CHAPTER 8

Range of motion of body segments is larger during the maximal instep kick than during the submaximal instep kick in experienced football players

Rob Langhout
Igor Tak
Roelof van der Westen
Ton Lenssen

Abstract

**Background:** Football players with groin injury refrain from maximal kicking. Previous groin injury is related to decreased hip range of motion (ROM). Information on ROM differences between maximal and submaximal kicking within players is lacking. The first aim of this study is to quantify ROM of body segments during the maximal (MaxK) and submaximal (SubK) instep kick at four keypoints. The second aim is to study ROM differences of tension arc and movement trajectories between MaxK and SubK.

**Methods:** Maximal (100% ball speed) and submaximal (70% ball speed) instep kicks from 15 experienced football players were registered with motion capture. ROM of hip, spine, pelvis and knee segments were determined at four keypoints. Differences in segmental ROM for the tension arc and movement trajectories between MaxK and SubK were studied. Effect sizes (ES) were calculated.

**Results:** Ball speed was 98.8(±9.0) km/h for MaxK and 69.5(±7.1) km/h for SubK. Three keypoints timed similarly (p<0.05) for MaxK and SubK. MaxK shows increased ROM for all segments (p<0.05) but not for hip flexion. MaxK results in enlargement of tension arc and movement trajectories. Spine flexion (ES 3.2) and pelvis posterior tilt (ES 2.2) show the greatest relative increase.

**Conclusions:** Maximal kicking shows larger segmental ROM than submaximal kicking. Enlargement of tension arc and movement trajectories relate to increased segmental velocity, according to biomechanical concepts. Central body actions play an important role in kicking. This information can be used to further identify kicking strategies in athletes with injury.
Introduction

Football players are skilled to kick the ball over long distances with high speed and precision to the target\cite{10,125,143}. The maximal instep kick is most suitable for this as this technique produces the highest ball speed when compared to other techniques\cite{129}. Powerful kicking is associated with large muscle forces\cite{171} and is the most frequent injury mechanism in football for acute groin pain\cite{210}. The dominant leg is most often affected\cite{210}.

The instep kick can be divided in phases, all marked by defined keypoints\cite{30,125,212} (Figure 1). During the backswing phase, maximal hip, spine, pelvis and knee movements generate a full body tension arc. This creates pre-stretch of muscles connecting the segments of upper body and kicking leg\cite{212}. Pre-stretch enlarges muscle contraction forces, by use of a stretch-shorten cycle mechanism, resulting in acceleration of segments during the leg cocking and acceleration phases\cite{24}. The greater the distance is over which these segments move (movement trajectory), the greater the potential to develop segmental velocity\cite{270}. Summation of segmental velocities finally determines ball speed\cite{106,130,184,262}.

![Figure 1](image.png)

**Figure 1.** Predefined keypoints and phases during the instep kick. Fig. 1a-b: Backswing phase from keypoint TO to MHE. Fig. 1b-c: Leg cocking phase from keypoint MHE to MKF. Fig. 1c-e: Acceleration phase from keypoint MKF to BI, with keypoint KF90 (1d) in between. Abbreviations: TO=Toe off; MHE=maximal hip extension; MKF=maximal knee flexion; BI=ball impact; KF90=knee flexion 90 degrees.
The adductor longus and the iliopsoas are the most affected muscles in football players with groin pain. These are proposed to be at risk during the backswing of the kick because of coincident timing of maximal eccentric contraction, maximal rate of lengthening and maximal hip range of motion (ROM).

Football players with previous groin injury are prone to re-injury and remaining physical deficits or altered movement patterns are considered risk factors. Decreased hip ROM is related to groin pain in athletes, however mechanisms explaining this relation are lacking. During an injury episode, powerful kicking remains affected as this provokes groin structures, forcing the footballer to switch to submaximal kicking strategies.

In order to identify possible atypical ROM characteristics of players with groin injury, quantification of the typical ROM characteristics of maximal and submaximal kicking is needed. To our best knowledge, no studies have been performed investigating ROM of hip, spine, pelvis and knee segments during the maximal and submaximal instep kick. Therefore, the first aim of this study is to quantify range of motion (ROM) of body segments during the maximal (MaxK) and submaximal (SubK) instep kick at four keypoints. The second aim is to study ROM differences of the tension arc and movement trajectories between MaxK and SubK.

The hypothesis tested is that segmental ROM increases from submaximal to maximal kicking.

