Football is the most popular sport worldwide, both at a recreational and professional level. Although there are numerous health benefits of football such as improved general health, wellbeing, fitness and muscle strength, there is also a risk of injury. Groin injuries continue to be a major problem in professional football and often lead to prolonged pain and have a high recurrence rate. Hölmich and co-workers recently showed in a large prospective study of 1000 football players that the most common types of groin injury were:

1. Adductor-related.
2. Iliopsoas-related.
3. Abdominal-related.

These injuries have been associated with muscle weakness, previous injury, lack of pre-season practice and level of experience. Repetitive stressing of the musculotendinous structures without adequate recovery has been proposed as a pathophysiological mechanism of groin injury in football. It has also been shown that the dominant leg was injured more frequently than the non-dominant leg, suggesting that kicking may indeed be part of the problem. The present article takes a closer look at the football kick from a biomechanical perspective and shows how the greatest loading of the groin musculature occurs during the backswing and leg cocking phases of the football kick.

BIOMECHANICS OF THE KICK

The football kick is a crucial component of the game, and has been studied by researchers of biomechanics under controlled laboratory conditions e.g. during a single maximal football instep kick. Biomechanics is the study of classical mechanics from physics applied to the human body during motion. Bodily motions occur as the result of several muscles pulling on bones rotating around joints e.g. the iliopsoas muscle pulling on the femur causing a rotational movement around the hip joint. Consequently, biomechanics most often involve the study of angular motion. Most people may be familiar with linear motion variables such as distance (meters), velocity (m/s), acceleration (m/s²) and force (Newton). People not familiar with biomechanics should know that for every linear motion variable there exists a corresponding angular motion variable, i.e.:

- angular displacement or ‘joint range of motion’ (θ, measured in radians or degrees) is the equivalent of distance,
- angular velocity (ω=θ/t) is the equivalent of velocity (‘speed’),
Angular acceleration ($\alpha = \omega / t$) is the equivalent of acceleration,
• moment of inertia ($I = \sum m r^2$) is the equivalent of mass,
• angular momentum ($H = I \omega$) is the equivalent of momentum,
• moment of force ($M = I \alpha$), often just referred to as 'moment', is the equivalent of force.

Thinking in this way, the biomechanics of football becomes easier to comprehend.

### Generation of Force during the Kick

From a biomechanical perspective, the football kick is a multidimensional dynamic open chain movement, which involves co-ordinated motion of multiple joints and segments. Thus, a given joint motion of the kicking leg must be influenced not only by other joint motions of the kicking leg but also by multi-joint motions of the entire body, i.e. all segments of the body are connected through one or more joints and thus influenced by each other's movement. Altogether the net moment of force acting around a specific joint e.g. the hip joint, results not only from the moment generated by the agonist muscles, but also from the antagonist muscles, reaction forces from the ground when the heel of the supporting leg hits the ground and motion-dependent moments originating from the joint rotation of other joints resulting in inter-segmental interaction. A rotating object such as a thigh rotating around the hip joint results in both centrifugal forces and gyroscopic moments, which affects nearby segments the most. Putnam analysed the influence of motion-dependent moments between adjacent segments (thigh and lower leg), and suggested that moment due to thigh angular velocity contributes to rotation of the lower leg and assists knee extension\(^{11}\). Several other studies have shown that movement of the thigh results in motion of the lower leg and that the motion-dependent moment due to thigh movement results in knee extension\(^6,8\). The motion-dependent moment may therefore play a crucial role in producing a high net moment of force, especially during the acceleration phase of kicking. Thus, energy is effectively transferred downwards from the hip to thigh to foot, like the motion of a whip, to maximise the power of the kick. This means that a high moment of force around the hip joint is crucial in achieving high velocity in the more distal segments. This in turn means that high force development of the hip and groin muscles are required, thereby increasing the risk of injury. For the remainder of this article we will therefore focus on the muscles of the hip and groin at high risk of injury.

