Current Perspectives of Biokinetics in Middle and Long Distance Running - An Examination of the 'Elastic Response'

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31:1/2; 25-40, 2016

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ABSTRACT

Most coaches recognise that biokinetic capabilities are important in the 'power' events of athletics: the sprints, hurdles, jumps and throws. There is a common misconception, however, that their role in the middle and long distance events is unimportant or insignificant. While these events do require an emphasis on metabolic capacity over time, they also involve repeated brief, explosive 'spikes' in power output each time the foot contacts the ground. Although they make an important contribution to performance - the author calls them a 'fourth energy system' - the elastic response processes at work in the middle and long distance running stride tend to be ignored by coaches and in coach education curricula. Drawing on recent research this article discusses in detail the physical structures and mechanisms operating in the stride, why endurance runners need to improve certain fundamental movements, what might limit these movements and how to manage limitations. The author proposes that, along with a re-evaluation of the stretch-shortening cycle, related terminology, including biokinetic, aponeurosis, stiffness and the 'windlass mechanism' and the concept and function of the lower kinetic chain muscle-tendon-aponeurosis units (MTAUs) be introduced to coach education materials.

AUTHOR

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Introduction

Athletics coaches have traditionally considered the sprints and hurdles, the jumps, the throws and race walking as 'technical' disciplines where the training aims of skill development and increasing physical capacity are of the same order of importance. Middle and long distance running events on the other hand have been viewed as 'non-technical' activities where endurance capacity determines success and the training emphasis needed to be almost exclusively on metabolic conditioning. However, once consideration is given to concepts such as mechanical efficiency and elastic response in the running stride, it becomes obvious that the development of skill is a key determinant of success in these events as well.

Most coaches recognise that biokinetic capabilities are important in the ‘power’ events of athletics: the sprints, hurdles, jumps and throws. There is, however, a common misconception that these capabilities and the role of elastic strength are unimportant or insignificant in endurance activities. But, the ability to apply force rapidly and accelerate your body mass is the rule rather than the exception in athletics. While the endurance events certainly do require an emphasis on metabolic capacity over time, they also involve repeated brief, explosive ‘spikes’ in power output each time the foot contacts the ground. Biokinetic contributions must be considered fundamental for both force production and metabolic energy-sparing and therefore it would be simplistic to think of these events as being solely sub-maximal activities.

The simplest contributor to any athletic performance is how the athlete creates, manages, utilises and expresses energy. The energy for middle and long distance performance derives from two principal sources, metabolic, or ‘bioenergetic’, sources and elastic, or ‘biokinetic’ sources. This is true for all events but with shifts in emphasis of source, production and expression. Bioenergetics has been defined for general medical and physiological use as “the biology of energy transformations and energy exchanges within and between living things and their environments”. Strictly, both the metabolic and elastic sources of a runner’s energy could be grouped under the umbrella of bioenergetics, but usually this term is used in athletics to focus on metabolic processes and the 'three energy systems': the ATP-CP, lactate and aerobic.

Bioenergetics and Biokinetics

For several years, I have used the term bioenergetic exclusively for the metabolic processes, systems and sources and the term biokinetic for the elastic or kinetic processes and sources. Now, I formally propose that this terminology be adopted as the standard in coach education, and that recognition be given that biokinetics is clearly a 'fourth energy system'. This separation is valid for the coach as the training activities to develop the two sources are distinct, while often having areas of natural synergy and overlap (Figure 1).

Biokinetic energy is an important part of every day of our lives. In both walking and running we go, for each leg, from one closed kinetic chain situation to a subsequent open kinetic chain environment, which is cyclically repeated. Running differs from walking in that it has a phase in the gait cycle where there is non-support and at this time, both legs are operating in an open kinetic chain situation. The open kinetic chain phases, whether single leg or double, are not passive or inactive but are dynamic environments, preparing the limbs for each subsequent ground contact. As we move more dynamically, as in running, the factors of posture, stability, functional flexibility and elastic return become increasingly important and, therefore, important to develop.

Endurance coaches have traditionally concentrated on the metabolic development of their athletes but have not, until relatively recently, recognised the biokinetic contribution and therefore have paid less attention to it. Many still have too great a focus on training the metabolic energy systems of their athletes, ignoring biokinetic development as a potentially equal, or greater, powerful, metabolic energy-sparing contributor to performance.

In this article we will examine how improving an athlete’s biokinetic energy production and expression will improve performance. We will discuss what structures and mechanisms are operating, why we need to improve certain fundamental movements, what might limit those movements and how to manage limitations. We will focus on the latest research results and methods and show how these are providing an ever-improving understanding of biokinetic energy production and its role and function in middle and long distance running performance.

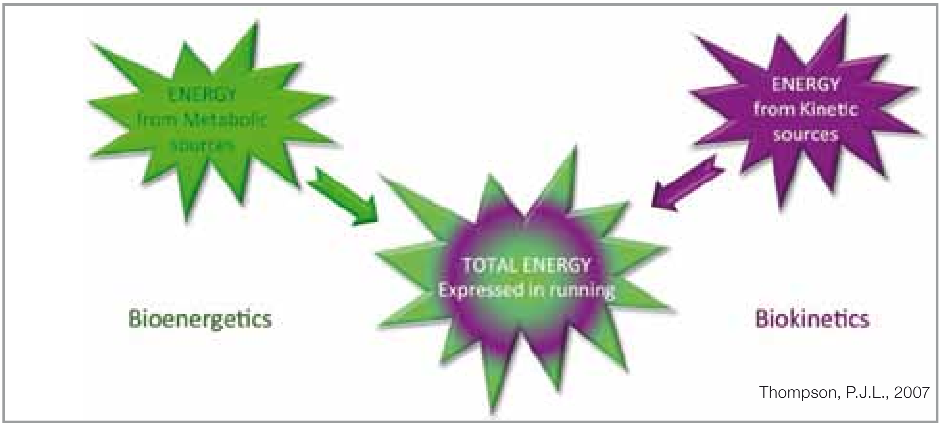


Figure 1: Energetics and running performance: Endurance running performance involves energy production, management, utilisation and expression with both bioenergetic and biokinetic contributions.

