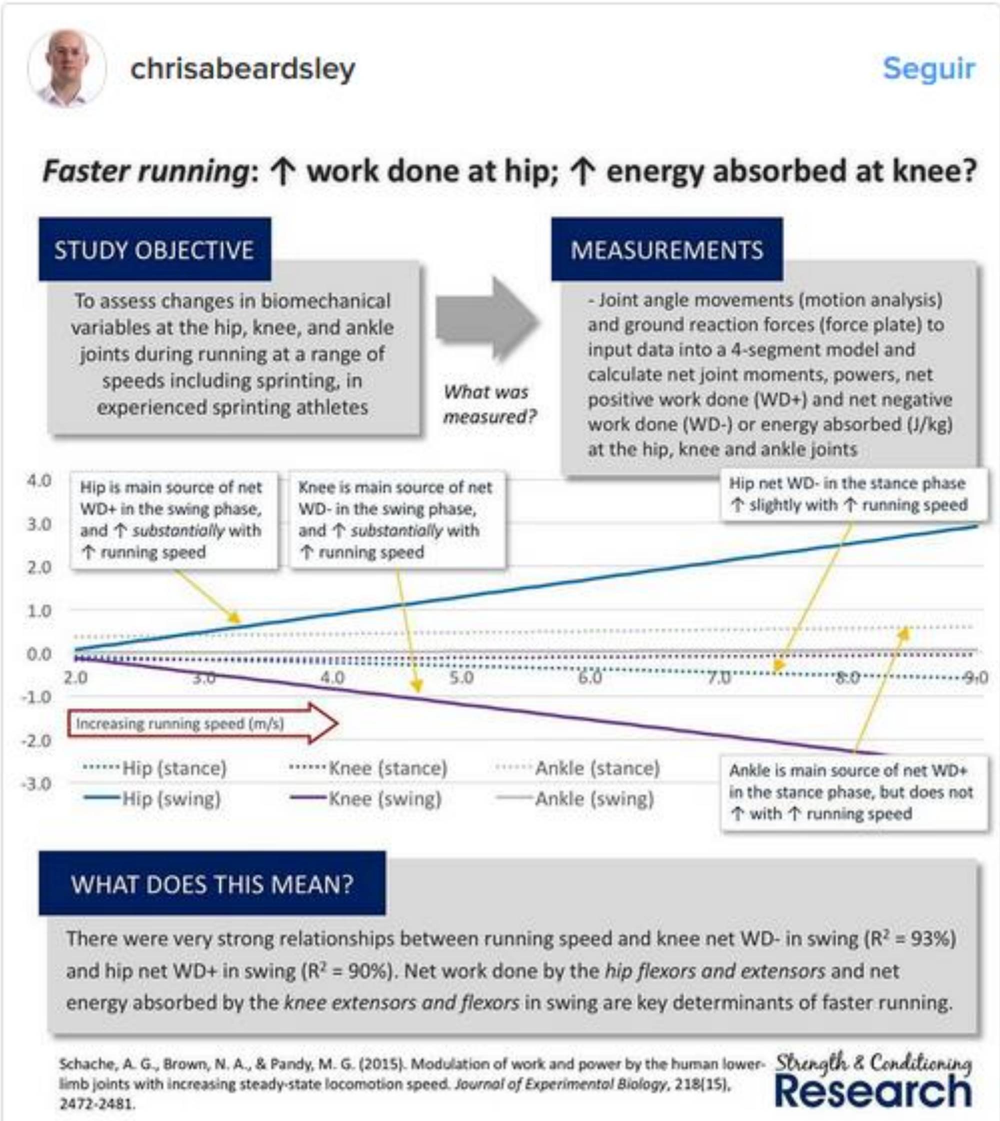
How does this play out in sport?

Looking at way in which muscles are strained in sport can help us check that the energy absorbed model still makes good sense. We can do this in at least two different ways: we can look at the *context* in which muscles are most commonly strained, and we can consider *which* muscles are commonly strained.

