IDENTIFICATION OF STRETCH-SHORTENING CYCLES IN DIFFERENT SPORTS

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In sports the stretch-shortening cycle (SSC) muscle actions are obviously natural. They are partly responsible for making the muscular performance more economical and/or better as compared to the use of isolated forms of muscle actions. In sport activities SSC can be traditionally identified by certain kinematic and electromyographic methods. An attempt is made to describe how one can go beyond these more simple ways by applying portable ultrasonography (US) to record fascicle-tendon interactions during various movements ranging in intensity from low to maximum. The observed results from a number of studies indicate that the original definition of SSC cannot be used to describe the SSC at the MTU levels of all muscles and all exercise conditions. However, the greatest merit of this US application is in its strength to explain more of the mechanism how the fascicle-tendon interaction differs between muscles and how the elastic energy may be involved in the performance potentiation.

KEY WORDS: elastic energy, ultrasonography, stretch reflex.

Isolated forms of muscle action have been traditionally used to assess the basic function of the neuromuscular system. From these forms (isometric, concentric or eccentric) isometric type has received greatest attention, especially in the study of muscle fatigue. The natural form of muscle function involves use of stretch – shortening cycle (SSC) muscle actions, in which the preactivated muscle is first stretched (eccentric action) and then followed by the shortening (concentric action). This SSC has important functions in locomotion: (i) to minimize unnecessary delays in the force-time relationship by matching the preactivated force level to the required level to meet the expected eccentric loading, and (ii) to make the final concentric action (push-off phase in running, for example) either more powerful (in maximal effort) or generating force more economically (in submaximal conditions) as compared to the corresponding isolated concentric actions. In running, the amount of gastrocnemius muscle preactivation is directly dependent on the expected impact load. The preactivated muscle-tendon unit is then lengthened during the ground impact. This active eccentric (braking) phase is followed without delay by the shortening (concentric) action. Depending upon the intensity of effort, this shortening or (push-off phase in running) can take place in many cases as a recoil phenomenon, with relatively low electromyographic activity.
Hopping, jumping and running are considered as most typical forms of SSC. Walking as well as counter-movement jumps (CMJ) are also SSC actions, because they include the sequence of stretch and shortening. The stretching (the braking phase) is, however, very often so slow in these two activities that by using both slow walking and CMJ it is hard to explore the mechanisms of performance potentiation in SSC. The definition of SSC also needs to be looked at more critically. It is often difficult to identify precisely the eccentric and concentric phases for the muscles. In general, however, evidence of the use of SSC in sport activities calls for utilization of the following techniques: kinematics, EMG, reaction forces and ultrasound methods For appropriate references please consult the three publications listed at the end of this paper. As a simple way of identifying SSCs, Fig 1. presents the use of angular velocity curves of the hip and knee joints during the functional propulsive phase of X-C skiing. As kinematic, kinetic, and EMG methods are widely known, the following few paragraphs make selected efforts to describe how ultrasound recording can be complemented to add our understanding of SSC, especially when the SSC is looked at the fascicle and tendon levels of the Muscle-Tendon Unit (MTU).

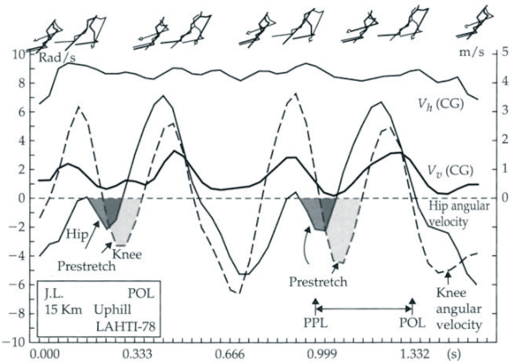

Figure 1: Horizontal velocity (Vh) and vertical velocity (Vv) of the body CoG together with the angular velocity curves of the hip and knee. The hatched areas represent the parts of the cycle where the extensor muscles of these joints are assumed to be prestretching (negative velocity) just prior to propulsion extension (positive velocity) (Komi & Norman 1987)

