UNIONE EUROPEA

UNIVERSITA' DEGLI STUDI DI VERONA

DIPARTIMENTO DI

Scienze Neurologiche, Neuropsicologiche, Morfologiche e Motorie

SCUOLA DI DOTTORATO DI

Scienze Biomediche e Traslazionali

DOTTORATO DI RICERCA IN

Scienze dell'Esercizio Fisico e del Movimento Umano

Con il contributo di

Fondo Sociale Europeo

CICLO *XXIV* **ANNO** *2009*

Muscle damage, repeated bout effect and training induced changes by different eccentric training modalities

S.S.D. _M/EDF-02

Coordinatore: Prof. Federico Schena

Tutor: Prof. Federico Schena

Tutor: Prof. Franco M. Impellizzeri

Ph.D. Candidate: Dott. Giuseppe Coratella

Summary

Chapter 1: Introduction

Resistance exercise is a very common method used to improve muscle strength. The achievement of adequate level of force is essential in several conditions, such as in rehabilitation, sport performance or daily activities, in which muscle function is required to maintain autonomy. Most of training methods include overload, usually represented by bars, handle weight or constant external load developed by isotonic apparatuses, specially used in field or gym. Another way to propose strength exercise is represented by isokinetic dynamometer which, keeping constant joint velocity, is specially used in rehabilitation and research laboratories. In addition, a new training technology has been realized, that is not gravity dependent and involves inertial movement.

It is common experience that after single session muscle usually met with soreness sensation, that accompanied by several markers, impairs performance. However, chronic training is usually coupled with improvements in muscle strength and structure.

Therefore, general aim of thesis is to compare different training methods measuring acute and short term adaptation, matching them by technique, volume and intensity. Particularly, we will focus on eccentric contraction, that has been demonstrated to have different features compared to concentric and isometric contraction.

Chapter 2: Background

2.1.: Muscle contraction.

Muscle contraction is characterized by a cascade of events, briefly described below. (modified by “Physiology of Sport and Exercise”, Wilmore et coll., fourth edition, 2008)

- An action potential originating in the Central Nervous System (CNS) reaches an alpha motor neuron, which then transmits an action potential down its own axon.
- The action potential propagates by activating voltage-gated sodium channels along the axon toward the neuromuscular junction. When it reaches the junction, it causes a calcium ion influx through voltage-gated calcium channels.
- The Ca2+ influx causes vesicles containing the neurotransmitter acetylcholine to fuse with the plasma membrane, releasing acetylcholine out into the extracellular space between the motor neuron terminal and the neuromuscular junction of the skeletal muscle fiber.
- The acetylcholine diffuses across the synapse and binds to and activates nicotinic acetylcholine receptors on the neuromuscular junction. Activation of the nicotinic receptor opens its intrinsic sodium/potassium channel, causing sodium to rush in and potassium to trickle out. Because the channel is more permeable to sodium, the muscle fiber membrane becomes more positively charged, triggering an action potential.
- The action potential spreads through the muscle fibre's network of T-tubules, depolarizing the inner portion of the muscle fibre.
- The depolarization activates L-type voltage-dependent calcium channels (dihydropyridine receptors) in the T tubule membrane, which are in

close proximity to calcium-release channels (ryanodine receptors) in the adjacent sarcoplasmic reticulum.

- Activated voltage-gated calcium channels physically interact with calcium-release channels to activate them, causing the sarcoplasmic reticulum to release calcium.
- The calcium binds to the troponin C present on the actin-containing thin filaments of the myofibrils. The troponin then allosterically modulates the tropomyosin. Under normal circumstances, the tropomyosin sterically obstructs binding sites for myosin on the thin filament; once calcium binds to the troponin C and causes an allosteric change in the troponin protein, troponin T allows tropomyosin to move, unblocking the binding sites.
- Myosin (which has ADP and inorganic phosphate bound to its nucleotide binding pocket and is in a ready state) binds to the newly uncovered binding sites on the thin filament (binding to the thin filament is very tightly coupled to the release of inorganic phosphate). Myosin is now bound to actin in the strong binding state. The release of ADP and inorganic phosphate are tightly coupled to the power stroke (actin acts as a cofactor in the release of inorganic phosphate, expediting the release). This will pull the Z-bands towards each other, thus shortening the sarcomere and the I-band.
- ATP binds myosin, allowing it to release actin and be in the weak binding state (a lack of ATP makes this step impossible, resulting in the rigor state characteristic of rigor mortis). The myosin then hydrolyzes the ATP and uses the energy to move into the "cocked back" conformation. In general, evidence (predicted and in vivo) indicates that each skeletal muscle myosin head moves 10–12 nm each power stroke, however there is also evidence (in vitro) of variations (smaller and larger) that appear specific to the myosin isoform.

Last two steps repeat as long as ATP is available and calcium is present on thin filament. While the above steps are occurring, calcium is actively pumped back into the sarcoplasmic reticulum. When calcium is no longer present on the thin filament, the tropomyosin changes conformation back to its previous state so as to block the binding sites again. The myosin ceases binding to the thin filament, and the contractions cease.

2.2.: Different muscle actions.

During a muscle contraction, sarcomere can exert tension modifying its length: in fact, it can shorten or lengthen and these actions are respectively named concentric and eccentric. When torque production occurs without its extent, action is called isometric. To the other side, considering force production, concentric action happens when load is smaller than torque, while a reverse condition features eccentric phase. Finally, isometric condition is characterized by equal amount of load and strength. Taking in to account velocity contraction, while null one corresponds to isometric, positive or negative speeds reflect shortening or lengthening muscle.

Even if resistance training is usually exercised concentrically and eccentrically, research has focused attention on acute and chronic effect differences when concentric or eccentric actions are emphasized or performed alone. As described by Hill (HILL, 1953), force depends on velocity: it decreases when concentric action (or positive velocity) is done faster, and increase when velocity is null (isometric) or negative (eccentric). As shown in figure 1, force expressed is higher during lengthening than shortening contraction. In fact, the former can externalize torque up to 180% of the latter (Kellis & Baltzopoulos, 1995). It is interesting to note that torque seems not impaired by negative velocity (Colliander & Tesch, 1989).

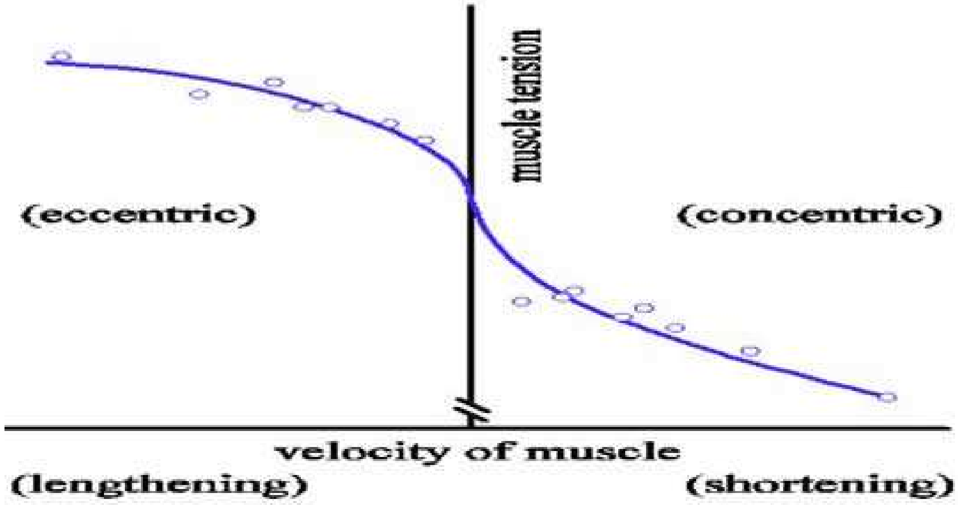

Figure 2.1: force velocity relationship as shown by Hill 1953.

2.3.: Neuromuscular aspects.

Analyzing neuromuscular parameters, differences have been found comparing concentric and eccentric contractions. Dissimilarities in central nervous system have been measured using electroencephalographic (EEG) signal: in fact larger cerebral area is involved while muscle lengthen than shorten. In addition, longer pre activation time and greater amplitude signal occur during the former condition (Yin Fang, Siemionow, Sahgal, Xiong, & Yue, 2004). It is interesting to note that these two parameters are positively related with intensity contraction (Y Fang, Siemionow, Sahgal, Xiong, & Yue, 2001). During positive action motor evoked potentials (MEP) are higher and monosynaptic neuron excitability is greater than in negative one, suggesting a method used by brain in order to protect muscle by excessive strain (Abbruzzese, Morena, Spadavecchia, & Schieppati, 1994). When considering amount of force produced during crescent rate of an isometric contraction, strength exerted by one motor unit has to be summed up to the subsequent, going on until torque is voluntarily constant. Conversely, a de-recruitment occur during descent rate. More aligned is the recruitment (or de-recruitment), higher is the control and less the force fluctuation. Negative part showed less motor control and higher torque variability, suggesting an altered neural feedback between two phases (Duchateau & Enoka, 2008)(Barry, Pascoe, Jesunathadas, & Enoka, 2007). It is known that lower electromyography signal is registered while performing an eccentric contraction (Tesch, Dudley, Duvoisin, Hather, & Harris, 1990). It seems, in fact, that size principle order recruitment could be altered, i.e., fast motor units are selectively recruited, as hypothesized by some researchers (Enoka, 1996)(Nardone, Romanò, & Schieppati, 1989). For example, they found activation in high threshold motor units those were silent during concentric or isometric contraction. Such aspect can be related to the skill velocity, suggesting that slow movement does not need fast twitch fibres activity (Nardone et al., 1989). Furthermore, higher EMG signal prior lengthening movement has been previously showed (Abbruzzese et al., 1994)(Enoka, 1996). Particularly, earlier activation has been registered in high threshold motor units, at least when task was known by the subjects. (Gandevia & Rothwell, 1987). There is no general consensus on this theory: some authors did not find any differences in motor unit recruitment order (Pasquet, Carpentier, & Duchateau, 2006)(Stotz & Bawa, 2001). Hoffman and stretch reflex, motor evoked potentials by transcranial magnetic and electrical stimuli are reduced during a resisting load, and is possible to relate them to spinal mechanisms (Abbruzzese et al., 1994). While contraction is performed by agonist muscles, inhibition of antagonist ones lead to a torque production. Anyway, antagonist muscles are activated in order to protect joints and avoid structural damages. Some studies investigated co-activation level (agonist – antagonist muscles) during dynamic contractions, resulting in non uniform outcomes. In fact, while studies showed no difference between eccentric and concentric actions (Pousson, Amiridis, Cometti, & Van Hoecke, 1999), co-activation resulted greater in the former (Pinniger, Steele, Thorstensson, & Cresswell, 2000), or latter (Kellis & Baltzopoulos, 1998).

Taking together, it is possible that a unique command is required to perform eccentric contraction, involving both central and peripheral neural commands. Even if this is not unanimously proved, we can affirm that some differences in neural drive exist when shortening or lengthening contractions are performed in vivo.

2.4.: Mechanical aspects.

Treating with the external torque, the muscle tendon system is stretched by sub or supra maximal load, allowing to the elastic component to give back greater force production. In this way, a minor metabolic cost is required, when it is matched for absolute or relative intensity load. The importance of tendon stiffness and its viscoelastic property could explain why, in vivo, fascicle length of gastrocnemius medialis is smaller than vastus lateralis when muscle is forcedly lengthened (G Guilhem, Cornu, & Guével, 2010). Due to tendon absorption energy capacity, mainly caused by interaction between proteoglycans and collagene fibres, during an eccentric action energy required is lesser than concentric. In fact, energy stored in tendon system, added to a limitation in motor unit recruitment, bring about a lower metabolic cost.(ABBOTT, BIGLAND, & RITCHIE, 1952)

2.5.: Muscle Damage.

After a single resistance training session, it is experienced that soreness sensation occurs in few hours, and it can last for several day. This general condition has been defined as Delayed Onset of Muscle Soreness (DOMS). However, such circumstance is particularly augmented after eccentric training session (Peake, Nosaka, & Suzuki, 2005). In fact, when sarcomeres are stretched during a lengthening contraction, they must resist to a load greater than tension produced, leading to greater muscle tension distributed among same number of fibres. Therefore, sarcomeres are progressively overstretched until disruption, showing a failure in their mechanical reconnection capacity. Rupture of myofibrils is accompanied by damage of sarcolemma, sarcoplasmic reticulum and T tubules membrane. Consequently, excitation contraction coupling is impaired and Ca2+ is free to move in sarcoplasm, activating degradation and renovation of muscle proteins (Uwe Proske & Allen, 2005). In addition, it disturbs Z line rearrangement, where contractile proteins result in supercontraction or disorganization (Allen, 2001). Such event is not clearly due by metabolic fatigue but to a mechanical initial insult.

These events are associated to exercise induce muscle damage, that involves symptoms as strength loss, muscle soreness and swelling, greater plasma Creatin Kinase activity. Such event is not clearly due by metabolic fatigue but to a mechanical initial insult (Lavender & Nosaka, 2008a).

Strength loss is evaluated as one of the most reliable and valid indirect measurement of muscle damage in vivo. It is mainly due to the incapability of overstretched sarcomeres to recreate actin-myosin crossbridges, and consequently to generate same tension at similar muscle length. In fact, tension-length relationship is right forwarded, meaning that muscle, at short length, is not able to produce torque similar to baseline condition(Morgan & Allen, 1999). It’s noteworthy that strength production is affected mainly by eccentric contraction, while concentric one does not impair torque, at least in not fatiguing tasks (Newham, McPhail, Mills, & Edwards, 1983). In fact, muscle incapability to repeat maximal efforts after concentric exercise is strongly due to metabolic or neural fatigue, and baseline is rehabilitated in few hours (Edwards, Hill, Jones, & Merton, 1977). In addition, while single shortening training session provokes 10-30% of force impairment, after lengthening single bout torque reduction is up to 65% of baseline performance (Priscilla M Clarkson & Hubal, 2002). It has been shown that muscle length training affects torque production: when exercise range of motion was performed at longer muscle, force decrement was significantly greater compared to the group that performs eccentric training at shorter quadriceps(Child, Saxton, & Donnelly, 1998). This observation could corroborate the “popping sarcomere theory”, proposed by Morgan in 1990, that briefly charge to the overextended contractile structure (actin and myosin) the failure of sarcomere relocation during muscle shortening (Morgan, 1990).

When muscle fiber is damaged, Creatin Kinase (CK) reach the haematic torrent after its transit through the lymphatic system and thoracic duct. Higher the damage, greater the amount of CK. Actually, CK is not the only protein used as indirect indicator of muscle damage. For example, proteins as myoglobin, heart fatty acid binding protein, troponin, myosin heavy chain and enzymes like lactate dehydrogenase, aspartate aminotransferase, carbonic anhydrase isoenzime II have been observed to augment after exercise induced muscle injury. However, due to strong increment of CK compared to the other proteins, it has been used as main blood marker (Priscilla M Clarkson & Hubal, 2002). Anyway, CK activity is strongly influenced by the exercise proposed to induce damage. Usually downhill running or eccentric resistance training are mostly used, but they differ in CK response after workout. In fact, while the former brings to a 12-24 hours CK concentration peak, correspondently to 100-600 IU, the latter caused delayed highest level, ranging from 96 to 148 hours, and its amount generally goes from 2000 to 10000 IU (P M Clarkson, Nosaka, & Braun, 1992). It is interesting to note that downhill running damage mechanism can be traced back to a myonecrosis process, while resistance training CK activity development has not been completely clarified (K Nosaka & Sakamoto, 1999). The main inconvenient with using CK blood concentration as muscle damage marker is a very large inter subject variability, recorded from 200 to 25000 IU, even if subjects with greater CK values were related with higher muscle damage measured by magnetic resonance, but relationship was not perfect (K Nosaka & Clarkson, 1996). Notwithstanding genetic factors can manage the CK variability, it seems correlated with serum glutathione concentration, that acts as enzyme preserver(Gunst, Langlois, Delanghe, De Buyzere, & Leroux-Roels, 1998).

Muscle soreness, measured by local muscle pressure, is believed to be a kind of controller of effort during muscle action. It has been shown that muscle pain is able to decrease motor evoked potentials induced by transcranial magnetic stimulation. Therefore, nociceptor action could reduce motor cortical excitability (Le Pera et al., 2001). Such situation is typical of DOMS: immediately after eccentric exercise, motor evoked potential are bigger than steady state (Carson, Riek, & Shahbazpour, 2002). It is possible to say that DOMS weaken subjects more than fatiguing task could really do. Protection by subsequent efforts is elicited by the presence of pain, that should avoid to muscle structure succeeding and a more serious damage(U Proske et al., 2003). Pain sensation differs among regions in which injury occurred. For example, elbow flexors workout provokes a greater soreness compared do downhill running or isokinetic knee extension, even if time course is not dissimilar. Anyway, it is well coupled to strength loss and CK plasma activity (Priscilla M Clarkson & Hubal, 2002). Instead, pain has different time course compared to swelling, although the mechanism is not clear. In addition, it has been suggested that soreness reflects the presence of chemical mediators, as histamines, prostaglandins and bradykinins, implicated in pain production, by stimulating type III and type IV afferents nerve, those send pain message to the central nervous system. Despite it, muscle pressure seems to be the physical stimulus that contributes to pain (Kazunori Nosaka, Newton, & Sacco, 2002).

Role of local and systemic inflammation is determinant after muscle damage. Muscle is invaded by neutrophils, together with natural killer, lymphocytes and anti inflammatory cytokines. Then, macrophages take place of neutrophils, and pro inflammatory cytokines act to start the reconstruction phase (Peake et al., 2005). Dealing with local inflammation, injury site is first reached by leukocytes, then, by neutrophils, usually up to 24 hours, and later by macrophages, which activity could last until 14 days. The role of both neutrophils and macrophages is to “clean up” the muscle by removing damaged tissue using reactive oxygen species, and then inducing production of pro inflammatory cytokines (Cannon & St Pierre, 1998). Interleukin 1ß and Tumor Necrosis Factor (TNF)α remains in muscle up to 5 days after injury and they breakdown the tissue damaged. Briefly, local inflammation reaction is predominantly pro inflammatory (Hamada, Vannier, Sacheck, Witsell, & Roubenoff, 2005). Systemic inflammation activity has been widely studied compare to the local one, simply because of minor invasiveness of blood analysis compared to muscle biopsy. Summarizing, the amount of leukocytes activity is strongly influenced by the area of muscle involved in the physical task. The most important factor is interleukin 6, which action is determinant to involve anti or pro anti-inflammatory effect. (Peake et al., 2005) The fluid accumulation is the cause of muscle swelling, that persists for several days.

2.6.: Repeated Bout Effect.

After muscle damage condition due to a performing of single eccentric training session, there is an adaptation that permits, when same bout is repeated, to have less symptoms of injury. Such adjustment is called Repeated Bout Effect. For example, one of most important changes is a decreased increment of CK blood concentration, that often remains unvaried after the second session (P M Clarkson et al., 1992). Furthermore, less muscle soreness and swelling occurs, in addition to a less reduction in force production, leading to a faster recovery (Jamurtas et al., 2005). It is really interesting to know that such condition is maintained up to six months. In other words, six months later an initial eccentric training session, and without performing other training bouts during this time, muscle preserves its self by a subsequent similar injury (Kazunori Nosaka, Sakamoto, Newton, & Sacco, 2001). Otherwise, even if recovery from first bout has not fully completed, a further second training does not exacerbate significantly injury symptoms (K Nosaka & Clarkson, 1995).

Several theories have been proposed to explain the repeated bout effect. For example, authors found difference in reducing EMG signal after 2 bouts of eccentric exercise (respectively -28% and no changes compared to the baseline), concluding a neural adaptation process. It is possible, in fact, that slow twitch motor units take part earlier during second lengthening session, in order to avoid a great structural damage to fast twitch ones (Hortobagyi et al., 1998)(K Nosaka & Clarkson, 1995).

Another possibility is that fibres susceptible to stretch injury can be replaced by more resistant ones. Researchers have focused attention on muscle volume after a repeated lengthening bout. Two weeks later from first bout it resulted 10% smaller compared to baseline, suggesting that irreversibly damaged contractile proteins were carried out. After bout 2, indirect markers were slightly altered, letting to think that this injury phase could be reversible, cause of lack of muscle volume loss measured by MR (Foley, Jayaraman, Prior, Pivarnik, & Meyer, 1999). Due to the fact that loss in muscle volume does not seem to be possible to be a long term exercise adaptation, a more plausible explanation is that fragile sarcomeres have been destroyed, removed by immune response and replaced by stronger ones, in order to avoid successive damage. When the reparation process is complete, a greater amount of desmine should prevent irreversible subsequent injury (Malm & Yu, 2012).

It has been proposed that inflammatory response could mediate the repeated bout effect. Monocytes and neutrophils activation, as well as latter blood circulation was lower after a second bout of eccentric exercise performed 3 weeks later than first one. Due to the fact that both cells could be responsible of further injury when they go into the muscle fiber, Pizza and colleagues concluded that immune response could be less tuned (Pizza et al., 1996). However, it has been showed that cytokines, released as mediators of acute inflammation, and particularly interleukyine-6 is not correlated with other indirect markers damage such as soreness and serum myoglobin concentration (Croisier et al., 1999).

Moreover, another way to explain the damage reduction is the increase of the number of sarcomere in series. Such adaptation should minimize injury due to a over lengthening exercise, by the increase of stretch resisting proteins (Whitehead, Allen, Morgan, & Proske, 1998).

Both muscle injury and repeated bout effect appear age-related. When comparing them between young and old men, less damage and a minor protection were conferred by sub maximal eccentric training in older than in younger subjects (Lavender & Nosaka, 2008a). In another study, they found difference in passive ROM at the baseline, proposing that smaller elbow extension found in elderly was attributable to a kind of joint protection (Lavender & Nosaka, 2006). In addition, as described previously, training at shorter muscle has been proved to cause less damage, mechanical stress resulted lower in old group (Kazunori Nosaka, Newton, Sacco, Chapman, & Lavender, 2005). Another possibility is related to histological reasons. Authors found different biceps brachii composition in older compared to young, with a significant reduction in II type fibers in the latter's muscle (Monemi, Eriksson,

Eriksson, & Thornell, 1998). It has been showed that fast twitch fibers are more susceptible to damage, and the shift toward slow twitch ones in elderly could explain such circumstance (Jones, Newham, Round, & Tolfree, 1986). Supporting the difference in damage susceptibility between slow and fast twitch fibres, it has been proved that fast velocity eccentric contractions induce higher damage compared to slow ones (D. Chapman, Newton, Sacco, & Nosaka, 2006). We discussed previously that size principle during lengthening contractions, especially when performed at high angular velocities, could not reflect the size principle order recruitment (Nardone et al., 1989). Therefore, workload can be performed by a lower number of motor units, making them more damageable. In addition, supporting similar theory, narrower Z bands have been found in II than I type fibres (Luther, Padrón, Ritter, Craig, & Squire, 2003). Furthermore, upper arms has been found to develop higher muscle damage symptoms than lower limbs (Jamurtas et al., 2005). Even if it is possible suppose that daily activities contain eccentric actions such as downhill walking-running or downing steps, so creating a sort of repeated bout effect, this is not the only possible explanation. Due to the human locomotion, knee extensors contain an higher number of slow fibres compared to biceps brachii, making it more susceptible to strain injury. It is possible that fusiform muscles are more strain damageable compared to pinnate ones (Klein, Marsh, Petrella, & Rice, 2003).

The magnitude of protection from successive trainings has been proved to be dependent to the intensity of the first bout. Generally, higher the former, greater the latter, even if it does not appear in all the markers (Trevor C Chen, Nosaka, & Sacco, 2007). For example, strength loss after maximal eccentric second bout was not affected by protection when intensity of the first bout was 40% of maximal voluntary contraction (MVC), compared to 60%, 80% and 100%, while plasma proteins concentration was less after second bout even in group that performed first bout at 40% MVC. Another research showed that a pre conditioning adaptation is induced by only 10% MVC performed eccentrically, without the impairment of injury symptoms after the first session (Lavender & Nosaka, 2008b). Consistent to these observations, another study showed that, even if damage was related to the number of negative repetitions performed in bout 1, the recovery was unaffected by the alteration of number of repetitions in bout 2, even if performed when recovery was not fully completed (T C Chen & Nosaka, 2006). Such outcomes are corroborated by a work of Chen and co-workers, those previously demonstrated that 7 days of maximal lengthening exercise performed did not exacerbate muscle damage compared to passive recovery followed first bout (Trevor C Chen & Hsieh, 2001). Interestingly, repeated bout effect goes on when subsequent bout are performed in addition of bout 2. Strength decrement was smaller after bout 2 compared to bout1, but bout 3 and bout4 showed a subsequent adaptation by a further peak strength enhancement. However, plasma proteins concentration, muscle soreness and limb circumference did not show significant improvements after bout2. Each bout were separated 4 weeks from the previous or subsequent, during which dependent variables return to baseline (Trevor C Chen, Chen, Lin, Wu, & Nosaka, 2009).

