Level 3 ASCA Assignment.

Eccentric movements: Description, definition and designing programmes.

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Abstract

Muscle acts in one of three ways: overcoming an imposed load (concentric), yielding to a load (eccentric) or holding a load (isometric). Conditioning coaches and athletes are familiar with overcoming or holding loads, but are less familiar with yielding eccentric muscle actions. The relationship between force and velocity in eccentric actions is such that as the velocity of eccentric actions increase so too does the maximal force production, this is in stark contrast to concentric actions where force production is inversely related to velocity i.e. heavy loads are moved slowly. In addition, eccentric muscle actions are different to concentric or isometric actions in that they rely on sensory feedback to achieve a desired trajectory utilising alternative processes both neural and mechanical.

Eccentric exercise has been shown to improve: hypertrophy of muscle, muscular strength, adaptation to eccentric activity, neural cross-over, and assist those with low levels of cardiovascular fitness. The main disadvantages of utilising eccentric exercise are: delayed onset muscle soreness, damaged muscle cells, reduced neural reflexes, acute strength loss and an altered resting state.

Eccentric movements are however inherent to athletic activity. Eccentric training therefore needs to be part of an athlete's preparation for competition. It is worth noting that not all eccentric actions are the same, clumping eccentric movements into one group may cause specificity of training errors and confusion when talking between professions.

The movement purpose determines the mode of eccentric movement. Eccentric rehabilitation utilises low loads with low velocity; heavy eccentric training utilises high (heavy) loads, and the subsequent action is not necessarily a high velocity contraction; stretch-shortening cycle training involves extensive use of elastic energy generated in the musculotendinous unit and quickly initiated into a rapid concentric action.

Each of these modes are used to varying degrees in sporting movements, it is important to differentiate which mode or combination of modes is appropriate for the athlete. The drop jump may be a useful tool in determining an athlete's ability to utilise the stretch-shortening cycle or to attenuate force.

It is possible to apply appropriate training principles to heavy eccentric training and stretch-shorten cycle training. In doing so eccentric training will prepare athletes for competition and improve sporting performance.

Eccentric Movements: Description

Eccentric Muscle Action

Human movement is characterised by the neural activation of muscles to execute smooth movements. This is most evident in sporting or dance movements, where the muscle is called upon to function as a motor, a spring, a shock absorber or a stabiliser (32). Muscle work in all these functions according to the required demands of the movement. The definition of muscle actions can be summarised into three working methods:

1. Overcoming, the muscle shortens and overcomes the load – concentric
2. Yielding, the muscle lengthens as the load overcomes the muscle – eccentric
3. Holding, neither the muscle nor the load overcomes the other – the muscle neither lengthens or shortens (44, 68)

Movement is characterised by the interaction of these three modes of muscle action, figure 1 illustrates these interactions (68).

The utilisation of these muscle actions constitutes muscular strength. Strength qualities can be modelled along the continuum as shown in figure 2, representing the three major physical capacities (82).

Each of these capacities are characterised as a quality of physical capacity because of three factors:

1. Velocity of the movement i.e. quick or slow, as a function of time
2. Load, i.e. light or heavy mass
3. Repetitions, i.e. one, multiple or cyclical movements

The resultant term force requires an interaction between velocity and load, where force = mass x acceleration (68). The interplay between force and velocity is most clearly seen in figure 3 (5, 24, 47, 82). This model was first described in 1935, and popularised by the thermodynamic experiments of Hill in 1938 (36). Originally from experiments with a single muscle fibre from a frog, positive velocity indicates a concentric action, and negative velocity indicates an eccentric muscle action. Note the force produced by eccentric action is greater than both isometric and concentric actions. Further, this relationship between force and velocity relates to the load being moved or resisted. In concentric actions heavy loads may only be moved slowly and light loads quickly; that is force production is inversely related to velocity. However, for eccentric actions the relationship is different; as the velocity of eccentric actions increases so too does the maximal force production. This means that when overloading eccentrically very heavy resistances may be needed, but when training for explosive concentric movements, relatively light loads may be more suitable (5).

In contrast to examining a single muscle fibre athletes and conditioning coaches are concerned with movement. A muscle attached to a bone produces force, but it is the resultant torque produced about a joint that we are most interested in. This torque depends on the force exerted by the muscle and the moment arm relative to the joint. This is further complicated when considering that the force exerted by a muscle varies over the joint's range of motion, therefore muscle torque varies throughout the joint's range of motion. Figure 4a shows over six trials the torque exerted by the knee extensor muscles vary throughout the range of motion with peak torque at a knee angle of about 2rad (3.14 rad = complete extension).

Torque at a specific knee angle was selected, and data plotted on a force velocity curve. Figure 4b shows the torque-velocity relations of the knee extensor muscles in three conditions: voluntary contractions (▲), contractions evoked with electrical stimulation (○), and a combined voluntary and evoked contraction (●). The graph is qualitatively reminiscent of Hill's experiment with single muscle fibres (fig. 2).

