Gender difference in neuromuscular hip and knee joint control during single-leg landing.

Issei Ogasawara¹, Shumpei Miyakawa², Shigeyuki Wakitani¹

Abstract

Background: Female's altered lower limb control has been considered as a possible factor for their high anterior cruciate ligament injury rate. However, the detailed gender difference in lower limb control during impact activity is not well studied. The purpose of this study was to investigate the gender difference in neuromuscular hip and knee joint control during single-leg landing motion. It was hypothesized that the male and female subjects show different electromyographic activity patterns for controlling hip and knee motion and female characteristics would elevate their risk for anterior cruciate ligament injury.

Methods: Ten male and 8 female subjects took part in this study. Electromyographic activities of quadriceps, hamstrings and gluteus medius, and three-dimensional kinematic data of hip and knee were measured during single-leg landing task. Peak activities and timing of peak activities of each muscle were compared between genders. Gender differences in the hip and knee kinematics were also investigated.

Results: Female subjects showed significantly greater peak activities in vastus medialis, vastus lateralis and gluteus medius compared to male subjects ($p < 0.05$). Semitendinosus and biceps femoris in females peaked significantly earlier compared to male ST, BF and female quadriceps (ST; $p < 0.05$, BF; $p < 0.05$). Female subjects simultaneously exhibited greater knee valgus ($p < 0.05$) and hip adduction ($p < 0.05$).

Conclusion: Higher vastus medialis activities found in females were considered a strategy to resist knee valgus motion. However, higher vastus medialis activities may cause tibial anterior shear force but resist knee valgus unless synchronized hamstrings activities. Females showed greater hip adduction despite of high gluteus medius activities. This suggests that hip muscle weakness leads to failed hip control.

Keywords: neuromuscular control; hip; knee; anterior cruciate ligament

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I. Introduction

Anterior cruciate ligament (ACL) injury is a common and serious athletic injury. If performance level remains decreased, athletes will require surgical treatment and long-term rehabilitation to regain previous competitive level. Studies have repeatedly demonstrated that female athletes exhibit a 2- to 8-fold greater likelihood of ACL injury compared to their male counterparts\(^1\,2\), clearly representing a serious issue for female athletes.

Several factors such as anthropometrics\(^3\) and hormonal factors\(^4\) have been reported as reasons for this high injury rate in females. Various risk factors have been investigated, and decreased neuromuscular control of females has recently become a great concern as a possible factor elevating the incidence of ACL injury. This decade, studies aimed at characterizing dynamic neuromuscular control in females by comparing gender differences in lower limb kinematics and/or muscular activities during athletic tasks have been conducted, resulting in beneficial insights\(^5\,10\). Cowling et al.\(^5\) examined gender differences in lower limb muscle activities for single-leg landing with regard to the temporal pattern of muscle activities. In that research, female subjects exhibited less-synchronized hamstring muscle activity with respect to time of foot contact, suggesting that females could not utilize the hamstrings effectively due to decreased muscular control. Malinzak et al.\(^6\) compared thigh muscle activities between genders and found that females often jump and land with much higher quadriceps activities and smaller angles of knee flexion compared to males. Increased quadriceps activity with small angle of knee flexion has been considered as an inappropriate muscle activity because excessive quadriceps contraction has the potential to induce anterior tibial translation. This is one of the typical mechanisms working in the sagittal plane to increase stress on the ACL. These reports have thus revealed that female athletes usually conduct athletic activities under conditions of inadequate muscular control.