Stiffness

At its simplest, running is based on propelling the body forward while keeping its centre of mass (CM) relatively level during the running cycle. During impact with the ground, the leg acts much like a spring, absorbing energy and releasing it later in the running cycle. Following this model, the closer the 'stiffness' of the spring is to optimal, the better the elastic return and the less metabolic energy needed to run at a certain velocity (or you can run faster for the same metabolic contribution). Stiffness is, then, crucial and positive in defining performance capacities.

To give an example, think about what would happen if you were to run gently across a concrete car park adjacent to a sandy beach and continue straight onto the sand. What would happen? Most probably, when you hit the sand your legs would remain extended to a much greater degree at each joint than they were while running over the parking lot. In other words, your legs would become stiffer on the sand. The stiffness of the leg is a function of the lower kinetic chain involving the hip, knee, ankle, foot and first metatarsophalangeal joint (MTPJ) coupled with the muscles, tendons, aponeuroses and other connective tissues. If you were to sprint across the concrete onto the sand, you might well stumble and fall, as the legs might not have time to adjust to the new soft and giving surface and would not be sufficiently stiff to support the CM.

Usually the body is able to adapt to terrain and there will be a relative increase of leg stiffness on softer surfaces and a relative decrease on harder surfaces. Recent studies have confirmed that runners maintain similar motions of their CM on a range of elastic and natural surfaces by adjusting leg stiffness (MORITZ & FARLEY, 2005). Specifically, runners can increase the stiffness of their stance legs to compensate for softer surfaces or softer shoes. These studies strongly suggest that maintaining the CM motions by conserving the stiffness of the leg-shoe-surface combination is an important control strategy in running and may be a response developed in training by running over terrain of variable softness or elasticity and in shoes of variable cushion. This was confirmed by KARAMANIDIS et al (2006) reporting that adaptive improvements in running mechanics due to task experience were present for all surfaces and did not depend on age.

Incorrect stiffness on any surface produces negative results in either direction. If the lower kinetic chain is too stiff, then ground impact and reaction forces are increased and elastic energy is dissipated, lost, in the impact. If the stiffness is not sufficient then the energy is dissipated, lost, into the squidgy 'spring' and another consequence is that the muscles will have to activate more and thus use more metabolic, bioenergetic, energy.

Research supports the concept of an ideal or 'optimal stiffness' for any individual, with too much stiffness being associated with bony injuries, while too little stiffness is associated with soft tissue injuries. This seems to make intuitive sense, that if the force at foot-strike, whether rear-, mid- or forefoot is too high from too much stiffness, the soft tissues cannot absorb the strain and so this force is taken up in the bony structures. Conversely, if the stiffness is too low, the soft tissues must be employed to control the foot strike, leading to transfer of strain to the soft tissue (BUTLER et al, 2003).

At this point we need to keep stiffness as a valid concept and quality but move away from the mechanical and simplistic view of the bipedal Spring-Mass model for human locomotion that was first proposed by BLICKHAN (1989). In its time, it proved of great use for considering external kinematic and kinetic parameters but most biomechanists now agree that true stiffness of the human body is the combination of all the individual stiffness values contributed by muscles, tendon, aponeuroses, ligaments, cartilage and bone. To be useful, the model we use must be able to reflect more than one degree of freedom at the joints, multiple series and parallel elastic components, co-contractions, control by more than two muscles and bi-articular muscles. Instead of the linear Spring-Mass model, we need to consider a model of the lower kinetic chain in terms of the actions at the hip, knee, ankle and MTPJ (Figure 2). As has been previously stated, we now have access to locomotor data that was previously undetectable and/or unappreciated and this data is providing an ever-improving understanding of biokinetic energy production and its role and function in middle and long distance running performance.

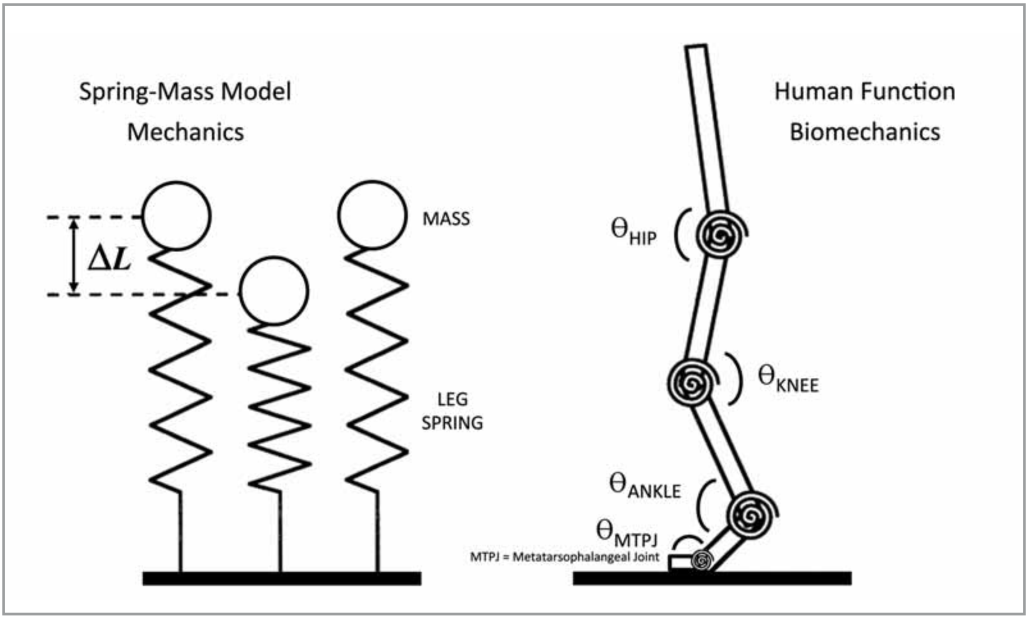


Figure 2: Comparison of the Spring-Mass model and the functioning lower kinetic chain: There is a move away from the mechanical Spring-Mass model towards a biomechanical model of the lower kinetic chain that takes into account the composite and complex kinematics and kinetics at the hip, knee, ankle and first metatarsophalangeal joints.