Figure 4b shows that higher levels of muscle torque are generated by electrical stimulation in eccentric muscular action, but higher levels of muscle torque are generated during voluntary activation in concentric, and isometric muscular action (24). Because the muscle torque was greatest during the electrically stimulated eccentric actions (traces i & ii, fig. 4a), it would appear that it is difficult to achieve maximum activation of the muscles during voluntary eccentric action. For the athlete and conditioning coach the practical implications of this figure are that electrical stimulation of the muscle combined with voluntary action is capable of producing higher levels of torque than by voluntary action alone. However, electrical stimulation does not enhance muscle torque when muscles are working in concentric or isometric actions.

This information is useful in the athletic setting, for the athlete requiring an increase in eccentric strength and has access to muscle stimulation equipment; it would not be a beneficial method of training for improving concentric strength. The data that figure 4 is based upon is from isokinetic actions, and over a single joint's range of motion; in practical terms it would be appropriate to employ this method of training to overcome an eccentric deficit in a single joint movement or to facilitate increased strength levels where they have plateaued over one specific joint movement. For example, in rehabilitating a strained hamstring in a cricket bowler electrical stimulation along with an eccentric hamstring curl is likely to generate greater torque than by voluntary activation alone. The integration of this type of training is best suited to an elite trainer with considerable training experience.

Note that the figures of torque production in eccentric mode have been reported 1.5-2.0 times the isometric torque; from figure 4b it would seem that 1.1-1.2 times the isometric torque is more appropriate than the higher figures achieved by theoretical modelling (37). Further, there is little increase in torque as angular velocity increases, suggesting for the practitioner that slow lengthening movements are an appropriate starting point for the trainer, as well as being safer to include in any programme there is little to be gained by increasing the eccentric angular velocity in terms of torque production.

These figures are concerned with movement over a single joint; the implication is that for multiple joint movements (most sporting movements) each muscle complex must be controlled for the desired movement outcome however, the muscle working within the movement will contribute force/torque as a result of the interplay of muscle action, velocity, load and repetitions.

Eccentric movement control mechanisms

As seen in figure 4, the force production for eccentric actions contrasts with that of isometric and concentric actions in voluntary activation. This would suggest that eccentric strength has a different method of control in comparison to the other two muscle actions (24).

In contrast to concentric or isometric actions, eccentric actions rely on sensory (afferent) feedback to achieve a desired trajectory. In addition fewer motor units are involved when compared to a concentric action (24). Due to the fact that muscle torque must be less than the load torque during an eccentric action, the control of the movement relies on the afferent feedback to provide information on the progress of the movement, the lower muscle torque also explains why there are fewer motor units involved in the movement.

Enoka (2002) explains that eccentric muscle action is different to the other two modes of muscle action, possessing unique properties including:
Cross-Bridge Activity; The lengthening of a muscle involves the stretching and 'popping' of individual sarcomeres as each attains its yield stress. It would seem that an eccentric action is a mechanical disruption of the chemical actomyosin bond, whereas in normal cross-bridge cycles adenosine triphosphate is bound and detached in an orderly manner (24). The loose binding theory of Toshio Yanagida provides another theory of this mechanism, maintaining that the myosin head slips over the actin-binding sites during the lengthening phase without requiring the myosin head to be flexed forcibly or 'popped' (51).
Motor Unit Activity; during eccentric action motor unit synchronisation is enhanced suggesting that the proportion of common input to pairs of motor units is greater during eccentric action.
Maximality of Activation; In spite of muscle force being greater during a voluntary eccentric action the EMG is substantially less than during a concentric action. This implies that voluntary maximal activation of a muscle during an eccentric action is not possible, for a fuller explanation see figure 4.
Submaximal Activation; Running downhill on a treadmill at the same intensity is accomplished by a gradual increase in oxygen consumption and in the EMG of leg muscles, as compared to running at the same intensity on a level treadmill where there is a constant level of oxygen consumption.
Afferent Feedback; feedback is at heightened levels from the muscle spindles during eccentric actions.
Reflexes; are reduced or depressed with movements requiring eccentric action.
Contralateral Effects; there is evidence of maximal eccentric training on one leg increased the peak torque on the contralateral leg. There was no change in peak torque for concentric actions.
Muscle Damage; delayed-onset muscle soreness (DOMS) is preferentially elicited by activity that involves eccentric actions.

Benefits of eccentric exercise

Whilst eccentric muscle action has different qualities to isometric and concentric muscle actions it is theoretically possible that the benefits of utilising eccentric actions may provide training and performance benefits for athletes. Many studies have investigated this idea some of which are presented in Table 1, as can be seen from these studies there are five primary benefits:

Improved size. Hypertrophy of muscle is one of the most commonly mentioned advantages of eccentric exercise, the rationale for this is thought to be a stimulation of growth through a greater process of breakdown. It is thought that through this breakdown there is an increase in local growth factors (45). Eccentric training is more effective than concentric training alone, possibly the greater tension on the muscle contractile elements through eccentric action combined with the greater protein degradation would promote a more positive anabolic response (7, 24). Even in studies investigating the disadvantages of eccentric exercise increases in cross sectional area of muscle are noted.

