Altered muscle activation following hamstring injuries

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ABSTRACT

Objective The purpose of this study was to compare the electromyographic (EMG) activity of gluteal and thigh muscles of sportspeople with a recent hamstring injury with uninjured controls during a weight-bearing task.

Study design Cross-sectional.

Setting University laboratory.

Participants 16 participants with a hamstring injury (hamstring-injured group, HG) and 18 control participants (control group (CG)) participated in the study.

Main outcome measure The EMG activity of gluteal, quadriceps and hamstring muscles was recorded during a movement from double- to single-leg movement using surface electrodes.

Results The EMG onsets of biceps femoris and medial hamstrings were significantly earlier for the HG injured and the uninjured sides in preparation for single-leg standing when compared with the CG average. There were no differences in onsets for the gluteal and quadriceps muscles when comparing the injured or uninjured legs of the HG to the bilateral average of the CG.

Conclusion The earlier onset of the injured and the uninjured hamstrings in preparation for single leg stance of the HG in comparison with the CG suggests an alteration in the motor control of these muscles. Altered neuromuscular control following a hamstring injury may be a factor to be considered in the rehabilitation of hamstring injuries.

INTRODUCTION

Non-contact hamstring injuries are common in sports that include sprinting, acceleration and kicking, and have a high rate of recurrence and decreased performance levels.1–5 Traditional rehabilitation and prevention strategies for this injury have used outcome measures that include hamstring muscle strength and flexibility.6–9 Interestingly, recent research has suggested that exercises focusing on improving neuromuscular control around the lumbar spine and pelvis,10 as well as sports-specific skills and enhanced balance performance, may also reduce recurrence.11 Impaired movement discrimination during open chain movements of the lower limb have also been associated with an increased risk of hamstring injury.12 Thus, disturbed sensory input and inhibited neuromuscular control may need to be considered in the evaluation of hamstring injuries.

Not only previous hamstring injury4,13–17 but also knee injury, osteitis pubis14 and calf-muscle injury18 appear to place the sportsperson at risk of either a new or recurrent hamstring injury. Anecdotal evidence suggests that lumbar19,20 and sacro-iliac disorders21 can also predispose people to hamstring injuries. Low-back,12 groin,13 pelvis24 and knee-joint25,26 injuries have been associated with altered electromyographic (EMG) activity of lumbopelvic and lower-limb muscles. Specifically, increased hamstring activity while walking has been observed in individuals with lower-back pain (LBP)27 and anterior cruciate ligament (ACL) deficiencies.28 Increased hamstring activity has also been observed during an experimental task of change from double- to single-leg stance in individuals with pelvic pain.24 and decreased activation of the gluteus maximus (GMax), and increased activation of hamstrings has been observed clinically in patients with hamstring injuries.29

Verrall et al14 suggested that following an injury of the knee or groin, the biomechanical properties of the lower limbs may change, thereby contributing towards increased susceptibility of a future hamstring injury. We have hypothesised that changes in neuromuscular control associated with other injuries, in particular, increased hamstring muscle activation, could potentially lead to increased cumulative loading for these muscles, thereby increasing their risk for injury.30 However, neuromuscular control as evidenced by EMG activation patterns of the agonist, synergist and antagonist pelvic and lower-limb muscles has not been investigated in sportspersons with hamstring injuries. Investigation of this potential injury mechanism may contribute towards a better understanding of neuromotor control of the hamstrings and lead to studies to determine whether exercise that focuses on neuromuscular control reduces the incidence and risk of hamstring injury.

The aim of this study was to compare the recruitment patterns of gluteal and thigh muscles during transition from double to single leg stance in participants with and without a recent hamstring injury. The secondary aim of the study is to compare the between-trial variability of EMG onsets in participants with and without a recent hamstring injury.