Methods

Subjects
Adult football players from a Dutch professional club were invited to participate in this study. They were informed prior to testing, giving them the opportunity to withdraw from this study at any moment. All players signed informed consent. The medical staff approved their participation. This study complied with the requirements of the declaration of Helsinki. No ethical approval was needed, as stated in the Dutch Medical Research Involving Human Subjects Act (WMO). Players were found eligible when they reported to be free from injury in the lower back, hip and groin over the last 6 months.

Motion capture
Motion was recorded using a three-dimensional motion-capture system with eight infrared (IR) cameras (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England) and two high-speed digital video (DV) cameras (Basler AG, Ahrensburg, Germany). The IR cameras recording rate was 200 Hz. The DV cameras recording rate was 100 Hz. The cameras were set up and calibrated in accordance with VICON’s guidelines. A standardized
static motion capture of every subject served as reference to be able to correct ROM and/or absolute joint angles (Figure 2). The anatomical position was used to gauge the output obtained from VICON. VICON Nexus was used for all the steps, calibrating, recording and analysing the data. Nexus presented 3D-constructions, marker labelling and kinematic calculations. Reflective 14-mm markers were attached to 31 body landmarks according to VICON’s full body model. Height and weight as well as leg length, knee width, ankle width, elbow width, wrist width, hand thickness and shoulder offset were registered for all participants. These data were entered in Nexus to provide the VICON Motion System with further information corresponding with the marker placement. The electronic data were synchronized with video-recordings and analogue data.

*Figure 2.* Standardized static motion captures from all subjects served as reference to correct for range of motion and absolute joint angles.
Preparation
All players performed a fifteen-minute standardized warming up before the motion capture procedures started. All were instructed to perform two maximal and submaximal instep kicks, aiming for a marked spot that was located one meter above the ground and four meters away from the ball position.

Data recording procedures
All procedures were completed in the clinical movement laboratory of the Maastricht University Medical Centre+, The Netherlands. Players were free in their ball approach. For players with right leg dominance, approach angles up to 45 degrees could be performed at voluntary approach speed due the kicking pitch set up in the laboratory (Figure 3).

Figure 3. Laboratory test setup.

Maximal and submaximal instep kick
Ball velocity was assessed with a ball speedometer (WG 54, D&L, Utrecht, The Netherlands). Maximal instep kicks were defined as kicks performing 100% of ball speed. Submaximal instep kicks were defined as kicks performing 65-75% of maximal ball speed. Every kick was performed with the dominant leg with a 20 second interval in between. The ball used was an official FIFA size 5 football (Derbystar, Goch, Germany).
**Kinematic analysis**

Basic values of the standard static motion capture were noted in order to correct for ROM values during the performance of the kicks. Definition and determination of keypoints are consistent with a previous study. Toe off of the kicking foot was defined as the start (0%) and ball impact as the end of the kicking motion (100%) (Figure 1). Duration of the maximal and submaximal kick was calculated and relative timing of keypoints was expressed as percentage (%) of the kicking motion. Parameters that adequately described the kinematic curves in amplitude and time for hip, spine, pelvis and knee were extracted from VICONS’s output.

**ROM at keypoints**

ROM of hip, spine, pelvis and knee was determined for both the maximal and submaximal kick at 4 keypoints; maximal hip extension (MHE), maximal knee flexion (MKF), knee flexion 90 degrees (KF90) and ball impact (BI) (Figure 1). The tension arc is the posture that is related to the wind-up of the body in order to store energy and stretch muscles before unwinding. The tension arc is defined as ROM of hip extension, spine extension, spine rotation to the non-kickside and pelvis anterior tilt at keypoint MHE and ROM of knee flexion at keypoint MKF. The movement trajectories for hip flexion, spine flexion, and spine rotation to the kickside and pelvis posterior tilt were defined from keypoint MHE till BI. The movement trajectory for knee extension was defined from keypoint MKF till BI.

**Tension arc and movement trajectories**

The tension arc is the posture that is related to the wind-up of the body in order to store energy and stretch muscles before unwinding. The tension arc is defined as ROM of hip extension, spine extension, spine rotation to the non-kickside and pelvis anterior tilt at keypoint MHE and ROM of knee flexion at keypoint MKF. The movement trajectories for hip flexion, spine flexion, and spine rotation to the kickside and pelvis posterior tilt were defined from keypoint MHE till BI. The movement trajectory for knee extension was defined from keypoint MKF till BI.