Improved strength. The most commonly mentioned outcome of eccentric training is an improvement in strength. In some studies it is simply an increase in muscular force, however there have been some specific studies that identified specific components of strength improvement from attenuating forces to increasing the rate of eccentric force development.

Enables preparation for performance. One of the more interesting outcomes of eccentric training is that after the initial eccentric training exposure, subsequent exposures to eccentric training illicit a decreased perception of muscle soreness and plasma creatine kinase levels (39). Concentric training does not have an 'inoculation effect' (3). Further, it has been shown that sub-maximal eccentric exercise can illicit the same protective effect whilst the training itself does not produce muscle damage (59).

Improves neural factors. Another intriguing outcome of eccentric training is the strength effect training can have on the non-trained contralateral leg. This cross-over education effect is thought to be like a neural overflow to the untrained limb. Other neural improvements have been in an increased neural activation and increased segmental reflexes.

Assists metabolic factors. Although not as many studies identify this as a benefit of eccentric exercise, there is good evidence of the lower energy cost of eccentric exercise through a lower cardiovascular stress and lactate response than concentric exercise (21, 42, 51, 69). The impact of this is that for people with low levels of aerobic fitness or energy levels this may provide a useful source of training without the concomitant loss of energy. Recently submaximal eccentric exercise has been shown to influence the early patterns of bone adaptation to training in women. This could be a useful training modality particularly for women up to age 30 years when peak bone mass is achieved (65).

An interesting outcome of an age related study showed that with age relative eccentric strength does not decrease to the same extent as concentric strength. The preservation of eccentric strength is important to the aging population; eccentric strength is likely to assist the elderly in maintaining their independence. A likely explanation for this outcome is that many activities of daily living require the controlled lowering of body weight into a seated position, because eccentric activities are commonplace eccentric strength is maintained more than concentric strength. Another explanation is that passive connective tissues in parallel with the contractile mechanism may be a contributing element in the generation of eccentric strength, increased stiffness, or resistance to stretch of connective tissues as a result of ageing may be a possible mechanism for the maintenance of eccentric strength in the elderly (8).

Negatives of eccentric exercise

The tired cliché of "no pain, no gain" would possibly best apply to eccentric training, as can be seen in Table 2, there are five main disadvantages when utilising eccentric exercises; soreness, damaged muscle cells, reduced neural reflexes, acute strength loss and an altered resting state.

Soreness. The most commonly quoted issue with eccentric exercise is delayed onset of muscle soreness (DOMS). It is readily apparent that maximal eccentric exercise is accompanied by DOMS. This can be a deterrent for those new to training, however for those athletes that recognise the benefits of eccentric exercise it is not necessarily a factor which will prevent them from utilising this method of training. It should be explained to the participant what they will feel like in the next 48 hours post exercise, and needs to be periodised into the overall programme.

Damaged muscle cells. In the muscle cells, eccentric exercise has a disruptive effect on almost all structures within the cells; it is this and the resultant inflammatory response that is thought to elicit DOMS. Specifically there is; dilation of the transverse tubule system, sacrolemnal disruption, distortion of myofibrillar components, fragmentation of the sarcoplasmic reticulum, lesions to the plasma membrane, cytoskeletal damage, swollen mitochondria, and changes in the extracellular myofiber matrix (23). As a result there is an increase in serum creatine kinase, and serum cortisol. The net impact of this cellular disruption is increased inflammation and in some cases an increase in the degeneration of cells through an increase in a local rise in Calcium ion (Ca^{2+}) which leads to sarcomere disorder and changes in excitation (3).

Reduced neural/reflexes. Because of the method of control in an eccentric action the resultant cellular disruption has an acute impact on strength, whether this is solely because of the disruption at the cell or at the neural interface is yet to be determined. However, what is clear is that there are concomitant neural and strength decrements as an acute response to eccentric exercise. Although not widely studied there is some initial evidence of a reduction in the stretch-shortening cycle (SSC) performance,(35) and proprioception (62) following exposure to eccentrically induced muscle damage. With repetitive exercise with maximal effort may also be a strong modifier of central and peripheral fatigue during subsequent maximal voluntary contractions (22).

Acute Strength loss. Strength loss is noted in a number of studies, as detailed above the fine definition of the cause is difficult to differentiate, but the outcomes are clear. Torque is impacted in all muscle actions (58) invariably if a study tested for strength, in whatever manner they deemed appropriate, there was an acute loss of strength (48-

72 hours). Through an appropriately planned programme strength will increase over time with eccentric exercise; however it is the acute loss of strength that is of initial concern because of the increased risk of injury.