METHODS

Participants Seventeen male participants clinically diagnosed as having a hamstring injury and 19 non-injured healthy male controls volunteered to participate in this study. All participants read the information sheet and signed a consent form, which was approved by the University of Otago Human Ethics Committee. Inclusion criteria for the hamstring-injured group (HG) were sportspersons who had: (1) sudden onset of non-impact posterior thigh pain during a match, competition or training within the previous 12 months; (2) an injury severe enough to have required intervention by a
health professional; (3) an injury severe enough to have caused the sportsperson to miss at least one official match, competition or at least 1 week of regular training; and (4) returned at least partially to sports training. The inclusion criteria for the control group (CG) were (1) no known history of hamstring injury in the past that required intervention by a health professional and (2) currently participating fully in their regular sports training. Exclusion criteria for both groups were (1) knee or lumbo-pelvic injury that required health professional intervention and (2) known neurological, cardiorespiratory or systemic disorder.

EMG recordings

EMG activity was recorded bilaterally using pairs of Ag/AgCl surface electrodes (Blue Sensor disposable electrodes; Medicotest A/S, Ølstykke, Denmark), which were placed on the following muscles using Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles guidelines: vastus lateralis, vastus medialis, rectus femoris, biceps femoris (BF), medial hamstrings (MH), glutaeus medius and GMa, with a centre-to-centre distance of 25 mm. The ground electrode was positioned on the sternum. The skin was prepared by shaving and cleaning with alcohol swabs, and abraded firmly with a hand towel to reduce the electrical impedance to less than 10 kΩ (1% of the system’s input impedance).

EMG data were collected with an eight-channel TeleMyo telemetric hardware system (Noraxon USA, Scottsdale, Arizona). The system’s amplifier has a gain of 2000 and an input impedance of 10 MΩ. The analogue EMG data from the receiver were forwarded to an analogue-to-digital converter (National Instruments) and sampled at a rate of 1000 Hz using EVaRT 4.0 software (Motion Analysis, Santa Rosa, California).

Procedure

Participants stood wearing their own sport shoes with one foot on each of two Kistler force plates (BP2436 and OR6-5; Advanced Medical Technologies, Newton, Massachusetts, interfaced with the Evart 4.0 software and also sampled at 1000 Hz). They were instructed to move one leg into 90° hip flexion (marching movement) as fast as possible on the foot that is lifted off the force plate, indicating full weight-bearing on the electromyographic-monitored leg.

Data were exported to LabVIEW version 5.0, band-pass filtered between 20 and 450 Hz using a fourth-order Butterworth filter and full-wave-rectified. The onset of EMG was identified using the point at which the EMG amplitude first increased by more than three SD, for a minimum of 25 ms from the baseline level, defined as 100 ms at the commencement of the trial.

Force plate data (vertical ground force) were used to determine initiation of movement. The hip-flexion movement resulted in an anticipatory postural adjustment (APA) whereby weight was first shifted onto the moving leg before it was lifted. This appeared as an increase in the vertical ground force (at T1) of that leg before the force decreased until it reached zero when the foot lifted off the force plate (T2) (figure 1). The start of the APA (T1) was determined for each trial using a Microsoft Excel graph (figure 1). All muscle onsets for the hip-flexion task were expressed relative to T1, with a negative value indicating onset of activity prior to the APA and a positive value indicating onset following the APA. The time at which the foot lifted off the force plate (T2) was computed by using the LabVIEW version 5.0 program as the point at which the z-force reached zero (figure 1). The reaction time was defined as the difference between the times of the visual signal and the start of the APA (T1), and the movement time was defined as the difference between the time of the visual signal and the time at which the foot lifted off the force plate (T2).

Statistical analysis

Mean differences (95% CI) between groups were calculated for EMG onsets. Within-group differences were analysed using paired t tests, comparing injured with uninjured sides of the HG, and the CG preferred with non-preferred sides. Preliminary analysis showed no significant side-to-side differences for variables of the controls. For the between-group analyses, the variables of the preferred and non-preferred sides of the controls were thus averaged. The variables of the HG injured and the uninjured sides were compared respectively with the controls’ bilateral average using independent t tests. The α level was set at 0.05.

