International Journal of Human Movement and Sports Sciences 10(2): 294-302, 2022 http://www.hrpub.org
DOI: 10.13189/saj.2022.100220

Musculoskeletal Asymmetry in Young Soccer Players: Differences between the Dominant and Nondominant Leg

Shuji Taketomi[1,2,*], Kohei Kawaguchi[1,2], Yuri Mizutani[2], Ryota Yamagami[1], Shin Sameshima[1], Seira Takei[1], Tomofumi Kage[1], Kenichi Kono[1], Hiroshi Inui[1], Sayaka Fujiwara[2,3], Sakae Tanaka[1], Toru Ogata[2,3]

[1]Department of Orthopaedic Surgery, Faculty of Medicine, The University of Tokyo, Tokyo 113-8655, Japan
[2]UTokyo Sports Science Initiative, The University of Tokyo, Tokyo 113-8655, Japan
[3]Department of Rehabilitation Medicine, Faculty of Medicine, The University of Tokyo, Tokyo 113-8655, Japan

Received December 23, 2021; Revised February 21, 2022; Accepted March 15, 2022

Cite This Paper in the following Citation Styles

(a): *[1] Shuji Taketomi, Kohei Kawaguchi, Yuri Mizutani, Ryota Yamagami, Shin Sameshima, Seira Takei, Tomofumi Kage, Kenichi Kono, Hiroshi Inui, Sayaka Fujiwara, Sakae Tanaka, Toru Ogata , "Musculoskeletal Asymmetry in Young Soccer Players: Differences between the Dominant and Nondominant Leg," International Journal of Human Movement and Sports Sciences, Vol. 10, No. 2, pp. 294 - 302, 2022. DOI: 10.13189/saj.2022.100220.*

(b): *Shuji Taketomi, Kohei Kawaguchi, Yuri Mizutani, Ryota Yamagami, Shin Sameshima, Seira Takei, Tomofumi Kage, Kenichi Kono, Hiroshi Inui, Sayaka Fujiwara, Sakae Tanaka, Toru Ogata (2022). Musculoskeletal Asymmetry in Young Soccer Players: Differences between the Dominant and Nondominant Leg. International Journal of Human Movement and Sports Sciences, 10(2), 294 - 302. DOI: 10.13189/saj.2022.100220.*

Abstract The purpose of this investigation was to clarify the differences in the musculoskeletal profiles between the dominant leg (DL) and nondominant leg (NDL) of Japanese soccer players. This study included 227 young elite soccer players (121 males and 106 females with mean ages of 19.0 and 17.5 years, respectively). Anthropometric measurements were obtained. In addition, joint range of motion measurements was performed for internal rotation of the hip, ankle dorsiflexion, and knee extension. Muscle flexibility tests were performed on the iliopsoas, quadriceps femoris, hamstring, gastrocnemius, and soleus muscles. Moreover, isometric knee extension, flexion strength, and isometric hip abduction strength were measured. Single-leg balance tests were also performed. As a result, in male soccer players, DL's knee flexor strength and hip abductor strength were significantly stronger than in the NDL. In female soccer players, knee extension and knee flexion strength of the DL were significantly stronger than the NDL. In male soccer players, the hamstring-quadriceps ratio of the DL was significantly greater than NDL. DL demonstrated a significantly lesser center of pressure excursion in the single-leg balance test in male and female soccer players. In both male and female soccer players, the quadriceps muscle of DL was significantly more flexible than those of the NDL. There was no difference in the internal rotation angle of the hip joint between the DL and NDL in male soccer players. In contrast, the internal rotation angle of the DL was significantly (1.6°) greater than NDL in female soccer players. For some anthropometric measurements, muscle flexibility tests and joint range of motion measurements, the difference between the DL and NDL was significant but not large enough to be clinically relevant. In conclusion, the present study showed musculoskeletal asymmetry between the DL and NDL in young male and female soccer players.