Protection from damage of subsequent bout of eccentric exercise has been showed to be typical of lengthening contraction. In other word, reduction in muscle damage is possible only if during the first bout subject exercised eccentrically. Outcomes from Whitehead and coll. led to the support this hypothesis. In their study, subjects have been previously divided in two groups: one group did not have a previous training, while another groups performed concentric exercise as first session. Symptoms of muscle damage were then recorded after an eccentric bout. They found that after concentric session, muscle damage markers were significantly higher compared to the control muscle, that had no exercise(Whitehead et al., 1998).

2.7.: Training induced changes

Speaking about short term training, several studies investigated the effect of resistance training on muscle strength, hypertrophy, architectural adjustments, changes in mechanical and neural property and alteration in fiber type number proportion. The importance of negative phase during training has been underlined by Tesch and coll., those demonstrated that its absence during training decrease strength improvement after 19 weeks of training (Dudley, Tesch, Miller, & Buchanan, 1991). However, relatively few studies compared training performed only eccentrically or concentrically. A recent meta-analysis brought into comparison studies in which resistance training included these methods, excluding researches in which subjects were special populations, like elderly or under 18, or pathologic subjects (Roig et al., 2009). Main outcomes are that, compared to shortening, lengthening exercise improves slightly more total strength (i.e., sum of concentric, eccentric and isometric peak torque), when eccentric workload intensity was equal or greater than concentric. Outcomes remain similar when considering studies in which intensity was comparable, while became favorable to the former if its intensity was higher. In addition, also training and testing angular velocities were similar, eccentric improves total strength more than concentric, while outcomes were analogous when it was not comparable. When testing single contraction modalities, eccentric improves more than concentric lengthening test, independently by intensity or velocity matching. Such outcomes were not the same in concentric mode, when there is a similar improvement between two training methods. Equivalent increments were found also when isometric MVC were considered. The fact that total strength resulted superior after eccentric training only could be attributable to higher loads those can be used during a resisting action. In fact, when eccentric phase was overloaded, it result in a greater amount of force (T Hortobágyi, Devita, Money, & Barrier, 2001). Similar outcomes derived from resisting overloading methods in bench press training (Doan et al., 2002).

It's known that resistance training promotes muscle protein synthesis, resulting in hypertrophy. Mechanical stimuli have been proved to be triggers of gene expression that modulates protein increasing, and they are strategically placed on sense muscle cell strain. Such gene expression is showed to be up regulated during lengthening exercise, that is clear stretch signal (Hentzen et al., 2006)(Goldspink, 1999). Several studies confirmed that eccentric training is more effective than concentric in inducing increment of Cross Sectional Area (CSA), or muscle mass (Seger, Arvidsson, & Thorstensson, 1998)(Farthing &

Chilibeck, 2003). It is interesting to note that several methods are used to assess muscle mass or volume, such as Magnetic Resonance, Dual Energy X-ray Absorptiometry (DEXA), computerized tomography (CT) or simply muscle girth. Of course, the last one should be considered with caution, due to low reproducibility.

Shift in fiber type due to resistance training is actually a debatable argument. One study showed that eccentric increase more than concentric training type II-a fiber area and percentage, while it decreased in number and no alterations were detectable in type I (T Hortobágyi et al., 1996). In any case, it is clear that structural increment and changes are possible only if training lasts 6-8 weeks or more (G Guilhem, Cornu, et al., 2010). In addition, dealing with muscle mass augmentation, a really important part is made by endocrine system. Indeed, testosterone and growth hormone blood concentration has been showed to acutely improve after single session of resistance training. Authors previously divided subjects into traditional and enhanced eccentric bench press training, but no difference in endocrine augmentation response occurred between groups. (Yarrow et al., 2008)(Yarrow et al., 2007).

Production of muscle force is strongly influenced by its architecture, i.e., the spatial arrangement that sarcomeres and fascicle have in such muscle. Main factors those affect torque production are fascicle length and thickness and pi pennation angle, that is the angle between tendon aponeurosis and muscle fascicles. For example, larger muscles produce higher torque, due to greater number of force producing contractile in parallel proteins. In addition, muscles with a larger pennation angle have an increased physiological cross sectional area, and consequently they are able to develop higher force. Pinnate muscles show higher ability to produce torque near their sarcomeres optimum length and they are also able to develop more work at low shortening speed. This is mainly due to the fact that pinnate fascicles rotate during their shortening process, conveying a inferior distance than tendon one. In contrast, muscle with longer fibres, due to the high number of serially sarcomeres placed in the fascicle, is accomplished to develop strength over longer lengths and capable to contract at high shortening velocity (Muhl, 1982)(Powell, Roy, Kanim, Bello, & Edgerton, 1984)(Blazevich, Gill, & Zhou, 2006). Overall muscle architecture is really plastic and it depends on the joint and the activities for which joint its self has been, evolutionarily speaking, build up. In this way, each muscle involved in a joint has developed its own architecture. One of most studied ones is quadriceps, due to its dimension and its relative simple function. This research project will involve specifically quadriceps, there we will describe its main characteristics. The most important task of quadriceps muscle is the knee extension, together with hip flexor (specially two joint muscle as rectus femoris). Daily activities such as walking, stepping or running involve quadriceps near to its full extension but, when performing special patterns like squatting and lifting, range of force production dramatically increases. In addition, just due to the latter task, it has to be capable to gain a really great amount of torque. Anyway, it should be designed to get optimum functional ability, by the interaction of the main four muscles, i.e. rectus femoris, vastus lateralis, vastus medialis and vastus intermedius. The last one is deeper than the former ones, so usually literature refers to those measurable by ultrasound. Blazevich and coworkers examined inter and intra variability in 31 recreationally active men and women, with the following results(Blazevich et al., 2006). Primarily, factors as torque, shortening velocity and contraction modality act as modulator of single muscle activation, leading to a proper utilization of the muscle with the best architecture involved in the task. Accord previous study, when whole quadriceps increments force, the most important muscle are vastus lateralis (VL) and vastus medialis (VM), while rectus femoris (RF) contribution augmented, and vastus intermedius (VI) decreases its activity (Zhang, Wang, Nuber, Press, & Koh, 2003). Furthermore, VL has been showed to increase its activity during isometric and eccentric contractions, while no difference appeared during concentric contraction among VL, VM and RF (Danny M Pincivero, Gandhi, Timmons, & Coelho, 2006). In addition, during fatiguing task, RF decrease more than VL and VM (Mullany, O’Malley, St Clair Gibson, & Vaughan, 2002). Such proportion remains unaltered after resistance training, but absolute EMG signal decreases, showing a more efficient way to produce torque (D M Pincivero & Campy, 2004).

Along a single muscle, due to its pattern, fascicle angle should not be constant, but it can vary together with its length, in order to response to force and task variation. Thus, in order to generate higher force, fascicle angle increase and when a greater efficiency is required, fascicles are arranged more parallel to the aponeurosis (Blazevich et al., 2006). For the same reason, some regions could be more susceptible to hypertrophy compared to others, with the assumption that it is related to fascicle strain (Goldspink, 1999). Indeed, it has been reported that proximally to VM and distally to VL fascicle angle appear relatively smaller (Blazevich et al., 2006), and it can justify greater fascicle found in those regions (Häkkinen et al., 2001). Analogous outcomes occurred in gastrocnemius medialis (Narici et al., 1996).

Due to its plasticity, muscle architecture is alterable after resistance training, and its effect is also functional in performance. For example, it has been shown that longer vastus lateralis fascicles are coupled with better sprint performance in well trained males (Kumagai et al., 2000). It is noteworthy that such adaptation is typical of sprint runners: in fact, when comparing vastus lateralis architecture among sprinter and endurance athletes, the former has longer fascicle and less pennation angle compare to the latter, symptom of high flexibility of muscle structure (Abe, Kumagai, & Brechue, 2000). Researchers have focused their attention on parameters as contraction mode velocity during resistance training, in order to understand if they could influence muscle architecture. It is known that high velocity contraction is an effective stimulus to induce fascicle thickness and length adaptations, as showed by Alegre and coll., those use explosive concentric squat as training (Alegre, Jiménez, Gonzalo-Orden, Martín-Acero, & Aguado, 2006). It is also important to note that training at high power production seems to be a great determinant on architecture adjustment, more than strength training (Blazevich, Gill, Bronks, & Newton, 2003). Concerning contraction modality, outcomes derived from different resistance training are not uniform. Based on animal models, authors found an increased number of sarcomere in series after downhill running, while uphill running did not provoke changes in fascicle length (Lynn & Morgan, 1994)(Butterfield, Leonard, & Herzog, 2005). Blazevich and coworkers did not find any differences in fascicle length increment after concentric or eccentric only training in human quadriceps(Blazevich, Cannavan, Coleman, & Horne, 2007a). However, due to the fact that increment in fascicle length occurred also in shortening training group, they were able to attribute this alteration to a wide range of motion used during knee extension training, supporting the hypothesis that excursion range could be a primary stimulus for architecture adaptation (Koh & Herzog, 1998). Fascicle angle augmentation has been related with increment in fascicle thickness. Indeed, due to the fact that increased fascicle angle permits a greater amount of muscle contractile structure to attach to aponeurosis, and consequently allowing to the rotating fibers to develop force near their optimum length, pennation angle likely contributes to strength gains after few weeks of training (Blazevich, Cannavan, Coleman, & Horne, 2007a). Such outcomes are confirmed by Narici and colleagues, which found an early adaptation in quadriceps after enhanced eccentric training (Seynnes, de Boer, & Narici, 2007).

After a single eccentric training session, an increase of muscle joint stiffness usually occurs. Main reasons for such outcome are could be traced back to the initial fibers rupture that release Ca2+ and induce residual actin myosin cross bridges to the reparation process, such as edema that induces passive painful strain resistance and to a connective tissue reconstruction (Lapier, Burton, Almon, & Cerny, 1995)(Lakie & Robson, 1990)(Chleboun, Howell, Conatser, & Giesey, 1998). Instead, chronic eccentric training causes a reduction in muscle-tendon passive stiffness, mainly because of increment of serially sarcomeres. Therefore, a right shift occurs in length tension relationship, allowing higher torque expression at longer muscle, and letting muscle to reach higher distance (G Guilhem, Cornu, et al., 2010). In addition, tendon stiffness is positively altered after short term eccentric training, promoting a greater energy restitution during stretch shortening cycle (Mahieu et al., 2008).

2.8.: Cross Education Effect.

One of the training induced changes is the Cross Education Effect, or contra lateral effect. It consists, when performing a single limb resistance training, in an improvements in opposite untrained limb.

Mechanisms that could explain such adaptation remain unclear. First of all, no changes in untrained limb occur nor in cross sectional area, measured by magnetic resonance, neither in enzymes activity or fiber type (Ploutz, Tesch, Biro, & Dudley, 1994)(Houston, Froese, Valeriote, Green, & Ranney, 1983). Furthermore, no significant EMG activity has been recorded during single limb exercise in the other one (Evetovich et al., 2001). Anyway, increased bloody flow and other vascular modifications occurred after fatiguing resistance tasks, even if such adaptation appears to be due to a systemic outflow of neurogenic or metabolic vasodilators (Yasuda & Miyamura, 1983). Therefore, due to a lack of structural modifications, it is possible that such phenomenon could be due to neural factors.

It has been proposed that untrained limb motor pathways could be better arranged after unilateral exercise, re-organizing the neural drive more efficiently. These modification could be placed both in cortical and in spinal command, due to the fact that both has been demonstrated to be acutely excited during high load contractions (Tibor Hortobágyi, Taylor, Petersen, Russell, & Gandevia, 2003). Dealing with the former, higher motor evoked potentials of contralateral muscle are facilitated during moderate or high force voluntary contraction (W Muellbacher, Facchini, Boroojerdi, & Hallett, 2000). In addition, transcallosal pathways could be involved in this process. Indeed interhemispheric inhibition, that is normally active when muscle is slightly active or relaxed, is almost absent during unilateral great torque expression (Lee & Carroll, 2007). Moreover, ipsilateral cortex activity is increased during conventional unilateral resistance training (Dettmers et al., 1995).

Spinal pathways has been proved to be affected by unilateral exercise or training. However, modifications did not occur in H reflex during single limb contraction, and rather it was depressed while strong torque was exerted by trained wrist in the opposite one (Tibor Hortobágyi et al., 2003). One possibility is that reciprocal agonist – antagonist inhibition could be affected in passive limb during opposite voluntary movement, even if the role of Renshaw cells in untrained limb remains to be established in humans(Lee & Carroll, 2007).

An alternate theory suggests that main adaptations could be placed in supraspinal area, and some modifications could be present in contra lateral emisphere. Indeed, it has been shown that when a lateral primary motor cortex excitability is impaired by TMS, the contra lateral one is able to maintain force output. Instead, during a bilateral stimulation, torque decreases (Strens, Fogelson, Shanahan, Rothwell, & Brown, 2003). When we speak about cross education effect, we should take in consideration the idea that a kind of motor learning may happen after a repeated single limb task. Therefore, if we consider the ability of produce force like for example writing or mirror tracing, for which contra lateral motor learning has been demonstrated, we should imagine it as well as an incomplete ability transfer, because torque increment usually occur for 35% of trained limb strength gain (Lee & Carroll, 2007). It is accepted that motor learning involves many cerebral areas like primary motor cortex, prefrontal cortex, basal ganglia, pre-motor, posterior parietal and cerebellar cortices (Wolf Muellbacher et al., 2002)(Sanes, 2003). However, it is not established which of these ones could give a major contribute during cross education.

However strength improvements in untrained limb has been reviewed in a meta analysis. One of the most important inclusion criteria was the presence of a control group, i.e. a group that did not perform any training, in which totally untrained limb strength has been measured. (Munn, Herbert, and S. C. Gandevia.) The average force augmentation in passive limb has resulted to correspond to 35% of trained limb strength increment, or, in other terms, to 8% of baseline values. Even if there is no direct evidence on a superiority of a specific contraction modality, particularly isometric or dynamic, Hortobagyi showed that eccentric was superior than concentric training (T Hortobágyi, Lambert, & Hill, 1997).

2.9.: Detraining.

When a training interruption occurs, physiological modifications gained during exercising period are not always kept over time. By definition, detraining is termed as an inactivity period longer than 4 weeks (Mujika & Padilla, 2000). It is known that strength improvements are able to resist over time. Two groups of high or low intensity resistance training performed by elderly men had different force retention over time, with the former that was able to perform better than baseline after 12 months of detraining, while the latter up to 4 months. Furthermore, contraction testing modality seems to influence the strength loss after cessation activity period. As a matter of fact, eccentric torque was preserved while concentric strength was lost after 3 months of detraining, that followed 12 weeks of resistance exercise (Andersen, Andersen, Magnusson, & Aagaard, 2005)(Fatouros et al., 2005).

Due to the fact that quadriceps cross sectional area returned to baseline, it appears that neural factor influenced such outcomes. When training was performed by previously untrained subjects, it has been speculated that neural long lasting adaptations could include both disinhibition of inhibitory interneurons during high intensity contraction and reduced presynaptic inhibition during muscle lengthening (Andersen et al., 2005). In fact, when power athletes underwent to a 2 weeks of detraining, eccentric peak was the only modality in which torque decreased, while concentric and isometric peak force remains unaffected. In addition fast twitch fiber area decreased significantly (T Hortobágyi et al., 1993). Supporting such outcomes, rate of force development, i.e. the ability to generate force as fast as possible, has been shown to tend to decrease after detraining. (Blazevich, Horne, Cannavan, Coleman, & Aagaard, 2008).

Architectural adjustments were maintained after 3 months of detraining. In fact, both fascicle angle and fascicle length retained improvements gained during training. Interestingly, training modality contraction does not seem to have an influence on it (Blazevich, Cannavan, Coleman, & Horne, 2007a). In another investigation it has resulted that gender, but not age, could condition strength retention increment (Ivey et al., 2000).

Less is known about detraining on untrained limb, after an unilateral training. Shima and colleagues found an increment of MVC, iEMG and voluntary activation in untrained limb after training but not after a detraining period (Shima et al., 2002). To the contrary, other authors reported a retaining of contra lateral strength increment after detraining when training was performed eccentrically (Housh, Housh, Weir, & Weir, 1996a) or concentrically (Housh, Housh, Weir, & Weir, 1996b). In addition, when training were similar to testing modality, it has been found that untrained limb maintained 1RM augmentation. (Weir, Housh, Housh, & Weir, 1997).

2.10.: Isokinetic Vs Isotonic

When eccentric resistance training is performed in vivo, for example a knee extension, there are 2 main methods with which execute it. We refers to Isokinetic contraction when subject produce torque against a lever arm that moves at constant velocity imposed by an apparatus (e.g. isokinetic dynamometer). Instead, when a constant external load goes over the force expressed by muscle, we usually define it as isotonic contraction. Even if torque varies along the entire range of motion, mainly cause of acceleration and lever arm length variation, in literature it is classically referred as isotonic (G Guilhem, Cornu, et al., 2010). Difference in muscle architecture and neural patterns comparing both isokinetic (ISOK) and isotonic (ISOT) during acute eccentric knee extension contractions has been recently published (Gaël Guilhem, Cornu, & Guével, 2011). Main outcomes are described below.

Figure 2.2: Isokinetic device.

Figure 2.3: Isotonic device.

First of all, referring to a 30° to 90° as range of motion (0°= full extension), while torque exerted in ISOT was by definition constant along almost the entire movement, force produced, compared to the former, was significantly lower in ISOK from 30° to 50° and significantly greater from 65° to 85°. Instead, while ISOK showed by definition a constant angular velocity, ISOT had a significant higher speed from the movement beginning up to 60°. Such different mechanical behavior does not reflect dissimilarities in acute architectural adjustments. In fact, fascicle angle showed a similar decrease, both in ISOK and ISOT, after 60°, as well as fascicle thickness. Increment in fascicle length occurred similarly in both groups after 70°.

Neural activity, measured by EMG, elicited differences between 2 modalities. Average EMG signal was higher in whole quadriceps during ISOT compared to ISOK, without difference among VM, VL and RF. Difference in Root Mean Squared (RMS) amplitude was found with angle variation: ISOT showed higher activity from 30° to 50° and lower signal from 70° to 85°. Co – activation level resulted higher during ISOT compared to ISOK, by measuring Biceps Femoris (BF), from 30° to 55°.

However, no studies compared eccentric training induced changes between ISOK and ISOT. Considering strength gains, higher increment has resulted from researches that used eccentric ISOT exercise compared to those that exercised it by dynamometer. In contrast, ISOK provokes average higher hypertrophy compared to ISOT, while fiber II type area increased similarly. Due to lack of studies, it was not possible to systematically compare muscle architecture adaptations between ISOT and ISOK, even if both seem to promote it. ISOT lengthening training it has been showed to augment muscle activation more than ISOK and it was the only method that reduced co-activation antagonist, while no changes appeared in ISOK (for a detailed review, see G Guilhem et al. 2010).

2.11.: Inertial technology

Resistance training classically needs an external overload, provided by bars, handle weights, isotonic or isokinetic devices. With exception of the latter, these methods are dependent of gravity. One of the problem related with a prolonged permanence in absence of gravity is a marked atrophy and loss of bone density, as showed in spacemen (Adams, Caiozzo, & Baldwin, 2003)(LeBlanc et al., 2000). Due to the fact that resistance training counteracts atrophy and bone density decrement, but of course it would not be performed classically because of ipogravity, a new device has been recently developed by Tesch and coworkers (Berg & Tesch, 1994). Such apparatus offers resistance employing the inertia of its flywheel, therefore can be defined as gravity independent. In this way, the concentric phase imparts spin against the flywheel’s inertia. When the strap (that links subjects to the device) is totally unwound, the flywheel starts to recoil it until the strap arrived to a stop. Using this stratagem, the eccentric phase is enhanced by the kinetic energy developed during the concentric action (Norrbrand, Fluckey, Pozzo, & Tesch, 2008). Using flywheel system in leg extension or squatting exercise, improvements in muscle volume, strength and EMG signal during eccentric phase was recorded after short term training compared to classical resistance training (Norrbrand, Tous-Fajardo, Vargas, & Tesch, 2011)(Norrbrand et al., 2008).

Figure 2.4: Inertial Flywheel squat device.

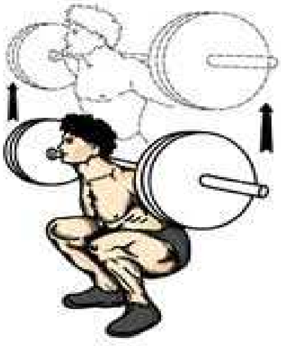

Figure 2.5: Classical squat with barbell.

2.12: Aim of the research project.

As previously explained, different acute and chronic effects are tipical of eccentric contraction, that can be performed separately, coupled with concentric (e.g. classical resistance training) or ehanced by inertial device.

Therefore, aim the research project can be divided in 5 main topics:

1. When threating with ISOK Vs ISOT, lack of knowledge exists on a systematic comparison, matched for volume, on repeated bout effect. Therefore, first study will measure the eccentric exercise induced muscle damage and further adaptations due to above mentioned resistance methods.
2. In addition, to our knowledge, no studies directly compared eccentric ISOK and ISOT measuring training induced changes. Hence, aim of the third study is evaluate quadriceps strength and structure after lengthening unilateral training.
3. Eccentric enhancement due to inertial device (YoYo) is expected to provoke muscle injury and possibly further adaptations, those may attenuate it when repeated twice. So, aim of the third study is to verify if the eccentric enhancement induces muscle damage and, consequently, repeated bout effect.
4. Previously, authors compared training effect between YoYo squat and classical resistance methods, focusing only on strength and muscle structure arrangement. Anyway, transfer in sport performance, as jumps, sprinting or changing direction ability, has not still related with its eccentric overload. However, when comparing YoYo with classical squat, it has to be considered that only the former permits to execute maximally all repetions. (Norrbrand et al., 2011). In addition, another classical field method, i.e. squat jump, requires maximal concentric action, followed by a braking phase that reminds to the eccentric enhancement caused by YoYo's inertia. Therefore, aim of the fourth study is to measure quadriceps strength, mass and architecture, as well

as transfer in perfomance induced by YoYo squat or weighted squat jump.

5. Aim of the fifth study is evaluate time course of muscle strength, mass and architecture after a short term unilateral training and detraining. In addition, we want to evaluate alterations in untrained limb.

Chapter 3: Study 1

Repeated Bout Effect Induced by Isotonic Vs Isokinetic Eccentric Exercise

Coratella G[1], Impellizzeri FM [2 3], Schena F[1 2]

[1]Department of neurological, neurophisiological, morphological and movement science, University of Verona, Italy.

[2] CeRiSM, Research Center in for Sport, Mountain and Health, Rovereto, Italy.

[3]Schulthess Kilinik, Zurich, Switzerland.

Abstract

Lengthening contraction is well known to induce muscle injury and it confers protection to a subsequent eccentric session, i.e. repeated bout effect. Dynamic negative action can be performed resisting to an external load (e.g.: isotonic) or using isokinetic device. Aim of the study is to measure muscle damage and repeated bout effect induced by both lengthening exercise modalities.

Thirty males were randomly assigned to isokinetic(IK) or isotonic(IT) group and they tested at baseline, immediately after and up to 4 days after 60 supra maximal eccentric contractions. CK activity, strength loss and muscle soreness were taken as indirect markers of muscle damage. Same protocol was repeated after 4 weeks.

Compared to baseline, IK and IT resulted in augmented injury symptoms after first bout. Compared to first bout, second bout resulted in significantly lower muscle damage both in IK and IT. After first bout, compared to IK, IT showed increased CK activity (+30±13%), higher strength loss(+40±14%) and greater soreness (+34±8%), $p<0,05$ for all parameters. After second bout, compared to IK, IT showed similar CK activity (+12±4%, n.s.), higher strength loss (+24±4%, $p<0,05$) and similar soreness (+10%±5%, n.s.).

Both IK and IT induced muscle damage after first bout. Second bout resulted in less damage for both IK and IT. IT induced significantly greater damage compared to IK, but it confers more protection after second bout. It is concluded that neural and mechanical factor influenced difference between IK and IT eccentric induce damage.