**Statistical analysis**

Data were analysed for normality of distribution by the Shapiro-Wilk test. When found normally distributed, these are presented as mean (±standard deviation). Paired samples t-tests were used to detect differences between MaxK and SubK. Differences were studied on the timing of keypoints and on ROM of hip, spine, pelvis and knee at keypoints (MHE, MKF, KF90 and BI). Differences in ROM between MaxK and SubK were calculated and analysed for the tension arc with paired samples t-tests. Differences in ROM of the movement trajectories were analysed accordingly. In order to study contributions of individual segmental changes to the hypothesized ROM differences between MaxK and SubK, effect sizes (ES) were calculated ((meanMaxK - meanSubK)/SDSubK). Data were processed using SPSS 20 (Statistical Package for the Social Sciences, IBM, Chicago, US). The α-level for statistical significance was set at 0.05.
Results

Subjects
From 28 players who were invited, 10 players sustained low back pain, hip or groin pain over the last 6 months, 2 did not want to participate and 1 was not able to participate on the assessment day due to club professional obligations elsewhere. Finally, 15 football players (age 22.1(±5.0) yrs, height 1.81(±0.09) m and weight 80.8(±8.42) kg) were recruited. Of all these, 13 players displayed right and two players left leg dominance. All had played football for at least 13 years. None of the players reported discomfort during kicking.

Ball speed, kick duration and timing of keypoints
Ball speed was 98.8(±9.0) km/h for the maximal kick and 69.5(±7.1) km/h for the submaximal kick. Total duration of the kick was 0.256(±0.047) seconds for MaxK and 0.268(±0.048) seconds for SubK. There were no differences in timing of keypoints MHE, MKF and BI between MaxK and SubK (MHE: 46.0(±4.9)% , MKF: 72.9(±2.4)% and BI: 100.0(±0.0)%, all p<0.05). Keypoint KF90 timed differently: MaxK 86.7(±2.2)% vs SubK 79.4(±4.3)%.

ROM at keypoints
Segmental ROM for MaxK and SubK at four keypoints is shown in Table 1 and illustrated in Figure 4. When compared to SubK, MaxK shows increased ROM at keypoint MHE for hip extension (mean difference (MD) 9.0°, ES 1.1), spine rotation (MD 8.5°, ES 1.1), spine extension (MD 2.9°, ES 0.4) and pelvis anterior tilt (MD 1.3°, ES 0.2). Keypoint MKF shows increased ROM for knee flexion (MD 18.1°, ES 2.0).

Keypoint KF90 shows increased ROM for hip flexion (MD 7.6°, ES 0.8), spine rotation (MD 8.5°, ES 0.7), spine flexion (MD 14.6°, ES 1.6) and pelvis posterior tilt (MD 4.2°, ES 0.8). Keypoint BI shows increased ROM for spine flexion (MD 19.0°, ES 2.4), pelvis posterior tilt (MD 14.2°, ES 2.1) and spine rotation (MD 3.0°, ES 0.4) (all p<0.05). In contrast, keypoint BI shows decreased ROM of hip flexion for MaxK when compared to SubK (MD 5.4°, ES -0.6). Post hoc analysis of the kinematic data shows that this is the result of reversed hip motion prior to ball impact during MaxK, which is not observed for SubK. Knee angles at ball impact show no difference between both kicks.

Tension arc and movement trajectories
Differences between ROM of the tension arc and movement trajectories for MaxK and SubK are shown in Table 2 and illustrated in Figure 4A-C. The tension arc increases for MaxK compared to SubK, which is mainly due to the increase of ROM of knee flexion (keypoint MKF), hip extension and spine rotation (keypoint MHE). When compared to
Table 1. Range of motion (in degrees) depicted as mean (±SD) at four keypoints for MaxK and SubK. Positive values indicate hip-, spine- and knee flexion, pelvis posterior tilt and spine rotation to the kick side. Negative values indicate hip-, spine- and knee extension, pelvis anterior tilt and spine rotation to the non-kick side.

<table>
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<tr>
<th>Keypoint</th>
<th>MHE</th>
<th>MKF</th>
<th>KF90</th>
<th>BI</th>
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<td></td>
<td>MaxK</td>
<td>SubK</td>
<td>MaxK</td>
<td>SubK</td>
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<td>Hip flexion</td>
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<td>(±8.4)</td>
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<td>(±7.1)</td>
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Abbreviations: MaxK=maximal instep kick; SubK=submaximal instep kick. MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact. *P value < 0.05.