Hip motion also influences knee kinematics. Video analysis of non-contact ACL injuries has demonstrated that abnormal hip joint motions such as excessive hip adduction and/or internal rotation are concomitantly observed at the moment of valgus knee collapse\(^11\,12\). Laboratory controlled studies have demonstrated that dynamic hip adduction and hip internal rotation, which are similar to the actual injury posture, are often seen in female populations\(^10\,13\). These facts indicate that female athletes may tend to exhibit abnormal hip positions such as adduction and internal rotation, indirectly placing the knee joint toward the midline of the body and increasing knee valgus angle. To clarify the reasons why females exhibit such risk-elevating limb positions, various studies have been conducted. Zazulak et al.\(^9\) examined hip muscular control during single-leg landing, and found lower gluteus maximus (GMAX) activities in female subjects and concomitant dynamic hip adduction during landing. Zeller et al.\(^10\) also investigated gender differences in gluteal muscle activities using a single-leg squat task, and although no significant gender differences were found in their study, females exhibited a tendency toward higher GMAX and lower gluteus medius (GMED) activities. While showing conflicting results, these two reports showed gender characteristics of hip muscle activity which may affect hip motion. Additionally, dynamic knee valgus was observed in both studies; this finding may suggest that the knee alignment was affected by hip joint control. Successful control of hip joint is very important for proper knee alignment. The knee joint has small range of motion (ROM) in the frontal plane. Co-contraction of knee extensor/flexor muscles help to stabilize the joint by increasing joint stiffness; however, there are limited muscular options that directly resist valgus knee stress. The hip joint is much less-constrained but has musculature to control frontal plane motion, thus it can indirectly control the frontal plane knee alignment in weight acceptance phase. Thus
acquisition of a proper hip joint control is quite important for dynamic knee control.

The importance of hip function is becoming recognized, but the literature remains limited. In addition, due to conflicting results among limited studies, reasonable agreement has not been obtained on how female characteristic of hip control influences the knee joint biomechanics. Furthermore, specifically focusing on the frontal plane, the relationship between hip/knee dynamic alignment and muscular control of females has not been well-studied. The purpose of this study was thus to clarify the female characteristics of hip and knee joint control through evaluating gender differences in lower limb kinematics in the frontal plane and electromyographic (EMG) activities of knee extensor/flexors and hip abductors.

II. Methods

A. Subjects

Subjects comprised 10 healthy male subjects (mean age, 24.8 ± 4.3 years; height, 172.7 ± 6.5 cm; weight, 70.9 ± 9.1 kg) and 8 healthy female subjects (mean age, 23.0 ± 1.0 years; height, 161.3 ± 4.2 cm; weight, 53.1 ± 7.4 kg). The subjects did not participate in the any kind of competitive sports or trainings during the research period, and no history of lower extremity injury or surgery was present in any subject. Physical characteristics of participants are shown in Table 1. Prior to participation, written informed consent was obtained from all subjects and all study protocols were approved by the local ethics committee.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Male (n=10) Mean ± SD</th>
<th>Female (n=8) Mean ± SD</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>24.8 ± 4.3</td>
<td>23.0 ± 1.0</td>
<td>0.15</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.7 ± 6.5</td>
<td>161.3 ± 4.2</td>
<td>&lt;0.05*</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.9 ± 9.1</td>
<td>53.1 ± 7.4</td>
<td>&lt;0.05*</td>
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</table>

*B denotes statistically significant difference between men and women

B. Experimental Settings

The dominant leg of each subject was determined to be the leg that the subject usually uses to kick a ball for the consistency with the previous studies 14–16. For the preparation of motion capture, 10 markers were attached bilaterally to the anterior superior iliac spine (ASIS) and great trochanter (GT), and to the dominant-side patella, medial and lateral femoral epicondyles, medial and lateral malleoli and great toe (Fig. 1). All markers were placed by the same examiner to maintain consistency.

Surface EMG activities of 5 muscles, i.e., vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), biceps femoris (BF) and GMED, on the dominant side of each subject were recorded using Ag–AgCl bipolar surface electrodes (NT–511G; Nihon Kohden, Tokyo, Japan). EMG electrodes were placed parallel to the direction of muscle fibers.
with spacing of approximately 20 mm. A reference electrode was placed on the sternum. Electrode locations were determined by palpating the muscles to maximize the signal from a particular muscle while subjects were contracting their muscles. To decrease skin impedance, the surface of the skin was shaved, scrubbed using skin preparation gel (YZ-0019; Nihon Kohden) to exfoliate epidermal debris and cleaned with alcohol. To minimize the influence of movement artifacts, the electrode cables were firmly taped down to the subjects’ body. Surface EMG signals were amplified using a multiteleimeter (WEB-5000; Nihon Kohden) and sampled by an A/D converter (MP100WSW; Biopac Systems, Goleta, USA) at a sampling frequency of 1,000 Hz for each muscle.