While studying stiffness in relationship to running velocity, it has been found that there is a direct relationship between these two parameters, with stiffness increasing as velocity increases. At the joint level, there is a significant increase in ankle joint stiffness with increases in running velocity, reflecting that a stiffer ankle joint can better stabilise the application of greater propulsive forces associated with increasing speed. Stiffness also appears to be related to stride parameters as it has been shown that at a given velocity a longer stride length is associated with lower stiffness and this has also been confirmed when the stride length has been consciously manipulated by the athlete. As athletes deliberately lengthened their stride, their stiffness reduced. This illustrates again that there is no single, absolute ‘fix' for performance since, on the one hand, increasing the stride length of a runner may be beneficial to performance but it should be balanced by the recognition that this stride alteration may decrease the vertical stiffness of the runner, which could negatively influence running velocity and performance.

It has been shown that strength training has an impact on leg stiffness with low repetition training of five repetitions and less, coupled with loads of 80% and greater of 1 Rep Max resulting in increased stiffness. In one interesting study a protocol of 6 x 10 second strides with a weighted-vest (20% body mass) completed 10 minutes prior to performance had a significant priming effect on leg stiffness and running economy, (BARNES et al, 2015). Relationships between change scores of the priming group showed that the increased leg stiffness could explain all the improvements in performance and running economy. It was postulated that the associated major effect on subsequent peak treadmill running velocity would translate into enhancement of competitive endurance performance. Further studies are indicated to confirm and ascertain the optimum protocol and conditions for this priming of stiffness prior to running performance in training and competition.

To summarise stiffness is to view it as a responsive, adaptable, qualitative mechanism involving the joints and tissues of the lower kinetic chain that determines the ability to optimise biokinetic energy production and expression. As stiffness increases to an optimum there is a concomitant increase in the athlete’s running economy (RE), one of the key determinants of running performance. There is ample evidence that the control of stiffness and the attaining of optimal stiffness is a trainable response in the athlete, both neurologically and through adaptations of the related tissues, the muscles, tendons, aponeuroses and ligaments. It is, however, currently unclear how much of the tissue response in action is a conscious response and how much is unconscious but this not a limiting factor nor a ‘need to know’ for application by coaches and athletes training to improve stiffness.

Optimal stiffness can be achieved by the runner's adaptive responses to:

- running on surfaces of varying compliance, on the continuum from effectively non-compliant, solid surfaces such as cement to hyper-compliant, particulate surfaces such as sand;
- running in shoes with midsoles of varying cushion and including barefoot running for the very small minority of runners whose lower kinetic chain flexibility and function permits;
- not over-striding, either naturally or deliberately;
- using low repetition, high intensity resistance training;
- priming for running performance using a weighted vest;
- increasing running velocity.

Running Economy

Running economy (RE) is an accepted measure of the efficiency of the athlete in producing performance and improvements in RE have been shown to correlate very highly with improvements in performance. RE is a reflection of the efficiency of both bioenergetics and biokinetics. It may be inferred that any improvement in RE that is not associated with changes in bioenergetic contributions is a direct result of improvements in the biokinetic contribution. In reality, it is difficult to 'split' RE and identify which of the two sources is primarily contributing to any improvements at any given point in time, but we do know that the importance of the biokinetic contribution in running is being increasingly identified and has not previously been sufficiently trained for.

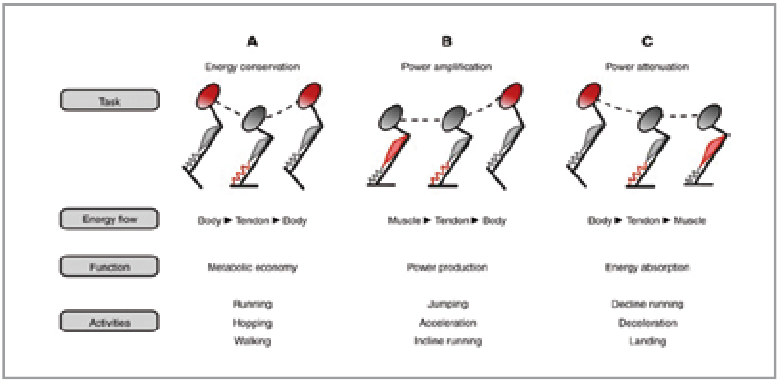
In an investigation of the effects of resistance training on RE and whether "increased tendon-aponeurosis stiffness and contractile strength of the triceps surae (TS) muscle-tendon units induced by resistance training would affect running economy", the authors found that the resistance training group showed a significant increase in their RE (ALBRACHT et al, 2013). They also stated that, "neither kinematics nor fascicle length and elongation of the series-elastic element (SEE) during running were affected by the intervention. The unaffected SEE elongation of the GM (gastrocnemius medialis) during the stance phase of running, in spite of a higher tendon-aponeurosis stiffness, is indicative of greater energy storage and return and a redistribution of muscular output within the lower extremities while running after the intervention, and this improvement in functional efficiency might explain the improved RE." This suggests that with a relatively short intervention of 14 weeks, resistance training resulted in the muscle action becoming more efficient in absorbing strain to accommodate improvements in tendon-aponeurosis stiffness, yielding improved RE.