Keywords Injury Prevention, Leg Dominance, Soccer, Asymmetry

1. Introduction

Musculoskeletal injuries are common in sports, and thus injury prevention is becoming increasingly important. Leg dominance or musculoskeletal asymmetry has been reported to be a risk factor for lower extremity injuries, including anterior cruciate ligament injuries, stress fractures, and muscle strain [1-7]. For example, Brophy et al. reported that when limited to a non-contact injury mechanism, females are more likely to injure the anterior cruciate ligament in their supporting leg, whereas males tend to injure their kicking leg in soccer players [2]. Fousekis et al showed players with eccentric hamstring strength asymmetries were at greater risk of sustaining a hamstring muscle strain in male soccer players [8]. Furthermore, Takei et al. clarified that an increase in iliopsoas muscle tightness in the kicking leg was a predictive risk factor for spondylolysis in adolescent male soccer players [5]. In addition, single-leg hop distance asymmetry is a risk for ankle injury [9, 10]. Symmetry and asymmetry are also important not only as injury risks, but also as indicators of an athlete's return to play after injury. It is generally recommended that before returning to sports, athletes with leg injury should achieve symmetrical bilateral power between the injured leg and the uninjured leg, indicated by a difference of less than 15% [11-17]. Some sports that involve movements such as kicking and one-legged jump require a constant preference of one leg over the other. In particular, there is a division of roles in soccer between the athlete's dominant leg (DL) and nondominant leg (NDL) because of the kicking, dribbling, and other movements associated with handling the ball. Thus, there may be asymmetry in the musculoskeletal profiles of the lower extremities. Identifying the differences in characteristics between DLs and NDLs in soccer players may help to elucidate how leg dominance and musculoskeletal asymmetry are related to injury risk and improve injury prevention. Although there have been several reports on the differences in characteristics of DL and NDL in soccer [18-20], the data are not sufficient. There are few systematic and comprehensive studies comparing DL and NDL including anthropometries [21], muscle strength, balance ability, joint range of motion, and muscle flexibility, whereas most have focused on limited factors such as muscle strength [17, 22] or neuromuscular control [23], or on a single joint such as the hip joint [19]. In addition, most reports are from Europe and the United States, and there are few data for Asians. There are no investigations that show the characteristics of DL and NDL of Japanese soccer players. Therefore, the purpose of this study was to clarify the differences in the musculoskeletal profiles between the DL and NDL of Japanese soccer players.

2. Materials and Methods

2.1. Participants

This study included 227 soccer players (121 males and 106 females with mean ages of 19.0 (range, 15–22) and 17.5 (range, 15–21) years, respectively). All subjects were young elite soccer players from four soccer teams, including a university men's soccer team, a university women's soccer team, an elite academy men's soccer team (under 16–18 category), and a women's high school soccer team. Each of these four teams had won the title(s) of the national or regional soccer tournament in their respective category in the past 3 years. This investigation was part of a prospective study of predictors of sports injuries, the UTokyo Sports Science Initiative (UTSSI) sports injury prevention project [11], including athletes from other sports and senior- and recreational-level soccer players. Among them, soccer players from high school and college teams on a competitive level were included. Data obtained from preseason participation physical screenings were retrospectively analyzed over 2 years (2019–2020). Consequently, only one set of measurement data was used for each player within this period. The newest data were used if the players participated in the screening twice. The UTSSI sports injury prevention project was approved by the Institutional Review Board. The patients and their families provided comprehensive written consent to participate in the study, including publication. Participant information was shown in Table 1.

Table 1. Participant information

	Male (n = 121)	**Female (n = 106)**
Age (years)	19.0 ± 2.1	17.5 ± 1.9
Body height (cm)	174.1 ± 5.8	160.5 ± 5.3
Body weight (kg)	68.8 ± 6.8	55.8 ± 5.9
Body mass index (kg/m^2)	22.5 ± 1.8	21.6 ± 1.6
Years of experience (years)	13.3 ± 2.9	9.4 ± 3.8
Leg dominance (right/left)	100 / 21	102 / 4

Data are shown as the mean ± standard deviation.