Altered resting state. The cellular damage has a related effect on the resting state of the subject. Most notable is the decrease in range of motion, probably because of the localised inflammation and DOMS. Consistent with the decrease in range of motion is the increase in leg-spring stiffness (35). A useful view of the disruption caused by an active lengthening muscle is seen in figure 5. During lengthening weaker sarcomeres are stretched so that on the force-length curve they exhibit little strength and are stretched in an uncontrolled fashion. The passive structures prevent further lengthening. Repeated overextension of sarcomeres leads to disruption. Should the area of disruption be significant it elicits membrane damage. With tearing of the t-tubules the excitation-contraction coupling becomes dysfunctional. At this point the fall in tension is reversible with caffeine, however if not reversed damage to the sarcoplasmic reticulum would ensue accompanied by uncontrolled release of Ca^{2+} triggering local contractures thereby raising passive tension. As the fibres die tension falls and breakdown products of dead and dying cells leads to local inflammation and associated swelling (62).

Although DOMS is the most identified negative for eccentric exercise it should be seen as part of the whole process of the cascade, in which there is a loss of heat, incurred damage to cells and fibres at many levels and a concomitant reduction in neural potentiation as well as a loss in strength, resulting in an altered resting state.

Many clinicians and trainers have not utilised eccentric exercise because of this perpetual cascade (DOMS) and a perception that the risk of injury is increased by allowing an athlete to train this way. This is an uneducated response; eccentric movements are inherent to athletic activity. Whilst it is true that eccentric training leads to DOMS it does not follow that there is an increased risk of injury. A thorough programme for an athlete will assess the needs and should that include eccentric strength then eccentric training must be included in the training programme.

Cricket, for example, has identified that eccentric muscle actions account for a significant part of the batter's and bowler's playing demands (52). It must therefore be a part of the athlete's preparation for competition. It is possibly inappropriate to claim that exercise results in muscle injury. It may be more appropriate to conclude that intensive exercise initiates a muscle remodelling process enabling hypertrophy in skeletal muscle (31).

Eccentric Movements: Definition

Eccentric modes of movement

It is common for researchers to identify any lengthening of muscle as eccentric action whatever the condition of the movement. Whilst there is sufficient evidence that eccentric muscle actions are controlled in a different manner to concentric and isometric actions, it is worth noting that not all eccentric actions are the same. In table 3, the methods for controlling the lowering of a load and releasing elastic loads are characterised by:

- An increase in muscle fibre length
- A trajectory controlled and dependent on afferent feedback

Whereas the eccentric action during the SSC and isokinetic muscle actions is different. During the SSC fibre length may not increase during the stretch, and the trajectory replicates a spring response of the muscles involved rather than a feedback-dependent trajectory. During an isokinetic movement there may be an increase in muscle fibre length, but the task requires resisting the load rather than the production of a feedback-dependent trajectory (24).

This clumping of eccentric movements into one group can cause specificity of training errors and confusion particularly when talking between professions. For example 'eccentric' training has become a common method of rehabilitation for physiotherapists, this type of training generally purposes to rehabilitate tendons rather than muscles. Based upon the interplay between load and velocity of eccentric movements three distinct modes of eccentric movement can be classified as shown in Table 4. Note also that the movement purpose determines the mode of eccentric movement.

Eccentric rehabilitation

From around 1984 the concept of eccentrically training tendons has been explored by physiotherapists (15). Chronic overuse conditions in the Achilles and patella tendons include tendinosis characteristics. That is, thin and frayed collagen fibres, losing their parallel orientation. The fibres demonstrate unequal and irregular crimping, loosening, and increased waviness. There is a lack of type I collagen, and increased quantities of type II and III collagen which lacks the tensile load bearing qualities of type I (43).

In a recent review of eccentric strengthening for patients with Achilles tendinopathy (40) seven studies were reviewed, four randomised, and three non-randomised. The loadings for five studies were light, one moderate, and one heavy. The heavy load study progression was from initially body weight to weights in a back pack to using a standing calf raising machine (2). The review notes that loading guidelines were rarely used in the studies reviewed, and that velocity of movement was generally classified as slow.

The use of a single leg squat exercising into tendon pain on a 25° decline board has indicated clinical gains for rehabilitation in athletes with patellar tendinopathy. The load was initial body weight, and increasing the load with 5kg plates in a backpack (81).

The rationale for these rehabilitation programmes has been suggested that the mechanical loading stimulates cellular protein synthesis and upregulation of nuclear protein (16). The tension created on the musculotendinous unit through eccentric exercise may assist the new proteins in their orientation. It is worth noting that eccentric exercise will increase the time under tension for the musculotendinous junction.

Although most of the interest has been eccentric training for the tendon, there has also been investigation into the prevention of hamstring injuries utilising eccentric hamstring training. For the purposes of prevention of injury rather than rehabilitation the Nordic hamstring exercise was performed twice a week for four weeks. The loading is bodyweight, as the subject kneels on the ground with heels restrained by a partner; s/he allows the torso to lower to the ground using an eccentric action of the hamstrings to control descent to a prone position (13). This exercise is an intense exercise particularly for larger heavy athletes, it ought to be noted that integration of this exercise into a programme requires eccentric training experience prior to implementing this exercise into their programme. This method requires validation to determine if indeed it prevents hamstring injuries, but it demonstrates another interesting use of eccentric training for prehabilitation and rehabilitation.