The Stretch-Shortening Cycle

We have seen that leg stiffness is highly related to running economy but it seems that no single lower-body measure can completely explain differences in RE between individuals or genders and it is therefore likely determined from the sum of influences from multiple lower-body attributes, operating within a stable whole-body kinematic and kinetic environment. One of these attributes described in previous literature is the 'stretch-shortening cycle' (SSC). There has recently been a re-evaluation of the traditionally taught SSC and its role in biokinetic energy production. The traditional view of the elastic properties of the lower kinetic chain was to imagine an active SSC, with the muscle-tendon system acting like a rubber band. While loading and stretching, energy would be stored primarily in the muscle (eccentric phase), with some stretching of the tendon and this energy would be regained at muscle shortening (concentric phase) for toe-off. This is now viewed as an over-simplistic and misleading description of the variability of responses of the body's tissues to differing locomotor demands.

The re-evaluation of the SSC has been the consequence of modern research equipment and techniques that can examine both the internal and external kinematics and kinetics of biokinetic tissue *in vivo*, in the moving individual. Not surprisingly, we find that the performance and properties of living tissue *in situ* and undergoing specific movements are very different from what we have seen previously when examining tissues *in vitro*. This is yielding new insights and understandings of human locomotion and the dynamic interaction and synergy of tissues to respond to the variety of movement possibilities. Recent research has shown, for example, that the performance of the structures comprising the lower kinetic chain rather than adhering to a simplistic Spring Mass and SSC model, follow a function, time and order sequence that is dependant on the activity. Roberts & Azizi (2011) describe this variability and provide an informative summary diagram illustrating the energy flow and tissues' involvement between structures, when the desired outcomes are energy conservation, power production or energy absorption (Figure 3).

We now appreciate that, when running, energy conservation and metabolic economy are the desired outcome and that the eccentric contraction phase of the muscle effectively



Roberts, T.J. & Azizi, E., 2011

Figure 3: Proposed Energy Flow in a Variety of Activities

A schematic illustrating how the directional flow of energy in muscle–tendon systems determines mechanical function. (A) Mechanical energy is conserved (i.e. muscle work is reduced) when elastic structures store and recover cyclic changes in the mechanical energy of the body or an appendage. (B) Tendons loaded directly by the work of muscle contraction can release that energy rapidly to the body. If the energy is released more rapidly than it is stored, muscle power can be amplified. (C) A rapid decline in the mechanical energy of the body or an appendage can be temporarily stored as elastic strain energy, followed by the release of this strain energy to do work on active muscles. This mechanism has the potential to reduce peak power input to muscles, thereby functioning as a power attenuator. In the figure, red indicates the flow of energy between active muscle contraction, tendon strain energy and body kinetic/potential energies.

the elastic properties of the tendon, aponeuroses and connective tissue. The triceps surae need to be emphasised as being in isometric, or close to isometric, mode. This is essentially the same rubber band analogy except there is a recognition now that the muscle response and contribution in running is not as great as it was thought to be for creating force but is vital as a stabiliser and resistance. The rubber band is now the tendon, associated with the aponeuroses and the muscle fascia and the biokinetic contribution to performance will be optimal and most energy will be regained if the stiffness is optimal. The level of isometric stabilisation by the muscles and positioning of the joints helps determines the stiffness of the system and illustrates that there is a now a much reduced bioenergetic contribution, sufficient only to maintain the isometric contraction of the muscle. This is an application of the 'Fenn Effect', that states that active muscles use more metabolic energy when performing work than when only generating force (Figure 4).

But, what about the role of muscle co-activation, you might ask. Muscular co-activation, or co-contraction, concerns the simultaneous contraction usually of a pair of muscles. In running studies, co-activations are found to take place in the lower kinetic chain in both proximal and distal groups of muscles and

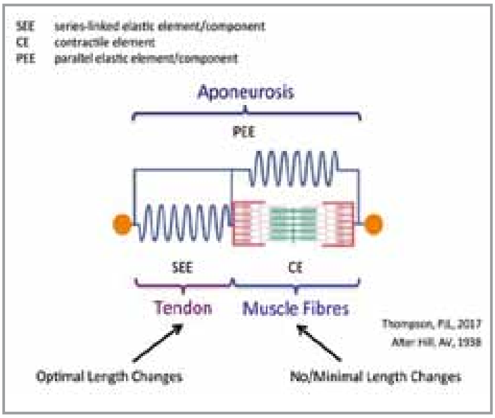


Figure 4: The Muscle-Tendon-Aponeurosis Unit – Functioning in the running action

these can help stabilise joints and contribute to the control of stiffness. There is a significant amount of research in the last fifteen years demonstrating both strong supraspinal origins for co-activations and that they are a learned response, a skill. But, contrasting research results in gait studies had left us unclear whether co-activations are metabolically beneficial. The precise role of muscular co-activation during running remains under-researched (TAM et al, 2017) but new directions are providing some answers.

Recently, it was found that the proximal and distal muscles in the lower kinetic chain acted differently under increasing running velocities. MOORE et al (2016) stated: "However based on previous suggestions, it is likely that the thigh (proximal) co-activations predominantly act during the loading phase of stance, helping to bring the knee into flexion. Without the simultaneous contraction of the quadriceps and hamstrings, the leg would likely collapse. The findings from the current study show that as velocity increases the co-activation in the distal muscles decreases. Whilst the reason behind these differing strategies can only be speculated upon, it is likely that the period of time when both legs are off the ground in running, which is not evident in walking, places different requirements on the muscle activations and recruitment. Less co-activation of the distal muscles could facilitate greater propulsion of the body, both upwards (off the ground) and forwards (in the direction of the run), as the gastrocnemius muscles plantarflex the foot."

