Side to side differences in hamstring muscle kinematics during maximal instep soccer kicking

Sinclair, Jonathan Kenneth

Available at http://clok.uclan.ac.uk/12583/


It is advisable to refer to the publisher’s version if you intend to cite from the work.

For more information about UCLan’s research in this area go to http://www.uclan.ac.uk/researchgroups/ and search for <name of research Group>.

For information about Research generally at UCLan please go to http://www.uclan.ac.uk/research/

All outputs in CLoK are protected by Intellectual Property Rights law, including Copyright law. Copyright, IPR and Moral Rights for the works on this site are retained by the individual authors and/or other copyright owners. Terms and conditions for use of this material are defined in the http://clok.uclan.ac.uk/policies/
Side to side differences in hamstring muscle kinematics during maximal instep soccer kicking

Jonathan Sinclair

Division of Sport, Exercise and Nutritional Sciences, School of Sport Tourism and Outdoors, University of Central Lancashire, UK

Received 26 June 2015 – Accepted 29 September 2015

Abstract. Hamstring strains are a common non-contact injury in soccer. The current study investigates bilateral differences in hamstring kinematics during maximal instep kicking. Thirteen male soccer players performed maximal instep kicks with their dominant and non-dominant limbs. Muscle-tendon kinematics of the four hamstring muscles during the kick movement were quantified using OpenSim software. Differences between dominant and non-dominant limbs were examined using paired t-tests. The results revealed that the biceps femoris long head (dominant = 165.28 ± 62.46 & non-dominant = 137.65 ± 52.17%), semimembranosus (dominant = 220.75 ± 43.35 & non-dominant = 131.23 ± 36.74%) and semitendinosus (dominant = 90.95 ± 16.69% and non-dominant = 80.47 ± 15.99%) experienced significantly greater strain when using the dominant limb. The current investigation provides key information regarding the mechanics of the hamstring group during maximal instep kicking, indicating that kicking with the dominant limb may place soccer players at increased risk from hamstring strain injury.

Key words: Hamstring, soccer, muscle-tendon, muscle strain

1 Introduction

Instep kicking is a skill that is fundamental to soccer performance and represents the most commonly used kicking technique in soccer (Kellis & Katis, 2007; Lees & Nolan, 1998; Lees, Asai, Andersen, Nunome, & Sterzing, 2010). It is important to generate high ball velocities when executing instep kicks as this improves the likelihood of scoring by reducing the amount of time that the goalkeeper has to react (Sinclair, Taylor, et al., 2014).

As part of their typical training regimen, soccer players are required to develop competency in kicking with both limbs (Carey, et al., 2001). Despite this, soccer players will typically demonstrate limb dominance in kicking mechanics (Dorge, Anderson, Sorensen, & Simonsen, 2002; Sinclair, Fewtrell, et al., 2014). The unilateral...
nature of soccer kicking has been proposed as a con-
tributing factor to the aetiology of injury in soccer players
(Dorge, et al., 2002). In relation to most other sports soc-
cer is associated with a high rate of injury which ranges
from 3.7–29.1 injuries per 1000 hours of game and train-
ing activity (Agel, Evans, Dick, Putukian, & Marshall,
2007). Aetiological analyses investigating injury locations
in soccer have shown that 60–80% of injuries occur in
the lower extremities (Agel, et al., 2007; Dick, Putukian,
Agel, Evans, & Marshall, 2007).

The majority of muscle injuries in soccer are non-
contact in nature (Uebelacker, Mueller-Wohlffahrt, &
Ekstrand, 2015). Hamstring strains are known to be the
most common non-contact injury in soccer (Arnason,
Andersen, Holme, Engebretsen, & Bahr, 2008; Dudebo,
White, & George, 2004; Ekstrand & Gillquist, 1982;
Ekstrand, Haglund, & Walden, 2011; Orchard & Seward,
2002; Orchard, Wood, Seward, & Broad, 1998; Seward,
Orchard, Hazard, & Collinson, 1993). Strain injuries
to the hamstring muscles are characterized by pain
in the posterior aspect of the thigh with accompanying
damage to the hamstring muscle fibres (Verrall,
Slavotinek, Barnes, Fon, & Spriings, 2001). Hamstring
strain injuries range in seriousness from grade I which
is characterized by microscopic tearing and minor loss
of muscle function through to grade III which repre-
sents a full muscle rupture with complete loss of func-
tion (Blankenbaker & Tuile, 2010). Aetiological research
has shown that hamstring strains occur at a rate of
3.0–4.1 per 1000 hours of match play and 0.4–0.5 per
1000 hours of training (Arnason, Gudmundsson, Dahl, &
Johannsson, 1996; Arnason, et al., 2004).

