WHY FENCERS SHOULD BOUNCE:

A NEW METHOD OF MOVEMENT TO ENGAGE THE STRETCH-SHORTENING CYCLE

Anthony N. Turner, PhD, ASCS, CSCS*D[1] and Johan Harmenberg, MD, PhD[2]

[1] London Sport Institute, Middlesex University, London, England

[2] Gungner Medical AB, Stockholm, Sweden

ABSTRACT

While teaching a heel first contact style of footwork in fencing (also referred to as toe contribution avoidance) is in keeping with long standing traditions, it is not conducive to today's modern style of fast paced and explosive fencing. Equally, fencers towards the elite-end seem to be gradually adopting a more spring-based style, as their body progressively and organically transitions to "ball of the foot" based footwork, in order for them to fence competitively in the manner they have intuitively associated with success. Therefore, if from a young age fencers are taught to make full use of the stretch shortening cycle (SSC) via "bouncing" or simply by initiating movement via the ball of the foot, this will expedite the learning process. It will demonstrate to them how the SSC can be used to move at greater speed, cover greater distances when advancing, retreating and lunging, and conserve the much-needed energy required to compete over day long competitions. This paper details the mechanistic underpinnings of the SSC and its application to the modern day fencer.

INTRODUCTION

Fencing is a combat sport with ancient traditions, with its roots from war and duels. Modern sport fencing was developed from the duelling system during the 19th century, inheriting centuries of tradition but without blood drawn (Cohen, 2002). In order to face the opponent at all times and to have the weapon ready for action at all times, fencers use a movement pattern that is specific to fencing only. This movement pattern is challenging and beginners spend years to reach mastery. All fencers assume a stationary "on guard" position with the weapon arm facing the opponent and the corresponding foot directed towards the opponent; the sole of the foot has full contact

with the floor. The back foot is positioned perpendicular to the leading foot, and approximately one-foot length apart; knees are lightly bent. As part of this movement pattern, fencers are coached from a young age to "step" forward (advance) and back (retreat), using a "heel-strike" motion in the advance and a "heel-push off" in the retreat. It is described in the following way (Garret, Kaidanov, & Pezza, 199): *"To advance, lift the toe of your leading foot and step forward (around a foot length in* (Garret, Kaidanov, & Pezza, 199)*, not more than 15 cm in* (Simmonds & Morton, 1997)*, land on the heel and place the foot flat. Then, pick up the back foot and move it equal distance forward. The retreat is simply the reverse and the leading foot pushes off with the heel."* This description is similar in all relevant literature (Cohen, 2002; Evangelista, 1996; Garret, Kaidanov, & Pezza, 199; Gaugler, 2004; Kronlund, 1962; Nadi, On fencing, 1996; Nadi, 1955; Simmonds & Morton, 1997) and is presently being taught in fencing clubs around the world. The main underlying principle is that the toes (or the ball of the foot) should not be allowed to contribute to fencing movements. This is in contrast to other fast motion combat sports such as boxing and taekwondo, where ball of foot contribution to all movements is fundamental.

It is unclear why this Toe Contribution Avoidance (TCA) to fencing motion is taught universally other than due to century old traditions, but it is tempting to speculate that duels and wars were fought on uneven surfaces and close contact with the ground at all times could be of vital importance for survival (Cohen, 2002). However, top competitive epee fencing has evolved continuously during the last 30 years towards higher speed, shorter fencing distance, and simpler and faster weapon movements (Harmenberg, Väggö, Schmitt, Boisse, Mazzoni, & Pingree, 2015). In top competitions, nearly all epee fencers bounce continuously in conflict with coaching traditions. The fencers are "bouncing" instead of the TCA technique as they travel across the piste and this is done via the balls of their feet. The ball of foot is used in three different situations: (1) the "on guard" position, i.e., bouncing instead of a stationary TCA, (2) shorter movements with bouncing instead of TCA type advances or retreats, and (3) in longer movements using push-offs with the ball of foot (with or without an initial bounce), making advances and retreats (and lunges) longer and faster than using TCA principles. The key to these three situations is to make full use of the stretch-shortening cycle (SSC).

The scientific principles of the SSC have previously been reviewed (Turner & Jeffreys, 2010). Bouncing can be continuous movement up and down to continually load (primarily) the Achilles tendons with elastic energy; the fencer is then always primed to move horizontally forward or backward, faster, and with greater energy conservation. Some movements instead require a single bounce, akin to the fencer rapidly "jabbing" the ground with the ball of their foot (we refer to it as a jab as it conceptualizes the need to initiate the bounce by actively hitting the ground, thus applying more force). Again, this single jab generates the elastic energy required to propel them in to motion in a more effective and efficient manner relative to TCA footwork. Of note, even without the jab, simply generating momentum via the ball of the foot enables a greater contribution from of the quadriceps relative to a heel push-off (including the benefits of pre-loading), as well as generating elastic energy from the tendon (albeit less than the previous two examples given that rate and magnitude of loading is less); these then increase the potential for maximal force production and impulse. Finally, as summarized in Epee 2.5 (Harmenberg, Väggö, Schmitt, Boisse, Mazzoni, & Pingree, 2015), there are strategic justifications why bouncing is rational. For example, if a TCA fencer attempts to advance, they need to lift the front foot, thereby shifting body weight to the back foot. Then the opponent can lunge and attack, which will be very problematic for the TCA fencer, since they cannot retreat given their body weight will be centred on the back foot. A bouncing fencer will not have this problem since they will never shift any body weight to a specific foot.