Table 2. Range of motion (in degrees) of tension arc and movement trajectories for MaxK and SubK. Positive values indicate hip-, spine- and knee flexion, pelvis posterior tilt and spine rotation to the kick side. Negative values indicate hip-, spine- and knee extension, pelvis anterior tilt and spine rotation to the non-kick side.

<table>
<thead>
<tr>
<th>ROM</th>
<th>Tension arc</th>
<th>Movement trajectory</th>
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<tr>
<td></td>
<td>MaxK</td>
<td>SubK</td>
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<tr>
<td>Hip flexion</td>
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<td>Spine flexion</td>
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<td>Spine rotation</td>
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<td>(±7.1)</td>
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Abbreviations: ROM=range of motion; MaxK=maximal instep kick; SubK=submaximal instep kick. *=P value < 0.05.
SubK, MaxK shows increased ROM of movement trajectories for spine flexion (MD 21.9°, ES 3.2), pelvis posterior tilt (MD 15.2°, ES 2.2), spine rotation (MD 11.5, ES 1.6) and knee extension (MD 18.3°, ES 1.8).

The movement trajectory of hip flexion does not differ between MaxK and SubK, which is due to the reversed hip motion prior to ball impact during MaxK (Figure 4A).

**Figure 4A.** Range of motion curves (in degrees) for the hip and knee from player 4 for MaxK and SubK. Positive values indicate hip and knee flexion. Negative values indicate hip and knee extension. Keypoint MHE marks the greatest difference for hip extension and MKF for knee flexion. KF90 marks maximal hip flexion for MaxK and BI marks maximal hip flexion for SubK. BI shows equal knee ROM for MaxK and SubK.

Abbreviations: ROM=range of motion; MaxK=maximal instep kick; SubK=submaximal instep kick; MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact.
Figure 4B. Range of motion curves (in degrees) for the spine and pelvis from player 4 for MaxK and SubK. Positive values indicate spine flexion and pelvis anterior tilt. Negative values indicate spine extension and pelvis posterior tilt. Spine flexion and pelvis posterior tilt show the greatest difference at keypoint BI.

Abbreviations: ROM=range of motion; MaxK=maximal instep kick; SubK=submaximal instep kick; MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact.

Figure 4C. Range of motion curves (in degrees) for spine rotation from player 4 for MaxK and SubK. Positive values indicate spine rotation to the kickside. Negative values indicate spine rotation to the non-kick side. Keypoint MHE marks the greatest difference of spine rotation.

Abbreviations: ROM=range of motion; MaxK=maximal instep kick; SubK=submaximal instep kick; MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact.
Discussion

The maximal instep kick shows increased ROM of upper body and kicking leg segments at predefined keypoints when compared to the submaximal kick. From these keypoints can be derived that maximal kicking leads to enlargement of the tension arc and movement trajectories when compared to submaximal kicking. Reversal of hip motion is found during MaxK prior to ball impact, which does not occur during SubK. Spine flexion and pelvis posterior tilt show the largest relative differences between MaxK and SubK.

This is the first study that reports in detail on ROM characteristics for the maximal and submaximal kick in experienced football players. In order to be able to identify possible atypical kinematic patterns that may relate to groin injury in football players, a detailed description of the typical ROM characteristics of the hip, spine, pelvis and knee during the maximal and submaximal instep kick must first be obtained.

Ball speeds are consistent with previous studies for the maximal and submaximal kick in experienced football players. Ball speed is the result of summation of segmental velocities. Different ball speeds relate to different kinematic patterns. Studies on kinematics of kicking should thus preferably present data on ball speed.

The maximal kick shows shorter duration and increased ROM of body segments when compared to the submaximal kick. This may be due to increased segmental velocity and agrees with the pre-stretch concept that increased ROM of the tension arc invokes larger muscle contraction forces. Therefore MaxK exerts higher loads on groin structures than SubK. This agrees with the clinical observation that players with groin pain avoid maximal performance.

Increased segmental ROM for MaxK when compared to SubK was found at keypoint MHE and MKF. This enlargement of the tension arc is mainly due to increased hip extension, spine rotation and knee flexion. Contribution of spine extension and pelvis anterior tilt is only small. For the tension arc, ROM of knee flexion shows the greatest relative difference between maximal and submaximal kicking. The tension arc provides potential for utilizing energy from pre-stretch and elastic components of the muscle–tendon complexes to increase muscle contraction forces.