Firstly then, muscle strains do seem to happen in contexts that involve building a great deal of momentum, and then maintaining it.

High-speed running causes most hamstring strains, and this has historically been modelled as like a bouncing ball (Cavagna et al. 1964). Athletes first absorb and then release kinetic energy in each ground contact phase, supplementing it only to make up for the losses of energy to friction and for any inefficiency in the system. This energy is stored and returned either by the passive elements of the same muscles, or from other muscles, through proximal-to-distal sequencing (Jacobs & Van Ingen Schenau, 1992; Jacobs et al. 1996).

Indeed, energy absorbed by the knee flexor musculature (the hamstrings) during the swing phase of running gait is closely linked to running speed in musculoskeletal models (Schache et al. 2015).



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In this important study, the researchers attempted to determine the relationship between the net work done and net energy absorbed at each of the lower body joints and running speed, in sprinting athletes. The swing phase was where the relationships were strongest. Net work done by the hip (flexors in initial swing, and extensors in terminal swing) was very strongly associated with running speed, and increased substantially with increasing speed. Net energy absorbed by the knee (extensors in initial swing, and flexors in terminal swing) was also very strongly associated with running speed, and similarly increased substantially with increasing speed. This suggests that the ability of the hip flexors and extensors to produce force, and the ability of the knee extensors and flexors to absorb it, during the swing phase is the key to faster running.

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This implies that the energy absorbed model does indeed make sense.

Secondly, we can see that the muscles that are most commonly injured are always those most heavily involved in energy transfer from one segment of the body to another, which are the two-joint muscles. For the hamstrings, it is very often the biceps femoris (long head) that is injured (Opar et al. 2012). Among the quadriceps, it is the two-joint rectus femoris muscle that is most commonly injured (Mendiguchia et al. 2013).

Again, this implies that the energy absorbed model stacks up.

Can eccentric training increase energy storage?

Yes, indeed it can.

Eccentric training the ability to absorb energy, likely by altering muscle architecture and passive elements within the muscle (Kay et al. 2016), which leads to specific gains in eccentric strength.

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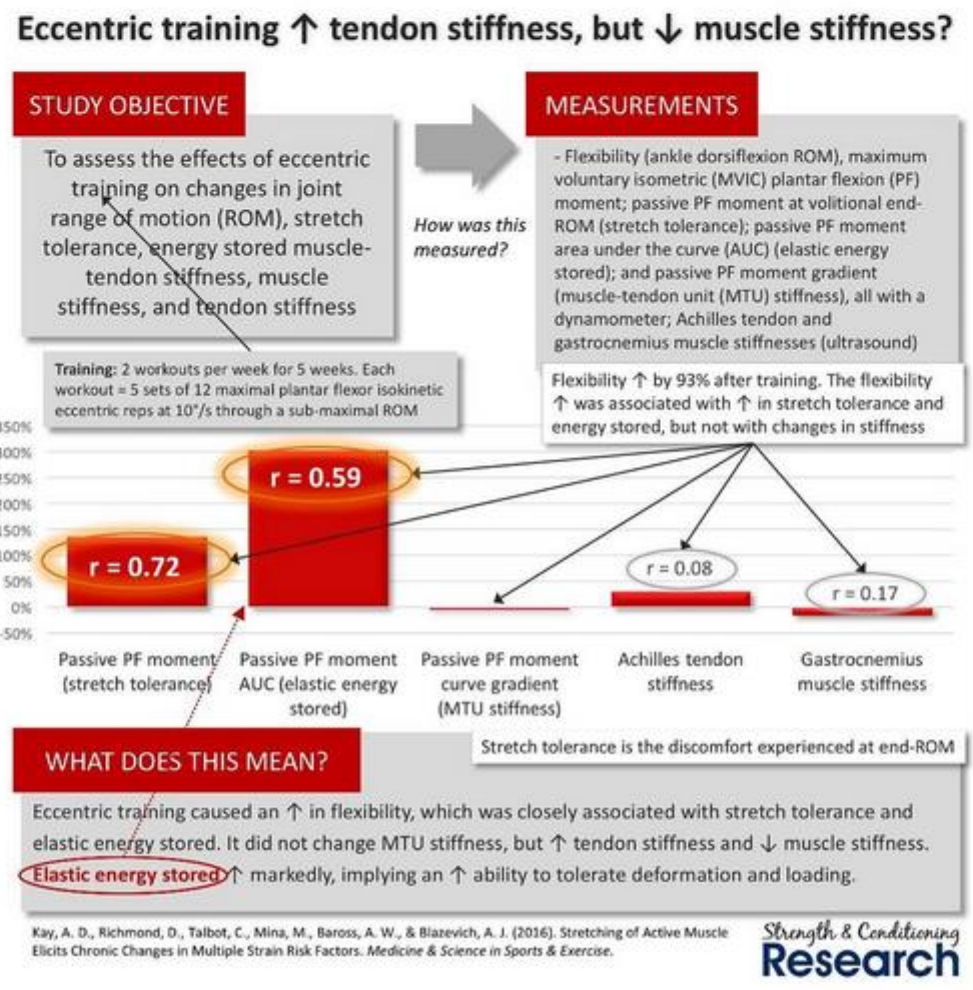