2.2. Measurements

This study analyzed anthropometric joint range of motion, muscle flexibility tests, muscle strength tests, and balance test data.

2.2.1. Anthropometric measurements

Bodyweight (BW) and body height were measured for each player, and each player's body mass index was calculated. Body composition was measured using InBody 270 (Biospace Co., Ltd., Seoul, Korea), a multifrequency impedance analyzer that can record a player's skeletal muscle mass of lower legs. Additionally, as a flat-foot index, the height of the navicular tubercle in each player's foot was measured.

2.2.2. Joint range of motion

Range of motion of crucial joints was performed for internal rotation of the hip, ankle dorsiflexion, and knee extension based on a previous study [24]. For the internal rotation of the hip, passive hip internal rotation angle in the prone position was measured. For ankle dorsiflexion, the weight-bearing ankle dorsiflexion angle with knee flexion was measured. For knee extension, the knee hyperextension angle was measured in a standing position with involvement of the quadriceps.

2.2.3. Muscle flexibility tests

Muscle flexibility tests were performed on the iliopsoas, quadriceps femoris, hamstring, gastrocnemius, and soleus muscles on both sides using methods described previously [24]. The average of the left and right sides was used as the result. This flexibility testing reported excellent intra-rater reliability for all muscle flexibility measures (intraclass correlation coefficients = 0.89–0.96) [25].

2.2.3.1. Iliopsoas

The iliopsoas muscle measurement was performed by obtaining the angle of the hip joint when the participants passively bent their opposite hip joint to the maximum with their hands in a supine position.

2.2.3.2. Quadriceps

The participant grasped the lower leg proximal to the ankle and pulled it toward the buttocks to measure quadriceps flexibility. The quadriceps muscle measurement was performed by bending the angle of the knee joint in a prone position. The examiner verbally reminded the participants not to lift their buttocks using muscle tension during the measurement.

2.2.3.3. Hamstrings

Hamstring muscle flexibility was performed with the hip at 90° of flexion in a supine position. The examiner held the participant's heel. The angle between the vertical line to the floor and the long axis of the tibia after the knee joint was maximally extended and was measured as hamstring muscle flexibility.

2.2.3.4. Gastrocnemius

The ankle joint active dorsiflexion angle was measured when maximally dorsiflexed in the supine position, with the knee extended and maintained in a neutral position relative to the varus-valgus angle of the ankle to measure gastrocnemius muscle flexibility.

2.2.3.5. Soleus

The ankle joint active dorsiflexion angle was measured when maximally dorsiflexed in the prone position with the knee at 90° of flexion to measure soleus muscle flexibility.

2.2.4. Muscle strength tests

2.2.4.1. Isometric knee extension and flexion

A Biodex Multi-Joint System 3 (Biodex Medical Systems Inc., Shirley, NY, USA) was used to measure knee flexion and extension muscle strength. The player performed a 5-minute warm-up routine of cycling on a stationary exercise bicycle before the measurement. The measurement order was randomized. The test was composed of isometric contraction with knee flexion and extension at 70°. The highest peak torque value was recorded. Strength measures were normalized to BW. The hamstring-quadriceps (H/Q) ratio was also calculated. The average of the left and right sides was used for the results.

2.2.4.2. Isometric hip abduction

The hip strength of the abductors was measured isometrically using a handheld dynamometer (μTAS F-1; Anima Industry Inc., Tokyo, Japan). All participants lay supine with their hips in a neutral position beside the wall, with both knees extended and their arms crossed over their chest during the test to standardize the testing procedure. The participants were instructed to abduct the leg as much as possible over 5 seconds, with 1 minute of rest between contractions. Consequently, the peak force was retained for further analysis. The dynamometer was placed on the lateral epicondyle of the femur, and the distance between the lateral epicondyle and hip center was measured. Isometric hip abductor strength was assessed using a handheld dynamometer, which shows good to excellent intratester and intertester reliability [26, 27]. Furthermore, the highest peak torque value was recorded. Strength measures were normalized to BW, and the average of the left and right sides was used for the results.