Use of ultrasonographic (US) techniques to capture SSC in dynamic movements: It is a common observation among researches working with US scanning techniques that it is more challenging to study dynamic than static situations. Especially demanding is to explore the manners how the fascicles and tendons behave during actual locomotor tasks. As already defined, the SSC involves by definition the entire MTU, although the fascicles and tendons may experience different changes in length. As the fascicles are controlled both by external stretch and internal activation, it is important to present the differences in length changes of fascicles and tendons in various muscles during SSC exercises. Our interest was prompted by the unexpected great differences is the literature regarding the fascicle behavior observed in the various studies. It is very likely that the usual US scanning frequency of 25 to 60 Hz that we and others have often used, is not sufficient to catch well enough the behavior of fascicles and tendons. An increase in the scanning frequency of ultrasonography was an important step forward in the study of how fascicles and tendons truly interact in rapid SSC movements. This fundamental question includes also the timing of the stretch to the muscle spindles that triggers the stretch reflex. In this regard, Fig. 2. presents a situation where high-speed ultrasound scanning (96-200Hz) of two muscles is performed while the subject is running on a 10m long force plate at various speeds. The set-up is demanding because it requires two separate ultrasound machines placed on a carriage. The carriage is then pushed by the experimenter along a rail constructed at the side of the force plate system. The measurements can be combined with the recording of electromyogram (EMG) activities of the relevant muscles and/or direct in vivo measurements of the Achilles (and Patella) tendon forces. The results were very consistent and showed typical inter-muscular differences as well as reliable behavior of the single muscle. They led further to hypotheses that, in addition to the existence of the stretch reflex potentiation during human SSC, changes in length of the fascicles and tendon, when acting together, depend on the movement task, movement intensity, and muscles involved.

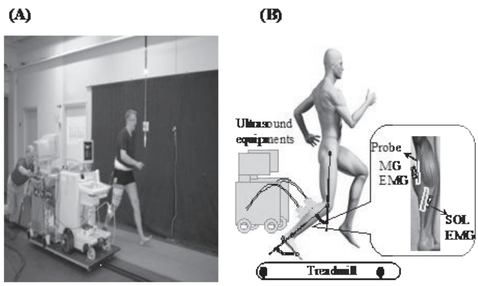

Figure 2: Set-up for the walking and running experiments on the ground (A) and treadmill (B). (Ishikawa & Komi. 2010)

Because the strict definition of SSC refers to the entire MTU, the stretching and shortening do not imply events in the fascicle and tendon parts of MTU. The question regarding the specific length changes in these two components is, however, very relevant, as it may explain better the difference in behavior of the various muscles under same movement conditions. More importantly, however, it helps to understand how fascicles and tendons interact as a function of movement specificity and intensity, for example. It has been suggested that the human skeletal muscle can adapt to the functional requirements of specific sport activities so that the working range of the sarcomere force-length relationship could be also movement task dependent. US studies of human fascicles have indeed confirmed this hypothesis. For example, the MG fascicles exhibit most likely different patterns of behavior during walking as compared to running when examined in the same subject group.

In walking, the fascicles remain isometric or even lengthen during the single leg stance phase (25-75% contact period) similarly to the MTU length changes. In running, however, the MG fascicles can shorten throughout the entire contact phase after a clear short-lasting stretch of the fascicles even though the stretch of the MTU can be greater in terms of amplitude and velocity during running. In addition, shortening of the MG fascicles in running is timed with increased preactivation just before the contact. The length at which the fascicles operate may thus be different in these two activities. In walking this fascicle length could correspond to the plateau part of the sarcomere force-length relationship. In running, it could correspond to the ascending limb of this force-length relationship.

One question that has yet to be answered is why the working length of the fascicles is not the same during these two activities. The shorter fascicle length during contact phase of running implies a reduced relative force output of the fascicles. However, the shorter fascicles may be beneficial as they result in a larger stretch of the tendon in running than in walking. The peak tendon length can be significantly greater in running than in walking. It is therefore likely that in running, where the MG fascicles are initially (at contact) very short and continue shortening during the short braking phase, the tendon stretch rate can be increased. The corresponding tendon recoil can then occur more rapidly due to the tendon's viscoelastic properties. Thus, no fixed "position" of the working length can be identified in the MG sarcomere force-length relationship for all SSC activities. It has also been observed that the MG fascicle length is dependent on running speed so that it becomes shorter with higher speeds of running. This may imply also that effective utilization of tendon elasticity is regulated by the fascicle length, which in turn is under the influence of intensity of effort of a specific SSC task. This poses also questions if the structural differences in fascicles and tendons could exist between different ethnic groups. For example, the better economy of running among certain African runners, as opposed to e.g. European and/or Japanese runners, could then have at least partly a rational explanation?