In a just published study by TAM et al, (2017), fourteen elite male Kenyan distance runners were examined at two relevant speeds, 12km and 20km per hour - 8:03 and 4:50 per mile respectively. Pre-activation in the forward swinging phase and ground contact of agonist-antagonist co-activation was determined. It was found that knee stiffness was correlated to Rectus Femoris-Biceps Femoris co-activation during both pre-activation and ground contact at both running speeds. Increased pre-activation was found at higher speeds and this supported previous research that neuromuscular activity during the forward swinging phase, open kinetic chain, is equally important and necessary to execute and maintain performance, rather than only during ground contact, closed kinetic chain. Muscle co-activations may come at some greater metabolic cost but it was suggested that there may exist an optimal inter-play between muscle co-activation, joint stiffness, and running economy. And, this may be part of the elite athletes' learned neuromuscular strategy and skill.

The Aponeurosis

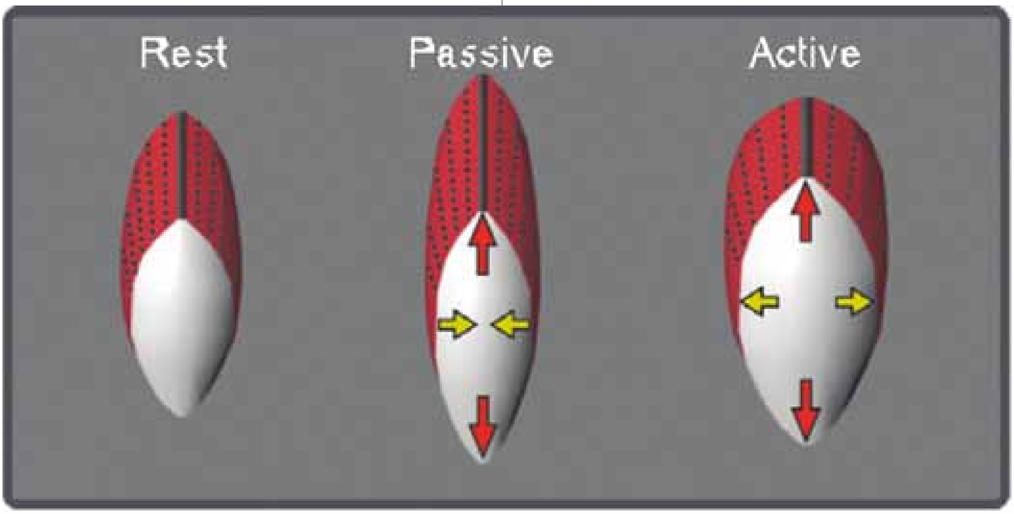
There is a need to review the elastic tissues involved with biokinetics since the research literature frequently uses the terms 'aponeurosis', and the plural 'aponeuroses', which have not yet been incorporated into coach education materials. All coaches are familiar with bones, muscles, tendons, ligaments and what they understand by 'connective tissue', but what are the aponeuroses and what are their properties and why might a coach need to know about them?

An aponeurosis is a ribbon or sheet of collagenous connective tissue, either as a separate structure or providing a wide area of attachment for one or both ends of flat muscles. Probably the best-known separate structure is the plantar aponeurosis on the under surface of the foot, commonly referred to as the plantar fascia. Probably all coaches are familiar with the plantar aponeurosis (PA) but this awareness is predominantly triggered from their athletes sustaining an injury to this structure, usually plantar fasciitis. But, with such awareness, how many coaches are actually knowledgeable of all the functions of the plantar aponeurosis? In one summary article KIRBY (2016) identified ten key biomechnical functions of the PA, reinforcing the vital contribution of this structure to the biokinetic function of the foot. Aponeuroses are found throughout the body but our focus will be on those in the lower kinetic chain, including but not limited to, the plantar aponeurosis.

To review, the human body is composed of just four basic kinds of tissue: nervous, muscular, epithelial, and connective tissue. Connective tissue is the most abundant, widely distributed, and varied type. It includes fibrous tissues, fat, cartilage, bone, bone marrow, and blood. As the name implies, connective tissues often bind organs and muscles together, hold organs in place, cushion them and fill space. It also includes the primary elastic tissues of tendons and aponeuroses that frequently work in synergy.

Aponeuroses are tough and resilient, similar to tendons in both function and composition, only tendons primarily serve to connect muscles to bones. The aponeurosis is a white, transparent sheath, a flat structure like a sheet, whereas a tendon is a white, shiny, rope-like structure. Both aponeuroses and tendons are capable of resisting considerable strain and have elastic properties that may return, amplify or attenuate forces. The difference lies in their structure that, in tendons only permits elastic properties relating to strain created from changes in their rope-like length. Aponeuroses, however, can react to strain in a biaxial manner and provide a multi-directional response to strain, endowing aponeuroses with the capacity to function across a range of stiffnesses dynamically (Figure 5). For many muscles, a significant portion of the tendon is an aponeurosis. The gastrocnemius aponeurosis, for example, is a sheet-like aponeurosis that is continuous and merges with the calcaneal tendon and extends over the gastrocnemius muscle bellies to provide an attachment surface for muscle fascicles.

All this specialised connective tissue making up the muscle-tendon-aponeurosis unit (MTAU) has tremendous collective elastic properties that can provide very quick forces provided, in level running, that it is pre-tensed (for example, the MTAU comprising the plantar aponeurosis, calcaneal tendon and gastrocnemius aponeurosis). These elastic tissues of the tendon-aponeurosis unit respond to training in the same way as other tissues of the body do, by adapting to appropriate stresses. When we consider developing 'strength' we must consider the development of both the contractile



Roberts, T.J. & Azizi, E., 2011

Figure 5: Variation in aponeurosis stiffness with biaxial loading.

A schematic of aponeurosis behaviour during active and passive force production. When the tissue is loaded biaxially during active force production the effective longitudinal stiffness of the elastic structure increases. This figure highlights the capacity of aponeuroses to function across a range of stiffnesses dynamically.

component of the muscle and also the elastic component of the muscle-tendon-aponeurosis unit if we are to develop and optimally use the athlete's biokinetic capacities.

