Short Communication B

THE STRETCH SHORTENING CYCLE: A BRIEF OVERVIEW

Philip Watkins¹
University of Derby, UK

ABSTRACT

The purpose of this paper is to examine the mechanics of the stretch-shortening cycle (SSC) and its influence on activities with high force and power requirements. The elasticity of muscle and tendons has been shown to enhance performance in SSC movements. Its importance in sprinting and jumping is well-documented and is typically characterised by an eccentric muscular contraction or stretch, followed immediately by a concentric muscular contraction. Specifically, the paper covers the mechanisms involved in the SSC, namely: tension time and the pre-tension effect, neural mechanisms and restitution of elastic strain energy and briefly introduces assessment of the SSC and concludes with practical applications. Coaches should encourage rapid, powerful movements that reduce the eccentric to concentric reversibility times of their athletes as well as emphasise the importance of minimising ground contact times. Measuring the SSC of athletes will enable coaches to monitor training adaptations and examination of ground contact times allow coaches to assess the nature of the SSC (fast or slow) being utilised to prescribe specific and appropriate training programs.

Keywords: Stretch-Shortening Cycle, Muscle Spindle, Golgi Tendon Organ, Muscle tendon Unit, Series Elastic Element.

¹ Please address correspondence and requests for reprints to Philip Watkins, Faculty of Education, Health and Sciences, University of Derby, Kedleston Road, Derby, England, DE22 1GB or e mail p.h.watkins@derby.ac.uk.

The elasticity of muscles and tendons has been demonstrated to affect performance in stretch shortening cycle (SSC) movements [32, 33]. The importance of the SSC in sprinting and jumping has been documented [18], and is typically characterised by an eccentric
muscular contraction or stretch, followed immediately by a concentric muscular contraction. Using a stretch immediately prior to a concentric contraction has been shown to increase the concentric phase resulting in augmented force production, power output [29, 17] and a shift in the force-velocity curve to the right [16]. The increased power output evident after a countermovement jump (CMJ) can be explained by the time to build up force, storage and reuse of elastic energy, potentiation of the contractile elements and reflex contributions [37]. Athletes can perform various forms of strength training to improve their ability to exert power using the SSC [23], understanding the mechanisms and assessment methods of the SSC may influence program design and enhance performance.

**Mechanisms of the SSC**

**Tension Time and the Pre Tension Effect**

During SSC movements, force rises in the eccentric phase, and the time available for force development is greater [36] than concentric only movements where the movement is performed immediately upon muscle activation. There is very little lengthening of the muscles in this eccentric phase, and the muscle action in the later dip is concentric. At the moment of transition (reversibility) from lengthening to shortening, the force is developed in isometric conditions and so the influence of high velocity is avoided [32, 36]. A continuation of tendon lengthening enables a body to continue to drop downward [36]. The importance of developing pre-tension before muscle shortening has been reported in the literature [13, 14]. Concentric movements that are immediately preceded by either isometric or eccentric actions lead to greater concentric torque when compared with purely concentric actions [30, 14].

For example, when performing a static jump (SJ), the movement begins as soon as force is applied, by the time substantial muscle forces have been generated, velocity has also increased. According to the force-velocity relationship, force must be developed when velocity is slow in order to achieve very high forces. Higher levels of muscle activation earlier in the movement allow muscles to produce greater forces over a range of joint angles thereby optimising performance [2, 5].

During the countermovement jump (CMJ) however, the body descends rapidly before the concentric phase and the total change in momentum (from high negative to high positive) is much greater than in a static jump (from zero to positive). Bobbert and Casius [1] report a 3 to 11cm increase in the maximum height attainable in the CMJ relative to the SJ. The total impulsive force required to achieve large changes in momentum is therefore high. The greater impulse translates to an increased change in momentum in order to maximize velocity at take-off [24]. In most high speed movements, the muscle force is developed in isometric conditions [36] through much of the movement, with the magnitude of lengthening and shortening of muscles depending upon the amplitude of the eccentric and concentric phases and the muscles involved. This near isometric contraction of the muscles allows large forces to be generated in accordance with the force-velocity relationship, as well as operate near their optimal length. Dropping too deeply during a CMJ may compromise jumping ability as a consequence of the muscles being taken beyond their optimal length for force production (8).
Neural Mechanisms

When muscles are forcibly stretched their tension rises sharply. SSC movements cause increases in the excitability of proprioceptors for an optimal reaction by the neuromuscular system. These changes are controlled and partially counterbalanced by two proprioceptors that are most relevant in SSC actions, the muscle spindle and the golgi tendon organ (GTO). Muscle spindles are located in the intrafusal fibres and are innervated by gamma-motor neurons. They are facilitatory mechanoreceptors that react to changes in muscle length to protect the muscle-tendon complex (10). The inevitable unloading of the muscle spindle during shortening of the muscle is counteracted by a concomitant shortening of the intrafusal muscle fibres. This stretch reflex occurs during the yielding phase (when the hip, knee and ankle joints are flexing), and compensates for muscle exposed to forcible stretches.

The Golgi-Tendon Organ (GTO) is located in the extrafusal fibres and innervated by alpha motor neurons [25]. GTOs act as a protective mechanism by responding to changes in tension rather than length and inhibit the agonist muscles and facilitate the antagonist muscles [4]. When muscle contractile forces reach a point where damage to the muscle-tendon complex may occur, GTOs increase afferent activity by inhibiting the motor neurons that innervate the stretched muscles, whilst simultaneously exciting the motor neurons of the antagonist muscles [4, 25]. Plyometric and strength training not only upregulate the stretch reflex, but also reduce the inhibitory reflexes (type III and IV receptors) [14].