Hamstring strains occur as a function of excess-
ive muscle lengthening during eccentric contractions
(Heiderscheit, Sherry, Silder, Chumanov, & Thelen 2010;
Mueller-Wohlffahrt, et al., 2013; Liu, Garrett, Moorman,
& Yu, 2012). Therefore, sports motions that require
frequent hamstring muscle lengthening may serve as
a precursor for aetiology of hamstring muscle strains
(Garrett, 1990; Garrett, Safran, Seaber, Glisson, &
Ribbeck 1987; Mair, Seaber, Glisson, & Garrett, 1996).
Clinical research has shown that the extent of muscle fibre
strain and the rate of muscle fibre lengthening are pri-
mary determinants of muscle strain injuries (Liu, et al.,
2012). Therefore rapid eccentric hamstring actions that
are associated with maximal velocity kick having been
linked to the aetiology of hamstring injuries in soccer
players (Orchard & Seward, 2002).

A small number of investigations have examined the
kinematics of the hamstring muscle group during sports
movements. Yu, et al. (2008) examined the mechanics of
the hamstring muscles during sprinting. Their findings
showed that the risk for hamstring muscle strain injuries
is greatest during the late stance and late swing phases
of overground sprinting. Higashihara, Nagano, Takahashi,
& Fukubayashi (2014) investigated the effects of forward
trunk lean on hamstring muscle kinematics during sprint-
ing. They showed that the strain load imposed on the
biceps femoris long head and semimembranosus mus-
cles was larger with forward trunk lean which lead to
the conclusion that injury risk in these specific muscles
may be enhanced. Similarly, Chumanov, Heiderscheit,
and Thelen (2011) studied hamstring muscle strain dur-
ing high velocity running. Their findings showed that the
greatest strain loads exist during the swing phase of run-
ning which lead to the conclusion that the hamstrings are
most susceptible to injury during this phase of the gait
cycle.

There is currently a paucity of information regarding
the mechanics of the hamstring muscle group during kick-
ing movements nor is there any consideration given to the
potential bilateral differences that may exist in hamstring
kinematics. Therefore the aim of the current study was to
investigate bilateral differences in the kinematics of the
hamstring group during maximal instep kicking.

2 Methods

2.1 Participants

Fifteen male soccer players (age = 18.20 ± 1.0 years;
height = 1.79 ± 0.11 m; body mass = 74.65 ± 5.54 kg)
were examined whilst performing maximal instep kicks
into a regulation goal with their right (dominant) and
left (non-dominant) foot. All participants were academy
level players contracted to a professional club in England.

2.2 Procedure

Kinematic information was calculated using a ten cam-
era motion capture system (Qualisys™ Medical AB,
Goteburg, Sweden) at a rate of 500 Hz. Each participant
performed maximal in-step kicks with a 5 m run up into
a regulation sized soccer goal. Five kicking trials were
obtained from each participant from the dominant and
non-dominant limbs. Dynamic calibration of the motion
analysis system was performed before each data collection
session.

Retroreflective markers (19 mm diameter) were placed
at the C7, T12 and xiphoid process landmarks and also
positioned bilaterally onto the acromion process, iliac
crest, anterior superior iliac spine, posterior super iliac
spine, medial and lateral malleoli, medial and lateral
femoral epicondyles and greater trochanter. This allowed
the trunk, pelvis, thighs, shanks and feet to be defined.
Carbon-fibre tracking clusters comprising of four non-
linear retroreflective markers were positioned onto the
thigh and shank segments. Static calibration trials were
obtained with the participant in the anatomical position
in order for the positions of the anatomical markers to be
referenced in relation to the tracking clusters/markers.
Table 1. Hip and knee joint kinematics (means, standard deviations and 95C.I's) from the dominant and non-dominant limbs.