RESULTS

Subject characteristics

Technical problems occurred with the data collection for one injured and one uninjured subject for both sides, and for the uninjured side of one HG subject. Thus, the total number of participants included in the data analysis of muscle onsets and amplitudes was 16 and 18 in the HG and CG respectively (table 1). Single electrodes had also occasionally moved during data collection, and so the number of participants included for specific muscle groups are defined in the data tables.

All participants were taking part in sports, which included rugby, soccer, hockey, netball and track athletics, at least twice weekly. In the HG, the mean time (±SD) since injury was 3.7±3.5 months (range 1–12 months), and the time before a return to partial training had been 4.3±2.1 weeks. Five of the...
participants had missed up to 3 weeks of full training because of
the injury, with 11 needing 4 or more weeks. Based on
self-report, eight participants (50%) had incurred their ham-
string injury on the preferred leg, and 12 participants (75%)
had incurred the injury in the lateral hamstring muscle. The
injury had been localised to the mid-thigh in 10 of the par-
ticipants (62.5%), with five in the proximal part (31.3%) and
one in the distal part. Five participants (31.3%) had incurred a
hamstring injury in the same limb, ranging from 10 months to
3 years prior to the latest injury. Five participants had incurred a
hamstring injury of the opposite limb (31.3%), ranging from
6 months to 3 years previously. Only two of the injured par-
ticipants had returned to preinjury competitive and training
level. Of the 14 participants that had not returned to preinjury
competitive training levels, 10 indicated that they had only
mild limitations with respect to strenuous sports or moderate
work. The remaining two participants reported discomfort
in the hamstrings during moderate work or sports activities.
Three HG participants were still undergoing exercise-based
rehabilitation supervised by a health professional at the time
of subject recruitment.

Temporal variables
There were no significant within-group differences for the
reaction and movement times, and for the muscle onsets.
There were also no significant differences for reaction time
when comparing the HG injured and uninjured sides with the
CG bilateral average (table 2). For the movement time, the HG
uninjured side was significantly faster than the CG bilateral
average (p=0.049, table 2).

Onsets of all muscle groups of the CG participants were
more likely to occur following the APA (T1, figure 2). There
were no significant differences for the onset of the gluteal
and the quadriceps muscles relative to the APA when com-
paring the HG injured side to the CG bilateral average and
between the HG uninjured side and the CG bilateral average
(figure 2, table 2). The onsets of BF and MH of the HG injured
and the uninjured sides were significantly earlier than the
CG bilateral average (figure 2). The CIs of the onsets of BF
and MH of the HG indicate that these onsets occurred before
the initiation of movement for some participants.

Coefficient of variations of temporal variables
Large mean co-efficient of variation (CVs) were found for all
EMG muscle onsets, namely above 100%, with the exception of
the onsets of GMa (table 2). In contrast, the reaction and move-
ment times had low mean individual CVs, ranging between 3%
and 25% (table 2). There were no significant within-group and
between-group differences for all temporal CVs (table 3).

DISCUSSION
Participants with a hamstring injury had earlier onsets of the
injured hamstring muscles and the contralateral side compared
with controls. However, a large variability was found for EMG
onsets for all participants, despite a small variability in the
speed of movement.

Muscle activity prior to initiation of movement is likely to
be controlled by feedforward mechanisms within the central
nervous system (CNS) and serves to prepare the whole body
and segmental stability for load acceptance, and maintenance
of equilibrium.34 35 This includes the first 50 to 100 ms follow-
ing the initiation of movement, the minimum time required
for feedback mechanisms to modify the muscle activity.35 36

The mean onset of BF and MH of the control participants
occurred more than 200 and 140 ms, respectively, following
the initiation of movement. In contrast, in the HG partici-
pants, the mean onsets were less than 100 ms for the injured
BF, and bilaterally for MH. The 95% CIs for these variables
(figure 2) indicate that in some of the injured participants, the
onsets of these muscles were prior to the start of the APA and
were thus likely controlled by feedforward mechanisms.
Earlier onsets were also found for the HG uninjured BF and
MH in comparison with the CG bilateral average indicating
that the changes in neuromuscular control are likely due to
changes within the CNS, additional to peripheral changes in
injured muscle.