Eccentric training is well-known to increase muscular strength, size, and fascicle length, as well as the angle of peak torque. This new study demonstrates that eccentric training is also very good at increasing the ability to store elastic energy, in tests of passive flexibility. A poor ability to store elastic energy has been identified as a key risk factor for muscle strains. This is because the ability to store elastic energy is essentially the ability to tolerate deformation and load, while lengthening. Since most muscle strain injuries occur within sub-maximal ranges of motion, it is likely deformation and load (and the subsequent need to absorb strain energy) that cause muscle strains, rather than excessive lengthening, as is often assumed. -------------------- #sandcresearch #strengthandconditioning #strengthtraining #strength #sportsscience #biomechanics #eccentric #eccentrics #eccentrictraining

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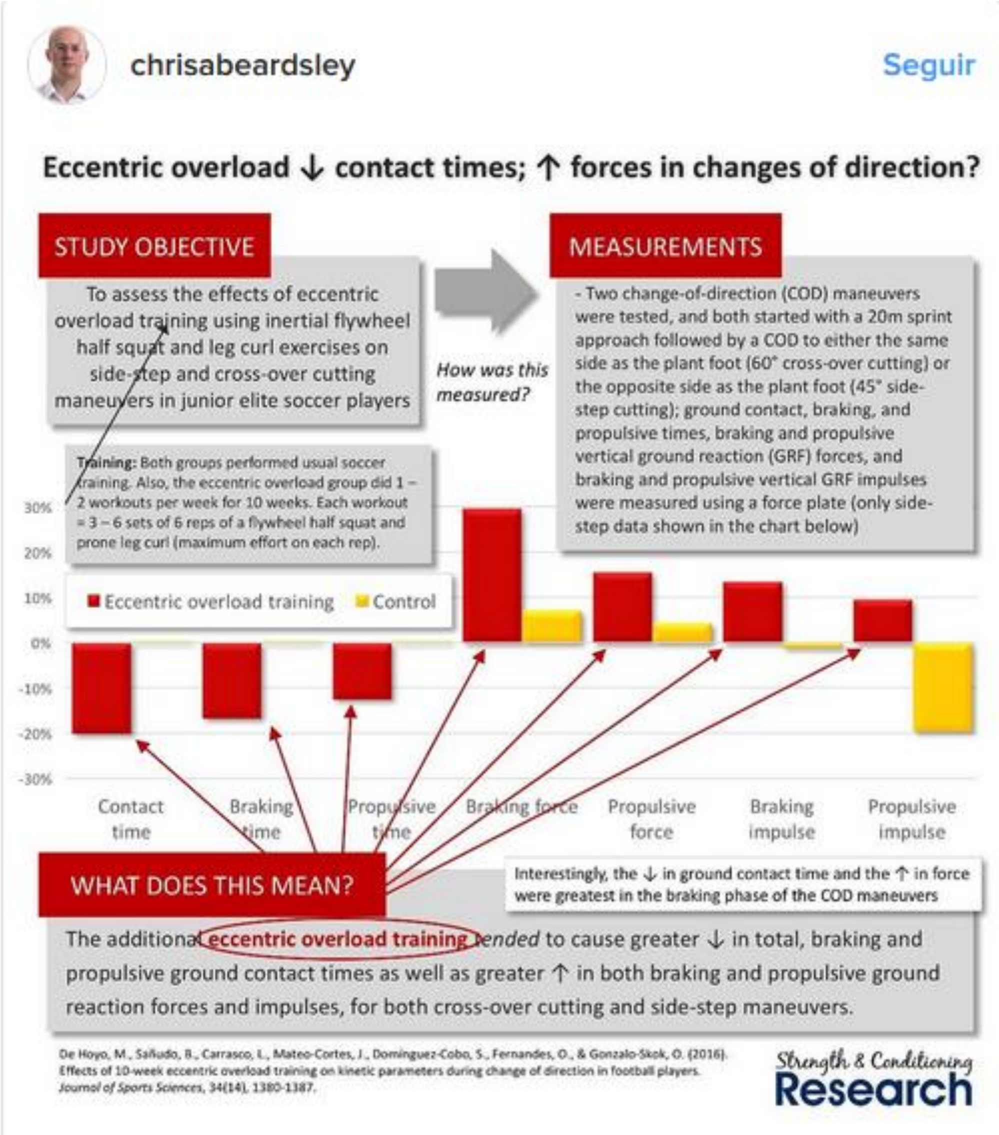
In line with this, we know that eccentric overload training can substantially improve the ability to produce and absorb force and impulse (force • time) during change of direction (COD) cutting maneuvers. And these improvements in force and impulse after eccentric overload training are greater in the absorbing (braking) than in the propulsive phases (De Hoyo et al. 2016).