C. Task Protocol

1. Maximal voluntary contraction (MVC) trials

After application of surface electrodes, MVC of each muscle was acquired. Subjects were asked to sit in a chair with hips at 90° flexion and knees at 60° flexion during MVC tests for the VM and VL. For ST and BF, subjects took a prone position on a bed with knees at 60° flexion and hip joint at neutral position. For GMED, subjects took a side lying position on a bed with 0° hip adduction/abduction. EMG was recorded for 5 s on 3 occasions, with verbal encouragement.

2. Landing Task

Subjects were required to perform a single-leg landing task from a 32-cm high platform using the dominant leg. Motion in each landing trial was captured using 3 digital video cameras (DCR-TRV17; Sony, Tokyo, Japan) at 60 Hz in synchronization with EMG recording using a custom-made device. If subject could not stay in single leg stance and utilized the contralateral leg just after landing, that trial was considered a failure. Additionally, if more than two of three video cameras could not capture the ASIS and GT markers, by torso rotation or inclination, that trial was also regarded as failure. Based on these criteria, we acquired 10 successful trials from each subjects. Video data of each trial were converted into AVI format file using Premiere Pro 1.5 software (Adobe Systems, San Jose, USA) and stored on a personal computer.

D. Data analysis

To remove movement artifacts, raw EMG signals were filtered using a high-pass fourth-order zero-lag Butterworth filter with cut-off frequency of 10 Hz. After full-wave rectification, signals were smoothed using a low-pass Butterworth filter (fourth-order, zero-lag, 10 Hz cut-off) to create the linear envelope. Choice of cut-off frequencies was done by two of authors. Before processing the EMG data, we tested 8 patterns of different frequency settings (5Hz~40Hz, each 5Hz step). There were less-drastic changes from raw signal form and proper noise reduction, we decided to use 10 Hz for smoothing. Preprocessed EMG signals from each muscle recorded in landing trials were normalized by a reference value defined for each muscle, which was calculated based on EMG signals recorded in an MVC test as follows. First, the EMG signal with the largest maximum value was selected from signals obtained in the 3 MVC trials. The reference value was then defined as the average of 100 samples around the maximum point. We calculated the following 2 parameters from normalized EMG signals: 1) peak %MVC (peak value), representing the activation level of muscle activity with respect to MVC activity; and 2) time of peak EMG activity (peak time), to examine temporal profiles of muscle activities. In this analysis, time of initial foot contact was set as 0 ms.

The 2-dimensional (2D) trajectories of markers were traced in every video of each landing instant using FrameDias2 software (DKH, Tokyo, Japan). A trajectory in 3-dimensional (3D) coordinates was then constructed from three 2D trajectories using DLT methods, and filtered using a fourth-order low-pass Butterworth filter (cut-off frequency, 6 Hz). To calculate joint angles, we defined 3 segments (pelvis, thigh and leg) and 3 local coord-
nate systems \((\Sigma_{\text{pelvis}} , \Sigma_{\text{thigh}} \text{ and } \Sigma_{\text{leg}})\) (Fig. 1). Each local coordinate system has three orthogonal unit vectors, i.e., pelvis: px,py,pz, thigh: tx,ty,tz, leg: lx,ly,lz. Hy in Figure 1 represents the sagittal axis of the hip joint, which was a cross product of tz and px\(^5\). Kx shows the transverse axis of the knee joint, which was equal to tx. Ky indicates the sagittal axis of the knee joint. This axis was a cross product of the lz and tx\(^8\). Hip adduction/abduction was defined as thigh segment rotation occurring about the Hy. Knee flexion/extension was defined as leg segment rotation occurring about Kx. Knee valgus/varus was calculated as leg segment rotation occurring about Ky. Angles representing hip adduction, knee flexion and knee valgus were considered positive, with other angles considered negative.

E. Statistical Analysis

Two-way analysis of variance (ANOVA) (2 genders by 5 muscle differences) was performed to check the significant effect of genders and muscle difference for EMG peak time and peak value. When a main effect was noted, a post-hoc Tukey-Kramer test was conducted. To check the significant gender effect on kinematics data as a function of time, two-way ANOVA (2 genders by time) was used. All statistical analyses were performed using StatView version 5.0 software (SAS Institute, Cary, USA). In all cases, values of \(p < 0.05\) were considered statistically significant.