With respect to bouncing's suitability to the different fencing weapons, the average action length must be considered. This is around 15 seconds in epee and around 5 seconds in foil, and 2-3 seconds in saber (Turner, et al., 2014). This means that epee fencers have sufficient time to develop a bouncing game and notably, all 16 top competitors in the 2016 Olympic games individual epee event can be classed as "bouncers". This is in contrast to foil and saber, where the actions are much shorter and both fencers use the time for fast and long movements. These fencers are more likely to utilise single bounces (or jabs), or simply benefit from the additional force generated via a ball of foot push-off. As such, we believe that use of SSC through adopting a "ball of foot" style of footwork, will be advantageous for all weapons.

This paper aims to explore the biomechanical rational as to why we believe the use of the SSC to fencing footwork should be advocated as part of coaching practice and athlete development within fencing. We will justify our challenge to the current, long-standing and traditional system, through an evidence base that centres on muscle tendon mechanics, namely the SSC. In particular, we will discuss how the body utilises the SSC for optimal propulsion and movement economy, and the clear crossover this has to fencing actions. We will then conclude this paper with suitable drills and training practices, designed to enhance these mechanics. As an aside, we will also identify the difference in loading forces associated with the two footwork strategies (i.e., bouncing *vs.* TCA) and thus their potential implications to injury.

WHY IS THE STRETCH SHORTENING CYCLE SO IMPORTANT TO ATHLETIC PERFORMANCE?

It is evident that you can jump higher following a countermovement jump (CMJ; i.e., incorporating a pre-stretch) than a squat jump (SJ; i.e., one with no pre-stretch). Improvements in the range of 20-30% (Bosco, et al., 1987), or differences in jump heights of ~ 2-4 cm (Bobbert & Casius, 2005) are likely noted. Similar differences would also be evident when moving horizontally and comparing a standing broad jump (SBJ) with and without a pre-stretch. Moreover, by increasing the load applied and the rate of loading during the countermovement, e.g., following a run-up or a drop jump (that is movements that increase the speed and the load experienced during the pre-stretch), jump height typically increases further (Aura & Viitasalo, 1989; Bobbert, 1990; McBride, McCaulley, & Cormie, 2008; McCaulley, Cormie, Cavill, Nuzzo, Urbiztondo, & McBride, 2007). This phenomenon is a consequence of what is termed the SSC, and describes an eccentric phase or stretch (Figure 1a), followed by an isometric transitional period (amortization phase; Figure 1b), leading into an explosive concentric action (Figure 1c). The SSC takes advantage of the tendons elastic properties and the muscle spindle reflex, whereby when a muscle is stretched, especially if stretched quickly, it is involuntarily stimulated to contract and shorten rapidly. Of note, bouncing is a series of SSC's.
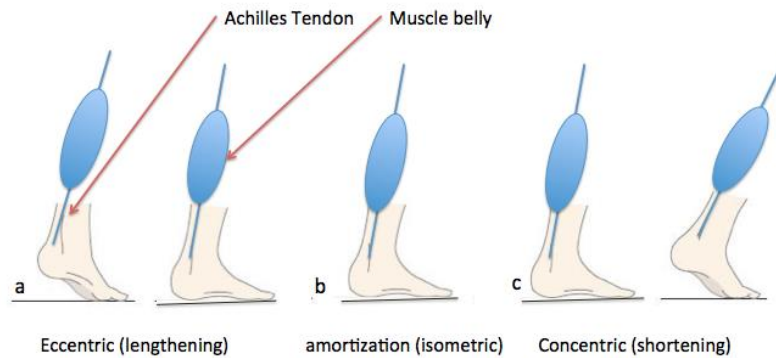
Figure 1a – c: The stretch shortening cycle (SSC). The SSC describes an eccentric phase or stretch (Figure 1a), followed by an isometric transitional period (referred to as the amortization phase; Figure 1b), ultimately leading into an explosive concentric action (Figure 1c). The SSC takes advantage of the tendon's elastic properties (for both power and energy conservation) and the muscle spindle reflex, whereby when a muscle is stretched, especially if stretched quickly, it is involuntarily stimulated to contract and shorten rapidly.

Aside from enhanced propulsion, efficient SSC mechanics enables the athlete to reduce the metabolic cost of movement (Bobbert & Casius, 2005; Bobbert, Gerritsen, Litjens, & Van Soest, 1996). For example, economical sprinting (i.e., efficient usage of the SSC) can recover ~ 60% of the mechanical energy used (Dalleau, Belli, Bourdin, & Lacour, 1998; Verkhoshansky, 1996; Voigt, Bojsen-Moller, Simonsen, & Dyhre-Poulsen, 1995), thus in effect, delaying time to fatigue. The SSC is therefore essential to many sporting endeavours, and unsurprisingly, many coaches look to incorporate training drills such as plyometrics, which can enhance the athlete's use of this mechanism. We should also note that the SSC is an innate action, and most sporting movements naturally call upon it given the aforementioned. Fencing coaching on the other hand requires its athletes to adopt positions and move in a sequence that does not capitalize on this biological potentiator of performance. A discussion of the mechanics that underpin the SSC will make this point clear.