Introduction.

Unaccustomed eccentric exercise is well known to induce muscle damage (K Nosaka & Clarkson, 1995)(Trevor C Chen & Nosaka, 2006)(Hubal, Rubinstein, & Clarkson, 2007). Indirect markers of muscle injury, such as strength loss, creatin Kinase serum concentration, soreness have been used to investigate time course effect after lengthening single session (Priscilla M Clarkson & Hubal, 2002). However, first bout of lengthening exercise confers protection against a subsequent bout of identical eccentric training (T C Chen & Nosaka, 2006)(K Nosaka & Clarkson, 1995)(Trevor C Chen et al., 2009)(Trevor C Chen et al., 2007). This event is called Repeated Bout Effect. Even if this phenomenon has been widely focused, the exact mechanism is not fully understood. Several hypothesis have been postulated to explain protection conferred by negative work. For example, compared to shortening contraction, eccentric exercise showed selective recruitment of II type fibres and lower EMG signal. It is possible that a rearrangement of motor unit order, using slow twitch type, could avoid subsequent fast twitch fibers damage (Hortobagyi et al., 1998; K Nosaka & Clarkson, 1995). In addition, pro / anti inflammatory markers balance can lead to lower soreness and oedema in the second training session, that does decrease muscle pain (Pizza et al., 1996). A theory called “popping sarcomere” regards structural adjustments: disrupted sarcomeres are replaced by stronger ones, by a greater desmin synthesis, in order to avoid line Z rupture (Morgan, 1990). Such protection seems to last up to 6 months (Kazunori Nosaka, Sakamoto, et al., 2001), and it appears to be age related (Dale W Chapman, Newton, McGuigan, & Nosaka, 2008), without gender differences (Priscilla M Clarkson & Hubal, 2002).

Most studies investigated repeated bout effect performing isokinetic(IK) or isotonic(IT) lengthening contractions. Main differences in acute isokinetic Vs Isotonic actions have been recently displayed, showing a different EMG/muscle length ratio, but it seems that IT reach a higher neural activation due to the action set, while IK task is to oppose to highest torque when subject starts to perform a contraction. Similar acute fascicle stretch and pennation angle occur both in IK and IT, suggesting neural differences those can explain different torque production behaviour (Gaël Guilhem et al., 2011).

To our knowledge, no study has detected difference between IK and IT using exercise induced eccentric muscle damage and repeated bout effect. Therefore, aim of the study is to measure effect of 2 different sessions of eccentric IT Vs IK training matched for volume load.

Methods

Experimental design: To investigate muscle damage, subjects were tested at baseline, immediately after training, and up to 4 days after the training. Then, to examine the magnitude of repeated bout effect, the same protocol were repeated after 4 weeks, during which subjects conducted their normal life, without further training engagement.

Subjects: Thirty healthy sport science students were randomly allocated to two experimental group, IK and IT. Knee, hip or ankle pain in the previous year was used as exclusion criteria, as well as any practice in eccentric training , i.e. alpin skiing. All subjects signed informed consensus and the study was previously approved by Ethical Committee of University of Verona

Testing.

Biochemical Marker. Creatin Kinase serum concentration was measured using capillary blood (Reflotron Plus, Roche, Germany). Blood was collected in a 32µ/l litium heparin single use capillary pipette (Reflotron PST, Roche, Germany) after prick by sterile single use lancing device (Accucheck, Roche, Germany).

Muscle soreness. A visual analogic scale (VAS) consisting of 100mm line with “no pain” at the left margin and “extremely painful” at the right margin, was assessed to detect soreness during quadriceps palpation. Subjects were seated and knee angle was 90°, while limb was totally relaxed. Palpation was standardized by operator at 50% of vastus medialis, vastus lateralis and rectus femuris length

Strength. Subjects performed torque measurements on Isokinetic dynamometer (Cybex, Lumex, Ronkokoma, NY, USA). Subjects were fixed on dynamometer seat: trunk and shoulders were blocked by two belts in order to have back close to the backseat. Tested knee was fixed by a belt and ankle was close to the lever. The untested leg was blocked by another lever. After warm up consisting in 10 submaximal eccentric and 10 concentric repetitions, subjects completed 3 maximal attempts in both modalities at 60°/s. Range of motion was from 90° to 5°(0°= full extension). Further set consisted in 3 maximal isometric repetitions at 60°. Subjects were motivated by the operator to perform the whole protocol as hardest as possible. At baseline, protocol was repeated twice, after 3 days, in order to avoid learning effect using isokinetic machine. Best torque was considered as baseline.

1RM. Single Isotonic Knee extension 1RM was tested on gym device (Leg extension, Technogym, Gambettola, Italy). Testing protocol started with warm up consisting in 2 sets per 15 repetitions. Based on formula

Theoretical 1RM= load/1,0278-(0,0278·n°executed repetition)

where load is expressed in KG lifted during set, 90% 1RM was used as initial 1RM attempt. Afterwards additional load of 2.5kg was added until subjects failed to lift the lever. The other limb was blocked by an operator. Same procedure was repeated with the other leg. Standardized verbal encouragements were adopted by the operator during each attempts.

Training: IK training consisted in 6 sets of 10 maximal isokinetic eccentric contractions at 60 deg/s, from 5° to 90° (0°= full extension) on isokinetic dinamometer (Cybex, Lumex, Ronkokoma, NY, USA). In order to maintain similar volume between two groups, Isotonic unilateral leg extension load was fixed at 120% 1RM. Such workload was chosen because average Eccentric / concentric isokinetic peak ratio calculated among all the subjects was 119.8±13%. Range of motion was approximately 90°, while subjects were instructed to maintain a 1,5 second as Time Under Tension (TUT), in order to execute each repetition at average speed of 60 deg/sec. Subject received time visual feedback. IT training was performed on Leg extension (Technogym, Gambettola, Italy).

Statistical analysis. All the dependent parameters were analyzed by three – way repeated measure ANOVA (Day X Session X Group) performed using SPSS 16.0(SPSS, Chicago, IL). Post hoc analysis using Bonferroni's correction followed to investigate factor Group (2 level), Session (2 level) or Days (6 level) significance. P level was fixed at p<0,05. Same analysis was repeated after log transformation.

Results

All subjects completed both training sessions. No accidents occurred during experimental period.

Baseline	**CK (iU/l)**	**soreness**	**1RM (Kg)**	**Isom Peak (N/m)**	**Conc Peak (N/m)**	**Ecc Peak (N/m)**
I Bout IK	318±206	1,2±1,0	68±16	280±38	233±36	316±54
II Bout IK	235±180	1,7±1,7	71±18	327±53	255±41	367±71
I Bout IT	255±177	0,9±1,0	57±12	242±62	211±33	256±55
II Bout IT	195±137	0,9±0,8	62±18	283±69	231±42	317±64

Table 2: Baseline values (Mean ±SD) measured in IK and IT before both sessions

No three –way interaction appeared in any dependent variables.

	session	**day**	**group**
CK	0,000	0,003	n.s.
Soreness	n.s.	0,000	n.s.
Ecc Peak	0,000	0,000	0,003
Conc Peak	0,000	0,000	0,019
Isom Peak	0,000	0,000	0,005
1RM	0,000	0,000	0,021

Table 3: significance level of One-Way ANOVA.

Creatin Kinase Blood concentration: CK activity was not significantly augmented after IK training, while in IT CK increased it after training in first session up to day 4, while CK did not appear to be significantly higher after second bout in both IT and IK.

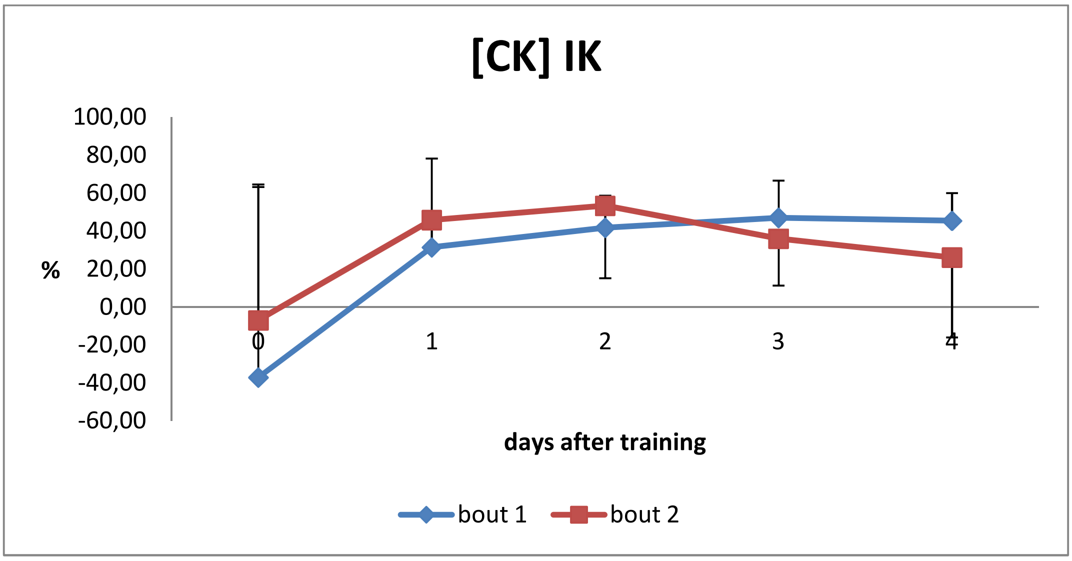

Figure 3.1: IK CK blood concetration. Values as Change % ± CI95%.Difference from baseline are not significant

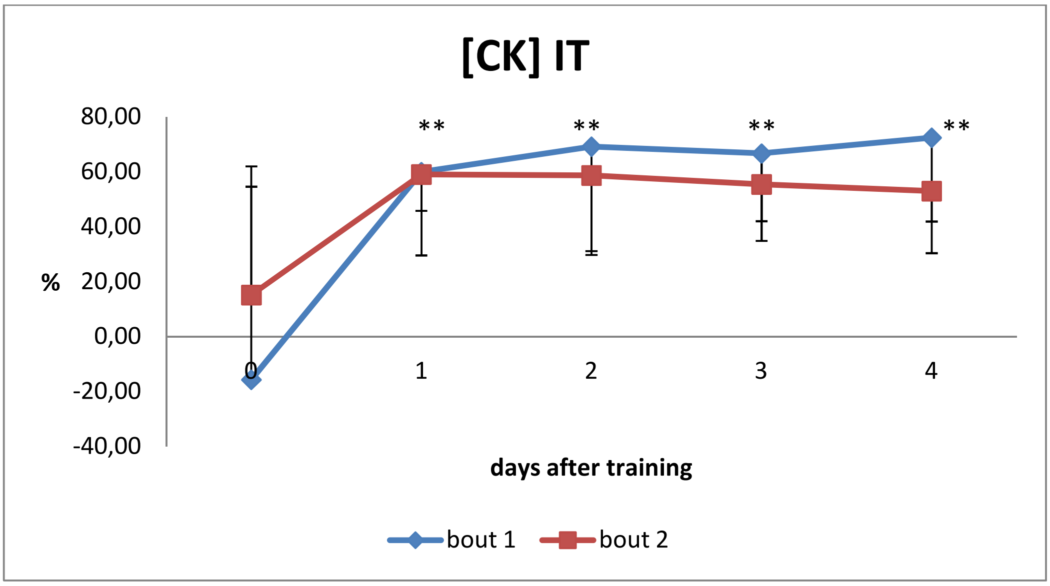

Figure 3.2: IT CK blood concentration: difference from baseline. Values as Change % ± CI95%.P<0,01**

Changes between bouts occurred after IT, while not significant alterations occurred after IK, maybe because of relatively low CK level after I bout.

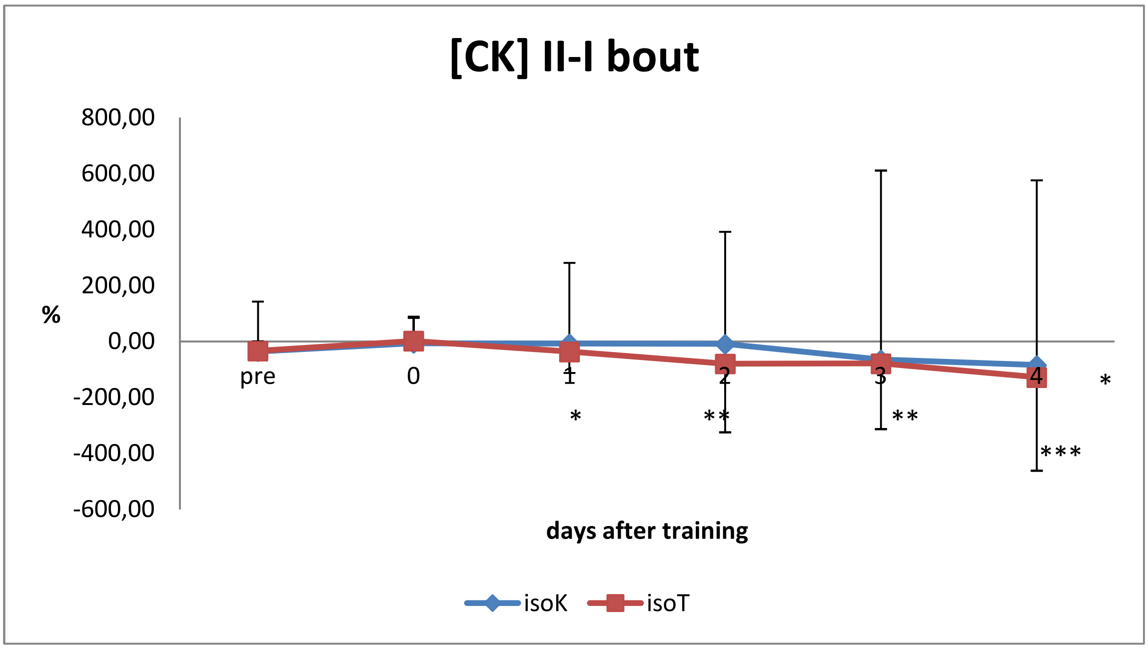

Figure 3.3: [CK] difference between bouts in IT and IK. Values as Change % ± CI95%. * p<0,05; p<0,01; *** p<0,001**

However, statistical analysis did not revealed difference between IT Vs IK during first and second bout.

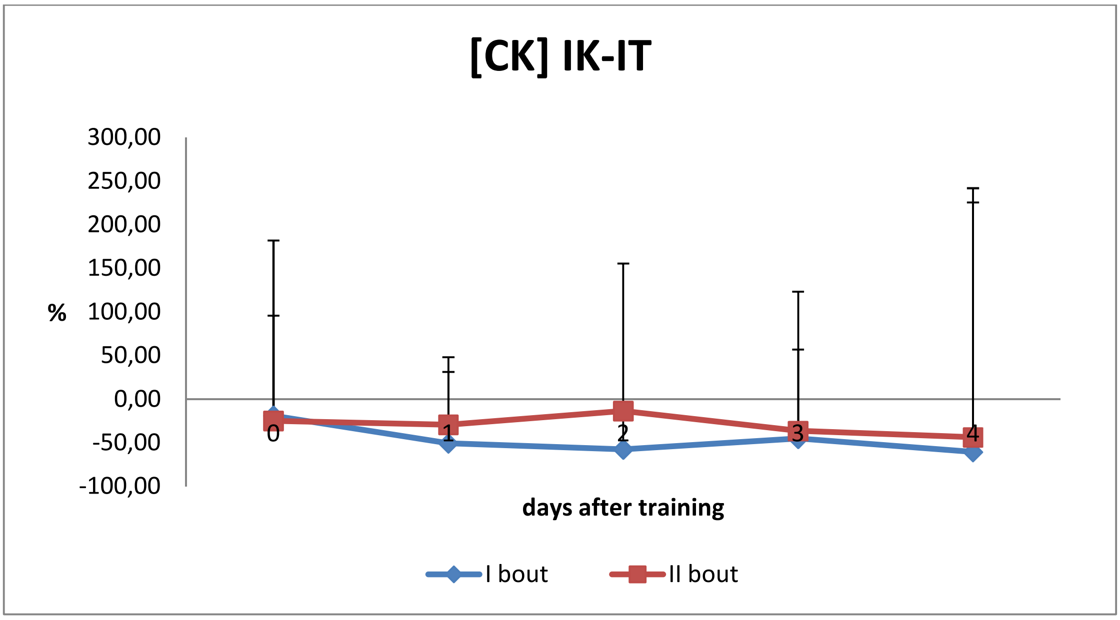

Figure 3.4: [CK] difference between bouts in IT and IK. Values as Change % ± CI95%. * p<0,05; p<0,01; *** p<0,001**

Muscle Soreness. Changes in muscle pain was not significantly higher in IK nor in first nether after second bout. However, after IT, soreness significantly augmented, keeping greater values also after second bout.

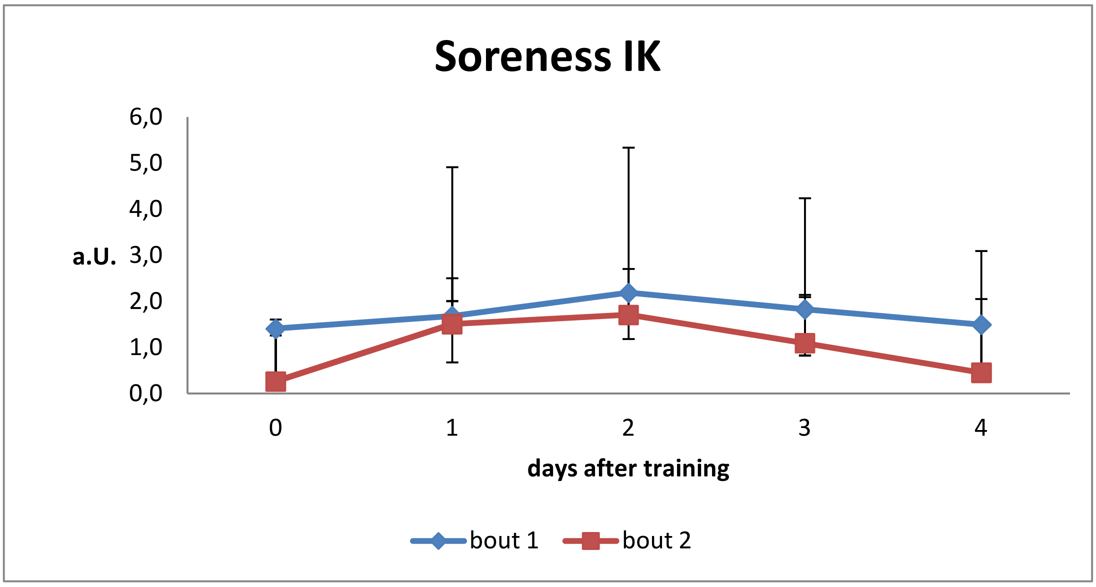

Figure 3.5: Change in Muscle Soreness compared to baseline. Data expressed as Change ± CI95%. Differences were not significant.

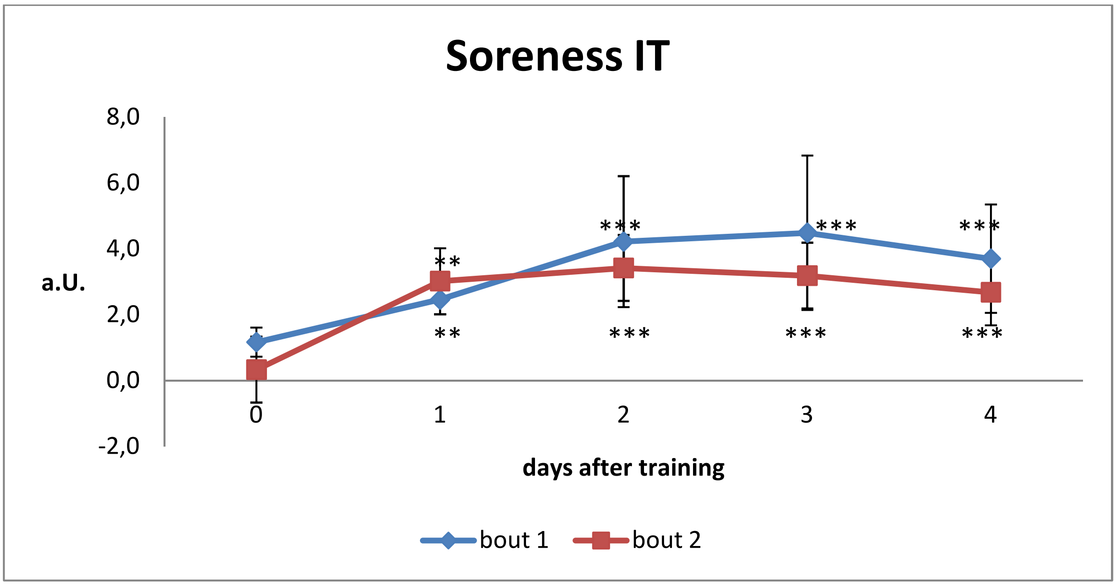

Figure 3.6: Change in Muscle Soreness compared to baseline. Data expressed as Change ± CI95%.* p<0,05; p<0,01; *** p<0,001**

No differences appeared between two bouts after IK and IT training.

.

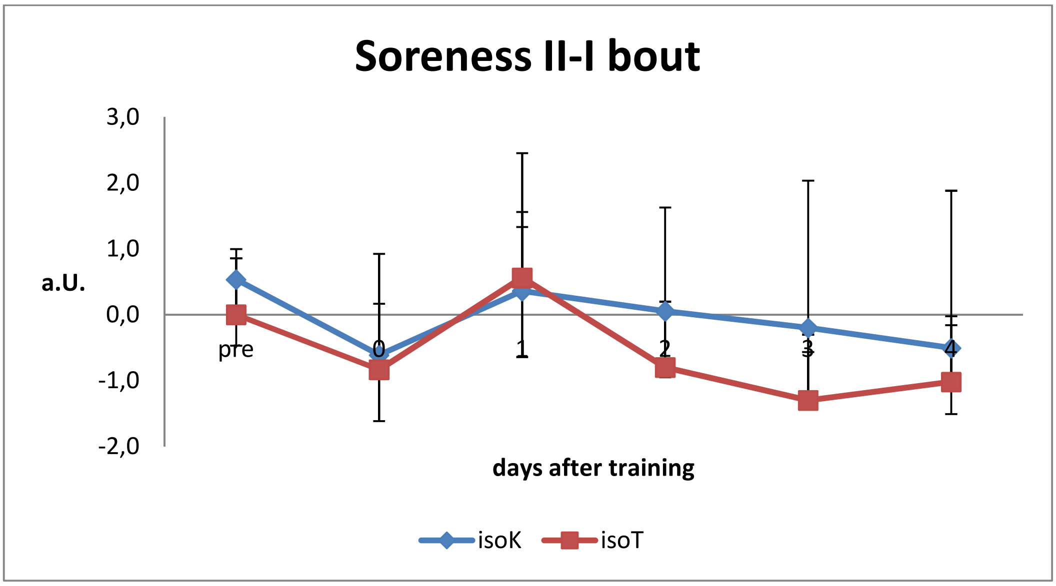

Figure 3.7: Change in Muscle Soreness compared to baseline. Data expressed as Change ± CI95%.* p<0,05; p<0,01; *** p<0,001.**

Group nonconformity occurred after 3 and 4 days during the first bout, while this dissimilarity disappeared after second training session

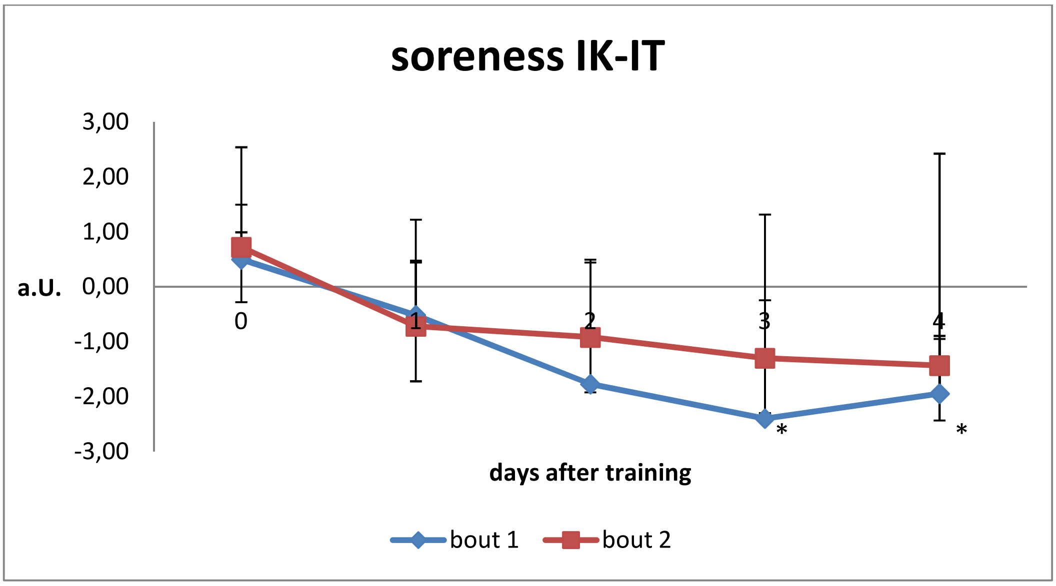

Figure 3.8: Change in Muscle Soreness compared to baseline. Data expressed as Change ± CI95%.* p<0,05; p<0,01; *** p<0,001.**

Strength. 1RM performance was significantly lower, compared to the baseline, after both sessions in IK until 24h, while recovery appeared to start after 2 days. After IT, strength was smaller than baseline until day 3. Comparing both sessions, the latter one had smaller strength decrease both in IK and IT, but the second one appeared to be more effective in protecting from muscle injury.