### Table 1

<table>
<thead>
<tr>
<th>Linear motion</th>
<th>Angular motion</th>
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<tr>
<td>Distance ($d$) (unit: meters)</td>
<td>Angle ($\theta$) (unit: radians)</td>
</tr>
<tr>
<td>Velocity ($v$)=$d/t$ (unit: m/s)</td>
<td>Angular velocity ($\omega$)=$\theta/t$ (unit: rad/s)</td>
</tr>
<tr>
<td>Acceleration ($a$)=$v/t$ (unit: m/s(^2))</td>
<td>Angular acceleration ($\alpha$)=$\omega/t$ (unit: rad/s(^2))</td>
</tr>
<tr>
<td>Mass ($m$) (unit: kg)</td>
<td>Moment of inertia ($I = \sum m x r^2$ (unit: kg.m(^2))</td>
</tr>
<tr>
<td>Momentum ($p$)=$m x v$ (unit: kg.m/s)</td>
<td>Angular momentum ($H = I x \omega$ (unit: kg.m(^2).s)</td>
</tr>
<tr>
<td>Force ($F$)=$m x a$ (unit: N)</td>
<td>Moment of force ($M = I x \alpha$ (unit: N.m)</td>
</tr>
</tbody>
</table>

Table 1: Terms used in linear and angular motion. For each linear motion variable there is a corresponding angular motion variable.

### Table 2

<table>
<thead>
<tr>
<th>Phases</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Preparation</td>
<td>From heel strike to toe-off</td>
</tr>
<tr>
<td>2. Backswing</td>
<td>From toe-off to maximal hip extension</td>
</tr>
<tr>
<td>3. Leg cocking</td>
<td>From maximal hip extension to maximal knee flexion</td>
</tr>
<tr>
<td>4. Acceleration</td>
<td>From maximal knee flexion to ball strike</td>
</tr>
<tr>
<td>5. Follow-through</td>
<td>From ball strike to toe velocity inflection</td>
</tr>
</tbody>
</table>

Table 2: The five phases of the football kick. All descriptions relate to the kicking leg.

3D motion analysis and phases of the kick

To analyse the motions of the football kick, 3D motion analysis can be performed in the laboratory. Reflective markers are placed on anatomical landmarks of the body and several high-speed video cameras record the motion. This allows detailed 3D reconstruction by the computer of the football player's movement\(^6,8\). 3D analysis can provide detailed insight into the kinematics of the player's movement, the kinetic chain, and co-ordination between body segments. This type of analysis is often combined with calculations of the moment of inertia of the segments to gain knowledge of the moment of force across different joints.

For simplification of the 3D motion analysis, the football kick is often divided into five phases (Table 2).

In biomechanical analyses, phases 2 to 4 are most often studied and described (Figure 1).
**BACKSWING**

The backswing phase is initiated when the toe of the kicking leg lifts from the ground. Hereafter the kicking leg moves backwards (hip extension) with the hip extending on average 29° resulting in a large stretch of both the iliopsoas and adductor muscles. There is, however, a large variation of the degree of hip extension and individual physical capacities between football players, putting some players at higher risk of injury than others. The hip abducts slightly and both internal and external rotation of the leg occurs during this phase. The knee flexes and internally rotates while the ankle everts. The backswing phase continues until maximal hip extension of the kicking leg, which occurs shortly after the supporting leg strikes the ground. During the backswing phase the upper arm on the opposite side of the kicking leg is lifted and moved backwards, which effectively creates a tension arc of the entire body to be released during following phases. The tension arc has a crucial role in effectively utilising the stretch-shortening cycle necessary to maximise power output of the kick. The backswing phase lasts approximately 160 ms.

**LEG COCKING**

The leg cocking phase is initiated when the hip is maximally extended during the backswing. Rotating the hip around the supporting leg while moving the kicking leg forwards (i.e. hip flexion) is a key component of this phase. During this phase the leg is moved forward (i.e. hip flexion), however at the same time the abduction continues, resulting in a continued stretch of the adductor muscles. The leg cocking phase continues until maximal knee flexion of the kicking leg. The leg cocking phase is very brief and lasts approximately 40 ms.

**ACCELERATION**

The acceleration phase commences at maximal knee flexion. As the name suggests, the purpose of this phase is to accelerate the leg to achieve a high impact-velocity with the ball. During this phase the thigh decelerates, creating knee extension moment due to the inter-segmental interaction, helping to further accelerate the lower leg towards the ball. The acceleration phase is brief and lasts approximately 60 ms.

To understand the ‘risky’ moments of these football kick phases we have to dig a little deeper into some basic biomechanical and physiological principles, namely:

- force-velocity properties of muscles,
- length-tension relationship of connective tissue and
- the science of electromyography.