2.2.5. Balance tests

2.2.5.1. Single-leg balance

A 1 m Footscan pressure plate (RSscan International, Flanders, Belgium) with 8,192 resistive sensors and 5.08 × 7.62 mm pixel resolution was used with a sampling frequency of 250 Hz to measure balance. One 30 second trial of a single-leg standing balance test was performed with the participants barefooted, and arms crossed over their chest with eyes opened. Subsequently, a 30-second interval, a 30 second trial for single-leg standing balance was performed for the contralateral leg. The total center of pressure (COP) excursion was measured as a balance parameter.

2.3. Statistical Analysis

Statistical analyses were performed using the BellCurve for Excel (SSRI Co., Ltd., Tokyo, Japan). A paired two-tailed Student's t-test was used to compare between DL and NDL in all tests. Cohen’s d effect size and mean differences were also calculated for each t-test. Statistical significance was set at $P < 0.05$.

3. Results

3.1. Anthropometric Measurements

Anthropometric data are presented in Table 2. There was no difference in skeletal muscle mass of lower legs between the DL and NDL in both male and female soccer players. In terms of arch height, the DL was significantly lower than the NDL in male soccer players. However, the difference was only 0.1 mm and Cohen’s d was small, 0.165. Therefore, it may not be relevant. In female soccer players, there was no difference in arch height between DL and NDL (Table 2).

3.2. Joint Range of Motion

Results of the range of motion of critical joints are shown in Table 3. There was no difference in ankle dorsiflexion angle between DL and NDL for both male and female soccer players. In male soccer players, the knee extension angle of DL was significantly smaller than NDL. However, the difference was 0.7° and Cohen’s d was also small. There was no difference in the female soccer players between DL and NDL. Conversely, there was no difference in the internal rotation angle of the hip joint between DL and NDL in the male soccer players, while the internal rotation angle of DL was significantly 1.6° greater than NDL in the female soccer players with small effect size (Cohen’s d; 0.172) (Table 3).

3.3. Muscle Flexibility

The results of the muscle flexibility tests are shown in Table 4. In male soccer players, the iliopsoas muscle and quadriceps muscle of DL were significantly more flexible than those of NDL. In female soccer players, DL's quadriceps and soleus muscles were significantly more flexible than the NDL. In contrast, the iliopsoas muscle of DL was significantly tighter than that of NDL. Although all difference is small, ranging from 0.5° to 1.2°, the differences between DL and NDL, at least in the iliopsoas and quadriceps of female athletes, may be relevant because the Cohen's d values are above 0.2 (Table 4).

3.4. Muscle Strength Tests

The muscle strength data results are presented in Table 5. In male soccer players, the DL's knee flexor strength and hip abductor strength were significantly stronger than the NDL, both in measured and body weight-adjusted values. In female soccer players, knee extension and knee flexion strength of the DL were significantly stronger than the NDL, both in measured and body weight-adjusted values. In addition, in male soccer players, the H/Q ratio of DL was significantly greater than NDL. For the items with significant differences, each Cohen's d was above 0.2 for all items, indicating that the significant differences between DL and NDL for muscle strength were relevant (Table 5).

3.5. Balance Tests

Balance data are presented in Table 6. DL demonstrated a significantly lesser COP excursion in the single-leg balance test in male and female soccer players. Reduced COP excursion indicates superior balance. Each Cohen's d was above 0.2 in male and female players, indicating that the differences between DL and NDL for the balance data were considered relevant (Table 6).

Table 2. Anthropometric measurements.