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Eccentric training is a popular method for reducing the risk of muscle strains, improving eccentric strength, and thereby developing athletic abilities that require the absorption of energy, such as sprinting and change of direction ability. Eccentric-only exercises (like the Nordic hamstring curl) are most well-known for developing eccentric strength. However, eccentric overload exercises (often involving flywheels) are rapidly becoming popular. Eccentric overload exercises involve both concentric and eccentric phases (unlike eccentric-only exercises) but the eccentric is harder than the concentric. This study assessed the effects of eccentric overload training with a flywheel device to perform squats and leg curls on the changes in mechanical variables during a change of direction maneuver. Training reduced ground contact times (especially in the braking phase) and also increased vertical ground reaction forces (again, most substantially in the braking phase). This suggests that eccentric overload training could be a very useful method for enhancing change of direction ability, and that the greatest improvements occur in the braking phase, probably because of transfer of eccentric strength to deceleration ability.

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How does eccentric training increase energy storage?

What causes this improvement in energy absorption after eccentric training?

Gains in energy absorption capability are moderate-to-strongly (r = 0.59) associated with increases in joint range of motion (Kay et al. 2016), which suggests a connection between increases in energy storage and an increase in muscle fascicle length. This is expected, because energy storage is the area under the stress-strain curve, and eccentric training increases muscle fascicle length.