Table 1 Participant characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control group</th>
<th>Hamstring-injured group</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects (n)</td>
<td>18</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Age (mean±SD)</td>
<td>22.6±5.0</td>
<td>24.8±5.2</td>
<td>0.22</td>
</tr>
<tr>
<td>Body weight (kg (mean±SD))</td>
<td>80.7±12.0</td>
<td>79.1±8.4</td>
<td>0.64</td>
</tr>
<tr>
<td>Body height (cm (mean±SD))</td>
<td>183.0±5.1</td>
<td>176.9±6.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Body mass index (mean±SD)</td>
<td>24.0±2.8</td>
<td>25.3±2.6</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 2 Between-group differences for temporal variables between the bilateral average of the control
group (CG) and the injured and uninjured limbs of the hamstring-injured group (HG)

<table>
<thead>
<tr>
<th>Dependent variable/ muscle group</th>
<th>HG injured side versus CG bilateral average</th>
<th>p Value</th>
<th>HG uninjured side vs CG bilateral average*</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (ms)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction time</td>
<td>-17 (-41 to 71)</td>
<td>0.154</td>
<td>-15 (-39 to 9)</td>
<td>0.217</td>
</tr>
<tr>
<td>Movement time</td>
<td>-39 (-90 to 12)</td>
<td>0.130</td>
<td>-54 (-108 to 0)</td>
<td>0.049</td>
</tr>
<tr>
<td>Electromyographic onsets relative to anticipatory postural adjustment (ms)†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>12 (-70 to 45)</td>
<td>0.663</td>
<td>-1 (-63 to 62)</td>
<td>0.982</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>-4 (-65 to 57)</td>
<td>0.888</td>
<td>59 (-126 to 9)</td>
<td>0.088</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>-197 (-299 to -94)</td>
<td>&lt;0.001</td>
<td>-155 (-287 to -23)</td>
<td>0.023</td>
</tr>
<tr>
<td>Medial hamstrings</td>
<td>-123 (-188 to -57)</td>
<td>0.001</td>
<td>-103 (-181 to -25)</td>
<td>0.011</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>21 (-48 to 91)</td>
<td>0.529</td>
<td>-25 (-99 to 48)</td>
<td>0.477</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>3 (-59 to 65)</td>
<td>0.919</td>
<td>-16 (-78 to 45)</td>
<td>0.589</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>15 (-43 to 74)</td>
<td>0.597</td>
<td>-18 (-76 to 40)</td>
<td>0.534</td>
</tr>
</tbody>
</table>

*Time: negative value: HG is faster than CG.
†Muscle onsets: negative value: HG onset is earlier than CG.

Reaction time: time from visual signal to anticipatory postural adjustment; movement time: time from visual signal to foot
being lifted off force platform.
The earlier onset of the hamstring muscles is similar to findings in participants with clinically diagnosed sacroiliac joint pain performing the same movement. However, no difference was seen for the GMa onset relative to APA between the two groups of participants in the current study, and so this does not support previous clinical observations of delayed onset of GMa being common in patients with hamstring injuries.

Despite the low individual variability of the reaction and movement time, the variability was high for the muscle onsets relative to APA, consistent with other reports of lower limb EMG onsets during functional movements. The large CVs of muscle onsets of injured and asymptomatic participants of the current study and that by Van Deun et al indicate that different strategies can be used by injured and uninjured participants to achieve the same movement.