	Male (n = 121)			Female (n = 106)		
	DL	NDL	P value	DL	NDL	P value
	Mean difference (95% CI)		Cohen’s d	Mean difference (95% CI)		Cohen’s d
Skeletal muscle mass of lower leg (kg)	9.5 ± 1.2	9.5 ± 1.3	0.898	6.8 ± 0.6	6.7 ± 0.6	0.378
	0.0 (-0.0 - 0.0)		0.002	0.0 (-0.0 - 0.0)		0.013
Foot arch height (cm)	4.6 ± 0.3	4.7 ± 0.3	0.010*	4.3 ± 0.3	4.3 ± 0.2	0.425
	0.1 (0.0 - 0.2)		0.165	0.0 (-0.0 - 0.1)		0.056

Data are shown as the mean ± standard deviation.

D, dominant leg; ND, nondominant leg; CI, confidence interval, *indicates p<0.05.

Table 3. Joint range of motion

	Male (n = 121)			Female (n = 106)		
	DL	NDL	P value	DL	NDL	P value
	Mean difference (95% CI)		Cohen's d	Mean difference (95% CI)		Cohen's d
Ankle dorsiflexion (°)	39.6 ± 5.8	39.0 ± 6.3	0.229	42.0 ± 6.1	41.6 ± 6.6	0.420
	0.6 (-0.4 - 1.6)		0.098	0.5 (-0.7 - 1.6)		0.074
Knee extension (°)	3.0 ± 4.2	3.7 ± 4.3	< 0.001*	6.9 ± 4.0	6.7 ± 4.2	0.424
	0.7 (0.3 - 1.2)		0.175	0.2 (-0.3 - 0.8)		0.053
Hip internal rotation (°)	36.5 ± 8.7	36.3 ± 8.4	0.644	51.4 ± 8.9	49.8 ± 9.5	0.022*
	0.27 (-0.9 - 1.4)		0.031	1.6 (0.2 - 2.9)		0.172

Data are shown as the mean ± standard deviation.

D, dominant leg; ND, nondominant leg; CI, confidence interval, *indicates p<0.05.

Table 4. Muscle flexibility

	Male (n = 121)			Female (n = 106)		
	DL	NDL	P value	DL	NDL	P value
	Mean difference (95% CI)		Cohen's d	Mean difference (95% CI)		Cohen's d
Iliopsoas (°)	5.4 ± 2.2	5.9 ± 2.5	0.011*	7.1 ± 4.0	6.2 ± 3.5	< 0.001*
	0.5 (0.1 - 0.8)		0.198	0.8 (0.3 - 1.3)		0.216
Quadriceps (°)	30.8 ± 6.5	32.0 ± 7.4	0.009*	30.7 ± 4.6	31.7 ± 45.0	0.020*
	1.1 (0.3 - 2.0)		0.163	0.9 (0.2 - 1.8)		0.200
Hamstring (°)	15.7 ± 7.6	16.1 ± 7.7	0.290	12.3 ± 7.1	12.3 ± 6.8	0.142
	0.5 (-0.4 - 1.4)		0.063	0.5 (-0.2 - 1.3)		0.078
Gastrocnemius (°)	12.4 ± 3.6	12.9 ± 3.6	0.209	12.4 ± 4.5	12.6 ± 4.2	0.370
	0.3 (-0.2 - 0.8)		0.089	0.3 (-0.3 - 0.8)		0.054
Soleus (°)	19.2 ± 5.4	18.7 ± 5.3	0.389	21.2 ± 5.6	20.5 ± 5.9	0.032*
	0.4 (-0.5 - 1.4)		0.079	0.8 (0.1 - 1.5)		0.133

Data are shown as the mean ± standard deviation.

D, dominant leg; ND, nondominant leg; CI, confidence interval, *indicates p<0.05.