Eccentric rehabilitation is mostly concerned with the rehabilitation of a tendon, or at times a musculotendinous junction. The load is generally low, and the velocity of movement generally slow. This increases the time of the structures under tension and may assist in cell orientation of new tissue.

Heavy Eccentric Training

Heavy eccentric training (HET) is characterised by attenuation or dissipation of the elastic energy, principally because the load needs to be controlled first, and the subsequent action is not necessarily a fast contraction. Following the controlled descent of the load because the load is heavy it can not be quickly concentrically acted upon see figure 4.

Heavy eccentric training is associated with high loads, and slow load lowering. The benefits of this type of training are:

- increased muscle hypertrophy (31, 41, 58, 75, 77)
- increased strength (7)
- increased relative strength (41)
- increased eccentric rate of force development (41)

Stretch-Shortening Cycle Training

In contrast to heavy eccentric training stretch-shortening cycle training involves extensive use of elastic energy generated in the musculotendinous unit, and quickly initiated into a rapid concentric action with the contact time with the ground (amortisation phase) intended to be as brief as possible (67, 78). During a rapid stretch-shortening cycle involving a small displacement during the stretch phase, there may not actually be an eccentric ‘stretch’ in the sense of lengthening sarcomeres.

Rather, the increase in muscle length may reflect stretch of the tendon; this would still contribute significantly to the resultant positive work completed by the muscle (24).

A common method of training the stretch-shortening cycle is plyometric training, which implements movement strategies maximising the contribution of elastic energy to stretch-shortening cycle movements (39, 46, 67, 78). Specifically, plyometric training improves:

- reactive strength (82)
- percentage of type IIb muscle fibre (59)
- power of subsequent concentric action (5, 32, 73)
- player preparation for competition (32, 73)

Plyometric exercise enables athletes to develop the stretch-shortening cycle of a movement, which can be difficult to develop with other training techniques (24). Further, the plyometric exercises illicit DOMS responses in athletes; however this has a prophylactic effect lasting up to six weeks (39).

Eccentric Training Modes

A suggested mechanism for increasing the ability to produce force is to utilise inherent musculotendinous stiffness (80). However, no relationship was found between musculotendinous stiffness and eccentric force production (79). The stiffness indicates the ability of the musculotendinous unit to attenuate force, the greater the stiffness the less ability to attenuate eccentric forces (72). It is possible that a stiff musculotendinous unit would be detrimental to eccentric force production, since the lengthening of the contractile component would increase the extension possibly reducing the overlap between the actin and myosin protein filaments (79).

Further, it may be that by increasing their musculotendinous stiffness athletes are inadvertently increasing the likelihood of injury through an inability to attenuate forces through eccentric mechanisms.

A compliant elastic system has been shown to maximise the use of elastic energy in a heavily loaded bench press movement, indicating that enhancement in the use of elastic energy through reduction of musculotendinous stiffness outweighs the performance improvement to the concentric phase of some SSC movements. Because the bench press movement is relatively slow, it is probably that a stiff musculotendinous unit is a greater advantage in movements requiring a more rapid development of force e.g. sprinting (79).

There are two primary modes of eccentric training for performance each one with their own specific characteristics and movement purpose. When movement of the centre of mass is viewed as a continuum, it clarifies the type of muscle modalities that are used naturally by the body to accomplish the movement. This can be seen in figure 6, where the movement from flight to landing to flight is represented. This depicts the actions of the prime movers, it is appropriate to say that at any one stage not all muscles will be active in the same mode, but as a representation of movement this indicates the interplay of force and velocity. Not all movements are a continuum of muscle actions some are a single explosive, holding, or yielding event, but for those that involve dynamic interplay of these three components it is possible to apply the following to the classical force-velocity curve. In figure 7, the stages of movement have been overlaid to give an impression of the mechanisms that the muscles must activate to achieve the same movement as in figure 6. What this figure depicts is the concept that the dynamic movement requires dynamic control of muscle action, which is switching from one mode to another, is critical to human movement.

Interestingly, in a review of a gastrocnemius muscle strain captured on video during an international cricket match it was proposed that the injury occurred close to the time when the muscle complex moved from an eccentric to an isometric phase (56). This is where an appreciation of the different types of eccentric training may assist in developing programmes that assist athletes avoid this kind of injury.

The primary differentiation between the two modes of eccentric action is whether the force is attenuated or stored as elastic energy to be utilised in a concentric action. Previous studies have shown that the recovery of elastic energy is dependent to a large extent on the time period between the stretching and shortening movement phases. Should a delay period occur the elastic energy is released as heat. The longer the delay the greater the loss of energy (68, 78, 83).