THE MECHANICS OF THE STRETCH SHORTENING CYCLE

During hopping, jumping, and running for example, our legs exhibit similar characteristics to a spring, whereby the leg spring compresses on ground contact and stores energy, before rebounding at push-off and releasing energy (Hobara, et al., 2008). It is recognized that the tendon (and here we are referring to the Achilles tendon) is the primary site for the storage of elastic energy (EE) (Kubo, Kawakami, &

Fukunaga, 1999; Lichtwark & Wilson, 2007). The magnitude of stored EE in the tendon (often referred to as strain or potential energy) is hypothesized to be proportional to the applied force and the induced deformation (i.e., the change in length, which usually represents tissues elongation and stretch) (Zatsiorsky & Kraemer, 2006) and supports for example, the high correlation ($r = 0.79$) between the tendons capacity to store EE and performance of distance runners (Verkhoshansky, 1996), and the difference in jump height between the CMJ and SJ as noted in the earlier example.

A common goal of training then, is to improve an athlete's ability to stretch their tendons. One of the ways in which this can be induced, is to increase what is referred to as "muscle stiffness" – here we refer to muscle stiffness by virtue of an active contraction, as oppose to that generated by passive inflexibility. To elaborate, because tendon and muscle are arranged in series (Hill, 1938), they are both subjected to the same forces. The distribution of stored energy amongst these tissues then, is therefore dependent on the induced length changes in each. Put simply, whichever tissue structure stretches the most, will store the most EE. Athletes that can generate muscle stiffness (i.e., have muscles able to resist being stretched), will see all movement at a joint primarily derived via stretch in the tendon, thus capitalising on the tendon's elastic properties. If an athlete cannot generate muscle stiffness, movement at a joint will be a consequence of stretch in both muscle and tendon, with any stretch in the muscle (given its lack of elastic properties) regarded as a waste of potential (elastic) energy.

Muscle stiffness is a trained quality and athletes will not be able to generate muscle stiffness if they are not strong enough and/or are inhibited by an involuntary nervous reflex, namely (in this scenario) the Golgi Tendon Organ (GTO) reflex. The GTO acts to reduce muscle stiffness as a safety mechanism, causing more movement (flexion) at a joint (given the muscle is now more compliant and cannot maximally contract to resist stretching). This has the effect of increasing the time available to dissipate landing forces, thereby protecting us from injury. Plyometric training (assuming gradually introduced and developed) inhibits the GTO reflex (enabling muscle stiffness) and together with strength training, works to strengthen the muscles so that they can tolerate the subsequently increased landing forces consequent to this adaptation. To describe this adaptation by way of an analogy, plyometric training

turns athletes from squash balls in to golf balls. Squash balls are compliant and thus compress at landing, dissipating all the force – they therefore do not bounce very high. Golf balls on the other hand, are stiffer, compress far less at landing, and therefore better able to store and use the potential energy as evidenced by a much higher bounce. This mechanistic understanding is used to formulate plyometric training as described in the concluding parts of this paper.

HOW FENCING MOVEMENTS COUNTERACT THE SSC

To use the SSC optimally then (in terms of both propulsion and economy of energy), we need to stretch the tendon. As such, its use is limited when we land on our heels, as per traditional fencing footwork (i.e., TCA). Consider the Achilles tendon, a long fibrous tissue designed for locomotion (note that some of the fastest animals, or those that must cover long distances, have very long tendons). Landing strategies that initiate ground contact via the ball (or the toe) of the foot are able to stretch this biological spring; in contrast, heel-based landings exert little stretch. To make this point explicit, see the landing strategies adopted in Figures 1, 2 and 3. In Figure 1a, the sprinter lands on the ball of his foot. In figure 1b, the ankle joint maintains stiffness (primarily via the calf and tibialis anterior muscles), and thus, even though this period represents the middle of the ground contact phase, the foot is not flat. This is likely the product of high muscular forces, which are able to resist deformation, inferring that the tendon has stretched and will forcibly, and at a lowered energetic cost, recoil. This then potentiates the initiation of the swing phase (Figure 1c). Compare that to a classical retreat in Figure 2. Classical footwork coaching dictates that the fencer push-off with the heel (Figure 2b) and in addition, the fencer is expected to have full floor contact with one foot at all times. The propulsion is thus generated via muscular effort, at a higher metabolic cost, and with little facilitation of the tendon. Anecdotally, distance travelled is also much less. We hypothesize therefore, that both the propulsion and energetic efficiency of traditional fencing footwork (i.e., TCA) is not optimised. With respect to movement economy, while a single bout may not tax metabolic demand too much, as the competition progress, this "squandering" of energy may come at a price (Turner, et al., 2017). As much as possible then, the "*on guard*" position should ensure fencers are equally ready to attack or retreat with the Achilles tendons in both legs preloaded with elastic energy.