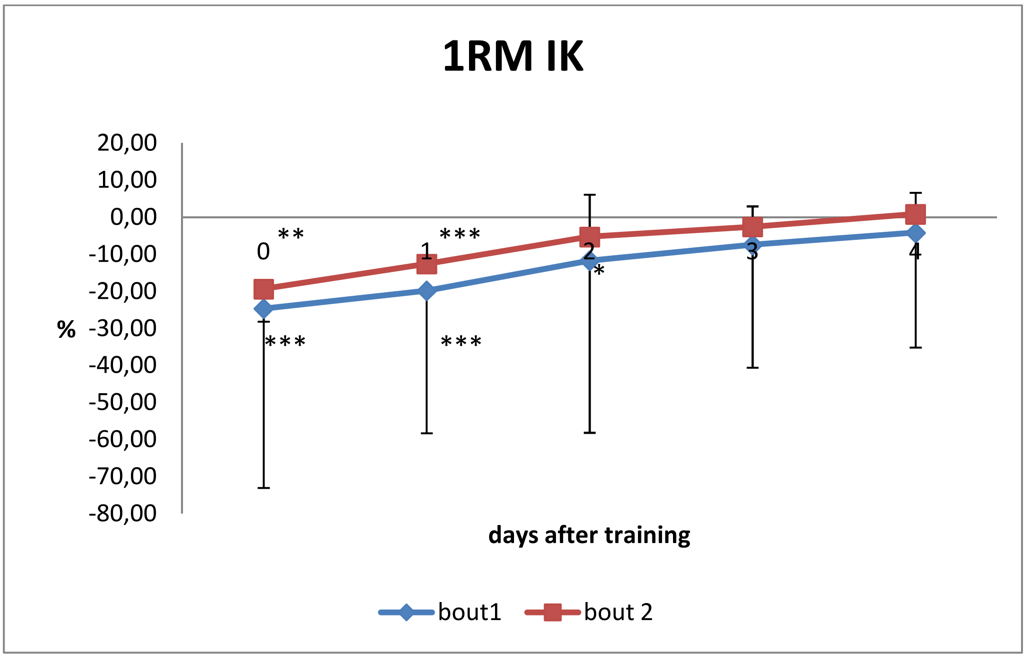

Figure 3.9: Change in 1RM compared to baseline. Data expressed as Change ± CI95%.* p<0,05; p<0,01; *** p<0,001.**

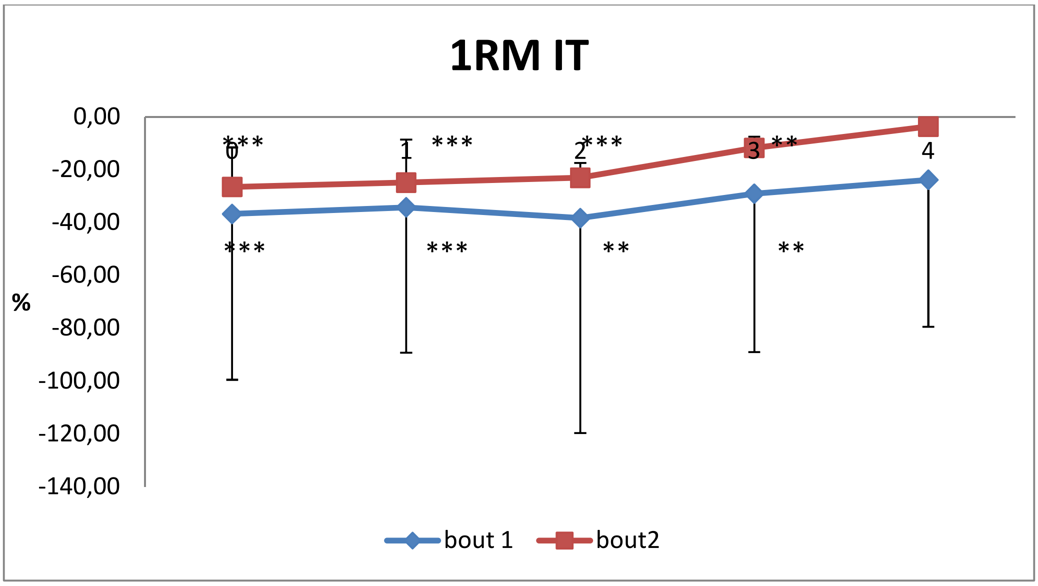

Figure 3.40: Change in 1RM compared to baseline. Data expressed as Change ± CI95%.* p<0,05; p<0,01; *** p<0,001.**

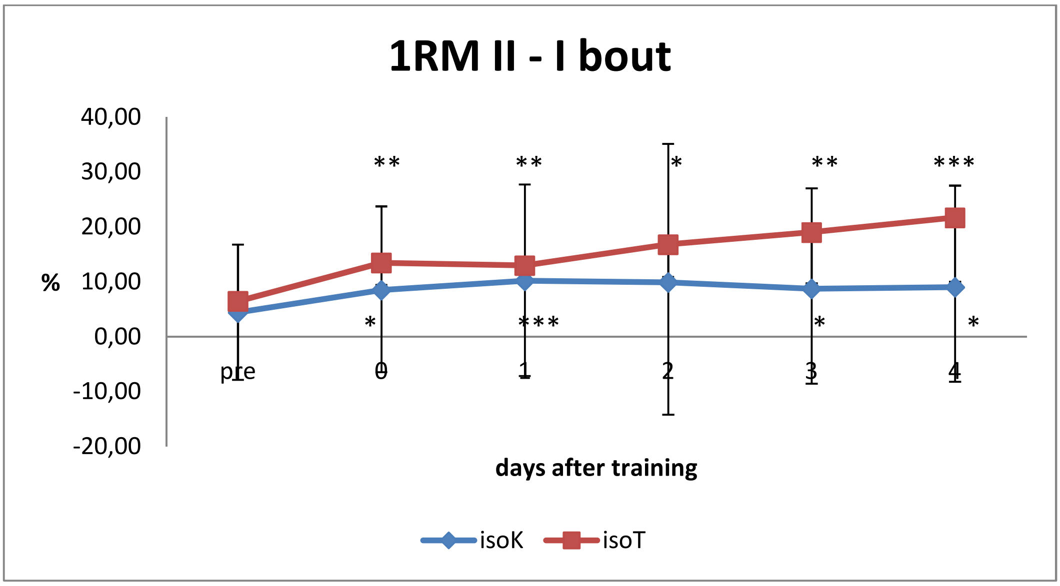

Figure 3.11: Change in 1RM between bouts. Data expressed as Change% ± CI95%.* p<0,05; p<0,01; *** p<0,001.**

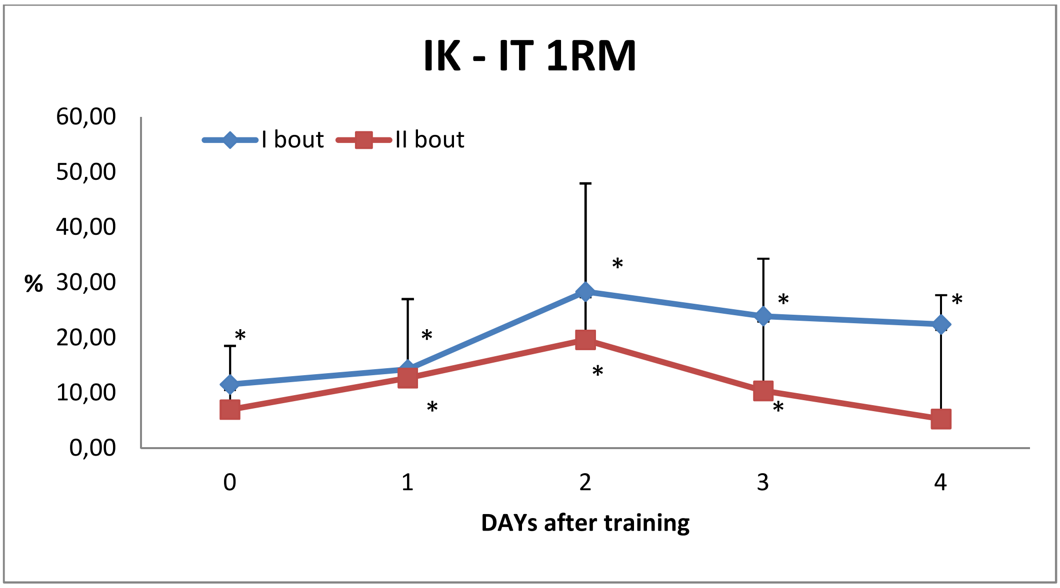

Figure 3.12: Change in 1RM between groups in both bouts. Data expressed as Change% ± CI95%.* p<0,05; p<0,01; *** p<0,001.**

Discussion.

Main outcomes are: 1) eccentric training stimulates muscle damage; 2) first bout confers adaptation that provokes less symptoms of muscle injury in a subsequent bout; 3)IT induces more damage compared to IK, but this difference is noteworthy lower after 1 month.

It is widely accepted that lengthening exercise induces muscle damage (Cleak & Eston, 1992; Lavender & Nosaka, 2006; Paddon-Jones, Keech, Lonergan, & Abernethy, 2005; Paschalis et al., 2005). CK serum activity showed a large inter subjects variability (120-2000 iU), confirming previous research (K Nosaka & Clarkson, 1996). Strength loss was average 25%, considering all subjects. Higher impairments has been previously reported, but a sort of division between high and low responders has been previously reported (Hubal et al., 2007). Muscle soreness and strength loss had similar time course, as some authors reported (Priscilla M Clarkson & Hubal, 2002). It has been shown that muscle pain is able to decrease motor evoked potentials induced by transcranial magnetic stimulation. Therefore, nociceptors action could reduce motor cortical excitability (Le Pera et al., 2001). Protection by subsequent efforts is elicited by the presence of pain, that should avoid to muscle structure succeeding and a more serious damage (U Proske et al., 2003). Taking together all indirect markers, it is possible to affirm that subjects resulted in lengthening exercise induced muscle damage, even if amount was relatively not high. It is showed that lengthening exercise performed by legs induce less damage compared to lengthening exercise performed by arms (Jamurtas et al., 2005). In addition we can consider our subjects as trained adults, even if no one used to perform resistance training. It has been proved that trained subjects resulted in lower muscle damage after eccentric bout (Newton, Morgan, Sacco, Chapman, & Nosaka, 2008).

After one month, when performing second eccentric bout, both IK and IT experienced a decrement in symptoms of muscle injury. Protection conferred by first eccentric session is well known to last up to six months (Kazunori Nosaka, Sakamoto, et al., 2001). Mechanical aspects (Morgan, 1990), such as neural (Hortobagyi et al., 1998) or inflammatory (Pizza et al., 1996) reasons have been proposed to explain the repeated bout effect, but we are not able to indicate one of this as most likely.

Difference IK Vs IT. All dependent variables indicated higher muscle damage performing IT exercise. This should be not dependent by amount of work: in fact similar work was exerted at 120% 1RM after 8 repetitions using IK and IT (Gaël Guilhem, Guével, & Cornu, 2010). Same authors detected higher angular velocity in IT from 30° to 65 ° (0°= full extension). In a previous study, it has been found longer soreness recovery performing fast Vs slow eccentric exercise, while strength loss was superior exercising slowly (Paddon-Jones et al., 2005). This should be explained by a neural adjustments that avoid injury when fast lengthening contractions are performed. However, angular velocities considered in such study (30°/s Vs 180°/s) are specific for slow or fast movement. In contrast, other authors found greater damage when lengthening occurred at faster compared to slower angular velocity (D. Chapman et al., 2006)(Dale Wilson Chapman, Newton, McGuigan, & Nosaka, 2008). It is possible that the number of cross-bridges capable of generating force could be smaller in the fast-velocity than in the slow, and this might induce greater mechanical stress per active cross-bridge during the fast-velocity lengthening contractions. Because fast twitch muscle fibers are more susceptible to fatigue, it is possible to speculate that the number of fast-twitch muscle fibers actually generating force decreases with an increasing number of contractions (Jones et al., 1986).

Torque exerted during range of motion was significantly greater in IT up to 50°, whereas it was inferior from 60° to 85°(Gaël Guilhem et al., 2011). Such combination of higher torque and velocity during a greater range of motion in IT could act as mechanical damaging factor. Electromyographyc RMS has shown, at 120% 1RM, an augmented muscle activation during IT compared to IK and it might contribute to increment muscle damage(Gaël Guilhem et al., 2011). Repeated Bout Effect has been shown to be dose dependent(T C Chen & Nosaka, 2006). If we accept a greater intensity training during IT Vs IK, we can understand how the difference between two bouts is accentuated when an isotonic exercise is performed.

In conclusion, it is possible to say that both isokinetic and isotonic gym eccentric knee extension provokes symptoms of muscle pain. Confirming literature, markers of muscle damage are reduced by protective effect of lengthening exercise. This study adds that the magnitude of repeated bout effect could be increased performing field training, maybe due to relative higher intensity when length muscle is more susceptible to damage.

Chapter 4: Study 2

Similar training induced changes between Isokinetic and Isotonic Eccentric Knee Extension

Coratella G.[1], Milanese C.[1], Impellizzeri FM [2] [3], Schena F[1][2].

[1]Department of neurological, neurophisiological, morphological and movement science, University of Verona, Italy.

[2] CeRiSM, Research Center in for Sport, Mountain and Health, Rovereto, Italy.

[3]Schulthess Kilinik, Zurich, Switzerland.

Abstract

Eccentric (ECC) training has been shown to induce greater effect than concentric training on strength, muscle mass and contra lateral adaptations. The majority of the studies have used isokinetic (IK) devices for investigating the acute and chronic effects of ECC training. However, isotonic (IT) apparatuses are more commonly available in sport setting. Aim of the study was to compare ISOK to ISOT ECC training by assessing the effects on muscle strength and mass.

Forty-nine healthy sport science students have been randomly divided in 3 groups: IK, IT, and control group (CG). Both training groups performed 50 ECC repetitions of knee extension at 120% of their maximal strength measured in concentric modality (1RM for IT and peak concentric torque for IK), for a total of 14 times in 7 weeks. Isometric maximal voluntary contraction (MVC), concentric and eccentric strength, 1RM, muscle mass and architectural alterations have been measured pre and post training.

Compare to CG, the IK group showed higher 1RM (12%, CI95% 6 to 19%), concentric (15%, 8 to 22%), eccentric (35%, 25 to 45%) and isometric (25%, 18 to 34%) maximal strength ($P<0.001$). Compare to CG, IT showed higher 1RM (14%, 9 to 20%), concentric (17%, 11 to 24%), eccentric (25%, 16 to 34%) and isometric (22%, 15 to 29%) maximal strength ($P<0.001$). No differences between ISOK and ISOT were found in 1RM (2%, -3 to 7%), concentric (-2%, -4 to 8%) and isometric (-3%, -8 to 3%) maximal strength. Only eccentric strength was higher in the IK compare to the IT group (8%, 1 to 14%). No differences between groups were found in muscle mass (0.419<P<0.769). Untrained limb improve strength in both training groups.

Eccentric training improved muscle peak torque and 1RM in physically active people. Data showed that neural adaptation is the main factor increasing muscle strength, while muscle mass apparently was not strictly related to it. IK and IT showed similar training effects. This study displayed that ECC training induced early strength adaptations.

Introduction

Resistance training is common method to induce strength increase. Traditional training involves concentric and eccentric actions, during which, while muscle generate torque, respectively shorten or lengthen. However, several studies showed differences when concentric or eccentric actions are executed. Dissimilar motor unit recruitment (Duchateau & Enoka, 2008; Enoka, 1996), different cortical activation (Y Fang et al., 2001) (Yin Fang et al., 2004) or inferior EMG signal during eccentric action (Komi, Kaneko, & Aura, 1987), as well as mechanical diversity, e.g., a muscular tendon complex stretching has been proved while muscle produce strength concentrically or eccentrically (G Guilhem, Cornu, et al., 2010). The latter is associated to exercise induced muscle damage, during which strength loss (Hubal et al., 2007), muscle soreness and swelling (Cleak & Eston, 1992; Prasartwuth, Taylor, & Gandevia, 2005), augmented Creatin Kinase blood concentration (K Nosaka & Clarkson, 1996; L. L. Smith et al., 1994), increased inflammatory markers (Peake et al., 2005) and decreased passive ROM (Trevor C Chen & Nosaka, 2006), those indicate acute muscle functionality impairment. Anyway, when a second training is performed, previous symptoms are attenuated, defining a so called Repeated Bout Effect, due to a inflammatory (Pizza et al., 1996), neural (K Nosaka & Clarkson, 1995) or mechanical (Morgan, 1990) causes.

Eccentric training is typically performed using isokinetic, i.e. constant velocity, or isotonic, i.e. constant external load. Main differences in acute isokinetic Vs Isotonic actions have been displayed by Guilhem and coll., showing a different EMG / muscle length ratio, but it seems that IT reaches an higher neural activation due to the action set, while IK task is to oppose highest torque when subject starts to perform a contraction. Similar acute fascicle stretch and pennation angle occur both in IK and IT, suggesting neural differences those can explain different torque production behaviour (Gaël Guilhem et al., 2011).

Focusing on training induced changes, a recent review considered researches those investigated muscle adaptations using isokinetic (IK) or isotonic(IT) eccentric regimen. When strength is considered, IT appeared to be more efficient than IK, while the latter seemed to induce greater muscle mass increments(G Guilhem, Cornu, et al., 2010). To our knowledge, no studies compared architectural changes and contra lateral effect using IK and IT eccentric training.

Due to a lack of studies that matched IT and IK exercise training for volume load, aim of the study is to measure strength, architectural alterations, muscle mass and cross education effect after short term unilateral eccentric IK or IT knee extension training.

Methods.

Subjects: Forty-nine healthy males were randomly assigned to IK, IT or control group (CG). Exclusion criteria were knee orthopedic diseases and continuous use of leg extension during their training in the previous six months. All subjects gave written informed consensus before the study, which was approved by the Human Research Ethics Committee of University of Verona.

Training*:* IK session consisted in 5 sets of 10 maximal isokinetic eccentric contractions at 60 deg/s, from 5° to 90° (0°= full extension) on isokinetic dinamometer (Cybex, Lumex, Ronkokoma, NY, USA). In order to maintain similar volume between two groups, Isotonic unilateral leg extension load was fixed at 120% 1RM. Such workload was chosen because average Eccentric /

concentric isokinetic peak ratio calculated among all the subjects was 119.8±13%. Range of motion was approximately 90°, while subjects were instructed to maintain a 1,5 second as Time Under Tension (TUT), in order to execute each repetition at average speed of 60 deg/sec. Subject received time visual feedback. IT training was performed on Leg extension (Technogym, Gambettola, Italy). Training lasted 7 weeks, 2 sessions per week.

Testing procedures. The same measurements order was maintained in each test session, in order to standardize all conditions. Both legs were tested.

Strenght measurement.

1RM. Single Isotonic Knee extension 1RM was tested on gym device (Leg extension, Technogym, Gambettola, Italy). Testing protocol started with warm up consisting in 2 sets per 15 repetitions. Based on formula

Theoretical 1RM= load/1,0278-(0,0278·n°executed repetition)

where load is expressed in KG lifted during set, 90% 1RM was used as initial 1RM attempt. Afterwards additional load of 2.5kg was added until subjects failed to lift the lever. The other limb was blocked by an operator. Same procedure was repeated with the other leg. Standardized verbal encouragements were adopted by the operator during each attempts

Maximal voluntary contraction (MVC). Subjects performed torque measurements on Isokinetic dynamometer (Cybex, Lumex, Ronkokoma, NY, USA). Subjects were fixed on dynamometer seat: trunk and shoulders were blocked by two belts in order to have back close to the backseat. Tested knee was fixed by a belt and ankle was close to the lever. The untested leg was blocked by another lever. After warm up consisting in 10 submaximal eccentric and 10 concentric repetitions, subjects completed 3 maximal attempts in both modalities at 60°/s. Range of motion was from 90° to 5°(0°= full extension). Further set consisted in 3 maximal isometric repetitions at 60°. Subjects were motivated by the operator to perform the whole protocol as hardest as possible. At baseline, protocol was repeated twice, after 3 days, in order to avoid learning effect using isokinetic machine. Best torque was considered as baseline.

Lean muscle mass. Changes in fat free mass of trained(T) and untrained leg(UT) were detected by Dual Energy X-ray Absorptiometry (DEXA) (QDR Explorer W, Hologic, MA, USA). The lower limit of the thigh sub-region were obtained by a flat parallel line between femur and tibia; the upper one by a line that crosses perpendicularly the neck of femur. Amount of lean thigh mass was considered in this study.

Architectural measurements. Architectural analysis has been done on both T and UT vastus lateralis muscle. A strong correlation between vastus lateralis and whole quadriceps was previously demonstrated (Blazevich et al., 2006). The measurement was obtained on muscle at 39% of distal leg length. Subjects seated with limb flexed at 90° and muscle completely relaxed. The image was acquired by an ultrasound scanner(Acuson P50, Acuson Corporation, CA, USA). The ultrasound was oriented longitudinally to the fascicle length and perpendicularly to the skin. Two images of the same muscle were acquired. Measurements of pennation angle and fascicle thickness were obtained by a software(ImageJ, NIH, Maryland, USA).Fascicle thickness was the distance between the two aponeurosis and pennation angle was the angle between fascicle and aponeurosis.Finally fascicle length was calculated by a formula

Fascicle length= $\sin(\gamma+90^\circ)*FT/\sin(180^\circ-(\gamma+180^\circ-\theta)$

where y is the angle between deeply and superficial aponeurosis, θ is the pennation angle and FT is fascicle thickness (Blazevich et al., 2006).

Statistical analysis: Analysis was performed with SPSS 16.0(SPSS, Chicago, IL). A three-way repeated measures Anova (Time x Group x Side) was used to detect conditions interaction. Then paired post hoc effects were investigated using Bonferroni correction. Significance level was fixed at $p<0,05$. Analysis was repeated after log transformation

Results

Training has been completed by all subject. No accidents occurred during workout.

	IK	IT	CG
	T		
1RM (Kg)	55±7/ 60±10**°°	58±11 / 64±13***°°°	65±14/64±14
Conc Peak (N/m)	220±34 / 237±52**°°	235±50 / 247±52*°°	254±53 / 242±50
Ecc Peak (N/m)	259±45 / 344±58***°°°§§	294±73 / 332±64***°°°	308±85 / 296±71
Isom Peak (N/m)	239±48 / 273±61***°°°	269±57 / 285±58**°°°	273±63 / 252±56
FFM (Kg.)	6,16±2,28/ 6,18±2,29	7,41±1,30/7,42±1,16	8,07±1,23/8,02±1,43
Pennation angle(°)	8,65±2,04 / 9,59±2,16	8,71±1,85 / 9,06±2,51	8,14±2,45/8,49±1,75
Thickness(mm)	21,3±3,6 / 24,7±5,4**	19,4±2,9/23,6±2,7***	22,2±4,2 / 22,6±3,9
Fascicle length(cm)	9,8±3,5 / 11,3±4,4**	10,3±1,4 /11,7±1,4**°	11,1±2,0 / 11,2±1,9
	UT		
1RM (Kg)	55±9 / 59±10*°	59±12 /63±14**°	64±12 /63±12
Conc Peak (N/m)	221±30 / 230±32	232±42 /232±43	242±56 / 232±50
Ecc Peak (N/m)	269±48 /297±44**°°	284±62 / 305±63*°	284±71 / 274±66
Isom Peak (N/m)	241±42 / 257±47*°	272±52 / 268±46	260±62 / 248±55

Table 4.1: Changes in dependent variables at Pre(Mean±SD) / Post (Mean±SD). T= trained limb UT: not trained limb.
Pre Vs. Post. *p<0,05; **p<0,01; ***p<0,001.
Training Vs CG. °p<0,05; °°p<0,01; °°°p<0,001.
IK Vs IT. § p<0,05; §§ p<0,01; §§§ p<0,001

Strength. Similar changes occurred in both groups after training. 1RM increased in IK(7,6%, CI95% 3,3 to 12,1) and IT(9,5%, CI95% 5,5 to 13,5), as well as concentric peak torque (7,0%; 2,9 to 11,5 Vs 5,3%; 1,5 to 9,2) and isometric peak torque (14,1%;9,5 to 19 Vs 6,0%;2,1 to 10,1). All parameters were significantly higher than CG (p<0,001), while no difference was revealed comparing training groups. Only eccentric peak torque was greater (p<0,01) in IK (32,4%; 24,9 to 40,6) than IT(14,2%; 8,2 to 20,6), probably due to a sort of learning effect, considering that training and testing were executed in the same modality.