### III. Results

#### A. EMG results, Peak time

Figure 2 shows the smoothed and normalized EMG signals observed 300 ms before and after initial foot contact for both genders. Asterisks denote the peak activity of each trial. The activities of VM and VL started before the initial foot contact and the peak activities concentrated after landing, but those activity levels quickly decreased after those peak activations. This trend for VM and VL was consistent among the genders. The activities of ST and BF also gradually increased before the initial foot contact, and those peak activities appeared before and after the contact. The peak activities of females’ BF occurred relatively earlier than those of females’ ST. GMED started to activate before the initial foot contact as well, and those activity level were maintained throughout the single-legged standing phase.

ANOVA revealed that the genders and muscle difference had a significant effect for EMG peak time (genders; \(p < 0.05\), muscle difference; \(p < 0.05\) respectively). There was no significant genders-by-muscle difference interaction \((p=0.50)\). Post-hoc test showed that female ST and BF peaked significantly earlier compared to male ST and BF (ST; \(p < 0.05\), BF; \(p < 0.05\)) (Fig. 3). There was no gender difference in peak time of VM, VL and GM. Table 2 shows a within-gender, inter-muscle comparison of peak time. Female ST and BF peaked significantly earlier compared to female VM, VL and GMED (ST vs VM; \(p < 0.05\),

#### Table 2. Within-gender differences in mean peak time of %MVC during single-leg landing.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Peak time (ms) (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VM</td>
</tr>
<tr>
<td>Male</td>
<td>115.9 ± 38.4</td>
</tr>
<tr>
<td>Female</td>
<td>93.7 ± 38.6</td>
</tr>
</tbody>
</table>

a denotes significant difference vs VM \((p<0.05)\)
b denotes significant difference vs VL \((p<0.05)\)
c denotes significant difference vs ST \((p<0.05)\)
d denotes significant difference vs BF \((p<0.05)\)
e denotes significant difference vs GMED \((p<0.05)\)
Figure 2: Normalized EMG signals for each muscle from both genders. The asterisks denote the peak values of each signal. The vertical dashed line indicates the time of initial foot contact.

Figure 3: Gender comparison of mean peak time of %MVC during single-leg landing. The transverse dashed line represents initial foot contact. The asterisk indicates a statistically significant difference between male and female subjects. In ST and BF, female subjects showed significantly earlier peak time compared to male subjects. In this study, the time of initial foot contact was defined as 0 ms.

ST vs VL; p < 0.05, ST vs GMED; p < 0.05, BF vs VM; p < 0.05, BF vs VL; p < 0.05, BF vs GMED; p < 0.05). In particular, female BF peaked before foot contact even though all the other muscles peaked after landing (Table 2). On the other hand, in male subjects, only BF peaked earlier than VM and VL did (BF vs VM; p < 0.05, BF vs VL; p < 0.05). A significant peak time difference between ST and the other muscles, observed in female ST, did not observed in male subjects.

B. Peak value

Genders and muscle difference had a significant effect for EMG peak value (gender; p < 0.05, muscle difference; p < 0.05). There was a significant
genders-by-muscle difference interaction ($p < 0.05$). Post-hoc test showed that female VM, VL and GM activities were significantly higher than those of male subjects (VM; $p < 0.05$, VL; $p < 0.05$, GM; $p < 0.05$) (Fig. 4). Hamstring muscle ST and BF in both genders activated to almost the same levels and there were no significant differences. Table 3 shows a within-gender, inter-muscle comparison of EMG peak value. Both male and female subjects showed in peak value as higher activities in knee extensor VM and VL, and lower activities in ST and BF, however, female VM showed especially higher activities and its peak value was significantly larger than all the other muscles (VM vs VL; $p < 0.05$, VM vs ST; $p < 0.05$, VM vs BF; $p < 0.05$, VM vs GM; $p < 0.05$). In male subject, VM and VL showed significantly higher activities than those of male ST, BF and GM (VM vs ST; $p < 0.05$, VM vs BF; $p < 0.05$, VM vs GMED; $p < 0.05$, VL vs ST; $p < 0.05$, VL vs BF; $p < 0.05$, VL vs GMED; $p < 0.05$), however, there was no significant difference between VM and VL peak value.