Similarly, fencers traveling at speed up and down the piste can better undertake this feat by limiting heel contact, maximizing ball of foot contacts, and thus Achilles tendon stretch. This is why fencers should bounce. An alternative of performing the retreat is shown in Figure 3, where the fencer pushes-off with the ball of the foot instead of the heel. This gives the fencer the possibility to preload the Achilles tendon with elastic energy (more so if the movement is initiated with a single bounce). Again distance is increased, which is especially notable with multiple consecutive retreats.

Figure 2a-c (left to right): Classical retreat. From the on-guard position with full floor contact with both feet (Figure 2a), the fencer pushes-off with the heal of the front foot while the back foot moves back a limited distance to land with full floor contact (Figure 2b). Finally, the front foot is moved back to reach the on-guard position once more. The recommended distance varies from one-foot length to not more than 15 cm. The classical advance is simply the reverse.

Figure 3a-d (left to right). A ball of foot facilitated retreat. From the on-guard position where the floor contact is mainly facilitated by the ball of the foot (Figure 3a), the fencer pushes-off with the ball of the front foot while the back foot moves back a controlled but longer distance compared

with the classical retreat, to land with the ball of the foot (Figure 3b). After landing with the back foot, the front foot follows (Figure 3c) to finally reach the on-guard position once more, where the front foot lands with the ball of the foot (Figure 3d). Anecdotally the distance covered is ~ 3 times that covered with the classical retreat. The advance is similarly performed in the reverse order using the ball of the foot both for the push-off of the back foot, as well as the landing of both feet. The use of SSC can further facilitate both the retreats and the advances using this technique, either from a single bounce (or jab) in a stationary on-guard position, or in the performance of multiple advances or retreats or in any combination thereof.

LANDING FORCES AND THE LIKELIHOOD OF INJURY

We should also take a moment to describe the benefits the use of SSC has to injury reduction. Professor Liberman et al., (2010) investigated the difference in impact forces between heel striking and forefoot (ball of the foot) striking while running. Heel striking generates a large transient impact spike, which sends a shock wave up through the body (Figure 4a). In contrast, striking with the ball of the foot generates minimal impacts forces with no impact transient (spike; Figure 4b). This is a key finding as one of the key factors around the aetiology of overuse injuries (especially stress fractures) is the initial ground reaction force, and its rate of loading at landing may be key (Milner, 2009). Furthermore, and by way of example, a common injury affecting army recruits is stress fractures, typically to the tibia (Jones, Thacker, Gilchrist, Kimsey, & Sosin, 2002; Milgrom, Giladi, Stein, & Kashtan, 1985; Milner, 2009). Stress fractures are an overuse injury caused by fatigue damage to the bone (Milner, 2009). Essentially, inadequate time for remodelling means that osteoclastic re-absorption of bone outstrips the osteoblastic formation of new bone, resulting in a weakened bone (Jones, Thacker, Gilchrist, Kimsey, & Sosin, 2002). The pathology of stress fractures is such that a reduction in running volume can reduce its occurrence, and military studies have reported that reducing running volume by approximately half, reduces stress fractures by half (Jones, Shaffer, & Snedecor, 1999; Shaffer & Almeida, 1996). In a fencing context, where fencers undergo several hours of training each week, and all involving TCA footwork, it is likely that heel-striking will expedite the likelihood of an overuse based injury (albeit stress fractures being an extreme example). A reduction in impact forces (magnitude and rate of loading) by virtue of ball of foot landings may be able to attenuate this. Furthermore, when you consider that impact forces travel up the skeletal system, bouncing SSC allows these

forces to be shared among the ankle, knee and hip joint (Turner & Jeffreys, 2010); TCA in contrast, sees these forces distributed over the knee and hip only (Turner, et al., 2014). Of course, oftentimes fencers will lunge and in an effort to maximise distance, will land heel first. This is a practicality of the technique in this context, with the reduced volume of TCA movements as we advocate herein, potentially seeing the injurious implications of this largely mitigated.
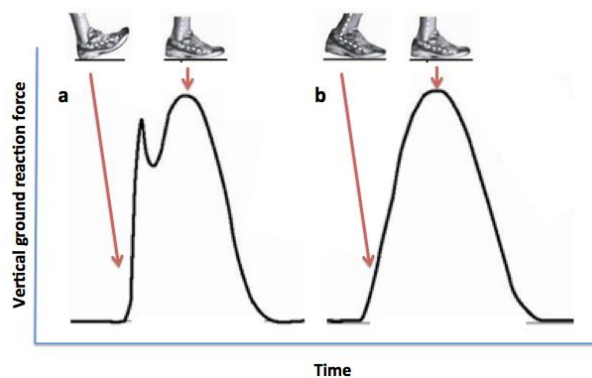

Figure 4a-b: Difference in impact forces between heel striking and forefoot (ball of the foot) striking while running (Lieberman, et al., 2010)**. Heel striking generates a large transient impact spike, which sends a shock wave up through the body (Figure 4a). In contrast, striking with the ball of the foot generates minimal impacts forces with no impact transient (spike; Figure 4b).**

In summary, heel striking is associated with large impact spikes, characterised not only by their magnitude, but also by their rate of loading. While TCA may represent lower impact values compared to running, the impact trauma will accumulate over time given the volume of training undertaken by fencers. Use of SSC driven technique serves as a means of organically attenuating the risk of high training loads (i.e., without the need to manipulate footwear, training surface, or limit high impact tasks such as lunging for example). Equally, the muscle tendon properties are such that muscle stiffness involuntarily adapts to the "hardness" of surfaces and footwear, thus serves as a naturally occurring "cushion" to these constant changes – see Ferris and Farley (1997) for a review of this natural modulation of leg stiffness.