As can be seen in Table 5 various sports can be classified by eccentric actions in the sporting field. In understanding the role of eccentric action in sporting activity, it follows that a greater appreciation of how to train the sportsperson for their chosen sport can be gained. In classifying the sports there are those for which eccentric action of muscles is largely negligible, generally this concerns cyclic actions or activities in mediums where there is no need to absorb force e.g. water. In sports which require rapid acceleration the SSC becomes a very important activity mode, usually these sports are involved in generating and transferring force to an implement or body segment in order to change direction or impart force to an implement. Sports which utilise the SSC and the need to attenuate force (HET) generally involve a collision. This may be between opposing athletes or between an athlete and the ground, the ability to control the body's motion when in a collision or contact situation is important from a sports performance point of view, but also in enabling the athlete to repeat this action many times without inducing injury. There are few sports which are solely involved in attenuating force (HET), however it can be argued that skateboarding where on landing from a jump attenuating force and maintaining posture on the board is critical to a successful jump. For all sports mentioned in table 5 there will be components of the sport that may lend itself more to one or more modes of eccentric movement at various times.

Therefore it is important to differentiate the mode of training the athlete requires. In some activities it may be sufficient to only train the one method of eccentric action, e.g. sprinting, whereas in an open environment i.e. team games the training of both forms of eccentric action is likely to be warranted in order to be able to limit injury exposure as well as maximising performance in the various movement components inherent within the game.

Eccentric Movements: Designing programmes

Testing eccentric strength/power

Differentiating between the two modes of eccentric training for muscle is an important consideration for the specificity of the programme that the athlete will undertake (36, 64, 66). Proficiency in one quality of strength, but deficiency in another may not be appropriate for an athlete in a particular sport or position. It is important therefore to accurately identify the specific qualities implicit to the sport, and the methods used to develop these qualities (29, 82).

Strength and power testing should:
(a) quantify relative significance of strength and power to the sporting movement;
(b) discriminate athletic performance within their athlete subgroup;
(c) identify those suited to specific sport movements;
(d) monitor the impact of interventions (training and rehabilitation) (1)

The athlete should be assessed to determine where the deficit is most apparent in order that the athlete is able to train this modality to improve functional sporting performance. This is appropriate for eccentric actions as well as the more traditional assessments of concentric or isometric strength.

Prior to undertaking plyometric training it is common to recommend that the athlete should have completed several weeks or months of sprinting and resistance training, or the ability to squat 1.5 to 2.5 times body weight (12, 73). It is not clear why concentric strength is recommended prior to undertaking plyometric (SSC) training; a better recommendation may be the ability to control eccentric loads. Nonetheless there should be some adaptive training with suitable progressions prior to beginning testing or training in eccentric actions.

There are several methods for assessing the reactive stretch-shortening cycle reflex utilising accessible equipment (20, 71, 72). To assess the heavy eccentric strength is a more difficult process in part because of the need for more specialised equipment (75, 79, 82).

Although these concepts need further investigation and validation it is possible that for determining an athlete's ability to utilise the SSC or to attenuate force the drop jump may be a useful assessment tool. In particular investigation of the contact and flight times as suggested by Voss (2003). The protocols for the assessment of the drop jump are:

- The drop jump is performed by dropping from a certain height to convert the landing velocity by a double legged take-off into vertical height.
- Drop heights should be in the range of 35 – 45cm, the same height should be used for each test and subsequent retesting.
- The athlete drops off the box in an upright position, landing without bending the knees because it will alter the distance of the drop.
- A bent knees take-off should also be avoided – this too would increase the drop height and can often affect the concentration on the execution of a reactive ground contact.
- Ankle flexion must be restricted, not allowing the heels to touch the ground.

- Arms, if used at all, should be kept close to the body for limited assistance.

The athlete should land on a contact mat capable of measuring contact times. Swift performance equipment (www.spe.com.au) produce a contact mat capable of measuring contact and flight times.

The athlete should complete several jumps until the tester is confident that the technique of jumping is achieved. Once sufficiently familiarised with the technique the athlete performs six trials, the best result is then used to calculate the efficiency coefficient (E). The efficiency coefficient of the drop jump is determined as E = ((Flight Time x Flight Time)/Support Time)/1000.

The interplay between support and flight times is important for determining the athlete's efficiency. Should an athlete have a short support time, and long flight time the evaluation would be positive, whereas a short support time and short flight time is seen as a negative outcome. In table 6 there is an illustration of evaluations of the results of this test, it would be appropriate for a coach to establish his individual and group norms from systematic testing of his athletes. The efficiency rating has non-dimensional values ranging from 0.50 to 3.50, it climbs with increased flight and reduced support time until an individually optimal combination has been reached. The aim is always to reach in the individual support times under 140ms.

Because the contact time is thought to be most optimal under 140 milliseconds, this test assists in determining whether the athlete is able to execute a SSC eccentric action. For the athlete who is able to efficiently utilise elastic energy this test could be used to ensure there is no significant drop in this ability whilst ensuring that the athlete is able to attenuate higher eccentric forces, the opposite would be true for the athlete with a low efficiency rating.