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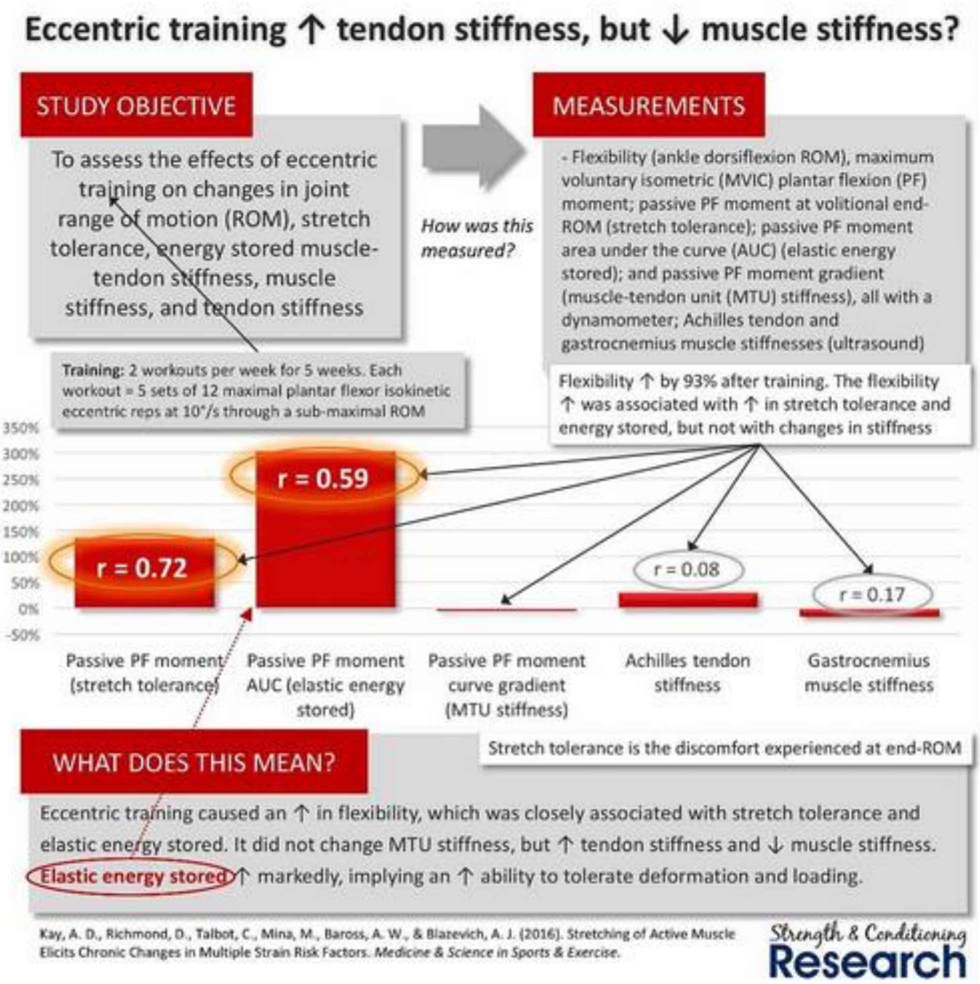

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Eccentric training is well-known to increase muscular strength, size, and fascicle length, as well as the angle of peak torque. This new study demonstrates that eccentric training is also very good at increasing the ability to store elastic energy, in tests of passive flexibility. A poor ability to store elastic energy has been identified as a key risk factor for muscle strains. This is because the ability to store elastic energy is essentially the ability to tolerate deformation and load, while lengthening. Since most muscle strain injuries occur within sub-maximal ranges of motion, it is likely deformation and load (and the subsequent need to absorb strain energy) that cause muscle strains, rather than excessive lengthening, as is often assumed. -------------------