<table>
<thead>
<tr>
<th></th>
<th>Dominant</th>
<th>Non-dominant</th>
<th>% Difference</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>95% C.I</td>
<td>Mean</td>
</tr>
<tr>
<td>Pelvis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike (°)</td>
<td>10.52  1.47</td>
<td>9.71–11.33</td>
<td>11.52  1.19</td>
<td>10.86–12.18</td>
</tr>
<tr>
<td>Angle at maximum hip flexion (°)</td>
<td>17.63  1.68</td>
<td>16.69–18.57</td>
<td>23.48  2.57</td>
<td>22.06–24.90</td>
</tr>
<tr>
<td>Range of motion (°)</td>
<td>7.11  1.99</td>
<td>6.01–8.22</td>
<td>11.96  2.55</td>
<td>10.55–13.38</td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike (°)</td>
<td>–14.25 –1.44</td>
<td>–15.03–13.45</td>
<td>–11.57  0.58</td>
<td>–10.98–11.06</td>
</tr>
<tr>
<td>Angle at maximum hip flexion (°)</td>
<td>68.55  7.30</td>
<td>64.50–72.59</td>
<td>60.73  6.39</td>
<td>57.20–64.27</td>
</tr>
<tr>
<td>Range of motion (°)</td>
<td>82.79  6.60</td>
<td>79.14–86.45</td>
<td>72.30  6.53</td>
<td>68.69–75.91</td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike (°)</td>
<td>81.00  6.36</td>
<td>77.48–84.52</td>
<td>81.07  7.91</td>
<td>76.69–85.45</td>
</tr>
<tr>
<td>Angle at maximum hip flexion (°)</td>
<td>39.05  1.98</td>
<td>21.95–44.15</td>
<td>33.23  2.37</td>
<td>27.08–40.69</td>
</tr>
<tr>
<td>Range of motion (°)</td>
<td>67.95  6.91</td>
<td>64.13–71.78</td>
<td>61.84  6.53</td>
<td>58.22–65.46</td>
</tr>
</tbody>
</table>

2.3 Data processing

Dynamic trials were digitized using Qualisys Track Manager in order to identify anatomical and tracking markers then exported as C3D files to Visual 3D (C-Motion, Germantown, MD, USA). Kinematic data was smoothed using a cut-off frequency of 15 Hz with a non-phase shift low-pass Butterworth 4th order filter. Five kicking trials were obtained from each participant from the dominant and non-dominant limbs. Kicking trials were defined from the instance of stance limb touch down to maximum hip flexion (R). Kinematic parameters from the kicking limb that were extracted for statistical analysis were 1) angle at stance limb footstrike, 2) angle at maximum hip flexion and 3) range of motion representing the angular range of motion from footstrike to maximum hip flexion.

OpenSim software was used to quantify muscle-tendon lengths during the kicking movements (Delp, et al., 2007). Muscle kinematics were quantified using the gait2392 model using Openns v3.2. This model corresponds to the 92 muscle–tendon complexes in the human body that are modeled using the Hill recommendations based on the associations between force-velocity-length (Zajac, 1989). These muscle properties were then scaled based on each participant’s height and body mass based on the recommendations of Delp, et al., (1990). Muscle–tendon lengths are determined by the positions of their proximal and distal muscles muscle origins. The muscle–tendon complexes which were evaluated as part of the current research were the biceps femoris long head (LH), biceps femoris short head (SH), semimembranosus and semitendinosus. Muscle kinematic parameters that were extracted for statistical analysis were 1) change in length throughout the kicking movement 2) strain (representative of the change in length divided by original length at the start of the movement) and 3) maximum lengthening velocity.

2.4 Statistical analyses

Descriptive statistics (means, standard deviations and 95% confidence intervals) were calculated. To compare differences in hamstring muscle kinematics between the dominant and non-dominant limbs, paired t-tests were utilized with statistical significance accepted at the p ≤ 0.05 level (Sinclair, Taylor, & Hobbs, 2013). Effect sizes were quantified using partial eta² (pη²). In addition to this percentage differences were also calculated. The Shapiro-Wilk statistic for each condition confirmed that the data were normally distributed. All statistical procedures were conducted using SPSS 22.0 (SPSS Inc., Chicago, IL, USA).

3 Results

3.1 Angular kinematics

The hip joint at footstrike was shown to be significantly (p < 0.05, pη² = 0.60) more extended in the dominant foot compared to non-dominant. In addition the hip was also found to be significantly (p < 0.05, pη² = 0.35) more extended at the instance of maximum hip flexion in the dominant limb. Finally, the hip range of motion was significantly (p < 0.05, pη² = 0.50) larger when using the dominant foot compared to non-dominant (Tab. 1, Fig. 1a).

The knee joint was significantly more flexed (p < 0.05, pη² = 0.42) at the instance of peak hip flexion in the non-dominant limb (Tab. 1, Fig. 1c). Finally at the pelvis, range of motion was significantly greater (p < 0.05, pη² = 0.40) when kicking with the non-dominant limb (Tab. 1, Fig. 1c).