Changes in the fusimotor-spindle system have been reported with experimentally induced muscle pain. Cameron et al suggested that sportspeople with lower movement discrimination scores had an increased risk for incurring a hamstring injury. The earlier onsets of the hamstring-injured muscles during the double- to single-leg stance may reflect changed proprioception following an injury of the hamstring muscle. From a clinical perspective, patients with a history of hamstring injuries often complain of persistent feelings of discomfort or tightness in their hamstrings which prevent them from reattaining full preinjury training levels. These symptoms may be present beyond the time frame normally considered to be necessary for healing of myotendinous structures. It is in these patients that changes in neurophysiological mechanisms may be evident, possibly leading to facilitation of hamstring contraction during functional movements. We suggest that this could contribute towards persistent lowered thresholds for pain or discomfort during sporting activity, such as when the athlete leans forwards while sprinting to catch a ball. Alternatively, injury of the muscle may affect the sensory input, leading to inappropriate muscle preprogramming that may place the muscle itself, or other structures of the kinetic chain, at risk of further injury.

Increased hamstring activity during walking has been observed in individuals with LBP and ACL deficiencies. These injuries have been associated with increased risk for incurring hamstring injuries. We have suggested that injuries that result in loss of stability of any joint in the lower extremity and lumbopelvic area may increase the load of the hamstring muscle group. Increased ‘base’ activation or cumulative loading of the hamstring muscles could theoretically decrease the pain- and injury-free window of movement and activity before injury thresholds are reached. Such altered activation may be a substantial contributing factor towards development of a first or recurrent hamstring injury, as well as persistence of symptoms and decreased training levels following an injury.

**Figure 2**  Mean time (95% CI) of electromyographic onsets for the stance side during transition from double- to single-leg standing of the hamstring-injured group (HG) injured and uninjured sides and the control group (CG) bilateral average. *HG injured side versus CG bilateral average and HG uninjured side versus CG bilateral average: p<0.05. APA, start of the anticipatory postural adjustment; BF, biceps femoris; FO, contralateral foot lifted off the force plates; GMa, gluteus maximus; GMe, gluteus medius; grey area, 95% CI of the means of time from APA to FO for combined groups; MH, medial hamstrings; RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis.

**Table 3**  Between-group comparison (two-tailed independent t tests) of coefficient of variations of the temporal variables of the injured limb of the hamstring-injured group and the bilateral average of the control group during the transition from double- to single-leg stance.

<table>
<thead>
<tr>
<th>Dependent variable/muscle group</th>
<th>Hamstring-injured group injured side n</th>
<th>Mean (95% CI)</th>
<th>Control group bilateral average n</th>
<th>Mean (95% CI)</th>
<th>Mean differences (95% CI)*</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction time</td>
<td>16</td>
<td>19.53 (14.93 to 24.12)</td>
<td>18</td>
<td>22.12 (17.75 to 26.50)</td>
<td>−2.59 (−9.19 to 4.00)</td>
<td>0.429</td>
</tr>
<tr>
<td>Movement time</td>
<td>16</td>
<td>8.72 (7.05 to 10.38)</td>
<td>18</td>
<td>10.19 (8.62 to 11.75)</td>
<td>−1.47 (−3.85 to 0.90)</td>
<td>0.216</td>
</tr>
<tr>
<td><strong>Muscle onsets relative to anticipatory postural adjustment (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gastus medialis</td>
<td>15</td>
<td>174.92 (61.32 to 288.52)</td>
<td>17</td>
<td>121.75 (79.57 to 163.92)</td>
<td>52.17 (−67.80 to 183.15)†</td>
<td>0.401</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>15</td>
<td>72.09 (−12.31 to 156.49)</td>
<td>18</td>
<td>48.52 (17.62 to 79.43)</td>
<td>23.57 (−63.80 to 110.94)</td>
<td>0.586</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>16</td>
<td>139.40 (72.55 to 206.25)</td>
<td>18</td>
<td>105.00 (61.36 to 148.65)</td>
<td>34.39 (−46.82 to 115.61)</td>
<td>0.395</td>
</tr>
<tr>
<td>Medial hamstrings</td>
<td>16</td>
<td>187.09 (105.82 to 268.37)</td>
<td>18</td>
<td>139.91 (100.29 to 179.54)</td>
<td>47.18 (−43.55 to 137.90)</td>
<td>0.297</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>15</td>
<td>171.22 (81.65 to 250.79)</td>
<td>18</td>
<td>174.39 (94.72 to 254.06)</td>
<td>−3.17 (−121.35 to 115.01)</td>
<td>0.957</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>15</td>
<td>174.95 (16.33 to 333.56)</td>
<td>17</td>
<td>183.08 (96.61 to 269.55)</td>
<td>−8.13 (−190.43 to 174.16)</td>
<td>0.928</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>15</td>
<td>110.09 (64.05 to 156.14)</td>
<td>18</td>
<td>167.32 (89.48 to 245.15)</td>
<td>−57.22 (−156.29 to 41.84)</td>
<td>0.248</td>
</tr>
</tbody>
</table>