Table 5. Muscle strength

	Male (n = 121)			Female (n = 106)		
	DL	NDL	P value	DL	NDL	P value
	Mean difference (95% CI)		Cohen's d	Mean difference (95% CI)		Cohen's d
Knee extension						
Strength (Nm)	236.0 ± 49.6	240.5 ± 54.6	0.196	164.5 ± 41.0	155.4 ± 36.5	< 0.001*
	4.5 (-2.4 - 11.5)		0.088	9.1 (4.1 - 14.0)		0.234
Body weight-adjusted (%Nm/kg)	342.0 ± 60.2	346.2 ± 63.5	0.318	293.4 ± 57.8	277.8 ± 54.2	< 0.001*
	4.3 (-4.2 - 12.7)		0.070	15.5 (7.0 - 24.1)		0.279
Knee flexion						
Strength (Nm)	124.3 ± 25.8	115.8 ± 26.7	< 0.001*	77.2 ± 16.7	71.7 ± 15.1	< 0.001*
	8.5 (5.4 - 11.7)		0.326	5.5 (3.1 - 7.9)		0.346
Body weight-adjusted (%Nm/kg)	181.6 ± 34.8	167.9 ± 32.7	< 0.001*	138.1 ± 25.3	127.9 ± 27.5	< 0.001*
	13.8 (8.9 - 18.7)		0.410	10.2 (5.3 - 15.1)		0.389
Hip abduction						
Strength (Nm)	190.8 ± 38.8	182.5 ± 39.9	< 0.001*	111.9 ± 25.3	110.5 ± 23.2	0.296
	8.3 (4.9 - 11.6)		0.211	1.3 (-1.2 - 3.8)		0.055
Body weight-adjusted (%Nm/kg)	277.0 ± 49.6	264.6 ± 50.3	< 0.001*	194.7 ± 37.4	192.3 ± 32.1	0.344
	12.4 (7.4 - 17.3)		0.250	2.3 (-2.4 - 21.9)		0.069
H/Q ratio	0.54 ± 0.12	0.49 ± 0.10	< 0.001*	0.49 ± 0.13	0.47 ± 0.10	0.286
	0.05 (0.03 - 0.08)		0.493	0.01 (-0.01 - 0.04)		0.119

Data are expressed as the mean ± standard deviation.

H/Q, hamstring-quadriceps; DL, dominant leg; NDL, nondominant leg; CI, confidence interval, *indicates p<0.05.

Table 6. Balance tests

Total COP excursion	Male (n = 121)			Female (n = 106)		
	DL	NDL	P value	DL	NDL	P value
	Mean difference (95% CI)		Cohen's d	Mean difference (95% CI)		Cohen's d
Single-leg balance (mm)	468.2 ± 167.9	500.9 ± 158.5	0.010*	361.6 ± 105.1	386.6 ± 105.1	0.008*
	32.7 (7.8 - 57.5)		0.201	24.9 (6.6 - 43.3)		0.238

Data are shown as the mean ± standard deviation.

COP, center of pressure; DL, dominant leg; NDL, nondominant leg; CI, confidence interval, *indicates p<0.05.

4. Discussion

Anthropometric measurements, joint range of motion, muscle flexibility, muscle strength tests, and balance tests showed significant differences between the DL and NDL for both male and female soccer players. In particular, there was a clear difference between the DL and NDL in muscle strength tests, balance tests, and muscle flexibility tests. Crucially, this difference may be why leg dominance is a risk factor for sports injuries in soccer players and may also be a critical factor in injury prevention. Conversely, for anthropometric measurements and some muscle flexibility tests and joint range of motion measurements, the difference between the DL and NDL was not significant or very small even if it was significant, suggesting that the relevance to injury prevention was not high. However, even if the average difference is slight, there is a possibility that the asymmetry may be significant in some players. This should not be ignored from the viewpoint of injury prevention.

Although several investigations show the physical characteristics of soccer players, there are very few investigations on the physical aspects of Japanese soccer players [24]. Furthermore, there are no papers that comprehensively show the characteristics of DL and NDL of Japanese soccer players making this study the first report of its kind. Using normative data from young male and female soccer players, we can identify deficiencies in muscle function in healthy and injured players. Furthermore, the physical condition of each player can be compared with the normative data to guide training, rehabilitation, and prevention programs. Since there is little information on comprehensive reference values, including physical characteristics, joint laxity, muscle flexibility, muscle strength, and balance ability, the results of this study can be used for comparison in future studies involving soccer players.