METHODS TO ENHANCE SSC MECHANISMS

The optimal method to train SSC ability is plyometrics (Kyrolainen, Komi, & Kim, 1991; McBride, McCaulley, & Cormie, 2008; Myer, Ford, Brent, & Hewett, 2006; Potteiger, et al., 1999; Rimmer & Sleivert, 2000; Schmidtbleicher, Gollhofer, & Frick, 1988; Spurrs, Murphy, & Watsford, 2003). The following sections outline how plyometric exercises can be progressively integrated into an athlete's training program, and also outlines appropriate methods of performance evaluation.

Plyometrics covers a wide range of fundamental movement skills such as jumping, hopping and bounding; in its simplest form, plyometrics revolve around two basic capacities, jumping and landing. While appearing relatively simple exercises, they are in fact quite complex and as such, appropriate time should be allocated to their development. Therefore, this requires a progressive system of exercises to be set up, through which an athlete can pass to ensure they have the required technical mastery to be able to perform each in a manner that both maximizes performance gains, but also minimizes injury risk.

Ideally, in terms of maximizing performance, plyometric training should be preceded by strength training to reduce the risk of injury to the muscle tendon complex, facilitate the dishinhibition of the GTO, and increase the quality and quantity of Type IIa (from Type IIx) fibers. The latter point is of significance due the high correlation between the percentage of Type II fibers and power output (Coyle, Costill, & Lesmes, 1979) and is therefore likely to increase the athletes' net potential to develop power (Komi, 2003). Below is a suggested progression of drills:

1. Jump ropes
Jump ropes are an effective entry stage plyometric drill as shown by Miyaguchi and coworkers (Miyaguchi, Sugiura, & Demura, 2014). In addition, the movement pattern of jump ropes has similarities with the "on guard" bouncing which make jump ropes practice even more attractive. The risk of injury is limited compared to more advanced plyometric drills. It should be noted that "double-under" jumps place greatest demand on the SSC (Miyaguchi, Sugiura, & Demura, 2014) with data showing that subjects use approximately 70% of energy from the SSC, and are therefore effective for reinforcement of SSC ability.

2. Jump to box

This stage develops basic jumping abilities and also crucially, landing ability, in a controlled environment. By excluding the time gravity has to act, landing forces can be minimized, and landing technique taught to beginner athletes, or athletes with current landing problems. Varying the height of the box (i.e., gradually increasing it and eventually aiming to jump to a box higher than the athlete's belly button) can provide a challenge to the athlete's jumping ability, while still minimizing landing forces. Moving from a double leg to a single leg landing can further challenge the athlete's landing ability. All landings should be made with the shoulders, knees and toes in line, to ensure load is appropriately distributed across both the knee and hip joints.

3. Drop lands or jump and stick

This stage builds upon the athlete's landing capacity developed in stage one, and develops their ability to control landing (eccentric) forces. Initially, exercises in this stage can involve low amplitude movements (i.e., stepping from a low box or taking short horizontal jumps if working from the floor), but progression can be provided by increasing the amplitude of movement, and by moving from double to single leg landings. As well as further developing landing technique, this stage allows the athlete to adapt to high landing forces through learnt GTO reflex inhibition. This stage, and the amplitudes within, should be dictated by the quality of the movement and not be progressed until the athlete can stick the landing with appropriate levels of control, and with appropriate foot contact. Heel contact for example, is suggestive of GTO reflex and the athlete's inability to optimally store energy in the tendons, which is essential to the amortization phase (and duration of) used in the subsequent stage (Flanagan & Comyns, 2008). So heel contact should be avoided (of note the gap between the heel and floor should be large enough to swipe a credit card under – it should not be so big as to fit a golf ball). In addition, and described in the preceding text, this stage also requires the development of muscle stiffness through pre-activation tensioning (where muscle activation begins during the flight phase prior to contact with the floor) and antagonist co-contraction (i.e., the tibialis anterior contracts in concert with the gastrocnemius and soleus to "lock" the joint in position) and may therefore take several weeks to develop (Kyrolainen, Komi, & Kim, 1991).