Muscle mass. DEXA exam did not show augment in muscle mass neither in IK (0,6%;-1,6 to 2,7) nor in IT (0,5%; -1,2 to 2,2).

Architectural adjustments. Fascicle length significantly increased in IK (14%; 4,8 to 24) and IT (14,2%; 5,8 to 23,4). Similarly, fascicle thickness was greater in IK(14,6%; 5,7 to 24,1) and IT (21,9%; 13,4 to 30,9). In both cases no difference was detected comparing training groups. Pennation angle remained unchanged both in IK(0,9°; -0,7 to 2,6) and IT(0,3°; -1,1 to 1,8).

Cross Education Effect. Considering untrained limb, strength augmentation occurred similarly when tested 1RM(6,3% in IK Vs 6,5% in IT) and eccentric peak torque (11,2% Vs 7,8%). Isometric peak torque was higher, compared to baseline, only in IK(6,3%; CI95% 0,4 to 12,6), even if such increment was not significant if compared with IT. Finally, concentric peak torque did not increase.

Discussion

Main results of this study are: 1) short term eccentric supra maximal knee extension training improved strength; 2) IK and IT showed analogous effects on quadriceps force; 3) fascicle length increased similarly after training; 4) untrained limb showed similar adaptation.

When performing eccentric only resistance training, it has been widely shown that it induces strength increase (Roig et al., 2009). Our outcomes did not detect a difference in term of strength gains after IT or IK. Such outcomes did not agree with review by Guilhem et coworkers, that found an higher effectiveness of IT training (G Guilhem, Cornu, et al., 2010). However, authors matched force increments for number of sessions, when total volume was not considered. For example, the studies that used IT training knee extension ranged from 40% to 150% of 1RM or eccentric maximal repetition (Pavone & Moffat, 1985) (Sorichter et al., 1997), from 6 to 60 sessions (Spurway, Watson, McMillan, & Connolly, 2000)(R. C. Smith & Rutherford, 1995). When considering IK training, it is supposed that each eccentric contractions is performed maximally, but angular velocity should be considered. Previous researches that investigated torque improvement in quadriceps used constant velocity ranging from 30°/s (Blazevich et al., 2003) to 120°/s (Duncan, Chandler, Cavanaugh, Johnson, & Buehler, 1989), while sessions number ranged from 12 (Mayhew, Rothstein, Finucane, & Lamb, 1995) to 60 (Miller et al., 2006). When comparing resistance training exercise volume, several methods has been proposed (McBride et al., 2009). In our study, average eccentric isokinetic peak torque was 120% of the concentric one, and consequently, IK training was supposed to be performed around such average workload. In order to equalize volume, IT group performed training at 120% 1RM, and time under tension was kept similar by a visual feedback. In this way, similar volumes could have led to similar strength gains. Eccentric peak improved much more in IK than in IT, but this difference can be due to the fact that training and testing modalities were equal (e.g.: learning effect).

Muscle mass increment was not detectable after 7 weeks, confirming that such adaptations involves processes those require usually more time. (G Guilhem, Cornu, et al., 2010)

Changes in muscle architecture has been shown in both training groups. Increment in fascicle length has been previously reported after eccentric training in few studies. However, contrasting outcomes derived from IK coupled concentric - eccentric training, after which no adjustments in fascicle length, thickness and pennation angle occurred using same our angular velocity (60°/s) after 5 weeks(Blazevich, Gill, Deans, & Zhou, 2007), whereas same author detected changes in fascicle length and pennation angle after IK concentric or eccentric slow speed (30°/s) training after 5 and 10 weeks. (Blazevich, Cannavan, Coleman, & Horne, 2007b). In addition, using an enhanced eccentric protocol, early adaptations occurred after 3 weeks in fascicle length after bilateral leg extension (Seynnes et al., 2007). In our data, fascicle length increment could reflect an increased number of serially sarcomeres (Butterfield et al., 2005), while unchanged pennation angle is linked to unaltered quadriceps mass(Kawakami, Abe, Kuno, & Fukunaga, 1995)(Blazevich, Cannavan, Coleman, & Horne, 2007b).

Strength increment occurred also in untrained limb. Few studies investigated cross education effect using IK or IT lengthening training. Hortobagyi and coll. reported that, expressed in percentage of trained limb increments, eccentric training improved eccentric torque by 77%, while concentric torque increased by 16% and isometric by 40%. (HORTOBAGYI, LAMBERT, and J. P. HILL 1997) To our knowledge, no study investigated cross education using eccentric IT supra maximal training. In this research 1RM, in untrained limb, increased by 83% in IK and 68% in IT compared to trained leg, while eccentric peak torque incremented by 35% in IK and 55% in IT. In contrast, only IK improved isometric peak torque (44%), while no changes were detectable measuring concentric torque. The latter should refer to training testing modality relationship, but we should expect a greater cross education in IK eccentric torque. (Lee & Carroll, 2007). However, mechanism remain to be clarified. We used control group, that did not involve any training, without strength improvements in both legs. The importance of control group has been explained by Gandevia and coworkers, cause of testing familiarization that involves trained subjects (Munn et al., 2004). We found inter group differences, supporting time course contra lateral adaptations.

In conclusion, this study suggests that IK and IT, when engaged with similar training volumes, resulted in similar strength gains and architectural adjustments. Furthermore, untrained limb had similar torque augmentation, while longer training period must be used in order to record muscle mass increase.

Chapter 5: Study 3

Repeated Bout Effect induced by eccentric isoinertial device.

Coratella G[1], Chemello A[1], Impellizzeri F M[2] [3], Schena F[1].

[1]Department of neurological, neurophisiological, morphological and movement science, University of Verona, Italy.

[2] CeRiSM, Research Center in for Sport, Mountain and Health, Rovereto, Italy.

[3]Schulthess Kilinik, Zurich, Switzerland.

Abstract

Muscle damage is proved to occur after eccentric training. Moreover, it confers protection to a subsequent session, i.e.: repeated bout effect. Aim of the study is evaluate if lengthening contraction enhanced by inertial flywheel squat will cause symptoms of muscle injury and following protection.

Twelve healthy amateurs males performed 100 maximal squat repetitions using inertial device. At baseline, after training and up to 4 days after CK blood concentration, Knee extensors strength, muscle soreness and jump performance were measured as markers of muscle damage. Same protocol was repeated after 3 weeks.

Compare to baseline, CK and muscle soreness increase respectively up to 3 and 4 days, while strength loss and jump height were affected only post training. The second bout revealed significant markers decrement.

Inertial flywheel squat induce classical symptoms of muscle injury, even if strength loss and performance could be positively influenced by neural patterns. Eccentric overload does protect muscle at least up to 3 weeks.

Introduction.

It’s well known that eccentric training induces muscle damage , i.e. DOMS (D. Chapman et al., 2006; P M Clarkson et al., 1992; Priscilla M Clarkson & Hubal, 2002; Paddon-Jones et al., 2005). However, first lengthening session confers protection, causing a reduction in muscle injury symptoms (Howatson, Van Someren, & Hortobágyi, 2007; M P McHugh, Connolly, Eston, & Gleim, 1999; Malachy P McHugh, 2003; K Nosaka & Clarkson, 1995; K. Nosaka, Sakamoto, Newton, & Sacco, 2001; Vissing, Bayer, Overgaard, Schjerling, & Raastad, 2009). In order to perform eccentric contraction, isokinetic device or constant external load are needed. It has been recently developed a device that intensifies eccentric action using the inertia (YoYo Technology ™, Sweden) (Berg & Tesch, 1994): such apparatus offers resistance employing the inertia of its flywheel, therefore can be defined as gravity independent. In this way, the concentric phase imparts spin against the flywheel’s inertia. When the strap (that links subjects to the device) is totally unwound, the flywheel starts to recoil it until the strap arrived to a stop. Using this stratagem, the eccentric phase is enhanced by the kinetic energy developed during the concentric action (Norrbrand et al., 2008). For example, during squatting, subject has to perform concentric action as fast as possible, and then resist to enhanced eccentric contraction.

To our knowledge, no studies investigated muscle damage induced by eccentric inertial enhancement. For these reasons, first aim of the study is to analyze muscle damage induced by inertial flywheel squat session. A second purpose is to verify if eccentric emphasis induces protection when the same training is repeated after 3 weeks. Even if such movement load is distributed among several muscle actions, quadriceps action is a key of squat performance (Finni, Komi, & Lepola, 2000) and it is possible to consider it as squat leading muscle. Finally, we want to use SJ and CMJ as marker of muscle damage, comparing their time course to the classical indirect methods.

Methods.

Experimental design. To investigate muscle damage, subjects were tested at baseline, immediately after training, and up to 4 days after the session. Then, to examine the magnitude of repeated bout effect, the same protocol was repeated after 3 weeks. Subjects were instructed to avoid any form of heavy physical activities 2 days earlier the baseline test and until the end of testing sessions. Basal values were collected 3 days before training.

Subjects. Twelve healthy sporty males (age 24y ± 3) were recruited for the experiment. Joint or muscle diseases were considered as exclusion criterion, in addition to regular eccentric training. All subjects signed informed consensus and the study was previously approved by Ethical Committee of University of Verona.

Training. Subjects performed 10 sets per 10 maximal repetitions of YoYo squat, with 1 minute recovery between sets. A visual feedback provided by an encoder (Smart Coach™, Stockholm, Sweden) reported intensity and work expressed for each movement, in order to monitor strength expression. They received standardized verbal encouragement to perform each repetition maximally. Subjects had 2 familiarization sessions in the previous week.

Testing.

Biochemical Marker. Creatin Kinase (CK) serum concentration was measured using capillary blood (Reflotron Plus, Roche, Germany). Blood was collected in a 32µ/l litium heparin single use capillary pipette (Reflotron PST, Roche, Germany) after prick by sterile single use lancing device (Accucheck, Roche, Germany).

Muscle soreness. A visual analogic scale (VAS) consisting of 100mm line with “no pain” at the left margin and “extremely painful” at the right margin, was assessed to detect soreness during quadriceps palpation. Subjects were seated and knee angle was 90°, while dominant limb was totally relaxed. Palpation was standardized by operator at 50% of vastus medialis, vastus lateralis and rectus femuris length.

Strength. Subjects performed torque measurements on Isokinetic dynamometer (Cybex, Lumex, Ronkokoma, NY, USA). Subjects were fixed on dynamometer seat: trunk and shoulders were blocked by two belts in order to have back close to the backseat. Tested knee was fixed by a belt and ankle was close to the lever. The untested leg was blocked by another lever. After warm up consisting in 10 submaximal eccentric and 10 concentric repetitions, subjects completed 3 maximal attempts in both modalities at 60°/s. Range of motion was from 90° to 5°(0°= full extension). Further set consisted in 3 maximal isometric repetitions at 60°. Subjects were motivated by the operator to perform the whole protocol as hardest as possible. At baseline, protocol was repeated twice, after 3 days, in order to avoid learning effect using isokinetic machine. Best torque was considered as baseline.

Performance. SJ was measured using Optojump (MIcrogate, Bolzano, Italy). Subjects were standing placed between two bars. They perform a SJ keeping free upper limbs, starting by a self selected position.

Statistical analysis. Dependent parameters were analyzed by two – way repeated measure ANOVA performed using SPSS 16.0(SPSS, Chicago, IL). Post hoc analysis using Bonferroni's correction followed to investigate factor Session (2 level) or Days (6 level) significance. P level was fixed at p<0,05.

Results

All subjects completed both training sessions. No accidents occurred during experimental period.

	CK (iU/L)	**Soreness (A.U.)**	**Ecc Peak (N/m)**	**Conc Peak (N/m)**	**Isom Peak (N/m)**	**SJ (cm)**
I Bout	**287±103**	**0.6±0,8**	**307±54**	**229±39**	**298±50,5**	**38,1±4,5**
II Bout	**193±101**	**0,5±0,7**	**325±56**	**237±34**	**326±65**	**38±5**

Figure 5.5: Baseline values expressed as Mean±SD. *p<0,05 between bouts

Only Soreness and Isometric Peak measurements revealed Session X Days significant interaction (respectively p<0,05 and p<0,01).

	session	**day**
CK	n.s.	n.s.
Soreness	0,000	0,008
Ecc Peak	0,000	0,012
Conc Peak	0,000	0,001
Isom Peak	0,000	0,001
SJ	0,028	0,003

Figure 5.6: significance level of One-Way ANOVA.

CK blood concentration . Compared to baseline, during the first bout, CK activity was significantly increased after 1(330%, CI 95% 44 to 1184, p<0,01) , 2(383%, CI95% 66 to 1309, p<0,01)and 3 days(239%, CI95% 17 to 881, p<0,01 and p<0,05), while, after second bout, CK level was not augmented. CK concentration was significantly lower after the second training session at day 2 (-50%, CI95% -70 to -19, p<0,05) and 3 (-43%, CI95% -70 to 0, p<0,05).

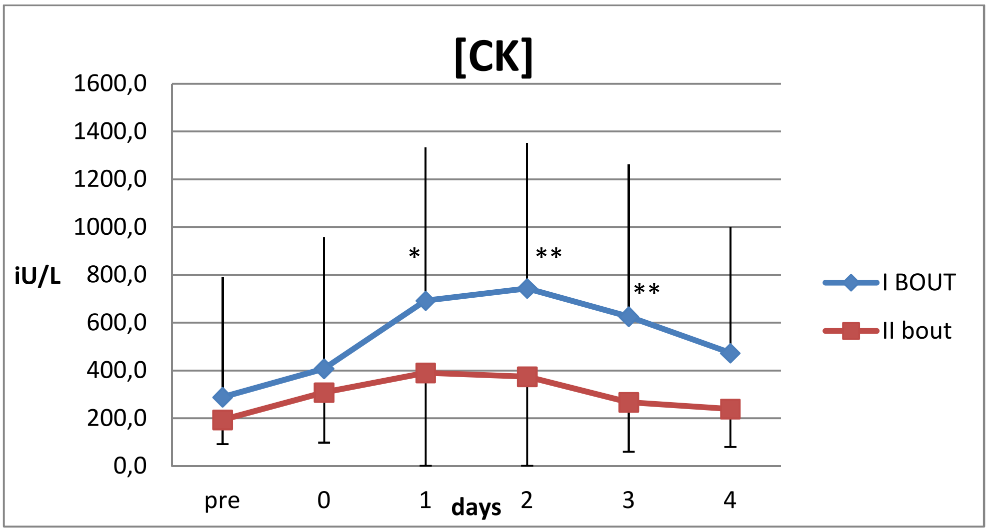

Figure 5.3. Time course CK blood activity during bout 1 and 2. *P<0,05 and ** P<0,01 compared to baseline.

Muscle soreness. Compared to the baseline, after first training session, pain was significantly higher at day 1 (4,9 a.u.., CI95% 2,4 to 7,4, p<0,001) 2 (5,5 a.u., CI95% 2,9 to 8,2 , p<0,001), 3 (4,1 a.u., CI95% 1,7 to 6,5, p<0,01) and 4 (3,0 a.u., CI95% 0,9 to 5,0, p<0,01), whereas, after second workload, soreness was superior only after 24 (2,2 a.u., CI95% 0,1 to 4; p<0,05) and 48 hours (3,1.a.u., CI95% 0,2 to 5,9; p<0,05) then returning at basal values . Keeping in account both sets, difference was found after 1 (-2.8 a.u., CI95% -4,3 to -1,3; p<0,01), 2 (-2,6a.u., CI95% -3,7 to -1,4; p<0,01), 3 (-2,4 a.u., CI95% -3,5 to -1,4; p<0,001) and 4 days. (-2,6 a.u., CI95% -3,4 to -1,8; p<0,001)

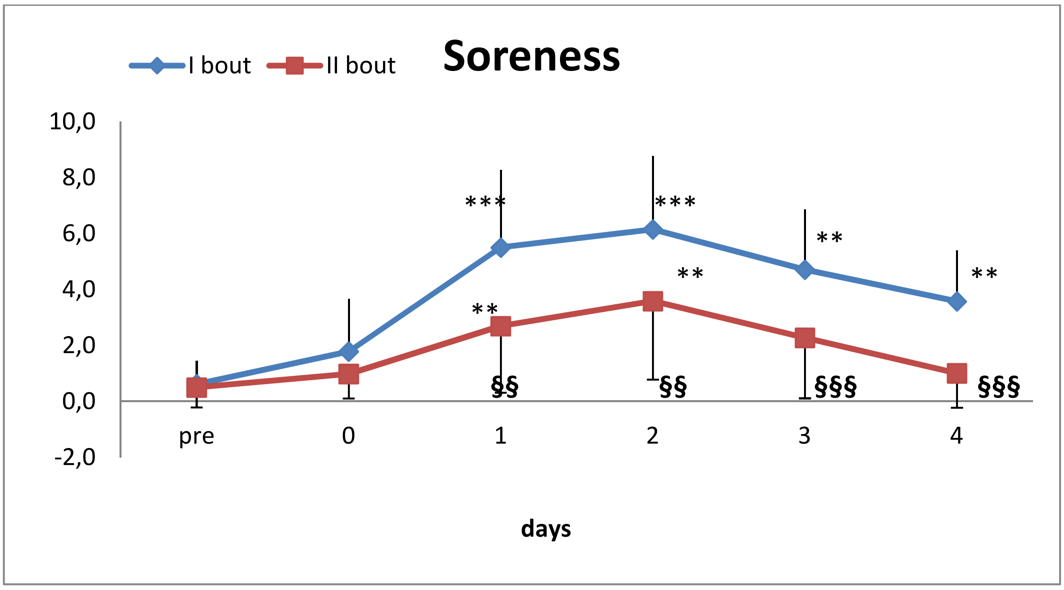

Figure 5.4. Time course muscle soreness during bout 1 and 2. **P<0,01 and *** P<0,001 compared to baseline. §§ P<0,01 and §§§ P<0,001 between bouts

Muscle strength. Compared to baseline, eccentric peak torque did not change significantly after both training sessions. However, it was significantly higher during the after the second bout at day 1(14,3%, CI95% 9 to 19, P<0,001), 2 (20,9%, CI95% 5 to 39,P<0,01), 3 (17,1%, CI95% 8 to 27, p<0,01) and 4 (17,2%, 7 to 29, P<0,01).

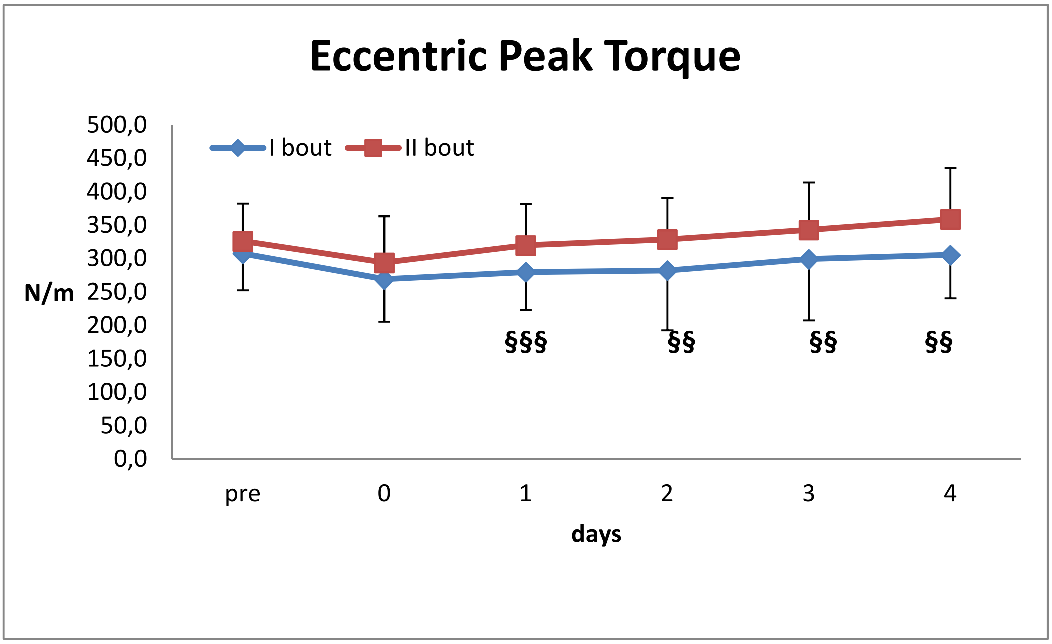

Figure 5.5.: Time course of eccentric peak torque during bout 1 and 2. **P<0,01 and *** P<0,001 compared to baseline. §§ P<0,01 and §§§ P<0,001 between bouts

Compared to baseline, concentric peak torque was significantly lower immediately after training in first bout (respectively -16%, CI95% -25 to -7, P<0,01) and second one (-9,4%, CI95% -17 to -2, P<0,05), while no differences appeared during other testing sessions, with exception of day4 of latter training, when torque was greater than baseline (6,8%, CI95% 2 to 12, P<0,05). Compared to the first bout, second session revealed higher values immediately after(11,9% CI95% 3 to 22, P<0,05), after 1 day (9,1%, CI95% 2 to 16, P<0,05), 2 days (15%, CI95% -2 to 35, P<0,05) 3 days (14,7%, CI95% 2 to 27, P<0,01), and 4 days (14,2%, CI95% 7 to 22, P<0,01).

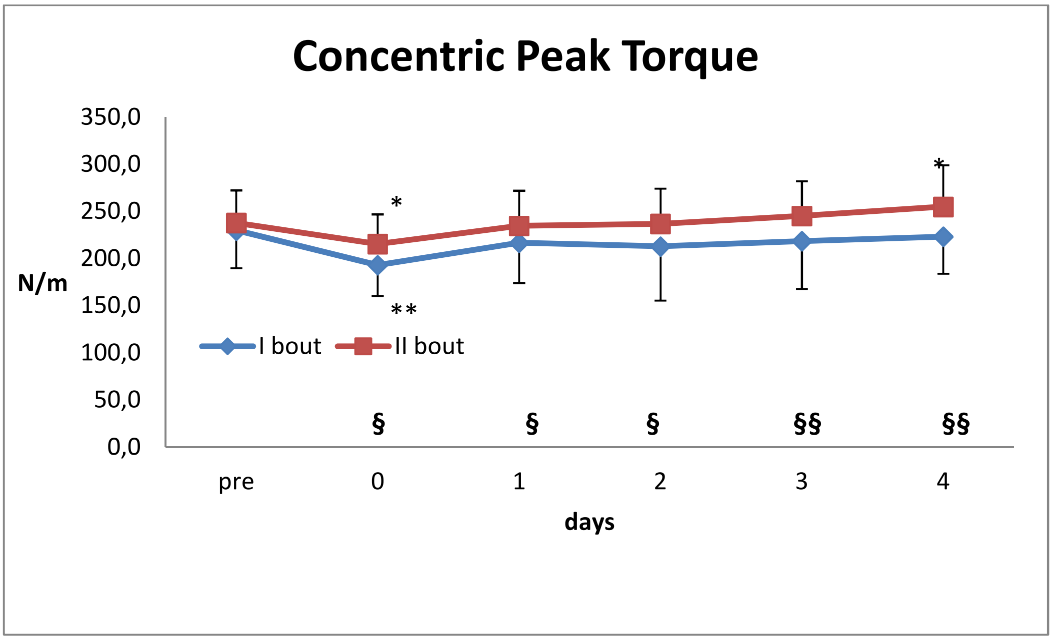

Figure 5.6.: Time course of concentric peak torque during bout 1 and 2. *P<0,05 and ** P<0,01 compared to baseline. § P<0,05 and §§ P<0,01 between bouts

Isometric Maximal Voluntary Contraction (MVC) remained not significantly altered during bout 1 and 2 except for torque immediately after training (respectively -9,1%, CI95% -15 to -3, P<0,01 and -11,9%, CI95% -17 to -7, p<0,001). Greater MVC after second bout resulted after 24h (11,2%, CI95% -2 to 24, p<0,05), 48h (14,0%, CI95% 5 to 24, p<0,01), 72h (19,4%, CI95% 10 to 30, P<0,001) and 96h (14,5%, CI95% 6 to 24, p<0,05).