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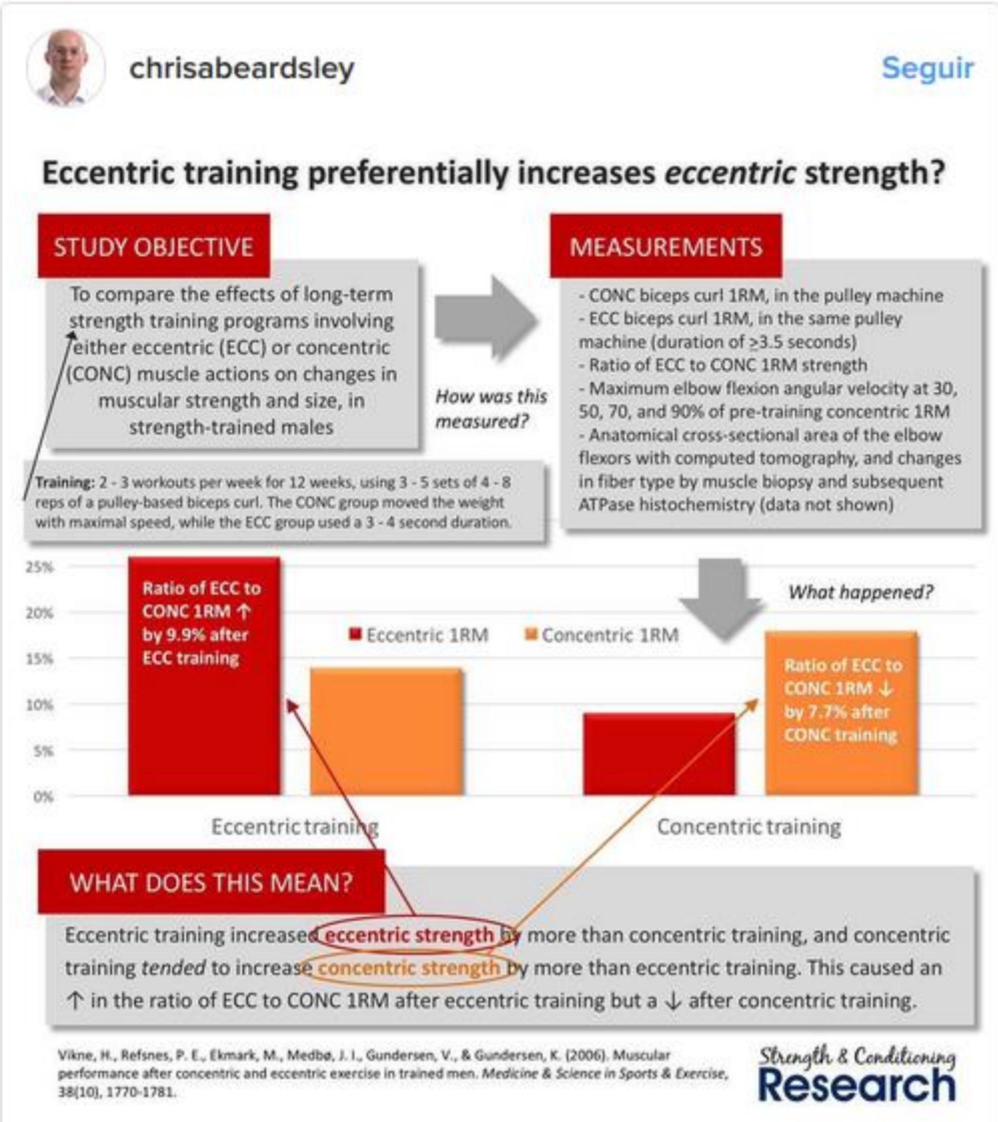
More importantly, however, gains in energy absorption capability are even more closely related (r = 0.92) to the peak passive moment measured (Kay et al. 2016). This could imply that the specific ability to produce eccentric force through the action of the passive elements within the muscle-tendon unit is the key contributory factor to energy storage capability.

On this basis, the *specific gains in eccentric strength* that are produced by eccentric training may be the key factor that reduces the risk of muscle strains.