The ability to attenuate forces is most evident in higher drop jump heights, it has been shown that for athletes with very elastic or compliant musculature dropping from a height of 80 and 100 centimetres the resultant relative drop height percentage was greater than the athletes with very non-elastic or stiff musculature at the same heights (72).

Therefore a combination of both tests utilising the drop jump at standardised heights could be of benefit in determining the athletes preferred mode of eccentric action.

Training for SSC power

Plyometric exercises are a popular method of developing SSC power, and have the advantage of utilising the athlete's body weight in replicating specific sport movements. Plyometric training is able to induce a training effect with a resulting enhancement in performance (24).

As with all conditioning plyometric training should be: specific to the sport and the individual, load progressive and monitored for appropriate improvement and recovery. There are many good descriptions of plyometric training, for further information refer to Chu, '*Jumping into plyometrics*' (12) or Brown et al, '*Training for speed, agility and quickness*' (10).

In more general terms:

Preparation: ensure that the athlete has had good physical preparation prior to commencing plyometric training, and that drills are progressed appropriately from simple to complex. Footwear and landing surfaces should have good shock-absorbing qualities (46, 73).

Load: Body weight

Frequency: one to three times per week, drills for upper or lower body regions should not be conducted on consecutive days (73).

Volume: The volume of plyometric training is dependent on the training experience of the athlete see table 7. There seems to be little evidence for the arbitrary numbers for the total workout. Recently it has been reported that training effects can be achieved using relatively low volumes of 3 sets of 6 repetitions across 2-3 exercises (67).

Note that recovery between exercises and exercise sessions is important due to the neural fatigue component of this type of exercise, which reduces the stretch reflex sensitivity (4). The athlete should be given sufficient recovery time in order that each repetition is close to maximal effort.

SSC training can also be completed with the upper body as shown in Chu (1998). The use of small medicine balls also enables the athlete to train the SSC for the shoulder as demonstrated in the 'Ballistic Six' programme for overhead throwing athletes (61). The 'Ballistic Six' programme uses six exercises to assist eccentric training of the shoulder in the cocking, deceleration and follow-through phases of throwing. The six exercises are shown in figure 8.

Heavy Eccentric Training

Heavy eccentric training assists in the development of eccentric strength production, loads in the range of 120% maximum using a slow movement speed three to four seconds per repetition, may maximise the growth stimulus as well as the musculotendinous unit's ability to attenuate eccentric force when required in sporting movements. The ability to decelerate is an integral part of playing open skill team sports (10). It is possible that heavy eccentric training may play a role in assisting athletes to develop this movement skill.

As with plyometric training, heavy eccentric training should be part of an overall programme containing appropriate training principles being: sport and individual specific, load progressive and monitored for appropriate improvement and recovery. Because of the resultant DOMS from this type of training, the athlete needs to be educated regarding the type of training that can be completed in subsequent sessions. Allowance for initial recovery from the first training session between 48 – 72 hours with active recovery activities incorporated e.g. cycling during the recovery period, the recovery time will decrease as the athlete adapts to the training stimulus to the point where two eccentric sessions a week are feasible without causing significant increases in DOMS. During the initial recovery phase further eccentric activities should be avoided e.g. plyometrics, downhill running etc.

Preparation: It is important that the athlete is an experienced weight trainer, for the inexperienced there are gains to be made from less stressful exercise modalities. It is also important that experienced spotters or training racks are utilised (75, 77).

Load:	110-120% of 1RM (9, 28, 29, 75, 76, 77, 83) would fit with the force-velocity curve. Some researchers have looked at loads of 150% (41). It would seem though that loads of 110-120% of 1RM would be appropriate for training.
Frequency:	once a week, during a heavy work-out phase (75).
Volume:	two to four sets per exercise (75), or two sets of supra-maximal added at the end of the training of the relevant muscle group (77), 2 sets of 6 repetitions (28).
Rest between Sets:	3-4 minutes.
Movement Time:	three to four seconds for the descent, the bar should achieve negligible acceleration (75, 76, 77).

There is potential for injury utilising this type of training, and therefore requires that the exercises be performed in a power rack, or on machines where the back is supported, it would be contraindicated as a general rule to use heavy eccentric training in exercises that involve minimal support for the lower back. In exercises like squats and deadlifts for example an uneven assistance from the spotters could produce twisting forces on the lower back under considerable loads (75, 76). Where loads up to 150% 1RM, are used it would be advisable to use mechanical stops to limit the downward movement so that only a small part of the total range of motion is used (41).

An example of an eccentric machine exercise is the seated hamstring curl with assistance on the concentric phase of the exercise that is the spotter pushes on the heel pad of the machine during the concentric phase (70). In this article the load is 3 sets of 12 repetitions, for an experienced athlete the load should be increased if working on heavy eccentric training. A simpler method is for the athlete to utilise the concentric strength of the other leg to raise the weight and then lower the weight with the leg being trained, this can easily be done in machines like the leg extension and leg curl machines.