Keypoints KF90 and BI also showed increased segmental ROM for MaxK when compared to SubK, which corresponds with the increased movement trajectories of spine, pelvis and knee. Spine flexion and pelvis posterior tilt show the greatest relative difference of movement trajectories between MaxK and SubK. This assumes an important role of central segment actions during maximal kicking. Spine rotation and knee extension also show substantially increased trajectories. The increased movement trajectory of knee extension for MaxK leads to higher angular velocity of knee extension. Angular velocity of knee extension is strongly related to foot and ball speed. Correlation coefficients between foot and ball speed reported in the literature are high (r > 0.74).
The hip flexion trajectory did not increase for MaxK when compared to SubK. This is due to the reversed motion of the hip during MaxK prior to ball impact. At keypoint BI, MaxK shows decreased ROM of hip flexion when compared to SubK.

Between keypoints KF90 and BI, spine flexion and pelvis posterior tilt coincide with hip extension for MaxK (Figure 4a,b). Pelvis posterior tilt and hip extension are identical osteokinematic movements of the hip joint. From KF90 to BI, the pelvis shows increased posterior tilt for MaxK compared to SubK resulting in hip extension. Other studies reported on hip extension but never explained this phenomenon as pelvic action. Spine flexion and pelvis posterior tilt are coupled motions that cause lumbopelvic flexion. This may assist in the proximal to distal kinematic sequence of the kicking leg, thereby enhancing ball speed.

Movement trajectories of spine and pelvis affect ball speed through dynamic coupling. Movements of distant segments attribute to ball speed by exchanging intersegmental forces that are the result of precise timing of peak velocities and ROM of these segments.

This study demonstrates increased ROM of hip extension during the backswing of the maximal kick, which causes pre-stretch and energy storage to increase muscle contraction force. When ROM of hip extension is decreased, this may affect pre-stretch and thus the energy transfer to develop the physiologic muscle contraction force. Hypothetically, hip flexors may compensate with extreme muscle work to induce high segmental velocity. This may explain the relationship between deficits of hip ROM and groin injury during the backswing.

The increased ROM of lumbopelvic flexion we observe during MaxK prior to ball impact may serve as a safety mechanism. Hip extension, as induced by lumbopelvic action, causes elongation of the hip flexors due to separation of their attachments. A previous study demonstrated maximal elongation of the adductor longus prior to ball impact. Lumbopelvic flexion may reduce the load exerting on the groin by elongation of the hip flexors, thereby preventing them from concentric contractions at ball impact.

Deficits of pelvis posterior tilt or increased pelvis anterior tilt likely relate to groin injury. For running, increased pelvis anterior tilt is related to hamstring injuries and low back pain. For kicking, no such relations have yet been demonstrated.

The results of this study demonstrate that the hip extends prior to ball impact during maximal kicking in 13 out of 15 players, while no hip extension occurred during submaximal kicking. Previous studies showed hip extension during kicks with the preferred leg but not with the non-preferred leg and during kicks with non-fatigued muscles but not during kicks with fatigued muscles.

We acknowledge some limitations. We observe a slightly longer duration of the maximal instep kick than reported in previous studies. Kicks with approach angles that exceeded 45 degrees showed reduced approach distance due to the kicking pitch.
set up in the laboratory (Figure 3). Although approach angles do not affect ball speed, lower approach speed may have influenced ball speed and therefore kicking duration\textsuperscript{56,57}. Furthermore, keypoint BI was visually determined using DV images at 100 Hz frequency. A higher frequency should facilitate precision of visual determination of this keypoint. This has relevance for kicking duration as ball impact lasts 10-15 ms\textsuperscript{130,133}. At last, as ball speed has been recorded from two positions, precise measurement could be affected. As this applies to both kicks, possible measurement failure might be equal for both kicks.

**Conclusion**

This study demonstrates that segmental ROM increases during the maximal instep kick when compared to the submaximal kick. The enlargement of the tension arc is related to higher pre-stretch and the increased movement trajectories enhance the potential to achieve high segmental velocity. Our findings suggest that the athlete’s flexibility is imperative for powerful kicks. Data from this study may serve as a basis for future studies to investigate ROM characteristics of players with recurrent injury, with emphasis on flexibility and timing of body segments.