4. Drop jump, or jump, jump, stick

This stage begins the true plyometric training where the SSC is utilized to enhance subsequent concentric performance. Here, the athlete performs a sequence of horizontal jumps of initially low amplitude, where the aim is to minimize ground contact time (GCT), while maintaining effective landing mechanics and body control. Again, this stage should be progressed to involve greater amplitude of jumps and the utilization of single leg activities. Ankling drills and rope skipping provide good examples of short response jumps. In addition, there is research suggesting that overall leg stiffness is correlated with ankle stiffness (Arampatzis, Schade, Walsh, & Bruggemann, 2001; Farley, Blickhan, Sato, & Taylor, 1991; Farley & Morgenroth, 1999), therefore ankling may provide a prudent starting point.

Emphasize horizontal drills and train like a sprinter

Given that lunging and fencing specific change of direction speed tests demonstrate greater correlations with SBJ distance (i.e., a horizontally directed jump) than vertical jump height (Turner, Bishop, Chavda, Edwards, Brazier, & Kilduff, 2016; Turner, Marshall, Noto, Chavda, Atlay, & Kirby, In press), plyometric training should ensure athletes are adequately exposed to horizontal-based drills. Equally, it is important that fencers train with low amplitude jumps given that fencers move so that they do not unnecessarily extend flight time, given that this period represents a vulnerability to attack. Therefore, low hurdle drills of varying distance are an effective method. The variation in distance ensures athletes learn to bounce in a manner that enables them to be reactive to stimuli. Again, moving in set pattern or with a predictable sequence of movements is to the advantage of the opponent. The concept of training like a sprinter will also serve the fencer well, with particular focus on acceleration drills, where a low foot recovery is desirable as well as generating momentum. As such, horizontal hopping (i.e., using one foot) and bounding (from one foot to the other) drills, including against additional resistance (such as sleds and resistance bands) will likely prove effective. Drills should evolve to be responsive to stimuli.

Change of direction speed (CODS) and Repeated lunge ability (RLA)

The drills 1- 4 above concern movements with force directed vertically. The critical fencing movements are performed mostly horizontally, so it is therefore of importance to develop drills mimicking the fencing situation. Several papers have

shown the importance of change of direction ability and repeated lunge ability in fencing (Turner, Bishop, Chavda, Edwards, Brazier, & Kilduff, 2016; Turner, et al., 2016; Turner, et al., 2017), and the aforementioned drills must ultimately be integrated in to these. As such, these actions should be performed making full use of the SSC technique. This includes push-off with the ball of foot both in advance (also the lunge) as well as in retreat, making these movements faster, longer, and more energy conservative. As one example, making an advance from a bouncing on guard position with push-off using the the ball of foot of the trailing foot, landing on the leading foot while elongating the Achilles' tendon, and immediately initiating a retreat with a push-off by the the ball of foot of the leading foot. This situation would, if correctly performed, make maximal use of SSC in contrast to the TCA movement described in the introduction and would naturally be applicable for all weapons.

The average active fencing time in 15 touch bouts has been assessed and varies between the different weapons. A change of direction drill should therefore mimic the most challenging action time for the specific weapon, suggestively the mean plus 2 standard deviations. For epee, this would mean an approximately 30 second drill time. We have used markings 3 meters apart with instructions to the fencers to make advance/retreats at maximal speed between the markings. The acceleration during 3 meters causes the fencer to be forced to make an abrupt stop from a high-speed motion when changing direction. Epee fencers need to cover the 3 meters approximately 20 times (with 19 changes of directions) for a work time of approximately 25-30 seconds. The drill can be repeated numerous times and it is recommended to target the observed break time from 15-touch matches between the sets. A variant is to replace the last advance before the change of direction with a lunge and thus assessing "repeated lunge ability" (RLA). These drills are designed to both mimic the competitive situation and to make full use of SSC ability.

EVALUATING THE SSC MECHANISM

As GCT is an important variable in plyometric training prescription, monitoring of this important variable is important and can be achieved using training/testing equipment such as contact mats and force plates and is available in real-time, possibly facilitating athlete motivation (Flanagan & Comyns, 2008; Newton & Dugan, 2002).

Moreover, calculation of the reactive strength index (RSI; flight time ÷ ground contact time) during activities such as drop jumps, can provide S&C coaches with a good indication of an athletes' SSC ability (Flanagan & Comyns, 2008; Newton & Dugan, 2002; Young W. , 1995; Young, Pryor, & Wilson, 1995). This is usually tested over the following drop heights: 30cm, 45cm and 60cm (Newton & Dugan, 2002) and as previously mentioned, efficient SSC mechanics should result in greater jump heights from greater drop heights. The ratio score, i.e., the RSI, is usually reported as it considers both variables; some athletes could get a low GCT but not jump high and vice-versa. Anecdotally, an RSI of ≥ 3 is considered excellent.

CONCLUSION

While teaching a TCA style of footwork in fencing is in keeping with long standing traditions, it is not conducive to today's modern style of fast paced and explosive fencing. Equally, fencers towards the elite-end seem to be gradually adopting a more spring-based style as their body progressively and organically transitions to SSC usage via the ball of the foot instead of heel focused push-offs and landings, in order for them to fence competitively in the manner they have intuitively associated with success. If from a young age fencers are taught to make full use of SSC, it is suggested that this will expedite the learning process, demonstrating to them how the SSC can be used to move at greater speed, cover greater distances when advancing, retreating and lunging, and conserve the much-needed energy required to compete over daylong competitions. In conclusion, we feel fencers should make full use of the SSC and therefore be taught to bounce.