Another method of heavy eccentric training is by using a weight-release device as shown in figure 9 (18). Rather than getting assistance to lift the load after being lowered eccentrically it is possible through the use of a weight-release device to release the weight and complete a concentric lift immediately. This has been shown to increase subject's 1RM. Because the eccentric component is difficult to structure without assistance from others this would allow individual's a little more independence whilst gaining from this mode of training.

A recently published paper on augmented eccentric loading (AEL), utilises an overload of mass e.g. dumbbells in a drop jump which is then released on contact and a forcible concentric action is followed (49). By increasing the mass that needs to be decelerated it may be the same as increasing the height of the drop jump, as shown by Walshe & Wilson (1997) the height of the drop and the resultant performance is in the shape of an inverted U. AEL may however be a useful method for developing the ability to attenuate force.

Volume and Velocity

To discuss the importance of intensity versus volume of eccentric exercise high intensity sessions of 12 sets of 10 maximal eccentric voluntary efforts with 2 minutes between sets, were compared to low intensity sessions of 50% of the individual's eccentric peak torque. Low intensity exercise ceased when total work equalled to that generated during high intensity exercise. Similar effects were observed for muscle damage, but high intensity had a more prominent effect on muscle performance. Suggesting that the volume rather than the intensity of the exercise that damages the muscles (60).

There have been few studies investigating the role of muscle action velocity's effect on muscle hypertrophy. One study has concluded that fast-velocity eccentric isokinetic training is more effective than slow eccentric, slow concentric and fast concentric isokinetic training for muscle hypertrophy and increasing strength (27).

More research is required to further define the roles of both volume and velocity on muscle strength qualities. These studies however assist conditioners in thinking about their athletes and possible methods for programming.

Preparation for and Recovery from Eccentric Training

As a precursor to high intensity/load eccentric training it may be useful to utilise low intensity/load repetitions and volume eccentric exercises. Exposure to a small number of non-damaging eccentric contractions can significantly improve recovery after a subsequent damaging eccentric bout (57).

Once an athlete has performed eccentric exercise additional exercises in the early recovery phase does not exacerbate muscle damage or affect the recovery process. This suggests that muscles may be able to tolerate sub-maximal eccentric loading every other day. It is however, unclear whether this training is beneficial, but does provide further understanding of how muscles work under chronic loading. The chronic effect of this type of training remains to be examined (54).

As a recovery strategy for athletes after eccentric exercise stretching appears to reduce levels of passive tension and consequently reduce stiffness sensations and soreness. A passive stretching regime is proposed as a specific benefit for someone who has muscle damage. The reduction in discomfort prior to another exercise bout is likely to aid the athlete to undertake further activity (63).

Practical Application

Eccentric actions regularly occur in sporting movements, it is important to recognise that there are three different types of eccentric movements:

1. eccentric rehabilitation for tendons
2. force absorption
3. stretch-shortening cycle.

When observing sporting movements analyse them whilst paying close attention to the amount of force required to be absorbed in landing and the subsequent movement. If maximum force/torque is required in the subsequent movement utilising the stored elastic energy would be important, if the elastic energy is not required for the next movement – force absorption is most important.

Test your athletes utilising the drop jump test to determine their ability to utilise elastic energy or to absorb force. Develop a training programme for your athlete based upon his/her results and the requirements of the sport.

If the athlete is new to eccentric training utilise low intensity/load repetitions and low volumes. This will limit the amount of muscle soreness the athlete experiences whilst enhancing the adaptation to eccentric movement and allow progression over time to heavy eccentric training (if appropriate) or plyometric training for increased utilisation of stored elastic energy.

Summary

Human muscle generates force to move objects at different rates however it not only generates force muscle attenuates force; at times storing the energy to be used in a rapid contraction or dispersing the energy to allow a controlled landing.

Eccentric muscle action generates greater forces than concentric or isometric muscle actions, and is controlled by different neural mechanisms. The benefits of eccentric exercise have been shown to be improved muscle size, strength, and neural activation. However DOMS is strongly associated with eccentric exercise set up by a cascade of cellular disruptions. Nonetheless, because eccentric activity is common in sports it is appropriate to assist the athlete in adapting to eccentric movements.

It is worth noting that not all eccentric actions are the same. Eccentric rehabilitation for tendons has become a common practice for chronic Achilles and patella tendons. This training is characterised by slow movement and low loads.

Eccentric training for performance should be separated into heavy-eccentric training and stretch-shortening cycle training. The distinction between the two forms of eccentric training is the time spent on the ground and whether it is short (SSC training) requiring a rapid concentric action immediately. Should the movement not be time dependant and the purpose is to attenuate force hence heavy-eccentric training should be utilised.

The sporting movement requires careful analysis to determine which type of training is required. Testing should be utilised to determine which type of training the athlete requires in order to augment their sporting performance.

Eccentric training has much to offer the athlete, despite the perceived negatives it is appropriate that athletes are prepared for competition with an appropriate exposure to eccentric training.

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