From several possibilities to characterize the different fascicular-tendon behavior (such as task, intensity and muscle specificity), influence of the exercise intensity may have special relevance to sport biomechanics. It is well established that in the drop jumps the performance increases as a function of the drop height until a certain breaking point, after which the added drop height (prestretch intensity) causes the maximum jump height to decrease. Reasons for this particular form of the drop height vs. rebound performance curve can be at least partly sought by examining how the fascicles and tendons interact in the different drop jump conditions. This may imply that fascicle and tendon behavior differs when both impact (braking phase) loads and rebound efforts are involved, and when these parameters are varied.

If the drop jumps are performed always with maximum effort, the drop height vs. jump height curve shows the well-established relationship with the performance decreasing after a certain breaking point. Three conditions can then be chosen for comparison of fascicle- tendon interaction: low drop, medium drop and extremely high drop. From these, the extremely high drop condition represents the reduced performance situation. When the dropping height exceeds the optimal impact load (medium drop condition), the MG fascicles are suddenly stretched during the braking phase (* in Fig. 3). This suggests loss of tolerance of the MG

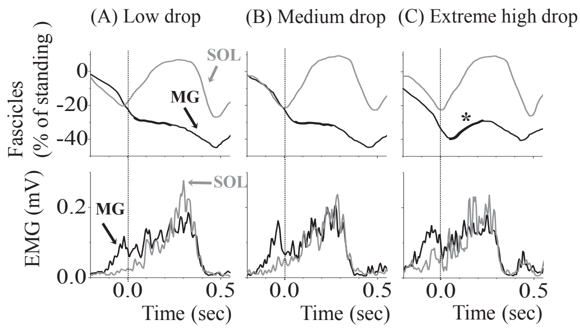

Figure 3: An example of the of fascicle-TT interaction in MG and SOL muscles during the contact of the short contact DJs with three different drop intensities. The vertical dotted lines indicates instant of the ground contact (Sousa et al. 2007).

fascicles to the high impact loads. In the initial braking phase of these extreme drop height conditions, tendons can still be stretched rapidly and can reach high forces (Achilles tendon force: 10-12 times body weight) in the early braking phase. If the MG fascicles were able to tolerate this extremely high impact braking phase, the elastic energy stored in the tendon could be increased and utilized during the push-off phase. Alternatively the tendons could experience structural changes due to extreme strain. The elastic energy stored in the tendon will be partially lost before the start of the push-off phase. Thus, the extremely high drop conditions do not favor effective utilization of elastic energy in tendons or fascicles. This notion has tremendous importance, when choosing the drop height conditions for SSC training in different sports. Fig 4. is our attempt to describe this particular hypothesis and it needs to be verified or rejected at different locomotor tasks, in which the stretch and shortening phases are varied with regard to intensity and coupling. This in fact is what SSC is in its importance and relevance for sport activities.

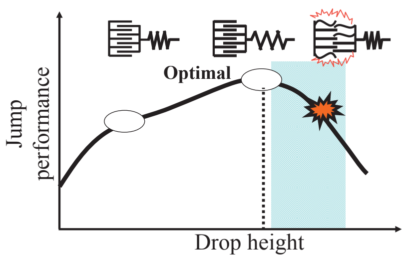

Figure 4: Schematic model of the jump intensity and muscle behavior. The curve is based on the findings shown in fig. 3 and it describes the relationship between the slope of MG fascicle length changes and Achilles tendon force (ATF) rate. The filled circle corresponds to the point where the rate of the MG fascicle length change is zero during the braking phase, and it can be considered as the point of the critical stretch load for the MG fascicles to use tendon elasticity effectively (Ishikawa & Komi 2010).

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