Research using a force-instrumented treadmill, foot and ankle kinematics and intramuscular electromyography (EMG) has begun to show the role of the intrinsic muscles of the feet and how they actively contribute to PA function and biokinetic energy production (KELLY, 2015). The study is the first reported *in vivo* evidence that the plantar intrinsic foot muscles function in parallel to the plantar aponeurosis, actively regulating the stiffness of the foot in response to the magnitude of forces encountered during locomotion. These muscles may therefore contribute to power absorption and generation at the foot, limit strain on the plantar aponeurosis and facilitate efficient foot ground force transmission, where previously it was thought that they were quite passive during the stance phase.

Genetic Endowment

Kenyan athletes and athletes of East African descent have increasingly dominated the middle and long distance events for both men and women since they first began competing internationally, heralded most noticeably from 1968, with the arrival of Kipchoge Keino at the Olympic Games in Mexico City. Researchers and coaches have both sought to explain this ongoing success as being partly, or wholly, attributable to the genetically determined ability to produce biokinetic energy, based on the structure of their lower legs and specifically, their calves and Achilles tendons. Recent research that applied both ultrasonography and kinematic analyses, along with EMG readings revealed that the ten Kenyans in a study "had longer gastro Achilles tendon at rest ($p < 0.01$) as compared with ten control subjects matched in height. Conversely, the stretching and shortening amplitudes of the tendinous tissues of the medial gastrocnemius (MG) muscle were significantly smaller in the Kenyans than in controls during the contact phase of hopping." (SANO et al, 2013). From this, the conclusion that the Kenyan medial gastrocnemius muscle-tendon unit is genetically optimised to favour efficient storage and recoil of elastic energy was widely reported in the popular media.

This research was rightly reviewed critically by several informed academicians since it compared 10 Kenyan international level athletes with 10 non-trained white athletes and so the stated conclusion was potentially fallacious and could just as reasonably been, "The muscle tendon unit of highly trained, international caliber athletes, is optimised to favor efficient storage and recoil of elastic energy when compared to people who are inactive and untrained." (TUCKER, 2013). But, what the study does clearly do is provide supporting evidence that tendon elasticity accompanied by greatly reduced muscle activity is the mechanism to optimise the biokinetic contribution and enhance performance. This elasticity is exhibited as an observable trait in Kenyan, Ethiopian, Eritrean Ugandan and Tanzanian, international athletes.

Further research of the same leg muscle profiles and muscle-tendon units by SANO et al (2015) used the same analysis parameters to compare 11 international Kenyan athletes to 11 'high-level' Japanese runners. At foot strike the Kenyan runners exhibited smaller stretching and shortening in the medial gastrocnemius muscle but a greater tendon contribution to the muscle-tendon shortening. In contrast the Japanese runners exhibited what can be thought of as the classic stretch-shortening cycle, SSC, with a high medial gastrocnemius EMG while braking, immediately post foot strike. While the findings suggest again that Kenyans have specialised structural characteristics that aid biokinetic energy production, it is a comparison of 'international' Kenyans with 'high-level' Japanese. This is better than the 2013 study, comparing 'international' with 'non-trained' athletes but still compares unmatched groups.

So, we are left wondering why Kenyan and East African runners are so dominant. If we think it is simply because they have longer Achilles tendons and elastic muscle-tendon units then this conclusion would be an over-application of the finding of the two studies by SANO et al. If we just recognise the characteristics that contribute to elite performance over lower performing athletes, then then we can point to these studies as providing evidence of another factor that all world-class distance runners, not just East Africans, need to possess. What we don't know, of course, is whether this particular factor of performance is a result of nature or nurture, whether the athlete becomes elite because of highly elastic tendons, or whether the tendon elasticity improves with training and over what time scales. To answer that would require a study over considerable time, a longitudinal study. But, there is indication that, as usual, what we currently observe is the result of a combination of nature and nurture, along with a possible myriad of associated non-biokinetic factors. For biokinetics, we must determine accurately whether the nature, the genetics of a group, give unique qualities that preclude other groups and what is the result of nurture and how can that be replicated and improved upon.

The Running Gait in the Support Phase

Coaches frequently get into heated discussions on how the foot should land when contacting the ground and whether this should be a coached attribute. Runners, however, appear to naturally adopt either a forefoot contact, mid-foot or a rear-foot contact, with the majority of habitually shod runners exhibiting rear-foot strike and the majority of habitually barefoot runners exhibiting a mid-foot to forefoot strike. Perhaps more important than 'how' the runner's foot strikes the ground is 'where' the foot strikes the ground, relative to the centre of mass. If the contact is too far in front of the CM there will be increased initial ground reaction forces with, accompanying, excessive braking. Braking lengthens ground contact time and disrupts the kinetic flow in the lower kinetic chain, with athletes exhibiting a rear-foot contact possibly pre-disposed to such braking. If the runner runs inside a compact 'box' with equal and optimal front and back-side ground kinematics, the rear-foot striker should have equal potential to optimise biokinetic energy production and expression as the forefoot or mid-foot striker.

In the support phase of the running gait, the runner moves from this initial ground contact to mid-stance, where the whole foot has ground contact and then proceeds to the propulsive phase culminating in toe-off. In the past, we observed a kinematic stability at mid-stance, with the whole foot flat on the ground but modern kinetic analysis has revealed that during this part of the gait cycle there is, in actuality, a dynamic internal kinetic environment in the foot and ankle. During mid-stance from initial 'foot flat' to 'heel off' the foot is pronated and, as a whole unit, is supple but stable, being everted, abducted and dorsiflexed, while there is a controlled forward progression of the athlete's CM with apparent kinetic consequences. The 'heel off' is actually the true beginning of the propulsive phase with research showing consistency in kinematics and kinetics through to toe-off, regardless of whether there was a forefoot strike, mid-foot or a rear-foot strike.