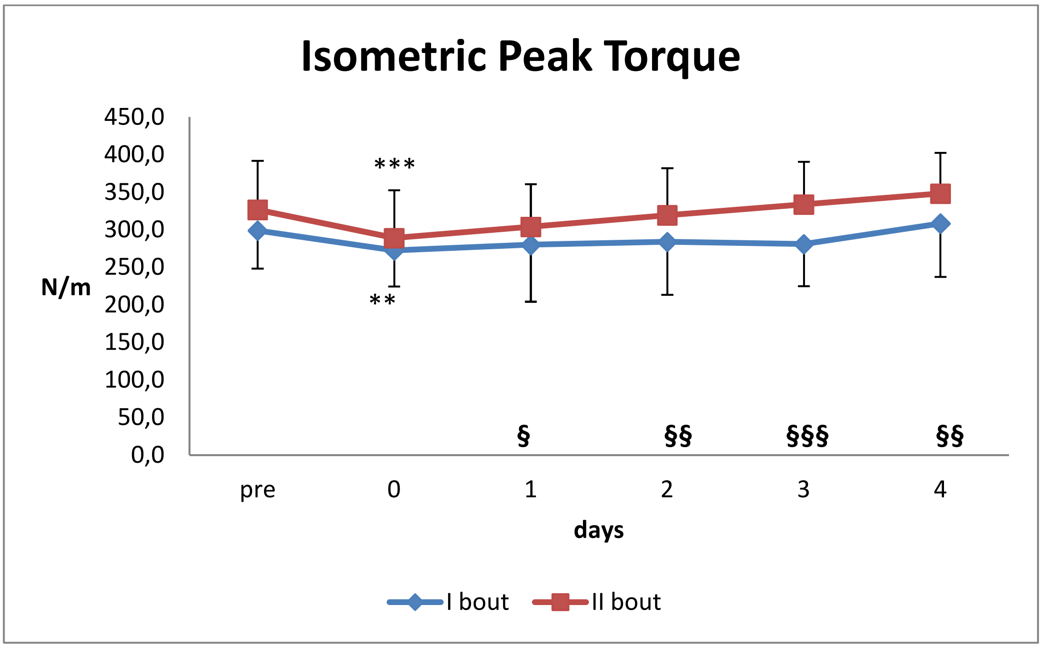

Figure 5.7. Time course of isometric peak torque during bout 1 and 2.P<0,01 and *** P<0,001 compared to baseline. § P<0,05, §§ P<0,01 and §§§ P<0,001 between bouts.**

Performance. Jump height was lower immediately after training and after 1 day in bout 1 (respectively -17,8%, CI95% -28 to -7, p<0,01 and -13%, CI95% -23 to -1, p<0,05). After 4 days was significantly increased in bout II compared to bout I (6,4%, CI95% 2 to 11, P<0,05).

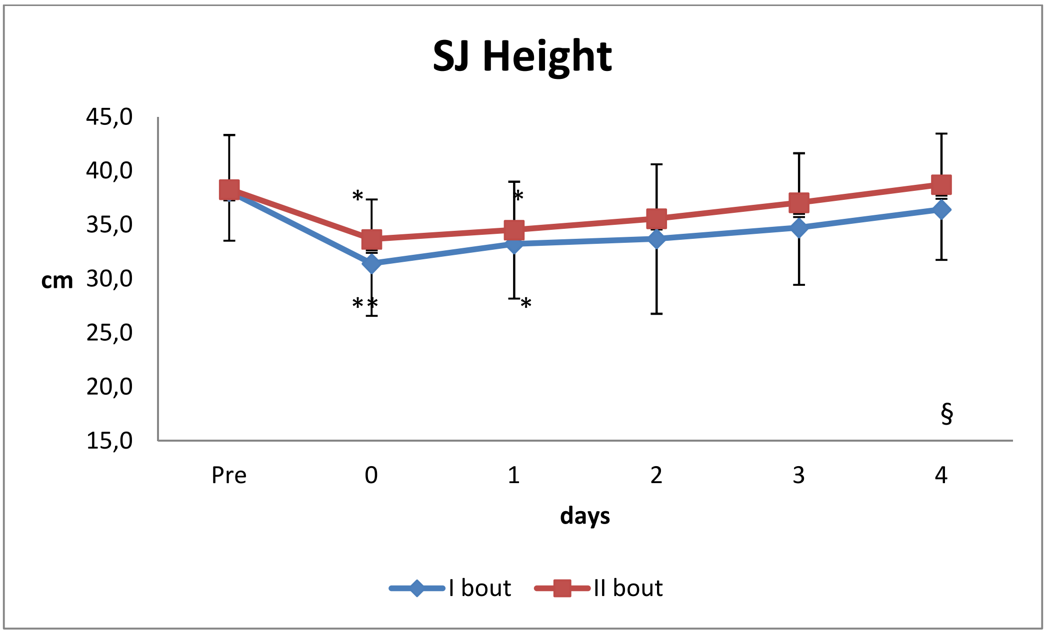

Figure 8. Time course of SJ performance during bout 1 and 2.P<0,01 and *** P<0,001 compared to baseline. § P<0,05, §§ P<0,01 and §§§ P<0,001 between bouts.**

Discussion

This is the first study, to our knowledge, in which YoYo flywheel was used to induce muscle injury and then Repeated Bout Effect.

Muscle damage. Creatin Kinase blood concentration, compared to the baseline, reached significantly greater values only in the first bout. Such CK activity, anyway, was lower when eccentric single joint exercise was performed (K Nosaka & Clarkson, 1996)(Jamurtas et al., 2005), due to load redistribution in squat multi joint exercise. We can hypothesize that good execution technique permitted to minimize muscle injury, even if each repetition was maximally performed. In addition, our subjects were physically active, and such condition could have influenced plasma CK activity (Newton et al., 2008). Finally, it is known that CK concentration has a large inter-subject variability (K Nosaka & Clarkson, 1996)

Strength had not impairment after time course, except for low performance due to fatigue. Quadriceps torque was almost unaffected by damaging training, probably due to a “self safe” range of motion, in which thigh was not parallel to flat at the lowest position.

However, quadriceps soreness after 1 day was augmented until day 4. Magnitude of DOMS has been showed to poorly reflect the magnitude of muscle damage, and it is scarcely correlated with other indirect markers(Kazunori Nosaka et al., 2002). Due to the fact that soreness is thought to be a kind of muscle structure integrity controller (U Proske et al., 2003), and considering the small quadriceps strength loss, we can suggest that other muscles (e.g.: gluteus) increased their intervention.

We used performance task to monitor muscle injury. Changes in jump height means that sport related actions are affected by heavy training. Significant reduction in similar training action lasted 24 hours, that is well linked to quadriceps strength loss. Neural factors should explain faster strength recovery compared to inflammation and soreness markers. We can speculate that an augmented inter muscular and intra- muscular coordination occurred rapidly to minimize strength and performance loss while inflammation developed its markers.

Repeated Bout Effect. With exception of CK serum concentration, markers of muscle damage were significantly inferior after second session compared to the first one(T C Chen & Nosaka, 2006; Lavender & Nosaka, 2008b) . (figure 5.2) Enhanced eccentric action during YoYo squat acted as protector against a second bout of same workload, and effect lasted at least 3 weeks. Lack of difference in CK concentration is due to a relative lower values in the first bout, as explained above. Strength loss and SJ performance should be mediated by neural control: anyway, quadriceps strength was significantly higher after second bout. These data suggest a change in neural pattern control, in which workload is re-distributed among muscles. Minor quadriceps soreness perceived in the second session support this hypothesis.

In conclusion, YoYo squat training induce muscle damage, and after 3 weeks, confers defense against a subsequent bout. Marked lengthening contraction can be addicted as main cause both for injury and protection. Performance index could be used as recovery indicator, but it should be coupled with other classical marker, in other to better understand when a full restore happened in subjects.

Practical Application

Monitoring YoYo squat recovery time is important to trainers and conditioners that propose such training to their athletes. Due to initial injuring effect, we can suggest to use it during pre season, and then periodically exercised to keep strength and performance higher. Squat jump could be used as good field damage marker, maybe coupled with perceived soreness, due to their easy suitability.

Chapter 6: Study 4

Comparison of traditional Vs inertial squat jump training effects on strength, muscle and performance.

Coratella G[1], Giorgi G[1], Trepin M[1], Milanese C[1], Impellizzeri FM[2 3], Schena F[1 2]

[1]Department of neurological, neurophisiological, morphological and movement science, University of Verona, Italy.

[2] CeRiSM, Research Center in for Sport, Mountain and Health, Rovereto, Italy.

[3]Schulthess Kilinik, Zurich, Switzerland

Abstract

Inertial flywheel squat has been proved to increment strength and muscle mass. Aim of the study is to measure transfer in performance, comparing it with a traditional field training.

Forty five healthy males underwent to inertial squat (IS) or weighted squat jump (WSJ) or control group. (CG) Before and after 16 sessions of 60 repetition knee extensors and flexors torque, lower limbs lean mass, quadriceps architecture, jump height, 30m dash, 20m shuttle and changing direction ability were tested.

Compare to CG, Knee extensors torque increased similarly in IS and WSJ, while only former improved knee flexors strength. Muscle muscle mass and fascicle length augmented more in IS than WSJ, as well as jump. Similar improvements occurred in 20m shuttle and 30m dash, while changing direction ability improved only in WSJ.

These data showed that both IS and WSJ are adequate stimuli to improve strength, and they should be used in sport with a great power development.

Introduction

Resistance training is frequently used by athletes and conditioners in order to improve strength. Classical exercise implies a positive work, while muscle shorten, and a negative phase, in which muscle lengthen. It is widely showed that eccentric contraction is an important stimulus to increase force and muscle mass(Goldspink, 1999; Roig et al., 2009)(Dudley et al., 1991). However, lengthening contraction needs to be performed using overload, in order to let muscle stretched by a load greater than torque developed. A new technology device has been developed to emphasize eccentric phase by inertial load(YoYo Technology™, Sweden). For example, while performing a squat exercise, subject is tied to a stripe that is unrolled during concentric contraction and it is rolled by inertia during landing phase, accentuating braking action (Berg & Tesch, 1994). Of course, faster the shortening contraction, greater the inertia, and consequently, higher the negative braking force developed.

Anyway, athletes and amateurs frequently include barbell squat in their workout to improve lower limb muscle force and power. Strength transfer to sport performance, such as sprinting and jumping, has been showed to be strongly correlated (Wisloff, 2004). Comparison between classical and inertial training has been recently studied, and the latter resulted in greater muscle mass and strength increment (Seynnes et al., 2007)(Norrbrand et al., 2011)(Norrbrand et al., 2008).

Nonetheless, weight training does not represent exactly the way of inertial exercising. Considering squat, only the last repetitions are performed maximally, while the use of flywheel permits to the trainee to exert each single movement with maximal strength (Norrbrand et al., 2011). However, while executing squat jump (SJ) the task requires a rapid rate of force development in order to move centre of mass vertically, while, immediately after landing, jumpers need to brake kinetic energy developed during the flight descending part, performing eccentric contractions. For these features, in addition to very important task specificity, SJ has been included in athletes and amateur classical workout (Voelzke, Stutzig, Thorhauer, & Granacher, 2012).

To our knowledge, no studies compared inertial flywheel squat (IS) with WSJ; in addition, transfer in performance of training induced changes have not been previously investigated. Therefore, aim of the study is to put in comparison WSJ with IS measuring strength, muscle architecture and mass, and their implication in performance tasks.

Methods

Study design: In order to maintain similar inertia, 25% of body weight were added in squat jump, i.e. weighted squat jump, WJS. One week earlier baseline testing, subjects familiarized with both training modalities. Testing measurements were assessed at baseline and one week later the end of training.

Subjects: Forty-five healthy males were randomized assigned to WJS, IS or control group (CG). Subjects with orthopedic and muscle diseases were excluded from the study. All subjects gave written informed consensus, and research was previously approved by the Human Research Ethics Committee of University of Verona.

***Testing procedures*.** The same measurements order was maintained in each test session, in order to standardize all conditions.

Lean muscle mass. Changes in fat free mass of lower limb was observed by DEXA (QDR Explorer W, Hologic, MA, USA). The lean mass amount of entire lower limbs was considered.

Architectural measurements. Architectural analysis has been done on both T and UT vastus lateralis muscle. A strong correlation between vastus lateralis and whole quadriceps was previously demonstrated (Blazevich et al., 2006). The measurement was obtained on muscle at 39% of distal leg length. Subjects seated with limb flexed at 90° and muscle completely relaxed. The image was acquired by an ultrasound scanner(Acuson P50, Acuson Corporation, CA, USA). The ultrasound was oriented longitudinally to the fascicle length and perpendicularly to the skin. Two images of the same muscle were acquired. Measurements of pennation angle and fascicle thickness were obtained by a software(ImageJ, NIH, Maryland, USA).Fascicle thickness was the distance between the two aponeurosis and pennation angle was the angle between fascicle and aponeurosis.Finally fascicle length was calculated by formula:

$$\text{Fascicle length} = \sin(\gamma+90°)*FT/\sin(180°-(\gamma+180°-\theta)$$

where γ is the angle between deeply and superficial aponeurosis, θ is the pennation angle and FT is fascicle thickness (Blazevich et al., 2006).

Strenght measurement.

Maximal voluntary contraction (MVC). Subjects performed knee extension and flexion torque measurements on Isokinetic dynamometer (Cybex, Lumex, Ronkokoma, NY, USA). Subjects were fixed on dynamometer seat: trunk and shoulders were blocked by two belts in order to have back close to the backseat. Tested knee was fixed by a belt and ankle was close to the lever. The untested leg was blocked by another lever. After warm up consisting in 10 sub-maximal eccentric and 10 concentric repetitions, subjects completed 3 maximal attempts in both modalities at 60°/s. Range of motion was from 90° to 5°(0°= full extension). Further set consisted in 3 maximal isometric repetitions at 60°. Subjects were motivated by the operator to perform the whole protocol as hardest as possible. At baseline, protocol was repeated twice, after 3 days, in order to avoid learning effect using isokinetic machine. Best torque was considered as baseline. Only dominant leg was tested. Eccentric Hamstring/ concentric quadriceps peak torque ratio (so called Functional Ratio) was calculated after test.

Performance test.

Jump. Squat Jump (SJ) and Counter Movement Jump (CMJ) performance was measured using Optojump (Microgate, Bolzano, Italy). During jump, arms were blocked on hips.

Velocity test. Running time of 10m and 30m dash was measured using infrared system (Polifemo, Microgate, Bolzano, Italy). After recovery, subjects performed 20m+20m shuttle test, in order to verify braking ability. Changing direction agility was tested by T test run. Subjects had to running forward from

A to B (5m), than turn right and run forward to D or C (5m), than brake and run forward to C or D, than brake again and run forward to B and reach A as finish.

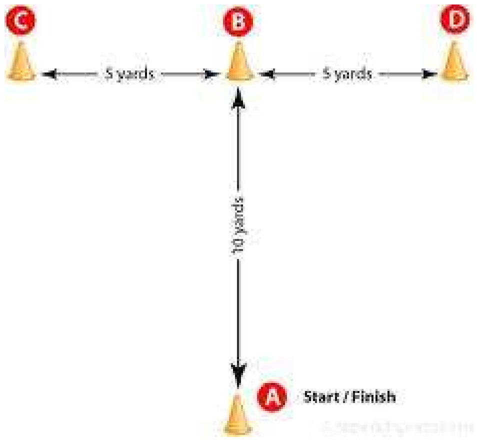

Figure 6.7.: T test.

Training: Both training groups performed 6 sets of 10 maximal repetitions, twice a week for 8 weeks. IS group was monitored during training by encoder (SmartCoach, Sweden). WJS subjects were instructed to brake as fast as possible after landing phase.

Statistical analysis: Analysis was performed with SPSS 16.0(SPSS, Chicago, IL). A two-way repeated measures Anova (Time x Group) was used to detect conditions interaction. Then paired post hoc effects were investigated using Bonferroni correction. Analysis of covariance was performed keeping baseline values as covariate. Significance level was fixed at p<0,05. Analysis was repeated after log transformation

Results.

All the participants concluded training. No accidents occurred during experimental period.

	IS	WSJ	CG
	Physiological measures		
Conc.torque(N/m)	226±39/241±40** ##	215±34/248±37***###	254±60/243±56
Ecc. ext. torque(N/m)	281±62/310±63**$	274±46/342±65***###	315±93/311±74
Isom ext-torque(N/m)	255±51/294±48***###	253±32/308±37***###	272±48/263±54
ConFlex torque(N/m)	146±26/159±30*$	133±25/132±25#	169±34/180±45
Ecc. flex torque(N/m)	195±46/218±53***$	175±41/177±34	199±38/204±43
Functional Ratio	0,88±0,32/0,94±0,28**##	0,82±0,12/0,71±0,08**$$$	0,74±0,11/0,72±0,16
Fat free mass(Kg)	*21,3±2,6/22,4±2,8***##*	21,6±2,2/22,1±2,2*	23,3±2,2/23,1±2,1
Pennation angle(°)	9,7±1,7/10,1±2,2	10,5±2,2/9,7±2,6	10,1±1,5/11,0±2,8
Fasc. thickness(mm)	24,3±2,2/27,2±2,3***	23,7±3,8/25,5±2,5**	26,8±3,2/27,1±2,1
Fascicle length(cm)	12,1±1,2/13,4±1,2***#	11,7±0,8/12,2±0,8*$$	13,2±1,5/13,3±1,3
	Performance measures		
10m dash(s)	1,93±0,13/1,90±0,08	1,95±0,19/1,85±0,18**##	1,89±0,12/1,92±0,08
30m dash(s)	4,54±0,23/4,47±0,20*	4,52±0,21/4,41±0,23**#	4,51±0,19/4,52±0,20
20m shuttle(s)	7,88±0,41/7,56±0,32***#	7,78±0,38/7,52±0,35***##	7,94±0,38/7,90±0,33
T test(s)	15,9±0,7/15,7±0,7 $$$	16,4±0,5/14,9±0,5***###	15,3±0,9/15,4±0,6
Squat Jump(cm)	37,6±5,8/41,8±5,9***##	38,6±5,7/40,3±4,9*	39,2±5,6/39,1±4,1
CMJ	39,5±7,1/43,5±6,9***##	39,4±6,4/41,1±7,1**$	40,5±4,7/42,0±6,7

Table 6.2: pre-post values mean±SD.

****p<0,05,**p<0,01,***p<0,001 pre Vs post***

$ p<0,05, $$ p<0,01, $$$ p<0,001 between training groups

#p<0,05, ##p<0,01, ###p<0,001 Vs control group.

Strength.

Both training groups improved extension torque significantly more than CG. However, when tested in eccentric modality, WSJ increased (24%, CI95% 18 to 30) more than IS (10%, CI95 5 to 16), p<0,01. Flexors torque improved only in IS both in Concentric (10%, CI95 2 to 17) and in eccentric mode(9%, CI95% 5 to 18). This data conditioned functional ratio: in fact, while IS improved it (0,07, CI95% 2 to 17), in WSJ it decreased (-0,10, CI95% -0,15 to -0,05).

Structural Changes.

Fat free mass. Both IS and WSJ increased lean lower limbs mass, respectively 5% and 2%, even if only the former is different from CG (p<0,01)

Architectural adjustments. No difference in vastus lateralis pennation angle were found in both training groups. Instead, fascicle thickness increased in IS (12%, 7 to 17) and WSJ (8%, 4 to 13). Also fascicle length increased in IS (11%, 7 to 15) and WSJ (4%, 1 to 8). However, the former was significantly higher compared to the latter (p<0,01).

Performance

Jump. When measuring Squat Jump, both training groups improved significantly after training compared to the baseline, respectively 11%(6 to 16) in IS and 4%(0 to 8) in WSJ, even if only the former was different from CG.(p<0,01). Jump with countermovement increased in IS (10%, 7 to 14) and WSJ (4%, 1 to 8) compared to baseline. Difference between groups emerged in IS Vs CG (p<0,01) and IS Vs WSJ (p<0,05).

Velocity. Considering variation compared to baseline, WSJ improved time on 10m (-5%, -8 to -2) and 30m(-3%, -4 to-1), while IS improved time only in 30m dash(-2%, -3 to -1), while no changes occurred in CG. Comparing groups, 10m and 30m dash performance was significantly different between WSJ and CG (p<0,01 and p<0,05). Shuttle test performance improved compared to pre training both in IS(-4%, -6 to -2) and in WSJ (-3%, -5 to -2); no difference was showed between training groups, while they were dissimilar from CG. Changing direction ability increased only in WSJ (-9%, -11 to -7) compared to baseline, and it was different Vs CG (p<0,001) and IS (p<0,001).

Discussion

Taking in consideration squat biomechanics, it's well demonstrated that quadriceps play an important role both in concentric and in eccentric phases (Finni et al., 2000). Therefore, strength and structure quadriceps modifications could be expected after 8 weeks of squat, performed as weighted jump or with inertial device. Analyzing torque, it's interesting to note that concentric and isometric peak resulted in similar increments in both training groups, while eccentric strength was significantly greater in WSJ. Such result could be due to the high inertia that weighted jump creates during landing phase. Subjects were instructed to brake as fast as possible, so eccentric power was enhanced. With 25% of body weight as overload, inertia increases dramatically, making augment eccentric torque.

Knee flexors action during squat jump is minor compared to knee extension. Rapid eccentric rate of force development occurs during take off, while landing is featured by forced concentric action. However IS improved flexors torque, while no variations happened in WSJ. When comparing both tasks, we can speculate that development of force by knee flexor is interrupted during flight, while co-contractions occurred in order to reverse the trajectory of centre of mass. Consequently the functional ratio increased significantly only in IS. The eccentric hamstring/concentric quadriceps strength ratio is particularly important in order to prevent hamstring overstretch injuries (Delextrat, Baker, Cohen, & Clarke, 2011).

Architectural adjustments occurred after training in both modalities. Enhanced lengthening contractions influenced fascicle thickness, surprisingly without affecting pennation angle. Lean lower limbs mass increased after training. Such result is contradictory to other studies, those showed correspondence between two parameters (Blazevich, Cannavan, Coleman, & Horne, 2007b). It is known that eccentric exercise promote muscle hypertrophy when training period is adequately lasting. Gene promoting protein synthesis expression is stimulated more by lengthening contraction because of mechanical receptors action (Goldspink, 1999). It is possible that IS slightly higher variation depends on longer time during which muscle work is performed eccentrically. In addition, work performed by ankle during landing is superior in weighted jump compared to yoyo, in which flight phase does not exist. In this way, work is more prominent in muscle that are more sensitive to hypertrophy. Fascicle length increased in both training groups, but increment was more prominent using flywheel. It' well established that a longer fascicles correspond to an augmented number of sarcomeres in series (Blazevich et al., 2006; Potier, Alexander, & Seynnes, 2009; Seynnes et al., 2007). In addition, lengthening exercise is showed to be an adequate stimulus to induce fascicle length arrangements(Pasquet et al., 2006).

Jump performance improved in both training groups, but significantly more in IS. Body weight only has been demonstrated to be the load that maximize power. When overload, expressed as percentage of 1RM or body weight, is added, power decreases, while strength is enhanced (Cormie, McCaulley, & McBride, 2007). The concentric phase of inertial squat is really similar to a unweighted jump, while 25% of body weight slightly impairs power production, focusing more on strength expression, as our data showed.

When force is transferred on running ability, both weighted jump seems to be better than inertial squat. It's known that higher quadriceps torque is well correlated with better sprint performance (Wisloff, 2004). Our results seem to confirm it, in fact, time on 10m dash improved only in WSJ. In addition, also 30m sprint time was lower in WSJ, while IS increased speed compared to baseline, but it did not show difference with CG.