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Eccentric training is a very popular training tool for athletes, because it is very effective for producing large gains in maximum strength, increasing muscle fascicle lengths, and reducing the risk of muscle strain injury. One important feature of eccentric training that is often overlooked is that it also alters the ratio of eccentric-to-concentric strength. In other words, after a long period of time carrying out eccentric strength training, you tend to increase eccentric strength by more than concentric strength. Similarly, after a long period of time carrying out concentric strength training, you tend to increase concentric strength by more than eccentric strength. This simple example of how strength is specific may well be one of the key reasons why eccentric strength is so effective for reducing muscle strain injury risk, as it enables the muscles to absorb more kinetic energy than they can typically produce. And the absorption of strain energy has been linked to the risk of strain injury.

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This fits with the idea that the specific gains in eccentric strength most likely occur because of increases in the stiffness of the passive elements of the muscle (which include both the extracellular matrix and titin), and because of alterations in neural control. These changes help the muscle resist lengthening, and increase the amount of energy stored whenever it does lengthen.

In line with this idea, one study has shown that titin (one of the passive elements) might be the energy-absorbing material within muscles that stops them from tearing when subjected to strain, although this research has only been performed at longer lengths than in normal movements (Leonard et al. 2010).

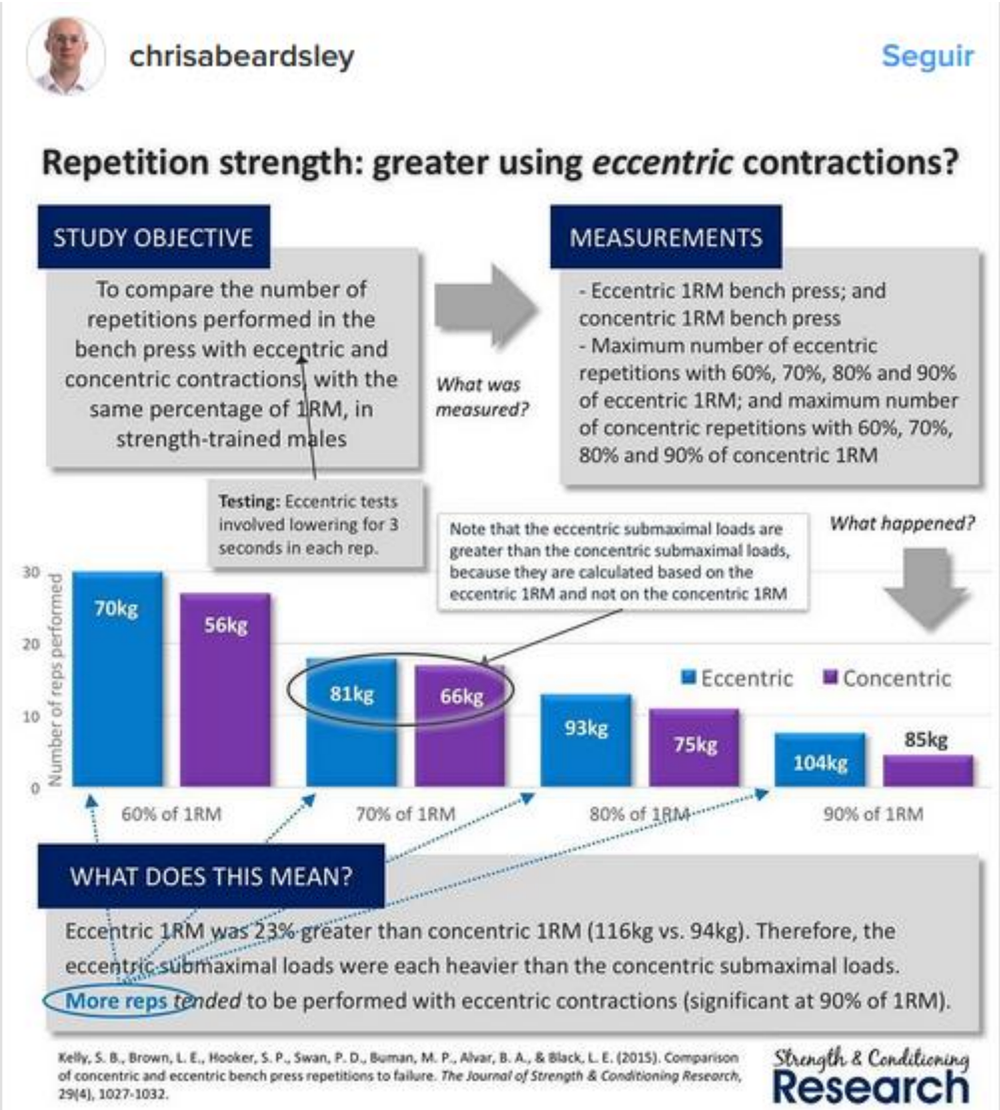
See more: causes of specific gains in eccentric strength