REFERENCES

Arampatzis, A., Schade, F., Walsh, M., & Bruggemann, G. (2001). Influence of leg stiffness and its effect on myodynamic jumping performance. *Journal of Electromyography and Kinesiology , 11*, 355-364.

Aura, O., & Viitasalo, J. (1989). Biomechanical characteristics of jumping. *International Journal of Sports Biomechanics , 5 *, 89-97.

Bobbert, M. (1990). Drop jumping as a training method for jumping ability. *Sports Medicine , 9*, 7-22.

Bobbert, M., & Casius, L. (2005). Is the countermovement on jump height due to active state development? *Medicine and Science in Sports and Exercise , 37*, 440-446.

Bobbert, M., Gerritsen, K., Litjens, M., & Van Soest, A. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise , 28* , 1402-1412.

Bosco, C., Montanari, G., Ribacchi, R., Giovenali, P., Latteri, F., Iachelli, G., et al. (1987). Relationship between the efficiency of muscular work during jumping and the energetic of running. *European Journal of Applied Physiology , 56*, 138-143.

Cohen, R. (2002). *By the sword. A history of gladiators, samurai, swashbucklers, and Olympic champions.* Toronto: Randoms House of Canada Limited.

Coyle, E., Costill, D., & Lesmes, G. (1979). Leg extension power and muscle fiber composition. *Medicine and Science in Sports , 11*, 12 -15.

Dalleau, G., Belli, A., Bourdin, M., & Lacour, J. (1998). The spring-mass model and the energy cost of treadmill running. *European Journal of Applied Physiology and Occupational Physiology , 77*, 257–263.

Evangelista, N. (1996). *The art and science of fencing.* Chicago: Masters Press.

Farley, C., & Morgenroth, D. (1999). Leg stiffness primarily depends on ankle stiffness during human hopping. *Journal of Biomechanics , 32*, 267-273.

Farley, C., Blickhan, R., Sato, J., & Taylor, C. (1991). Hopping frequency in humans: a test of how springs set stride frequency in bouncing gaits. *Journal of Applied Physiology , 191*, 2127-2132.

Ferris, D., & Farley, C. (1997). Interaction of leg stiffness and surface stiffness during human hopping. *Journal of applied physiology , 82* (1), 15-22.

Flanagan, E., & Comyns, T. (2008). The use of contact time and the reactive strength index to optimise fast stretch-shortening cycle training. *Strength and Conditioning Journal , 30*, 33-38.

Garret, R., Kaidanov, E., & Pezza, G. (199). *Foil, Saber and epee fencing. Skills, safety, operations and responsibilities.* Pennsylvania: The Pennsylvania State University Press.

Gaugler, W. (2004). *The Science of Fencing: A Comprehensive Training Manual for Master and Student: Including Lesson Plans for Foil, Sabre and Epee Instruction.* Maine: Laureate Press.

Harmenberg, J., Väggö, B., Schmitt, A., Boisse, P., Mazzoni, A., & Pingree, G. (2015). *Epee 2.5. The new fencing paradigm revised and expanded with new contributions from three world champions.* New York: SKA SwordPlay Books.

Hill, A. (1938). The heat of shortening and the dynamic constants of muscle. *Proceedings of the Royal Society of London. Series B, Containing papers of a Biological character. Royal Society (Great Britain), 126*, pp. 136–195.

Hobara, H., Kimura, K., Omuro, K., Gomi, K., Muraoka, T., Iso, S., et al. (2008). Determinants of difference in leg stiffness between endurance- and power-trained athletes. *Journal of Biomechanics , 41*, 506-514.

Jones, B., Shaffer, R., & Snedecor, M. (1999). Injuries treated in out- patient clinics: surveys and research data. . *Mil Med , 164*, 86-89.

Jones, B., Thacker, S., Gilchrist, J., Kimsey, D., & Sosin, D. (2002). Prevention of Lower Extremity Stress Fractures in Athletes and Soldiers: A Systematic Review. *Epidemiologic Reviews , 24*, 228-247.

Komi, P. (2003). Stretch-shortening cycle. In P. Komi, *Strength and Power in Sport* (2nd Edition ed., pp. 184-202). Oxford, UK: Blakwell Science.

Kronlund, M. (1962). *Fäktning.* Stockholm:: Norlins Förlags Aktiebolag.

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *Journal of Applied Physiology , 87*, 2090-2096.

Kyrolainen, H., Komi, P., & Kim, D. (1991). Effects of power training on neuromuscular performance and mechanical efficiency. *Scandinavian Journal of Medicine and Science in Sports , 1*, 78-87.

Lichtwark, G., & Wilson, A. (2007). Is Achilles tendon compliance optimised for maximum muscle efficiency during locomotion? *Journal of Biomechanics , 40* , 1768-1775.

Lieberman, D., Venkadesan, M., Werbel, W., Daoud, A., D. S., Davis, I., et al. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature , 463* (7280), 531-535.

McBride, J., McCaulley, G., & Cormie, P. (2008). Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. *Journal of Strength and Conditioning Research , 23*, 750-757.