C. Kinematic results

A significant gender effect was found in frontal plane knee and hip kinematics ($p < 0.05$). Female subjects demonstrated significantly greater hip abduction and knee valgus motion ($p < 0.05$) compared to male subjects (Fig. 5, Fig. 6). A significant genders-by-time interaction was found in knee valgus angle ($p < 0.05$) (Fig. 6). No significant gender effect was detected in knee flexion (Fig. 7).

![Figure 4: Gender comparison of mean peak value of %MVC during single-leg landing. The asterisk indicates a statistically significant difference between male and female subjects. In VM, VL and GMED, female subjects exhibited significantly higher peak values of %MVC than those of male subjects.](image)

![Figure 5: Male and female mean hip abduction/abduction angles as a function of time. Two-way ANOVA test showed that there was a significant main effect of genders in hip abduction/abduction angles. Gray-colored area represents the period when the gender differences exit.](image)

### Table 3. Within-gender differences in mean peak value of %MVC during single-leg landing.

<table>
<thead>
<tr>
<th>Gender</th>
<th>VM</th>
<th>VL</th>
<th>ST</th>
<th>BF</th>
<th>GMED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>84.2 ± 22.8</td>
<td>76.4 ± 17.7</td>
<td>30.2 ± 17.4</td>
<td>30.8 ± 17.9</td>
<td>40.3 ± 13.4</td>
</tr>
<tr>
<td>Female</td>
<td>142.5 ± 42.3</td>
<td>115.6 ± 23.6</td>
<td>27.7 ± 7.7</td>
<td>31.6 ± 10.4</td>
<td>76.4 ± 23.4</td>
</tr>
</tbody>
</table>

- a denotes significant difference vs VM ($p < 0.05$)
- b denotes significant difference vs VL ($p < 0.05$)
- c denotes significant difference vs ST ($p < 0.05$)
- d denotes significant difference vs BF ($p < 0.05$)
- e denotes significant difference vs GMED ($p < 0.05$)
Figure 6: Male and female mean knee valgus/varus angles as a function of time. Two-way ANOVA test showed that there was a significant main effect of genders in knee valgus/varus angles. A significant gender-by-time interaction was also found. Gray-colored area represents the period when the gender differences exit.

**IV. Discussion**

The purpose of this study was to investigate the gender difference in neuromuscular hip and knee control during single-leg landing task. In agreement with previous studies\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^10\), this study found that the female subjects exhibited the higher VM, VL, and GMED activities than those of male counterparts. ANOVA test for EMG peak value also found a significant gender–by–muscle difference interaction. This interaction clearly indicates that EMG peak values were influenced not only by muscle role difference but also gender difference, and suggests that male and female subjects utilized different neuromuscular strategy for hip and knee joint control. Females took more hip adducted and knee abducted positions after foot impact comparing to male subjects (Fig. 5, Fig. 6). Such lower limb orientations had reported as risk–elevated kinematics of ACL injury\(^11\)\(^19\)\(^20\)\(^21\). Female subjects tried to control these frontal plane joint motion by increasing their VM and GMED, however, kinematic results demonstrated that they couldn’t successfully keep their dynamic alignment after landing.

Figure 7: Male and female mean knee flexion/extension angles as a function of time. Two-way ANOVA test showed that there was no significant main effect of genders.