Why can’t we just do normal training instead?

Since normal strength training is made up of a lifting (concentric) and a lowering (eccentric) phase, it is *very tempting* to think that eccentric training is not necessary, especially if you are lowering under control.

However, if the energy absorption model of muscle strain injury is correct, then this is probably not the case.

You are likely never going to increase your eccentric-to-concentric strength ratio by doing normal strength training (where the load is the same in both phases) because the force you exert to move the same load relative to your maximum capability is much lower in the eccentric phase, than in the concentric phase, mainly because of large strength differences between phases (Kelly et al. 2015; Duchateau & Enoka, 2016).



> We are stronger eccentrically than concentrically. This means that we can lower a heavier weight under control than we can lift. Exactly how much stronger depends on the exercise or the movement, and the duration of the lowering phase, but is usually around 25 - 50%. Additionally, eccentric contractions require less energy to perform than concentric contractions, probably because they rely much more on the unique behaviors of the passive (elastic) elements within the muscle. So the findings of this study should be fairly unsurprising, although they are still very important. Repetition strength (true muscular endurance) was greater when using eccentric contractions than when using concentric contractions, even when using the same relative load in each case (the eccentric test used a percentage of eccentric 1RM, while the concentric test used the same percentage of concentric 1RM). This links in nicely to recent studies showing that eccentric overload training is particularly effective for increasing muscular endurance. This may suggest that the unique aspects that make eccentric contractions so effective for repetition strength are also themselves trainable.
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And since the amount of force you exert drives strength gains (albeit perhaps not hypertrophy) (Schoenfeld et al. 2014), this means your eccentric-to-concentric strength ratio will naturally drift downwards.

So how does eccentric training prevent muscle strains?

At the end of the day, my proposal here (which others may have made elsewhere) is that if you do concentric or normal strength training, then you will probably gradually reduce your ratio of eccentric-to-concentric strength, and you will therefore increase your ability to accelerate more than your ability to decelerate.

That means that when you start doing stretch-shortening cycle sports movements (like sprinting), you will end up being able to accumulate more kinetic energy than you can safely absorb.

On the other hand, if you use eccentric training, then you should naturally increase your ratio of eccentric-to-concentric strength, and this will increase your ability to decelerate to a greater extent than your ability to accelerate.

That means you can absorb more kinetic energy than you can accumulate. And if you think about it, it is not hard to see how this could reduce your risk of muscle strain injury.

Conclusions

Eccentric training produces specific gains in eccentric strength, which can be observed as an increase in the eccentric-to-concentric strength ratio. This gives muscles a greater capacity to decelerate, and absorb energy. This superior ability to absorb energy is probably why eccentric training then leads to a reduction in the risk of getting a muscle strain injury. Eccentric training is therefore an essential element of strength training programs for sport.

Although conventional stretch-shortening cycle (SSC) strength training involves an eccentric phase, it *decreases* the eccentric-to-concentric strength ratio. During SSC training, the force you exert is lower relative to your maximum ability in the eccentric phase, than in the concentric phase, because of large strength differences between phases. This means that the concentric phase is trained comparatively harder, and concentric strength increases by more than eccentric strength.

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