3.2 Hamstring kinematics

For the biceps femoris LH muscle the dominant limb was associated with a significantly (p < 0.05, pη² = 0.47)
greater change in length compared to the non-dominant limb. In addition the findings also showed that the strain experienced by the biceps femoris LH was significantly \((p < 0.05, \eta^2 = 0.47)\) greater when using the dominant limb (Tab. 2, Fig. 2a). In addition for the semimembranosus the dominant limb was found to have undergone a significantly \((p < 0.05, \eta^2 = 0.71)\) larger change in length. Also the strain experienced by the semimembranosus was significantly \((p < 0.05, \eta^2 = 0.73)\) greater in the dominant limb compared to non-dominant (Tab. 2, Fig. 2c). Finally, for the semitendinosus the dominant limb was associated with a significantly \((p < 0.05, \eta^2 = 0.39)\) larger change in length. The strain experienced by the semitendinosus was significantly \((p < 0.05, \eta^2 = 0.37)\) greater in the dominant limb compared to non-dominant (Tab. 2, Fig. 2d).

---

**Table 2. Hamstring kinematics (means, standard deviations and 95% the dominant and non-dominant limbs.)**

<table>
<thead>
<tr>
<th></th>
<th>Dominant</th>
<th>Non-dominant</th>
<th>% Difference</th>
<th>Effect size (\eta^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biceps femoris LH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in length (m)</td>
<td>0.34(0.05)</td>
<td>0.29(0.08)</td>
<td>0.24–0.34 15.70</td>
<td>0.47</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>165.28(62.46)</td>
<td>137.65(52.17)</td>
<td>108.76–165.54</td>
<td>18.24 0.47</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>1.53(0.06)</td>
<td>1.55(0.02)</td>
<td>1.39–1.68 1.38</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Biceps femoris SH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in length (m)</td>
<td>0.05(0.02)</td>
<td>0.06(0.01)</td>
<td>0.05–0.07 18.27</td>
<td>0.25</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>25.76(10.68)</td>
<td>30.40(6.88)</td>
<td>26.59–34.21</td>
<td>16.52 0.24</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>1.57(0.18)</td>
<td>1.60(0.13)</td>
<td>1.53–1.67 1.30</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Semimembranosus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in length (m)</td>
<td>0.36(0.04)</td>
<td>0.27(0.04)</td>
<td>0.25–0.29 29.88</td>
<td>0.71</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>220.75(45.35)</td>
<td>131.23(36.74)</td>
<td>110.89–151.58</td>
<td>50.86 0.73</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>2.69(0.11)</td>
<td>2.72(0.10)</td>
<td>2.60–2.83 1.13</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Semitendinosus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in length (m)</td>
<td>0.32(0.03)</td>
<td>0.28(0.04)</td>
<td>0.26–0.30 10.95</td>
<td>0.39</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>90.95(16.69)</td>
<td>80.47(15.99)</td>
<td>71.61–89.32</td>
<td>12.23 0.37</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>3.20(0.21)</td>
<td>3.41(0.15)</td>
<td>3.30–3.50 6.28</td>
<td>0.22</td>
</tr>
</tbody>
</table>

---

**Fig. 1.** Joint and segment kinematics (a = hip, b = knee and c = pelvis) from the dominant and non-dominant limbs (black = dominant and dash = non-dominant) (FL = flexion and PT = posterior tilt).
Side to side differences in hamstring muscle kinematics during maximal instep soccer kicking

**Fig. 2.** Muscle-tendon lengths from the dominant and non-dominant limbs (black = dominant and dash = non-dominant).

## 4 Discussion

The aim of the current study was to investigate bilateral differences in the kinematics of the hamstring group during maximal instep kicking. To the authors knowledge this represents the first investigation to quantify hamstring muscle kinematics during instep kicking. A study of this nature may provide important information to soccer clinicians regarding the aetiology of hamstring strain injuries as a function of maximal kicking actions.

The first key observation is that all of the four primary hamstring muscles tested in the current study exhibited eccentric lengthening in an almost linear manner throughout the kick movement. This is to be expected given the joint observed joint/segment kinematics during the instep kick movement; hamstring lengthening was required to support flexion and extension rotations of the hip and knee joints and also the posterior tilt of the pelvic segment during the kick (Lees, et al., 2010).

Of further importance is the finding that the dominant limb was associated with significant increases in strain magnitude of the biceps femoris LH, semimembranosus and semitendinosus muscles. The strain imposed on the hamstring muscle-tendon unit during the kick is a function of the flexion and extension patterns of the hip and knee joints (Opar, Williams, & Shield, 2012). Given the proximal and distal attachment of the aforementioned muscles to the ischial tuberosity and fibula/tibial heads; the increased angular range of the hip and extension of the knee joint when using the dominant limb served to enhance the strain imposed on the muscles.