**FORCE-VELOCITY RELATIONSHIP OF MUSCLES**

The force-velocity relationship illustrates how the force that the muscle is able to generate when fully activated depends upon the velocity of movement (Figure 2). For example, when the muscle contracts concentrically at high velocity, only little force can be generated. This is the case for the iliopsoas and adductor muscles during the final part of the acceleration phase of the kick where the muscles contract at high velocity. In contrast, when muscle is active during lengthening, so-called eccentric contraction, then high levels of force can be generated. The forces acting during fast eccentric contraction can easily be 5× higher than during fast concentric contraction. This is the case during the backswing and leg cocking phases for the adductor muscles and during the backswing phase for the iliopsoas where these muscles are stretching while actively contracting. It is clear that the backswing and leg cocking phases have the potential to induce high levels of force on the musculotendinous structures. However, to fully understand the forces acting on the connective tissue during different types and velocities of contraction we must also consider the length-tension relationship of the tendons.

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**Figure 1:** Illustration of the backswing, leg cocking, and acceleration phases of the football kick (reproduced with permission from Brophy et al 2007).
LENGTH-TENSION RELATIONSHIP OF CONNECTIVE TISSUE

Connective tissue, such as tendons, is the link between muscles and bones. Tendons are much stiffer than muscles due to their high collagen density. When tendons and other types of connective tissue are stretched, the tissue tension increases in a linear fashion after the very initial stretch. If the connective tissue is stretched to excessive lengths it will finally break. An important feature of connective tissue is that it displays viscoelastic properties, meaning that the faster the stretch, the higher the stiffness (Figure 3). This is a double-edged sword in football as a high stiffness is important in avoiding energy loss during explosive movements, where a high rate of force development is crucial for performance. However, at the same time, increased stiffness means that tension in the connective tissue is higher at any given length of stretch, meaning that a fast stretch of muscle-tendon complex increases the risk of injury. This is the reason that muscle-tendon sprains usually occur during fast movements but are rare during strength training with slow and controlled muscle contractions in spite of lifting heavy weights. This knowledge is important when studying the phases of the football kick with high stretching velocities of the muscles and tendons and where the muscle is active at the same time. From a biomechanical point of view, these are the ‘high risk’ phases of the kick. The muscle activity during the football kick, which has not been covered yet, can be studied using electromyography.

ELECTROMYOGRAPHY

Electromyography (EMG) is, as the name suggests, the study of electrical signals across muscles. During a football kick, the brain activates the appropriate muscles by sending electrical signals through the nerves to the muscles. The EMG amplitude reflects the summation of motor unit action potentials generated across the muscle fibres. The amplitude and shape of the measured EMG signal can be regulated by a combination of recruitment of motor units, firing frequency (discharge rate) of recruited motor units and degree of synchronisation of the motor unit action potentials. EMG can be measured either by surface electrodes placed on the muscles or by intramuscular EMG where wires are inserted, using a needle, into the muscle. The former approach is appropriate for superficial muscles like the adductor longus and external obliques, whereas the latter approach is necessary for deep muscles like the iliopsoas.

The most commonly used parameter is the EMG amplitude, which has a good correlation with muscle force. This means that by measuring EMG amplitude we can obtain a proxy measure of muscle force in situations where force transducers are inappropriate e.g. during the football kick where several muscles act together at high speeds. However, due to the force-velocity relationship of the muscle, force at a given level of EMG will depend on contraction mode and velocity (Figure 4). Thus, the same level of EMG results in higher forces during eccentric than concentric contraction, and the lowest levels of force will, in spite of high EMG levels, be obtained during fast concentric contraction. Consequently, interpretation of the EMG is only meaningful when at the same time considering contraction mode and contraction velocity of the muscles.
Brophy and co-workers studied EMG during the different phases of the football kick and found that EMG amplitude of the adductor longus and iliopectas was quite high – more than 60% of maximal EMG activity – during the backswing, leg cocking and acceleration phases. By looking at EMG alone we would then suspect that high forces acted on the muscle-tendon complex during all phases of the kick. However, this is not the case as eccentric muscle contraction occurs only during the backswing and leg cocking phases. Further, the fairly rapid stretch of the muscles, especially during the backswing phase, further increases tension in the connective tissue due to its viscoelastic properties, as previously described. Thus, the combination of a fast stretch at long muscle lengths together with a high level of EMG, i.e. a fast, high-force eccentric contraction, gives rise to the highest forces. These high forces that act on the muscles and tendons, especially during the backswing and leg cocking phases, increase the risk of injury from a biomechanical point of view.

CONCLUSION

The football kick is often divided into five phases:
1. Preparation.
2. Backswing.
3. Leg cocking.
5. Follow-through.

From a biomechanical perspective – taking force-velocity, length-tension relationships and EMG activity into account – the highest risk of groin injury occurs during the backswing and leg cocking phases, where the hip and groin muscles work eccentrically at high intensity and velocity.

References