McCaulley, G., Cormie, P., Cavill, M., Nuzzo, J., Urbiztondo, Z., & McBride, J. (2007). Mechanical efficiency during repetitive vertical jumping. *European Journal of Applied Physiology , 101*, 115-123.

Milgrom, C., Giladi, M., Stein, M., & Kashtan, H. (1985). Stress fractures in military recruits. A prospective study showing an unusually high incidence. *Journal of Bone and joint Surgery , 67*, 732-735.

Milner, C. (2009). Gait biomechanics and tibial stress fracture in runners. *ISBS-Conference Proceedings Archive. 2009 .*

Miyaguchi, K., Sugiura, H., & Demura, S. (2014). Possibility of stretch-shortening cycle movement training using a jump rope. *J Strength Cond Res , 28* (3), 700-5.

Myer, G., Ford, K., Brent, J., & Hewett, T. (2006). The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *Journal of Strength and Conditioning Research , 20*, 345–353.

Nadi, A. (1996). *On fencing.* Maine: Laureate Press.

Nadi, A. (1955). *The living sword. A fencer's autobiography.* Florida: Laureate Press.

Newton, R., & Dugan, E. (2002). Application of strength diagnosis. *Strength and Conditioning Journal , 24*, 50-59.

Potteiger, J., Lockwood, R., Haub, M., Dolezal, B., Almuzaini, K., Schroeder, J., et al. (1999). Muscle power and fiber characteristics following 8 weeks of plyometric training. *Journal of Strength and Conditioning Research , 13*, 275–279.

Rimmer, E., & Sleivert, G. (2000). Effects of a plyometrics intervention program on sprint performance. *Journal of Strength and Conditioning Research , 14*, 295–301.

Schmidtbleicher, D., Gollhofer, A., & Frick, U. (1988). Effects of stretch shortening time training on the performance capability and innervation characteristics of leg extensor muscles. In G. DeGroot, A. Hollander, P. Huijing, & G. Van Ingen Schenau, *Biomechanics XI-A* (Vols. 7-A , pp. 185-189). Amsterdam: Free University Press.

Shaffer, R., & Almeida, S. (1996). Musculoskeletal injury project: Naval Health Research Center. *43rd Annual Meeting of the American College of Sports Medicine*, *24*, pp. 228–247. Cincinnati.

Simmonds, A., & Morton, E. (1997). *Fencing to win.* London: The Sportmans Press.

Spurrs, R., Murphy, A., & Watsford, M. (2003). The effect of plyometric training on distance running performance. *European Journal of Applied Physiology , 89*, 1–7.

Turner, A., & Jeffreys, I. (2010). The stretch shortening cycle: Proposed mechanisms and methods for enhancements. *Strength and Conditioning Journal , 32* (4), 87-89.

Turner, A., Bishop, C., Chavda, S., Edwards, M., Brazier, J., & Kilduff, L. (2016). Physical Characteristics underpinning lunging and change of direction speed in fencing. *Journal of strength and conditioning research , 30* (8), 2235-2241.

Turner, A., Bishop, C., Cree, J, Edwards, M., Chavda, M., et al. (2017). Do fencers require a weapon specific approach to strength and conditioning? *Journal of strength and conditioning research , 31* (6), 1662-1668.

Turner, A., James, N., Dimitriou, L, Greenhalgh, A., Moody, J., et al. (2014). Determinants of Olympic Fencing Performance and Implications for Strength and Conditioning Training. *Journal of strength and conditioning research , 28* (10), 3001-3011.

Turner, A., Kilduff, L., Marshall, G., Phillips, J., Noto, A., Buttigieg, C., et al. (2017). Competition intensity and fatigue in elite fencing. *Journal of strength and conditioning research , 31* (11), 3128 - 3136.

Turner, A., Marshall, G., Buttigieg, C., Noto, A., Phillips, J., Dimitriou, L., et al. (2016). Physical characteristics underpinning repetitive lunging in fencing. *Journal of strength and conditioning research , 30* (11), 3134-3139.

Turner, A., Marshall, G., Noto, A., Chavda, S., Atlay, N., & Kirby, D. (In press). Staying out of range: Increasing attacking distance in fencing. *International Journal of Sports Physiology and Performance* .

Verkhoshansky, Y. (1996). Quickness and velocity in sports movements. *IAAF Quaterly: new studies in athletics , 11*, 29-37.

Voigt, M., Bojsen-Moller, F., Simonsen, E., & Dyhre-Poulsen, P. (1995). The influence of tendon Youngs modulus, dimensions and instantaneous moment arms on the efficiency of human movement. *Journal of Biomechanics , 28*, 281-291.

Young, W. (1995). Laboratory strength assessment of athletes. *New Studies in Athletics , 10*, 88–96.

Young, W., Pryor, J., & Wilson, G. (1995). Effect of instructions on characteristics of countermovement and drop jump performance. *Journal of Strength and Conditioning Research , 9*, 232-236.

Zatsiorsky, V., & Kraemer, W. (2006). *Science and practice of strength training.* Champaign, IL, USA: Human Kinetics.