The plantar aponeurosis, the plantar fascia, provides for some shock absorption at foot strike and has the vital contribution of potentially being able to take the relatively supple and compliant foot at foot strike and transform it, from heel off, into a firm platform for propulsion. During the evolution of bipedalism the hominin foot underwent a number of dramatic changes that converted it from a prehensile grasping organ to a strong propulsive lever, a significant evolutionary innovation. This process utilises what is known as a 'windlass mechanism', since in humans, dorsiflexion at the metatarsophalageal joints causes tightening of the plantar aponeurosis, which originates from the calcaneal tuberosity and inserts distally on the proximal phalangeal bases. The windlass mechanism at the MTPJs requires sufficient dorsiflexion to operate, as it is the dorsiflexion of the first MTPJ that creates tension, strain, in

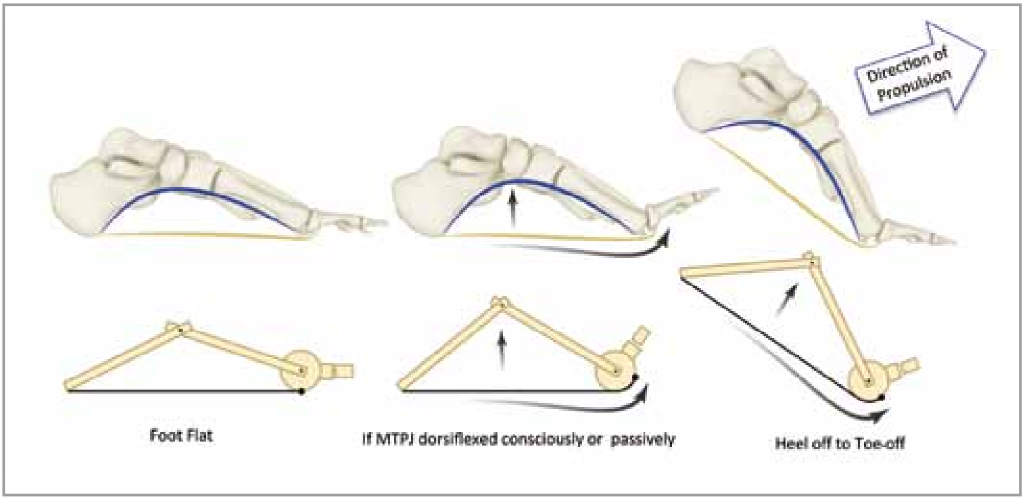


Figure 6: The Windlass Mechanism

The plantar aponeurosis, plantar fascia, is relaxed when the foot is flat in mid-stance but is observably tightened when the metatarsophalangeal joint is dorsiflexed, consciously or passively by hand. This reduces the distance between the calcaneus and the MTPJ and raises the longitudinal arch, transforming the supple, un-tensed foot into a rigid but potentially elastic, platform. When heel off commences the windlass mechanism is engaged to provide a stable platform against which to exert propulsive forces through to toe off.

the medial side of the plantar fascia. This strain has two primary effects: it draws the MTPJ and calcaneus towards each other raising the longitudinal arch and it transforms the supple untensed foot into a rigid but potentially elastic, unit, directing effective loading trough the ball of the foot. During this propulsive phase the foot becomes dynamically supinated, inverted, adducted and plantar flexed, if the windlass mechanism is engaged (Figure 6). The windlass mechanism can occur if a shoe is worn but the stiffer the shoe the more it renders the windlass mechanism unnecessary but this midsole stiffness may compensate for any lack of functional dorsiflexion in the MTPJ, as will be discussed under preconditions.

While some authors view the plantar fascia as only being passively rigid at toe-off there is evidence that the plantar aponeurosis stores and releases elastic strain, enhancing the elastic recoil of the Achilles tendon. In one study it showed that the plantar aponeurosis returned energy that, "amounted to approximately 5-10% of the combined lower limb joint powers during late stance and contributed to push-off slightly after peak power generation at the ankle" (WAGER, 2015). This study also supported that there can be kinetic differences in the early stance phase behaviour of the plantar aponeurosis between a non-rear-foot strike and a rear-foot strike but that these differences did not exist during toe-off. In a more recent study, STEARNE et al, 2016 used a novel insole technique that restricted compression of the foot's longitudinal arch and found the first reported, direct evidence that arch compression/recoil during running contributes to lowering metabolic energy cost.

Preconditions

From an examination of the tissues and structures that are involved for optimal biokinetic energy production it is possible to identify some clear preconditions that must all be met if the athlete is to be able to best create this energy. The athlete must, in summary, have appropriate mobility, stability, postural control, strength and neuromuscular control (DICHARRY, 2012).

Mobility: The athlete requires sufficient mobility in three areas during the propulsive phase of the running cycle, 1) hip extension, 2) ankle dorsiflexion and 3) big toe dorsiflexion at the metatarsophalangeal joint. The hip extension is required to permit the supporting thigh to move effectively posterior of the CM and to do this without over rotation of the hips in an anterior direction. The ankle dorsiflexion is required to avoid premature heel off at the end of the mid-stance, foot flat phase and the MTPJ dorsiflexion is vital if the windlass mechanism is to be engaged. When running, the dorsiflexion at the MTPJ commences at heel off and must be able to operate when the ankle is dorsiflexed for the windlass mechanism to function. Any testing of the mobility of the MTPJ should therefore be carried out with a dorsiflexed ankle, to test for this functional mobility, the functional MTPJ dorsiflexion. Authorities differ on how much functional dorsiflexion is required at the ankle and MTPJ but the minimum appears to be 30 degrees at each joint.