Although differences in muscle strain were shown between the dominant and non-dominant limbs, the biceps femoris LH, semimembranosus and semitendinosus muscles all experienced a substantial degree of strain regardless of limb dominance. Given the proposed relationship between muscle strain magnitude and the aetiology of muscle strain injuries the current investigation provides insight regarding the high incidence of hamstring strain injuries in soccer (Orchard, et al., 1998; Orchard & Seward, 2002; Seward, et al., 1993). Nonetheless, the statistical analysis showed that the biceps femoris LH, semimembranosus and semitendinosus muscles of the dominant limb experience significantly greater strain, leading to the conclusion that kicking with the dominant limb may place soccer players at increased risk from hamstring strain injury. Of further interest is the relatively low amount of strain experienced by muscle-tendon unit of the biceps femoris SH. It is hypothesized that this finding relates to the unilateral nature of the biceps femoris SH which attaches proximally to the lateral ridge of the femur rather as opposed to the ischial tuberosity. Therefore, this muscle unit is not involved to the same extent in hip flexion or in posterior pelvic tilt and thus the extent to which it is required to lengthen is reduced in relation to the other hamstring muscles.

The first key observation is that all of the four primary hamstring muscles tested in the current study exhibited eccentric lengthening in an almost linear manner throughout the kick movement. This is to be expected given the joint observed joint/segment kinematics during the instep kick movement; hamstring lengthening was required to support flexion and extension rotations of the hip and knee joints and also the posterior tilt of the pelvic segment during the kick (Lees, et al., 2010).

Of further importance is the finding that the dominant limb was associated with significant increases in strain magnitude of the biceps femoris LH, semimembranosus and semitendinosus muscles. The strain imposed on the hamstring muscle-tendon unit during the kick is a function of the flexion and extension patterns of the hip and knee joints (Opar, Williams, & Shield, 2012). Given the proximal and distal attachment of the aforementioned muscles to the ischial tuberosity and fibula/tibial heads; the increased angular range of the hip and extension of the knee joint when using the dominant limb served to enhance the strain imposed on the muscles.

Although differences in muscle strain were shown between the dominant and non-dominant limbs, the biceps femoris LH, semimembranosus and semitendinosus muscles all experienced a substantial degree of strain regardless of limb dominance. Given the proposed relationship between muscle strain magnitude and the aetiology of muscle strain injuries the current investigation provides insight regarding the high incidence of hamstring strain injuries in soccer (Orchard, et al., 1998; Orchard & Seward, 2002; Seward, et al., 1993). Nonetheless, the statistical analysis showed that the biceps femoris LH, semimembranosus and semitendinosus muscles of the dominant limb experience significantly greater strain, leading to the conclusion that kicking with the dominant limb may place soccer players at increased risk from hamstring strain injury. Of further interest is the relatively low amount of strain experienced by muscle-tendon unit of the biceps femoris SH. It is hypothesized that this finding relates to the unilateral nature of the biceps femoris SH which attaches proximally to the lateral ridge of the femur rather as opposed to the ischial tuberosity. Therefore, this muscle unit is not involved to the same extent in hip flexion or in posterior pelvic tilt and thus the extent to which it is required to lengthen is reduced in relation to the other hamstring muscles.
There are some limitations to the current work which should be acknowledged so that the observations can be appropriately contextualized. Firstly the current investigation utilized an all-male sample which may limit its generalizability. Barfield, et al. (2002) documented gender differences in kicking kinematics during maximal instep kicking. In addition to this clinical research investigating the prevalence of sports injuries has shown that there are gender differences in hamstring injury risk (Ristolainen, et al., 2010; Sallis, Jones, Sunshine, Smith, & Simon, 2001; Satterthwaite, Larmer, Gardiner, & Norton, 1996). It is therefore recommended that the current investigation be repeated using a sample of female soccer players.

In conclusion, although the mechanics of instep kicking have been examined extensively, the current knowledge regarding the mechanics of the hamstring muscles during this movement is limited. The present investigation therefore adds to the current knowledge by providing a comprehensive evaluation of hamstring kinematics during maximal instep kicking when using the dominant and non-dominant limbs. Importantly the current study showed that the amount of muscle strain in the biceps femoris LH, semimembranosus and semitendinosus muscles was significantly larger when kicking with the dominant limb. The current investigation therefore provides key information regarding the mechanics of the hamstring group during maximal instep kicking, which shows that when kicking maximally with the dominant limb soccer players may be at greater risk from hamstring strain injury.

Bibliography

Side to side differences in hamstring muscle kinematics during maximal instep soccer kicking