Interestingly, both groups decreased 20m shuttle time. Augmentation of eccentric torque explains the greater braking ability, necessary to change 180° direction running. Adjustment in fascicle length is related with higher velocity contraction (Blazevich et al., 2006). Neural and structural components influenced running performance, as well as changing direction agility (Serpell, Ford, & Young, 2010). Concerning latter, only WSJ improved it. It is possible relate it to a superior eccentric torque, that could has been transferred as a capacity to better perform repeated braking actions.

To summarize, to our knowledge, this is the first study that put together measurements of strength, structure and field performance using IS. In addition we wanted to compare it with a traditional power and strength training. It seems that the latter is more effective when strength is transferred on sprinting and changing direction capacity, while the former enhance jumping ability. IS training is able to increase functional ratio, symptom of greater torque balance between anterior and posterior thigh muscle, correlated with hamstrings overstretch rupture risk decrease. In addition, we have also consider that WSJ requires a really good exercise technique, in order to avoid injuries during training. Therefore, it should be not used with neophyte.

Chapter 7: Study 5

Muscle time course adaptations following unilateral eccentric and concentric resistance training.

Coratella G [1], Galas A [1], Impellizzeri FM [2] [3], Schena F[1] [2].

[1]Department of neurological, neurophisiological, morphological and movement science, University of Verona, Italy.

[2] CeRiSM, Research Center in for Sport, Mountain and Health, Rovereto, Italy.

[3]Schulthess Kilinik, Zurich, Switzerland

Abstract

Resistance training is classically performed dynamically using both concentric(CONC) and eccentric(ECC) phases (i.e.: CONC+ECC). However, muscle strength and structure gain has been proved superior when E was enhanced. In addition, when performed unilaterally, force has been shown to improve also in untrained limb. Finally after detraining period, adaptations are often retained. Therefore aim of the study is to compare different exercise methods measuring strength, mass and architecture after training and a short detraining. In addition we want to evaluate contra lateral effect and its time course.

Sixty women have been randomly divided in CONC, ECC, CONC+ECC or control group (CONTR). Training groups performed 7 weeks of equivolumetric unilateral knee extension, followed by 4 weeks of detraining. Maximal voluntary concentric, eccentric and isometric contraction, 1RM, muscle mass and muscle architecture were measured at baseline, after training and after detraining period. Measurements were performed on both legs.

After training, all groups improved concentric, isometric and 1RM compared to baseline, while eccentric torque was greater only in ECC. Muscle mass showed no increment, while fascicle length, fascicle thickness and pennation angle changed dissimilarly in each group. Untrained leg (UT) showed task related strength improvement, without affecting muscle mass, but with changes in muscle architecture. After 4 weeks, strength continued to increase in both in trained and

UT, muscle mass was higher only in ECC, while muscle architecture showed further adaptations.

We concluded that when training modes are matched for volume, similar strength adaptations occurred, even if training-testing modality enhance specific performance. Architectural adaptations contributed to develop torque and UT increment are mainly neural. Inactivity period increased strength in both limbs, and it should considered as super-compensatory process.

Introduction

Resistance training is widely used to get improvements in strength, preventing injuries and preserving an active style of life. During a dynamic contraction, muscle produces torque while sarcomere stretches out or shorten. These phases are respectively named eccentric (ECC) or concentric(CONC).

According force/velocity graph, eccentric contraction gain higher strength compared to concentric one (HILL, 1953). Several neurophysiological differences has been found studying CONC and ECC actions. For example, unique neuromuscular strategy (Enoka, 1996) (Kwon & Park, 2011), increased cross education effect (T Hortobágyi et al., 1997), lower EMG signal during action (Komi et al., 1987) while higher prior to the movement (Grabiner & Owings, 2002) have been showed comparing ECC to CONC. In addition, different brain activation patterns were registered using EEG while performing lengthening or shortening actions (Yin Fang et al., 2004).

Augmented load can be used while lengthening contraction is performed (Westing & Seger, 1989). Furthermore, higher metabolic efficiency (Goldberg, Etlinger, Goldspink, & Jablecki, 1975), with reduced cardiac and respiratory solicitation (Chung, Dean, & Ross, 1999) have been showed using ECC compared to CONC exercise. Anyway, higher muscle injury after eccentric training should anyway suggest attention toward sedentary or elderly people (Uwe Proske & Allen, 2005).

Eccentric phase has been demonstrated to be an important stimulus to improve strength (Dudley et al., 1991). A recent meta-analysis compared ECC only versus CONC only short term training, showing a superior effect of lengthening actions in muscle strength and mass development. Even if both concentric and eccentric training had augmented improvements when subjects were tested in the same modalities, the latter is superior when the total strength, i.e. sum of isometric, concentric and eccentric peak torque, is considered (Roig et al., 2009). Increment in muscle mass has been showed when training lasts six weeks or more (G Guilhem, Cornu, et al., 2010). This is thought to be due to an enhanced mechanical stimulus to the sensitive proteins that promote changes in gene expression profile occurring when sarcomere is stretched (Kostek et al., 2007). Architectural adaptations resulted by eccentric or concentric training. Changes in pennation angle, process linked to hypertrophy promotion and in fascicle length, process linked to contraction velocity occur after short term resistance training (Blazevich, Cannavan, Coleman, & Horne, 2007a).

Detraining effects. Nonetheless, in order to retain adaptations, people should preserve an active life style. However, people has not the possibility to train all over the year, so it’s important to understand behavior of physiological modifications following a detraining period. Young sedentary men maintained their knee extensors strength after 24 weeks of detraining (Lo, Lin, Yao, & Ma, 2011), while it didn’t happen in elderly women after 3 months (Carvalho, Marques, & Mota, 2009). It seems, anyway, that torque level after detraining can be influenced by intensity used during training, suggesting that higher loads should keep greater force values than moderate ones, even if it is not matched for the training volume (Tokmakidis, Kalapotharakos, Smilios, & Parlavantzas, 2009) (Fatouros et al., 2005). Fascicle length and pennation angle resulted in different values from the baseline after 14 recovery weeks, meaning that structural adjustments adapt rapidly and maintain their changes for a longer period (Blazevich, Cannavan, Coleman, & Horne, 2007a). Muscle mass has shown decrements when measured after long term detraining (Popadic Gacesa, Kozic, Dusko, & Grujic, 2011).

Cross Education Effect. It is known that unilateral resistance training induces changes also in untrained limb (Munn et al., 2004). Although causes remain unclear, it seem that neural mechanism should play an important role, excluding structural changes (Lee & Carroll, 2007). It has been shown that unilateral exercise involves contra lateral motor cortex, suggesting central neural mechanisms (Kristeva, Cheyne, & Deecke, 1991). It has been also proposed that untrained limb could be used as a sort of postural controller during single limb movement. (HELLEBRANDT, PARRISH, & HOUTZ, 1947). Cross education seems to be linked to the contraction modality, with a superiority of dynamic compared to isometric, and eccentric compared to concentric. (T Hortobágyi et al., 1997).

However, common resistance training is performed using both CONC and ECC actions(i.e.: CONC+ECC), that represents the majority of sports movements. While sub maximal contraction can be performed in both modalities, single or combined, training with supra-maximal overload involves ECC mode only. Furthermore, detraining has been defined as an inactivity period longer than 4 weeks (Mujika & Padilla, 2000), but less is known about short term recovery modifications. In addition, few studies investigated time course of contra lateral effect.

Aim of the study is to evaluate changes in quadriceps strength, mass and architecture after a short term unilateral knee extension training. A second purpose is measure adjustments after a short period following the end of the training. Finally, we want to monitor such adaptations in untrained limb.

Methods

Subjects. Sixty healthy sport science women students (age 25 ±6) were recruited for the study. Subjects were randomized in three training groups (CONC 16 ;ECC 15; CONC+ECC 15) and a control group(CONTR 14). Exclusion criteria were knee orthopedic diseases and continuous use of leg extension during their training in previous twelve months. All subjects gave written informed consensus and the research was approved by the Human Research Ethics Committee of University of Verona.

Study design. The experimental protocol lasted 12 weeks. Subjects were tested at week 1, 9 and 12 while they trained since week 2 to 8. No training was performed in week 10 and 11. Measurements assessed during test sessions were: Dual energy X-ray Absorptiometry for lower limbs composition, ultrasound image of the vastus lateralis in order to assess muscle architecture, while strength tests were then performed using isotonic knee extension 1RM and maximal voluntary contraction (MVC) on isokinetic dynamometer. Four subjects did not conclude the protocol for reasons unrelated with the study.

***Resistance training*.** Each subjects performed training twice a week for seven weeks. It consisted in unilateral knee extension on an isotonic device (Leg extension, Technogym, Gambettola, Italy). Training load for each group was determined in order to be theoretically the same: subjects, irrespective of the group, should have performed the identical individual training volume. Load was calculated keeping in account of external load, repetition number and space covered by the limb (McBride et al., 2009). ECC performed 5 sets per 10 repetitions at 120% 1RM, CONC 5 sets per 12 repetitions at 90% 1RM, CONC+ECC performed 6 sets per 6 repetition at 80% 1RM while CONTR did not train. ECC group was dispensed with concentric phase by operator who lifted the apparatus lever during each repetition whereas CONC group was dispensed with eccentric phase by operator who holded down the device lever. CONC+ECC group was training without any help by operator. For each training group range of motion was from 90° to 0° (full extension) and time under tension for each phase was approximately 1,5 seconds. Subjects received visual feedback in order to maintain constant time under tension. Recovery time between sets was 2 minutes.

***Testing procedures*.** The same measurements order was maintained in each test session, in order to standardize all conditions. Both legs were tested.

Lean muscle mass. Changes in fat free mass of trained(T) and untrained leg(UT) were observed by Dual Energy X-ray Absorptiometry (DEXA), (QDR Explorer W, Hologic, MA, USA). The lower limit of the thigh Subregion were obtained by a flat parallel line between femur and tibia; the upper one by a line that crosses perpendicularly the neck of femur. Amount of lean thigh mass was considered in this study.

Architectural measurements. Architectural analysis has been done on both T and UT vastus lateralis muscle. A strong correlation between vastus lateralis and whole quadriceps was previously demonstrated (Blazevich et al., 2006). The measurement was obtained at 39% of distal leg length. Subjects seated with limb flexed at 90° and muscle completely relaxed. The image was acquired by an ultrasound scanner(Acuson P50, Acuson Corporation, CA, USA). The ultrasound was oriented longitudinally to the fascicle length and perpendicularly to the skin. Two images of the same muscle were acquired. Measurements of pennation angle and fascicle thickness were obtained by a software(ImageJ, NIH, Maryland, USA). Fascicle thickness was the distance between the two aponeurosis and pennation angle was the angle between fascicle and aponeurosis. Finally fascicle length was calculated by a formula:

$$\text{Fascicle length} = \sin(\gamma+90°)*FT/\sin(180°-(\gamma+180°-\theta)$$

where y is the angle between deeply and superficial aponeurosis, θ is the pennation angle and FT is fascicle thickness (Blazevich et al., 2006).

Strenght measurement.

1RM. Single Isotonic Knee extension 1RM was tested on device (Leg extension, Technogym, Gambettola, Italy). Testing protocol started with warm up consisting in 2 sets per 15 repetitions. Based on formula

$$\text{Theoretical 1RM} = \text{load}/1{,}0278-(0{,}0278\cdot \text{n°executed repetition})$$

where load is expressed in KG lifted during set, 90% 1RM was used as initial 1RM attempt. Afterwards additional load of 2.5kg was added until subjects failed to lift the lever. The other limb was blocked by an operator. Same procedure was repeated with the other leg. Standardized verbal encouragements were adopted by the operator during each attempts.

Maximal voluntary contraction (MVC). Subjects performed torque measurements on Isokinetic dynamometer (Cybex, Lumex, Ronkokoma, NY, USA). Subjects were fixed on dynamometer seat: trunk and shoulders were blocked by two belts in order to have back close to the backseat. Tested knee was fixed by a belt and ankle was close to the lever, while not tested leg was blocked by another lever. After warm up consisting in 10 eccentric repetitions and 10 concentric repetitions, subjects completed 3 maximal attempts of in both modalities at 60°/s. Range of motion was fixed from 90° to 5° (0°= full extension). Further set consisted in 3 maximal isometric repetitions at 60°. Subjects were motivated by the operator to perform the whole protocol as hardest as possible. Tests were repeated for both legs.

Statistical analysis: Analysis was performed with SPSS 16.0(SPSS, Chicago, IL). A three-way repeated measures ANOVA (Time x Group x Side) was used to detect dependent variables adjustments. Then paired post hoc effects were investigated using Bonferroni correction. Significance level was fixed at p<0,05. Analysis was repeated after log transformation.

Results

	TIME XSIDEXGROUP
1RM	**0,000**
Isometric peak	**0,023**
Concentric peak	**0,014**
Eccentric peak	**0,000**
FFM	**0,022**
Pennation angle	0,074
Fascicle Thickness	0,692
Fascicle Length	0,748

Table 7.1.: time X group X side Interaction for each dependent variable.

Strength. Significant time x group x side interaction was found in 1RM (p<0,001) , concentric (p<0,05), eccentric (p<0,001) and isometric (p<0,05) peak torque. Time x side interaction was significant in all strength parameters (p<0,001); side x group showed no interaction as well as time x group, with exception of isometric peak (p<0,05). Factor time was significant (p<0,001) in 1RM, Eccentric and concentric peak, while was not in isometric peak measurements.

1RM, T leg. After training, significant changes in CONC (11,8±1,1 Kg; CI95% 9,0 to 14,6, p<0,001), ECC (3,8±1,2Kg; CI95% 0,8 to 6,7, p<0,01), CONC + ECC (6,5±1,1Kg; CI95% 3,7 to 9,3, p<0,001) occurs in T leg, while CG has no changes (-0,6±1,2Kg; CI95% -3,8 to 2,5, p>0,05). No difference resulted among training groups. After 4 weeks, strength values remained significantly higher compared to baseline in CONC (13,3±1,1Kg; CI95% 10,6 to 16,1; p<0,001), ECC (4,8±1,1Kg; CI95% 2 to 7,7, p<0,001), CONC+ ECC (8,7±1,1Kg; CI95% 5,9 to 11,4, p<0,001)with no difference in training groups while was unchanged in CG (0,0±1,2Kg;CI95% -3,8 to 3,8, p>0,05). No changes between Post and Post 2.

1RM UT leg. Compared to the baseline, post training adaptations was significantly greater only in CONC(4,0±0,7Kg; CI95% 2,1 to 5,9; p>0,001),while ECC (1,4±0,8Kg; CI95% -0,5 to 3,3; n.s.), CONC+ECC (1,2±0,8Kg; CI95% -0,7 to 3,0; n.s.) and CG (-1,4±0,8Kg; CI95% -3,5 to 0,6; n.s.). Nonetheless, recovery modifications emerged significantly greater compared to PRE test in CONC (6,3±0,9Kg; CI95% 4,1 to 8,6; p<0,001) and ECC (3,0±0,9Kg; CI95% 0,7 to 5,3; p<0,01); no differences in CONC+ECC (1,7±0,9Kg;CI95% -0,6 to 3,9;n.s.) and CG (-0,4±1,0Kg; CI95% -2,9 to 2,1; n.s.). No detectable differences were found among training groups and between Post and Post2.

1RM T Vs UT. Post training cross education effect outcome in 33% for CONC, 38% for ECC and 18% in CONC+ECC. After rest weeks, it resulted in 47% for CONC, 62% for ECC and 19% for CONC+ECC.

1RM	**PRE(KG)**	**POST(KG)**	**POST2(KG)**
CONC	34,2±8,9	46,0±11,1 ***	47,5±9,8 ***
ECC	33,7±6,5	37,5±6,5 **	38,6±6,2 ***
CONC+ECC	37,7±8,9	44,1±11,01 ***	46,3±11,2 *** $
CONTR	37,3±6,4	36,6±5,8	37,3±7,2
CONC	*32,2±6,87*	*36,2±6,87 ****	*38,5±7,84 ***$$*
ECC	*34,2±6,46*	*35,7±6,68*	*37,3±6,39 ***
CONC+ECC	*36,7±8,22*	*37,8±9,25*	*38,3±10,59*
CONTR	*36,4±5,59*	*35±5,74*	*36±5,98*

Table 7.2.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Concentric peak, T leg. Compared to initial status, training induced significant increments in CONC (15,1±3,1Nm; CI95% 7,4 to 22,8; p<0,001), ECC (17,4±3,2Nm; CI95% 9,4 to 25,4; p<0,001) and CONC+ECC (12,6±3,1Nm; CI95% 4,9 to 20,3;p <0,01), whereas CG had no changes (-0,8±3,5Nm; CI95% -9,4 to 7,9; n.s.). Resting time did not decrease peak value, keeping them significantly augmented compared to ones prior the training in CONC (20,3±3,8Nm; CI95% 10,8 to 29, 8; p<0,001), ECC (20,1±4,0Nm; CI95% 10,3 to 30,0; p<0,001) and CONC+ECC (15±3,8Nm; CI95% 5,5 to 24,5; p<0,01). No alterations in CG (-2,8±3,5Nm; CI95% -13,4 to 7,9; n.s.). Nothing changes between Post and Post2. Training groups did not differ among them.

Concentric peak, UT leg. Training induced changes were not significant in CONC (2,9±3,0Nm; CI95% -4,5 to10,2; n.s.), ECC (4,0±3,1Nm; CI95% -3,6 to 11,6; n.s.), CONC+ECC (-4,9±3,0Nm; CI95% -12,3 to 2,4; n.s.) and CG (-3,5±3,3Nm; CI95% -11,7 to 4,7; n.s.). Post 2 outcomes revealed significant Pre-Post2 differences only in ECC (14,0±2,8Nm; CI95% 7,0 to 21,0; p<0,001); no variations in CONC (5,5±2,7Nm; CI95% -1,2 to 12,2; n.s.), CONC+ECC (3,5±2,7Nm; CI95% -3,2 to 10,3; n.s.) and CG (-1,3±3,0Nm; CI95% -8,9 to 6,2; n.s.). Post-Post2 analysis showed significant increments in ECC (10,0±2,4Nm; CI95% 4,0 to 16,0; p<0,001) and

CONC+ECC (8,5±2,3Nm; CI95% 2,7 to 14,2; p<0,01); no detectable difference in CONC and CG.

Concentric peak T Vs. UT. Changes in UT leg were 18% for CONC, 23% for ECC and -39% in CONC+ECC after exercise sessions. Inactivity lead to 27% in CONC, 69% in ECC and 23% in CONC+ECC.

Concentric Peak	**PRE(N/m)**	**POST(N/m)**	**POST2(N/m)**
CONC	153,5±30,8	168,6±29,1***	173,8±32,1***
ECC	151,2±25,4	168,6±25,9***	171,4±25,6***
CONC+ECC	154,3±27	166,9±29**	169,3±34,1**
CONTR	157,7±30,2	156,9±29,9	154,9±35,1
CONC	*149±23,5*	*152,5±20,9*	*152,2±22*
ECC	*154,5± 28,8*	*158,5±24,7****	*168,5±26,1****
CONC+ECC	*156,3±27,3*	*151,3±26,7*	*159,8±33,1 $$*
CONTR	*155±24,5*	*151,5±27,1*	*153,7±27,7*

Table 7.3.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Eccentric peak, T leg. Compared to the baseline, only ECC (35,4±6,1Nm; CI95% 20,4 to 50,5; p<0,001) showed augmented eccentric peak torque. Instead, no variations occurred in CONC (3,1±5,9Nm; CI95% -11,4 to 17,7; n.s.), CONC+ECC (-2,8±6,1Nm; CI95% 17,9 to 12,2; n.s.) and CG (-6,7±6,6Nm; CI95% -22,9 to 9,6; n.s.). Recovery time increased peak torque, compared to starting test session, in CONC+ECC (23,1±7,1Nm; CI95% 5,6 to 40,6; p<0,01), in ECC (51,6±7,0Nm; CI95% 34,1 to 69,1; p<0,001), while no significant augmentation was in CONC (15,3±6,3Nm; CI95% -1,6 to 32,2; n.s.) and CG (-6,8±7,6Nm; CI95% -25,7 to 12,1; n.s.). A positive significant trend were found between Post and Post2 only in CONC+ECC (26,0±5,7Nm; CI95% 11,8 to 40,2; p<0,001) and ECC (16,2±5,7; CI95% 2,0 to 30,4;p<0,05).

Eccentric Peak, UT leg. Pre-post analysis showed negative significant changes in CONC(-14,7±5,2Nm; CI95% -28,3 to -1,0; p<0,05) and CONC+ECC (-21,1±5,5Nm;

CI95% -34,7 to-7,4; p<0,01), whereas no alterations were found in ECC (-5,1±5,7Nm; CI95% -19,3 to 9,0; n.s.) and CG (-14,2±6,2Nm; CI95% -29,4 to 1,1; n.s.). Post2-pre comparison demonstrated positive significant trend only in ECC (23,3±6,3Nm; CI95% 7,6 to 40,0; p<0,01), while results was similar to the baseline in CONC (-8,4±6,1Nm; CI95% -23,5 to 6,7;n.s.), CONC+ECC (9,2±6,1Nm; CI95% -5,9 to 24,3; n.s.) and CG (-11,4±6,8Nm; CI95% -28,3 to 5,5; n.s.). Interestingly, after resting period, compared to Post test, torque values were significantly greater only in ECC (28,4±5,4Nm; CI95% 15,0 to 41,9; p<0,001) and CONC+ECC (30,2±5,2Nm; CI95% 17,3 to 43,2; p<0,001).

Eccentric Peak, T Vs UT leg. When positive, ratio between trained and untrained leg was 45% in ECC and 39% in CONC ECC.

Eccentric Peak	**PRE(N/m)**	**POST(N/m)**	**POST2(N/m)**
CONC	210,7±36,5	213,8±33,8	225,9±35,3
ECC	208,9±36,4	244,4±37,2***	260,6±49,8***$$
CONC+ECC	219,8±47,3	216,9±53,2	242,9±52,4**$$$
CONTR	208,2±45,9	201,6±47	201,4±53,4
CONC	*213,3±42*	*198,6±26,9**	*204,9±32,2*
ECC	*217,7±33,8*	*212,6±36,3*	*241±42,6**$$$*
CONC+ECC	*214,9±41,6*	*193,8±45,2 ****	*224,1±52,6 $$$*
CONTR	*208,5±30,5*	*194,3±40,5*	*197,1±41,9*

Table 7.4.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Isometric Peak, T leg. Significant improvements occurred after training in CONC (19,5±6,2N; CI95% 4,2 to 34,7; p<0,01) and ECC (30,0±6,4N; CI95% 14,2 to 45,8; p<0,001), whereas CONC+ECC (7,6±6,2N; CI95% -7,6 to 22,8;n.s.) and CG (-3,0±6,9N; CI95% -20,1 to 14,0; n.s.) didn't show changes. Nevertheless, at the end of week 12, CONC (37,7±7,1N; CI95% 20,0 to 55,3; p<0,001), ECC (41,6±7,4N; CI95% 23,3 to 59,9; p<0,001) and CONC+ECC (23,9±7,1N; CI95% 6,2 to 41,5; p<0,01) showed increasing torque compared to the baseline, while CG (-

6,4±8,0N; CI95% -26,2 to 13,3;n.s.). During recovery period, all the training groups continued significantly to augmented MVC , respectively CONC (18,2±4,2N; CI95% 7,8 to 28,6; p<0,001), ECC (11,6±4,3N;CI95% 0,8 to 22,3;p<0,05) and CONC+ECC (16,3±4,2N; CI95% 5,9 to 26,6; p<0,01); CG (-3,3±4,7N; CI95% -14,9 to 8,3;n.s.) remains unchanged.

Isometric Peak, UT leg. Only ECC (16,9±6,0N; CI95% 1,9 to 31,8; p<0,05) showed Pre-Post difference, while CONC (-2±5,8N; CI95% -16,4 to 12,4; n.s.), CONC+ECC (-0,7±5,8N; CI95% -14,4 to 14,3; n.s.) and CG (-4,2±6,5N; CI95% -20,4 to 11,9; n.s.) were unvaried. Improvements went on in ECC (36,7±6,6N; CI95% 20,3 to 53,1; p<0,01), they appeared in CONC+ECC (18,3±6,4N; CI95% 2,5 to 34,2; p<0,05), but they were absent in CONC (7,4±6,4N; CI95% -8,4 to 23,2; n.s.) and CG (10,6±7,2N; CI95% -7,1 to 28,3; n.s.) in Pre Vs Post2 analysis. Post-Post2 comparison revealed significant changes only in ECC (19,9±5,3N; CI95% 6,8 to 33,0; p<0,01) and CONC+ECC (18,4±5,1N; CI95% 5,8 to 31,0; p<0,01).