Limited hip extension is frequently a problem and big toe mobility can limit the function of the most active ankle. It has been estimated that between 70% to 80% of all runners, including recreational runners, lack sufficient functional MTPJ dorsiflexion, with not only the associated consequence of lack of biokinetic energy production due to a poorly, or non-functioning, windlass mechanism but, additionally, kinetic strains transmitted to predispose or cause injury. These injuries are revealed in one or more of the structures and tissues making up the MTAU comprising the plantar aponeurosis, calcaneal tendon and gastrocnemius aponeurosis. We see chronic plantar fasciitis, Achilles tendon and calf issues, separately or in combination.

Stability: The athlete requires sufficient stability to counter the forces affecting the body, specifically segmental control of the spine, hips, ankle and foot. Any instabilities, no matter where they are in the whole-body kinetic chain, will cause biokinetic energy leakage or dissipation. Imagine driving a powerful Ferrari car with a rubber chassis. The required stability is many times linked to postural control centered on the pelvis. When you run, any lack of the necessary isometric core strength does not just lead to an absorption and wastage of energy. If the pelvis is not controlled and held isometrically in a neutral position, it will tend to rotate in one or more of three planes. If the lower back becomes 'swayed', the anterior pelvic tilt causes internal and external rotational changes to the lower limbs as the bones act as a system of connected levers making up the lower kinetic chain. The whole skeleton must be stable and in the correct positions to permit the MTAUs, the muscles, tendons and aponeuroses working in synergy, to optimally generate biokinetic energy.

Research is focusing more and more on biokinetic energy production in the lower kinetic chain and as our understanding of the uses of elastic and 'spring' mechanisms in movement has developed so has our understanding of the nature of the 'springs'. The ability to perform *in vivo* data collection has been essential in refining our view of the macro-structures, like tendons and aponeuroses and is providing new directions in the examination of the role, contribution and capacities of the epimysium, perimysium and endomysium, as well as molecular springs (ROBERTS, 2011). It appears that these intramuscular tissues may utilise elastic mechanisms to transmit and tolerate the loads generated by the muscle.

For the human animal we find that, most obviously towards the end of a race, as bioenergetic levels reduce and acidosis increases, the role of the elastic, biokinetic component becomes increasingly important. This is because it can potentially still operate powerfully under these conditions - provided it has been developed. If two athletes have equal bioenergetic capacities, the better performer throughout the race will be the one who has the greater biokinetic capacity.

Addendum - Implications for Coach Education

While writing this article I reflected that after a coach attends a coach education course or workshop, it can take several weeks or months before their athletes begin, once more, to understand their coach, depending on the how long the course was and the knowledge covered. This unwanted consequence of coach education can be avoided if the coaches are made aware of this potential pitfall while on the course, or if we simply don't give them any knowledge, as some sport science specialists might advocate! Coaches are and should be exposed to new material and ideas on courses but usually they are exposed using only technical language. To develop their coaching competence, how they do their coaching, they should identify how to translate any new knowledge, the 'what' of their coaching, into the language, cues and training practices of their athletes. The technical language should remain and be recognised as what coaches may use when speaking to coaching colleagues or specialists.

In an ideal world, all coaches would have access to the specialised support of doctors, physiotherapists, strength and conditioning practitioners, biomechanists, etc. In an even more ideal world, this specialised support might operate with an intermediary of separate 'sports diagnosticians' to assist in the application of the specialists' recommendations. These diagnosticians would be able to speak the technical language required by coaches and they would be able to speak the academic, technical language of the specialists and translate that into coaching technical language. Such a performance-coach-support environment was proposed in 'New Studies in Athletics' by SCHADE (2010). The author focuses on biomechanics and states: "The interaction between a coach and a biomechanical diagnostician is a crucial element of developing a modern high-level athlete’s performance." This concept is applicable across all sport specialisations. He explains the role of the sports diagnostician as being, "to provide an interface between science and practice. As such, the diagnostician cannot be fully in either camp but must be comfortable working in and speaking the language of both." It is stressed that the diagnostician speaks directly to the coach and only to the athlete with the agreement of the coach. Now, we have identified three 'languages': the language of the specialist, the language of the coach and the language of the athlete.

But, around the world the vast majority of coaches tend to work in isolation, without appropriate access to even specialised scientific or medical help, let alone a sports diagnostician. This is the reality. With this in mind, coach educators have to decide what knowledge coaches need to be given to support their developing coaching competencies. Effective competence-based coach education focuses rightly on both the 'how' and the 'what' of coaching. The 'how' develops a coaching competence that must be supported by the 'what', the knowledge that they need to have, to apply in their practical coaching. In this article I have defined the term 'biokinetics', addressed the topics of aponeuroses, the 'windlass mechanism', re-evaluated the stretch-shortening cycle and introduced a model for the flow of energy through the muscle-tendon-aponeurosis unit in various activities and recognised that it is not just a muscle-tendon unit, MTU, that we must consider but the muscle-tendon-aponeurosis unit, MTAU.

Each of these introduced terms and topics relate to the development and application of biokinetic energy. We now have to decide what the coach needs to know in these particular areas, bearing in mind that they will usually be operating in isolation. Having said that, coach education courses should not be seen as a 'one-stop shop' meeting all their knowledge needs but be purposefully developing the competence of the coach to create their own, individual support team. IAAF coach educators have found, globally, that there are few places where the sport science and medical expertise does not exist or cannot be accessed, provided the coach knows where to look and actively seeks. The coach needs an awareness of the factors that contribute and determine performance and what support he and his athletes, in their situation and performance paradigm, require. Then, it is for coach educators to decide the breadth, depth and language of this knowledge at the various levels of coach education.

This article has reviewed the latest research materials and proposed that there be a re-evaluation of the stretch-shortening cycle and the terms biokinetic, aponeurosis, stiffness and the 'windlass mechanism' be introduced to coach education materials, along with the concept and function of the lower kinetic chain muscle-tendon-aponeurosis units and a model for the flow of energy through the MTAU in various activities. It is now up to the teams of coach education specialists to determine and decide the manner and degree to which this is done.

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