*Positive value: the hamstring-injured group variable has a larger mean CV than the control group variable.
†Equal variances not assumed.

Movement time, time from visual signal to foot being lifted off force platform; Reaction time, time from visual signal to anticipatory postural adjustment.
What is already known on this topic

- Hamstring injuries have a high recurrence risk.
- Further, groin and knee injuries have also been implicating as a risk for future hamstring injuries.
- Changes in neuromuscular control associated with other injuries, in particular, increased hamstring muscle activation, could potentially lead to increased cumulative loading for these muscles, thereby increasing their risk for injury.

What this study adds

- Changes in neuromuscular control are evident in athletes with previous hamstring injuries.
- These residual impairments may need to be considered in rehabilitative programmes.

Clinical implications

Prospective studies with professional Australian Rules football players and soccer players have shown that implementing sports-specific training drills and balance exercises decreased the number of hamstring injuries. Further, Sherry and Best showed that rehabilitation consisting of progressive agility and trunk stabilisation exercises was more effective in preventing recurrence of hamstring injuries in comparison with a programme focusing on isolated hamstring stretching and strengthening exercises. Findings of the current study demonstrate evidence for residual impairments related to muscle activation of the injured hamstring muscles. Further comparative research investigating muscle activity of the lower limb and trunk muscles during different exercise protocols may clarify why such effects occur in the hamstrings injured. A clearer understanding of such issues may lead to more effective treatment and prevention strategies.

Methodological issues

As injury localisation was based on self-report, the diagnostic accuracy could be questioned. Although self-report of injury location has been shown to be reliable within 12 months of incurring the injury, information regarding severity of the initial injury and exact diagnosis could not be confirmed. Community-level athletes, such as those participating in this study, are unlikely to have had investigative imaging to confirm the injury. Despite the absence of such investigations to define the injuries, the participants of the HG were representative of those generally assessed and treated in community clinics for hamstring injuries, as defined by the inclusion criteria.

Double- to single-leg stance was chosen as the experimental task, as the hamstrings are considered to contribute significantly in clinics for hamstring injuries, as defined by the inclusion criteria. Hamstring injuries. Conclusions are limited to establishing whether there is any evidence for within- and between-group differences for the dependent variables. However, the research allowed identification of variables that could be considered for future prospective studies.

CONCLUSION

The findings of this study suggest that during the transition from double- to single-leg stance, earlier onsets of the hamstring muscles are likely to occur in participants with a previous injury of this muscle group. These differences in EMG activity may be associated with changes in lower-limb proprioception and neuromuscular control following a hamstring injury. Rehabilitative exercises of these muscles focusing on control of movement, agility and sports-specific skills could contribute towards decreasing the risk of injury recurrence.

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Competing interests

None.

Ethics approval

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Provenance and peer review

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