**A. Strategy to control frontal plane knee kinematics in female subjects.**

In this section, we discuss knee joint control in female subjects. Within females, VM activity was significantly higher than that of VL (Table 3). This difference between VM and VL was not found in male subjects. Additionally, from kinematic results, females showed greater knee valgus angle after landing (Fig. 6). These results suggest that females try to resist knee valgus by increasing VM activity\(^10\). Buchanan et al.\(^22\) reported that VM, ST and gracilis muscles show higher activities against knee valgus load than against varus knee load. Dhaher et al.\(^23\) also found that as valgus angle increased, VM activity increased accordingly. These studies suggest that the muscles located on the medial side of the knee specifically respond to knee valgus stress. However, the concern is that whether this VM activity is appropriate or not to avoid ACL injury because the aggressive activity of the knee extensors without proper hamstring activity would elicit the anterior translation of the tibia, resulting in a high load on ACL. The hamstrings of female subjects peaked much earlier than VM and VL (Table 2). BF in females especially peaked before initial foot contact. Male hamstring also tended to peak earlier (Table 2), but it was not as marked as female subjects showed (Fig. 3). These results indicate that, in females,
the peak activity of the quadriceps and hamstrings were not well synchronized as compared to male subjects. Cowling et al.\(^5\) examined the gender differences in thigh muscle activities during landing focusing timing characteristics. They found that female ST peaked earlier than males. This finding was partially consistent with our own. Our results and previous report suggest that females are not good at synchronizing their quadriceps and hamstrings during landing. As many studies have reported, isolated quadriceps contraction with lack of hamstring co-contraction causes anterior tibial translation\(^24\),\(^25\). For these reasons, VM activity, with which females tried to resist knee valgus, may pull the tibia anteriorly rather than protect the knee joint from valgus stress. Control strategy of knee joint in the frontal plane, using aggressive VM activity, is thus considered less-appropriate for avoiding ACL injury unless proper hamstring synchronization.

B. Female characteristics in hip joint control.

Although female subjects showed much higher GMED activities than male subjects, the hip joint displayed greater adduction (Fig. 5). These results indicate that females experienced difficulties in controlling the hip motion despite the higher GMED activities. Some interpretations have been suggested for failed stabilization of the hip joint from the perspective of muscular control. Zeller et al.\(^10\) investigated gender differences in hip muscle (GMED and GMAX) activities and lower limb kinematics during single-leg squats. In their kinematic results, similar to our own results, female subjects showed greater hip adduction than male subjects. In EMG results, although no significant gender differences were identified, the female subjects tended to display higher GMAX and lower GMED activities. These data suggest that women may have difficulty activating GMED muscles. Another study using a single-leg landing task was conducted by Zazulak et al.\(^9\). They investigated gender differences in EMG activities of hip muscles and found that female GMAX exhibited significantly lower muscle activities as compared with male controls. No gender differences in GMED activity were seen. Zazulak et al. did not check kinematic data, but dynamic knee valgus and hip adduction were observed on visual observation. Given these findings, lower activities of GMAX were suggested to cause internal rotation of the femur and lead to decreased hip stabilization. As these reports explained, lower hip muscle activities would hardly generate sufficient joint stiffness to stabilize the hip joint. However, the same interpretations cannot be applied to our findings, as we identified higher GMED activities in female subjects. Higher GMED activities found in female subjects may represent a compensation for weakness of hip abductors. To achieve adequate force generation, female GMED required almost 80% of maximum activation level. However, the female population is generally recognized as displaying hip muscle weakness\(^26\). Thus, in spite of higher GMED activities, female subjects could not generate sufficient joint torque enough to stabilize the hip joint. Another possible reason for higher GMED activities in female subjects was miss collecting of MVC signal which potentially results in over estimation of %MVC values. However, this technical mistake hardly occurred because a great care was taken to measure MVC signal as detailed in method section. Moreover, it is hard to consider that all the eight female subjects were over estimated by the same technical mistake. There are of cause difficulties in evaluating hip joint stability only with the EMG data, as EMG signals do not necessarily correlate with muscle force output. In this study, we utilized the relative value %MVC to enable comparisons between genders. As %MVC represents only the amount of muscle activity relative to own MVC level. For example, if the %MVC is identical between female and male subjects, the generated joint torque may differ between genders. Thus it is difficult to discuss joint stiffness generation using EMG data alone. To solve this issue, kinetics analy-
sis may be helpful. Although the present study did not include any kinetic parameters, a detailed investigation of the relationship between EMG activities and joint torque would provide greater understanding of joint stability.

In conclusion, this study found that the female subjects exhibited much higher VM, VL, and GMED activities with more hip adducted and knee abducted position than those of the male subjects during single-leg landing motion. Higher VM activities without proper hamstring synchronization may cause anterior tibial translation rather than to resist the knee valgus angulation. Female GMED could not resist hip adduction, despite of its higher %MVC values. Much greater hip abductor strength might decrease the female’s hip adduction and indirectly prevent knee valgus shift in the single-leg landing motion.

References