Isometric Peak, T Vs UT leg. ECC only displayed contralateral effect of 56% after training, whereas it grew up in ECC(88%), CONC+ECC (76%) and CONC (19%) after resting period.

Isometric Peak	**PRE(N/m)**	**POST(N/m)**	**POST2(N/m)**
CONC	174,3±29,7	193,8±28,7**	212±37***$$$
ECC	178,1±40,6	208,1±35,4***	219,7±41,1***$
CONC+ECC	188,3±32,2	195,9±36,8	212,2±31,9*$$
CONTR	190,3±25,9	187,2±43,4	183,9±47,2
CONC	*183,9±38,1*	*181,9±24,9*	*191,3±30,1*
ECC	*175±37,3*	*191,9±29,3**	*211,7±40,3***$$*
CONC+ECC	*179,3±30,2*	*179,3±24,5*	*197,7±29,9*$*
CONTR	*179,7±35,6*	*175,5±30,7*	*190,3±38,6*

Table 7.5.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Muscle mass. Significant time x group x side interaction (p<0,05) was found in lean leg mass. Time x side, side x group and time x group resulted in a not significant interaction.

Fat Free Mass (FFM) in T leg. No significant mass increments was measured comparing Pre Vs Post in CONC (0,4±57,8 g; CI95% -142,5 to 143,3; n.s.), CONC+ECC (-10,4±57,8 g; CI95% -153,3 to 132,5; n.s.) and CG (-66,5±64,6 g; CI95% -226,3 to 93,2; n.s.) while ECC (139,0±59,7 g; CI95% -8,9 to 286,9, p=0,072) was trendy higher. When measured after inactivity period, only ECC (266,6±73,6 g; CI95% 84,6 to 448,5; p<0,01) had significant augment of lean mass compared to initial amount, while CONC, CONC+ECC and CG did not show any changes.

FFM in UT leg. When compared Pre Vs .Post, Pre Vs. Post 2 and Post Vs. Post2, no group showed significant muscle mass modifications.

Fat Free Mass	**PRE(g)**	**POST(g)**	**POST2(g)**
CONC	5223,6±770,4	5224±761,7	5257,4±704,5
ECC	5289,2±712,1	5428,2±701,4	5555,8±665,2**
CONC+ECC	5154,5±749,2	5144,1±627	5097,1±610
CONTR	5461,8± 909,6	5395,3±856,2	5393,5±866,7
CONC	*5202,3±724,5*	*5086,2±765,7*	*5191,4±674,75*
ECC	*5319,3± 679,1*	*5338,89±680,4*	*5439,8±606,01*
CONC+ECC	*5172,6±678,8*	*5091,05±702,8*	*5122,3± 656*
CONTR	*5461,8± 909,6*	*5395,28± 856,2*	*5393,5±866,72*

Table 7.6.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Architectural adjustments. No time x group x side interaction was found in pennation angle, fascicle thickness and fascicle length. Time x side interaction was significant in all three architectural parameters (p<0,001), while side x group and time x group interactions were not significant. Factor side was not significant in fascicle length, fascicle thickness and pennation angle, whereas the latter had

P<0,01 for factor time, Fascicle thickness had p=0,050 and fascicle length was not significant. Between subject factor 'Group' was not significant (p>0,1)

Fascicle Thickness, T leg. Post-hoc analysis revealed Pre-Post significant difference in CONC (1,6±0,6mm; CI95% 0,1 to 3,1; p<0,05) and ECC (2,0±0,6mm; CI95% 0,4 to 3,6; p<0,05), while CONC+ECC (1,5±0,6mm; CI95% 0,0 to 3,0; P= 0,051) was trendy increased and CG (1,0±0,7mm; CI95% -0,8 to 2,7; n.s.) remained unvaried. Pre-Post2 comparison showed significant thicker fascicle only in CONC (1,4±0,5mm; CI95% 0,1 to 2,6;p<0,05) and ECC (2,7±0,5mm; CI95% 1,4 to 4,0; p<0,001). No groups enhanced difference when Post-Post2 post- hoc has been performed.

Fascicle Thickness, UT leg. Compared to PRE, only CONC (1,7±0,6mm; CI95% 0,1 to 3,2; p<0,05) showed fascicle thickness adjustment in after training. However, it disappeared after recovery period but it was present in ECC (1,95±0,6mm; CI95% 0,4 to 3,5; p<0,01). No difference appeared to be due the inactivity.

Fascicle Thickness	**PRE(mm)**	**POST(mm)**	**POST2(mm)**
CONC	20,9±3,0	22,6±3,0*	22,3±2,7*
ECC	20,9±2,8	22,8±2,2**	23,6±2,8***
CONC+ECC	20,5±3,7	22,1±3,9	21,5± 3,3
CONTR	21,7±2,5	22,6± 3,3	22,4±3,0
CONC	*20,7±3,2*	*22,4±2,8**	*21,8±2,9*
ECC	*21,3±3,0*	*22,6±2,5*	*23,2±2,6***
CONC+ECC	*20,6±3,6*	*21,2±3,3*	*21,3± 3,3*
CONTR	*22,1±2,7*	*22,6± 2,7*	*22,2±3,0*

Table 7.7.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Fascicle Length, T leg. There were no variations revealed by Post-hoc comparing Pre Vs. Post test. Only ECC (11,25±2,7mm; CI95% 4,5 to 18,1; p<0,001) showed longer fascicle comparing Pre Vs. Post2. Unvaried values comparing Post Vs Post2.

Fascicle length, UT leg. No structural changes appeared comparing Pre Vs Post. ECC (8,2±3,1mm; CI95% 0,5 to 16,0; p<0,05) only provoked increment in length after Pre Vs. Post2 analysis. No changes occurred due to detraining period only.

Fascicle Length	**PRE(mm)**	**POST(mm)**	**POST2(mm)**
CONC	104,1±14,4	111,3±14,5	110,2±14,7
ECC	104,6±14,2	111,5±12,2	115,8±14,2***
CONC+ECC	101,7±17,7	107,9±21,1	105,3± 16,6
CONTR	108,1±13,1	109,6± 16,1	112,7±14,2
CONC	*102,7 ± 15,3*	*109,5 ±13,1*	*107,6 ± 13,7*
ECC	*106,1 ± 14,3*	*110,6 ± 14,2*	*114,3 ±13,3***
CONC+ECC	*102,2 ± 15,9*	*103,6 ±14,9*	*104,4 ±16,0*
CONTR	*104,5 ± 14,1*	*109,6 ±12,7*	*109,4 ±13,9*

Table7.8.: Results are expressed as mean±SD. T Limb and *UT Limb*.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Pennation angle, T leg. Compared to the baseline, significant angle modification was enhanced after training in ECC (3,3±0,6 deg; CI95% 1,8 to 4,9; p<0,001) and CONC+ECC (1,9±0,6 deg; CI95% 0,4 to 3,7; p<0,01). However, CONC (1,7±0,6 deg; CI95% 0,1 to 3,3; p<0,05) had greater pennation angle after rest weeks, in addition of ECC (2,8±0,7 deg; CI95% 1,1 to 4,4; p<0,001) and CONC+ECC (2,2±0,6 deg; CI95% 0,6 to 3,7; p<0,01), those maintained their adjustments. No changes when comparing Post Vs Post2.

Pennation angle, UT leg. CONC (1,8±0,7 deg; CI95% 0,2 to 3,5; p<0,05) and ECC (3,1±0,7 deg; CI95% 1,3 to 4,8; p<0,001) had different angle after training period. Anyhow, only ECC (2,0±0,6 deg; CI95% 0,5 to 3,6; p<0,01) maintained alteration trough the inactivity time. No changes were due to this period only.

Pennation angle	**PRE(°)**	**POST(°)**	**POST2(°)**
CONC	8,8±1,4	10,2±2,4	10,5±3*
ECC	8±1,5	11,3± 2,4***	10,7±2***
CONC+ECC	9,0± 0,9	10,9±2**	11,2± 3**
CONTR	9,8± 2,1	10,2± 2	9,5±2,1
CONC	_8,6±1,7_	_10,4±2,1*_	_9,9±3,4_
ECC	_8,5± 1,2_	_11,6±3***_	_10,6±2,4**_
CONC+ECC	_9,8±1,9_	_10,5±3_	_10,8± 2,1_
CONTR	_10,9±2,1_	_11,3± 2,3_	_10,4±2,1_

Table 9: Results are expressed as mean±SD. T Limb and _UT Limb_.

p<0,05;**p<0,01;p<0,001 compared to PRE;**

$=p<0,05; $$=p<0,01; $$$=p<0,001 compared to POST.

Discussion

Strength. Confirming literature, short term high intensity resistance training, induced significant improvements in strength(T Hortobágyi et al., 1996)(Gjøvaag, Vikne, & Dahl, 2006)(Miller et al., 2006)(T Hortobágyi et al., 2000). As shown in Roig 2009, both CONC than ECC modes caused significant total strength increments (Roig et al., 2009). When compared testing modality, CONC improved 3 and 2 times 1RM compared respectively to ECC and CONC+ECC, showing a task specific change. Only ECC increased considerably eccentric peak torque, confirming lengthening training superiority in mode specific contraction testing (Duncan et al., 1989)**.** Anyway, superiority of ECC Vs CONC resulted when isometric peak was tested (CONC/ECC improvements 0,6), while training groups had similar isokinetic concentric peak. CONC+ECC, corresponding to a traditional resistance training, improved 1RM and concentric peak, i.e. similar testing – training modalities. Our results partially confirmed outcomes by Reeves and coll., who found increments in concentric torque, while no changes occurred in eccentric modality testing (Reeves, Maganaris, Longo, & Narici, 2009). Taken together, our results confirm a training-testing mode specificity, as reported in meta-analysis. Furthermore, we also remarked that total strength increments are higher performing ECC compared to CONC (Roig et al., 2009). However, we are in contrast with Narici and coworkers, that did not found concentric and isometric peak torque changes in ECC group (Reeves et al., 2009). It has also considered that higher training intensity could have influenced ECC superiority, when considered maximal lengthening exercise (T Hortobágyi et al., 1996).

Time course adaptation resulted in a greater amount of force after 4 weeks of inactivity. In fact, strength parameters improved in every training group, with the exception of eccentric peak, that was similar to baseline in CONC. It is also interesting to note that isometric peak was significantly higher than baseline in CONC+ECC only after 12weeks, and not immediately after the end of the training. It is known that resisting contraction requires longer adaptation than shortening in order to mediate muscle damage (Fitzgerald, Rothstein, Mayhew, & Lamb, 1991). It is possible, however, that resistance exercise, when matched for high training volume, could have a kind of delayed effect. In addition, we used high intensity training, that is proved to be superior in strength increments retaining (Fatouros et al., 2005). In addition, great volume and intensity training could represent a high stimulus to improve and retain strength improvements (Andersen et al., 2005). We suggest that this period should not be intended as detraining (Mujika & Padilla, 2000), but considered as maximization of super-compensatory process.

Muscle mass. Seven weeks of resistance training did not augment muscle mass significantly. It’s known, in fact, that resistance training acutely induces stimulus to protein synthesis genetic regulators (Barash, Mathew, Ryan, Chen, & Lieber, 2004) (Y.-W. Chen et al., 2002)(Hentzen et al., 2006)(Kostek et al., 2007). As attested by Goldpsink (Goldspink, 1999), lengthening fascicle constitutes an important mechanical signal that induce protein synthesis. In our study, ECC induced changes, even not significant, that attested better efficacy of lengthening training (Farthing & Chilibeck, 2003)**.** Nonetheless, at week 12, lean thigh mass was greater in ECC compared to the baseline, proving a longer time course mass adaptation, compared to neural and architectural adjustments. Using animal model, it has been showed a sort of cumulative effect on follistatin and myostatin regulation, that influence muscle hypertrophy, only after 20 but not 10 days. It seems to be a sort of cumulative effect that could induce a sort of time delay in lean mass accumulation(Ochi, Nakazato, & Ishii, 2011). Anyway, such effect should not be due to endocrine factors, cause of similar Testosterone and Growth Hormone (GH) increment after conventional or enhanced eccentric training (Yarrow et al., 2007).

Architectural adjustments. As shown by Blazevich, pennation angle increased after short term resistance training, especially when lengthening actions were performed (Blazevich, Cannavan, Coleman, & Horne, 2007a). In our study, alteration remains all over recovery time, and adjustments continued in CONC, showing a sort of time delay. Fascicle length adaptations reflects result previously showed in literature, with no rapid changes after short term resistance training (Blazevich, Gill, Deans, et al., 2007). However, such outcomes are in contrast with authors those found longer fascicles in vastus lateralis after 3 and 5 weeks of training (Seynnes et al., 2007)(Blazevich, Cannavan, Coleman, & Horne, 2007a). Length adjustments were remarkable after resting weeks only in ECC, symptom of higher effectiveness of eccentric training than concentric to promote structural adjustments. Few studies previously monitored time course of vastus lateralis fascicle length and pennation angle, so our outcomes are not comparable with further literature.

Cross Education Effect. Untrained limb showed strength improvements after training weeks. Anyway, it seems to be action specific, with a superiority of ECC in neutral task. In fact, ECC improved eccentric and isometric peak, while CONC only improved 1RM. Time course of cross education has been described by Shima and coworkers, those demonstrated that 6 weeks of detraining did not maintain strength level reached after training, while Housh et al. showed level similar to the post training (Shima et al., 2002)(Housh, Housh, Weir, & Weir, 1996a). Actually, we found that muscle architecture was modified in the untrained leg only in ECC. It is possible that it works as stabilizer during contra lateral movement, at least during isotonic contraction, as hypothesized by Hellebrandt (HELLEBRANDT et al., 1947). We also showed that time course of cross education reflects the strength gain on trained limb. It is possible that a kind of cross learning effect could influenced such mechanism, even if it remains to be investigated.

In conclusion, short term isotonic resistance training augment muscle torque. Lengthening action is important to improve total strength, while shortening remains task specific. Architectural modifications occurs quite quickly, despite of lack of muscle mass increment. Small time recovery maximize strength and increase muscle mass, the latter in eccentric only modality, confirming a superiority of this training. Untrained limb follows trained leg time course alterations, but it is strongly influenced by lengthening phase.

Practical applications. Resistance training should be planned keeping in account the time course adaptation of muscle strength, in order to get maximum peak in sport events. Adequate recovery time can maximize performance. In addition, managing contra lateral effect can helps in a faster muscle rehabilitation when a limb is injured or forced to immobilization.

Chapter 8: Conclusions.

The project showed that an eccentric contraction is a very important stimulus in order to gain muscle strength and structural adaptations. Due to the possibility to use supra-maximal loads, its effect is often delayed compared to concentric or classical training. Management of time course muscle damage and further protection results in a really important effect maximization. Classical training methods, as well as new technology devices has been showed to be effective when used during lengthening exercise. Neural component has proved to be highlighted both in acute and in chronic muscular modifications. However, muscle architecture showed its great plasticity after training.

To summarize, lengthening exercise should be used to increase muscle protection and to improve maximal strength. In addition, training volume should be always considered. Transfer in performance has been showed, so eccentric overload should be used during sport conditioning.

European Congress of Sport Science, Liverpool, 04-09/07/2011: Poster.

COMPARISON OF THE EFFECTS OF ISOKINETIC VS ISOTONIC ECCENTRIC TRAINING ON MUSCLE STRENGTH AND MASS.

Coratella G[1]., Impellizzeri F.M.[2,3], Schena F.[12]
[1]Department of Neurologic, Neurophysiologic, Morphologic and movement Science, University of Verona, Italy;
[2]CeRiSM, Research Centre for Sport, Mountain and Health, University of Verona, Rovereto, Italy;
[3]Neuromuscular Research Laboratory, Schulthess Clinic, Zurich, Switzerland

Introduction

Eccentric (ECC) training has been shown to induce greater effect than concentric training on strength and muscle mass (Roig, 2009). The majority of the studies have used isokinetic (ISOK) devices for investigating the acute and chronic effects of ECC training. However, isotonic (ISOT) apparatuses are more commonly available in sport setting. Aim of the study was to compare ISOK to ISOT ECC training by assessing the effects on muscle strength and mass.

Methods

Forty-nine healthy sport science students have been randomly divided in 3 groups: isokinetic eccentric training (ISOK, n=14), isotonic eccentric training (ISOT, n=17) and control group (CON, n=18). Both training groups performed 50 ECC repetitions of knee extension at 120% of their maximal strength measured in concentric modality (1RM for ISOT and peak concentric torque for ISOK), for a total of 14 times in 6 weeks. Isometric maximal voluntary contraction (MVC), concentric and eccentric strength at 60 °/s, 1RM, and muscle mass (using DEXA) have been measured pre and post training. All the dependent variables were analyzed after log transformation with ANCOVA using the baseline values as covariate and factor “group” as independent variable.

Results

Compare to CON, the ISOK group showed higher 1RM (12%, CI95% 6 to 19%), concentric (15%, 8 to 22%), eccentric (35%, 25 to 45%) and isometric (25%, 18 to 34%) maximal strength ($P<0.001$). Compare to CON, ISOT showed higher 1RM (14%, 9 to 20%), concentric (17%, 11 to 24%), eccentric (25%, 16 to 34%) and isometric (22%, 15 to 29%) maximal strength ($P<0.001$). No differences between ISOK and ISOT were found in 1RM (2%, -3 to 7%), concentric (-2%, -4 to 8%) and isometric (-3%, -8 to 3%) maximal strength. Only eccentric strength was higher in the ISOK compare to the ISOT group (8%, 1 to 14%). No differences between groups were found in muscle mass ($0.419<P<0.769$).

Discussion

Eccentric training improved muscle peak torque and 1RM in physically active people. Data showed that neural adaptation is the main factor increasing muscle strength, while muscle mass apparently was not strictly related to it (Hortobagyi, 1996). ISOK and ISOT showed similar training effects. This study displayed that ISOT ECC training can be used to improve muscle strength.

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American College of Sport Medicine, San Francisco, 29-05/02-06, 2012: Poster

Effects of Squat Flywheel Training on Strength, Muscle Structure and Performance.

Coratella G[1]., Giorgi G[1], Impellizzeri F.M.[23], Schena F[12].
[1]Department of Neurologic, Neurophysiologic, Morphologic and movement Science, University of Verona, Italy;
[2]CeRiSM, Research Centre for Sport, Mountain and Health, University of Verona, Rovereto, Italy;
[3]Neuromuscular Research Laboratory, Schulthess Clinic, Zurich, Switzerland

Introduction

Inertial flywheel device (YoYo Technology) is well known to induce strength adaptations and increase muscle mass after short term training. (Norrbrand 2011, Tesch 2004). Changes in muscle architectural parameters appropriate to improve peak torque has been described (Seynnes, 2007). However these adaptations were not directly related to specific performances like jump, velocity and change direction ability. Aim of the study is to evaluate quadriceps strength and architecture, lower limb fat free mass, and performance parameters after short term YoYo squat training.

Methods

Thirty-one healthy young males has been randomly assigned at training (TR) or control (CON) group. TR underwent 16 training sessions in 9 weeks each consisting in 60 maximal reps at YoYo squat. Maximal Voluntary Contraction (MVC), Fat Free Mass (FFM), Fascicle length and thickness, Squat Jump (SJ) and Countermovement Jump (CMJ) Height and time on 30m dash and 20m shuttle have been measured pre and post training. Analysis of covariate has been done after log transformation.

Results

Compare to CON, TR showed higher MVC isometric (avg 25%, CI 95 13% to 38%), concentric (10%, 2%to 19%), eccentric (9%, 2% to 17%) extension (for each parameters, p<0,01). [C1]In TR, FFM (4%, 1% to 7%), fascicle length (8%, 1% to 16%), fascicle thickness (6%, 1% to 15%) increased compare to CON (p<0,01). SJ (9%, 2% to 16%), CMJ (8%, 1% to 14%), 20m shuttle(-4%, -7% to -1%) significantly improve (p<0,05) in TR compare to CON. 30m dash did not improve significantly compare to CON(-1%, -4% to2%, p=0,445), indicating that 20m shuttle performance is specially due by an augmented control of decreasing and increasing speed[C2].

Conclusion

Augmented strength and changed muscle structure are in agreement with previous study. Longer fascicle is correlated with higher velocity of sarcomere contraction (Blazevich 2006). Outcomes show positive transfers in sport performance tasks, like jumping or braking and change sprinting direction. Flywheel device can be successfully used to improve performance in sport in which jumping or speed are key factors.

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European Congress of Sport Science, Bruges , 04-07/07/2012: Oral Presentation.

Effects of dose response load squat jump training on muscle strength, structure and performance.

Coratella G[1], Annicchiarico M[1], Trepin M[1], Impellizzeri FM[2][3], Schena F[1][2]
[1]Department of Neurologic, Neurophysiologic, Morphologic and movement Science, University of Verona, Italy;
[2]CeRiSM, Research Centre for Sport, Mountain and Health, University of Verona, Rovereto, Italy;
[3]Neuromuscular Research Laboratory, Schulthess Clinic, Zurich, Switzerland

Introduction

Squat jump training is a common method to improve athletic performance. The load that maximize power is around 30% of maximal dynamic strength, i.e. body weight only.(Cormie 2007) However, also weighted jump training has been proved effective to enhance jump or sprint(Mc Bride 2002) Few studies measured changes in muscle mass and architecture to better understand physiological mechanisms those lead to a better field performance. Aim or the study is to evaluate a dose response effect of weighted or unweighted squat jump training on muscle strength, mass structure, jump and sprint ability.

Methods

Forty eight healthy students were randomly assigned to body weight only (BW), 25% body mass weighted squat jump training (WJ) and control group (CON).Isokinetic quadriceps strength(MVC), lower limbs total lean mass (DEXA), architectural adjustments (ultrasound), Squat jump (SJ), 30m dash, 20+20m shuttle and ability T test were assessed before and after 8 weeks of 60 maximal jumps, twice a week. All the dependent variables were analyzed after log transformation with ANCOVA using the baseline values as covariate and factor "group" as independent variable.

Results

No differences appeared in CON. Compared to baseline, BW improved MVC (23%,16 to 30,$p<0,001$), lean mass (2%,1 to 4 $p<0,05$), fascicle length (11%,7 to 16, $p<0,001$), SJ (10%,6 to 15, $p<0,001$), 20+20m(-3%,-5 to -1 $p<0,05$). Compared to baseline, WJ improved MVC(22%,15 to 29,$p<0,001$), lean mass(5%,3 to 7, $p<0,001$) fascicle length (5% 0 to 9,$p<0,05$), SJ(5%,0 to 10,$p<0,05$), 20+20m(-3%,-6 to -1,$p<0,01$), 30m(-3% -1 to -5,$p<0,01$). All parameters were significantly different from CON. BW had significant alterations in muscle architecture compared to WJ, while the latter improved 30m dash and T Test running test more than BW.

Discussion

Jump training improved task related quadriceps strength, also by an increment of lower limbs lean mass, that caused a power transfer in jumping and shuttle test. Greater velocity contractions in BW caused different architectural alterations(Blazevich 2003). Higher changing direction agility and sprint power could be related to increased strength expression in WJ.

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Acknowledgements

At the end of a long journey, I need to stop and looking back to my travel.

First of all, my sincere thanksgiving goes to Prof. *Federico Schena* and Prof. *Franco M Impellizzeri*. They both gave the chance to have a great experience and the way to make it as best as possible.

As you can imagine, I could not have done my research project alone. So I must thanks *Ivan Camponogara* MSc, *Valentina Bellini* BSc, *Alessandro Chemello* MSc, *Marco Annicchiarico* MSc, *Gianluca Giorgi* MSc, *Marco Trepin* MSc and, of course, *Annalisa Galas* MSc. They all gave their best for our result.

Looking back, when you travel, even if only in your mind, you are not alone. So I need to remind who I met during my own way: *Barbara Pellegrini*, always helpful, *Cecilia Bellotti*, 8 years together, *Andrea Azzalin*, *Fabio Rubens Serpiello, Livio Zerbini, Francesco Bertiato,* maybe too few parties together, and Fabio *Pizzolato*. A special thanks to the last one, that first makes me really consider the idea to start a Ph.D course.

Looking back, *Nicoletta*, you make this journey funny, intense, colored and crazy.

Looking back, my experience in Verona has been amazing. A special thanks to lawyer *Sabrina De Santi*, who first believed in me.

Looking back, Eng. *Carlo Coratella*: style is what we make for it.

Looking back…but looking forward there's *YOU*.

In loving memory of my grandfather ***Prof. Riccardo Giorgio*** *(24/08/1924 – 13/07/2011): you have been always proud of me.*