Restitution of Elastic Strain Energy

Elastic energy stored in the series elastic elements (SEEs) (tendons, aponeuroses, cross-bridges, actin/myosin filaments, and possibly the giant protein Titin) in the eccentric phase is re-used during the concentric phase. At the onset of shortening, elastic recoil of these elements add to the work output of the muscle-tendon complexes involved in these actions [30]. Tendon recoil speeds are much greater than muscle shortening speeds, exercises with increasing stretching loads result in a reduction in muscle activation and surface EMG [7, 27] indicating an increased reliance on the elastic properties of the musculotendinous unit (MTU) during ballistic actions.

The control of the MTU stiffness has been shown to play an important role in making full use of the benefits of SSC movements [19]. It is defined as ‘the property of a system to resist an applied stretch’ [20, p653]. When no external forces are present these systems maintain a constant shape, however when acted upon by external forces they generate elastic force to oppose the external force and store and return elastic energy [20]. A stiffer spring-like action in the legs allows humans to run with higher stride frequencies than otherwise possible [9]. Tendon stiffness is constant, however, the stiffness of muscle is variable and depends upon the forces exerted. Fukunaga et al. [11] found that during the stance phase, subjects’ medial gastrocnemius muscle contracted isometrically, whereas the tendon lengthened by 7mm indicating greater tendon compliancy. Such tendons work as springs, and allow for storing and recouling large amounts of mechanical energy at each step [36]. Harrison et al. [12] demonstrated that sprinters used a stiffer leg spring at any given speed when compared with high calibre endurance athletes but suggested that endurance athletes may benefit from the
inclusion of SSC related activities in their training. Superior athletes can develop high forces, and the stiffness of their muscles when active exceeds the stiffness of their tendons [36].

When a muscle becomes active, high forces must be applied to stretch it, the greater the muscle tension, the greater the muscle stiffness. Increased stiffness has also been shown to enhance joint functional stability, and therefore plays a positive role in soft-tissue injury prevention [5]. It appears that MTU stiffness is an important variable for superior performance in SSC movements [33].

High movement speeds and high power outputs require the recoil of SEEs, so one of the main purposes of strength and power training is to improve muscle stiffness. It has been proposed that the influence of the facilitatory reflex which originates from the muscle spindles can be enhanced through training and can improve muscle stiffness. The role of the inhibitory force feedback component (from the GTOs) can be simultaneously decreased [15]. However, exercise selection and progression must be guided by training status, it has been reported that untrained subjects respond to the eccentric phase of a high stretch load with a period of inhibition [26]. The use of elastic energy is probably the key mechanism behind the increases in movement speed, power and efficiency that are observed in SSC movements.

**ASSESSMENT OF THE SSC**

Different approaches have been used to examine the effect of the SSC and its relationship to athletic ability [3]. Performance of the SSC is usually undertaken by adding a pre-stretch to a movement such as comparing a CMJ with a SJ performance. Both of these tests have been shown to be reliable and valid tests for estimating explosive muscular power [21]. Pre-stretch augmentation can be calculated as a percentage with % pre-stretch augmentation = [(CMJ – SJ)/SJ] x 100. Another approach is to measure the reactive strength index (RSI) (calculated as CMJ – SJ height) [22] which has been used in the practical strength and conditioning setting as a means to quantify SSC performance.

It has been suggested [27] that the SSC can be classified as either fast or slow. A fast SSC is characterised by short ground contact times (<0.25s) and small angular displacements of the hips, knees and ankles such as a depth jump. Slow SSCs involve longer ground contact times (>0.25s), larger angular displacements and can be observed when performing a maximal effort CMJ. Where a training stimulus is desired to improve performance in fast SSC movements, or to assess fast SSC function, the CMJ is not an appropriate modality [32, 17]. Therefore, appropriate exercise selections for training and assessment of the SSC should be guided by the principle of specificity and the demands of the sport.

**CONCLUSION**

The SSC is crucial for successful performance in many strength and ballistic activities. Plyometric exercises and sports that involve maximal sprinting and jumping are characterised by fast SSC movements. These techniques use rapid powerful movements that are preceded by a pre-loading countermovement that creates a SSC of the muscle [31]. Examples of
The Stretch Shortening Cycle: A Brief Overview

Crimson exercises include in-depth jumps, box jumps, hopping, bounding and medicine ball throws. Coaches should encourage fast, powerful movements that reduce the eccentric and concentric reversibility times and emphasise the importance of minimising ground contact time. Since strength and power training has been shown to increase muscle tendon stiffness which promotes effective use of the SSC, it is of benefit to both strength, power and endurance athletes.

Measuring the SSC of athletes will enable coaches to assess and monitor corresponding training adaptations. The principle of specificity determines the demands required in any sport, and examining ground contact times allow coaches to assess the nature of the SSC (fast or slow) being utilised. Athletes wishing to increase maximum sprinting velocity (fast SSC) should require plyometric exercises that involve short contact times. Athletes involved in sports that demand fast and/or slower SSC movements (e.g., rugby union or powerlifting), may benefit from combining plyometric training with exercises such as back squats, squat jumps, box squats, box-squats on to foam, over-speed eccentric squats with resistance bands and snatch and clean variations. Combining exercises that demand variation in movement velocities, increase mechanical energy, and target different phases of the SSC, may provide superior performance results. Consideration should be given to exercise selection and variation, training intensity and volume throughout the periodised program as well as the training status of the athlete.

REFERENCES