In soccer, the DL is responsible for kicking or handling the ball, while the NDL supports the body. During kicking, therefore, muscle strength may also be asymmetrical. The results of this study showed that in male athletes, the DL was significantly stronger in knee flexion and hip abduction, with no significant difference in knee extension. In contrast, the DL was significantly stronger in female athletes in knee extension and knee flexion, with no difference in hip abduction. The difference was not slight but enough to warrant clinical relevance. These gender differences in muscle strength asymmetry may be related to male soccer players using a "hip-dominant" approach to kicking.

In contrast, female soccer players use a "quadriceps-dominant" approach [28, 29]. There are several reports on the differences in muscle strength between DL and NDL or muscle strength asymmetry. Sliwowski et al. reported that knee extension and flexion in the DL were stronger than in the NDL in male elite soccer players [30]. On the other hand, DeLang et al. reported no asymmetry in muscle strength in all of the periarticular hip, knee extensor, and knee flexor muscles in male college soccer players [21]. Additionally, Chiaia et al. reported that mean hip abductor torques demonstrated no difference between dominant and NDLs in elite female soccer players [31]. Sliwowski et al. also reported an increase in symmetry of muscle strength at the international level when compared to the non-international level [30], which may have been influenced by the fact that the subjects in the present study were relatively young although at the elite level. Although asymmetry of muscle strength in the lower extremities and H/Q ratio has been reported to be a risk factor for several sports injuries, muscle strength differs between DLs and NDLs in soccer players clinically relevant information to know to enhance injury prevention.

There are several reports on balance asymmetry that also describe the relationship with leg dominance [23, 32, 33]. All of these reports stated that there was no difference in dynamic balance ability between the DL and NDL [23, 32, 33], which was different from the result of the present study that the balance of the DL was superior to that of the NDL. The difference in balance ability between the DL and NDL in the results of this study is not trivial and cannot be ignored. Balance asymmetry has been reported to be greater in the younger generation [20], and it is possible that the difference was due to the relatively young age of the athletes in this study. Balance asymmetry is a risk for lower extremity sports injuries. Given that lower extremity sports injuries such as ACL injuries are more prevalent at younger ages and that leg dominance is one of the risks for lower extremity sports injuries, it is essential to pay more attention to the difference in balance ability between the DL and NDL in young soccer players.

Regarding muscle flexibility, there was a difference in quadriceps and iliopsoas muscles between DLs and NDLs. Considering that the hip extensors are stretched during the back-swing phase of kicking, it is reasonable that the quadriceps have higher flexibility in the DL in both male and female soccer players and the iliopsoas have higher flexibility than the DL in male and soccer players. Ocarino et al. recently reported that the quadriceps and iliopsoas muscles of male soccer players had higher flexibility in the DL than in the NDL [19], which is similar to the results of this study. In the same report, Ocarino et al. showed that the hamstring of male soccer players had higher flexibility in the DL than in the NDL [19]. At the same time, there was no difference between DL and NDL in both male and female soccer players in the present study. Similar to the discussion on muscle strength, the paradox of iliopsoas flexibility between male and female soccer players in this study may be explained by the fact that male soccer players use a "hip-dominant" approach to kicking, whereas female soccer players use a "quadriceps-dominant" approach [28, 29].

In terms of the range of motion, female soccer players showed greater hip internal rotation range of motion in their DL than in their NDL, while male soccer players showed no asymmetry. Mosler et al. previously reported no effect of leg dominance on hip range of motion in male soccer players [34], while Ocarino et al. reported that the hip internal rotation stiffness of the DL was higher than that of the NDL in male soccer players [19]. In the present study, the results for male soccer players were similar to the former. Conversely, for female soccer players, Chiaia et al. reported no significant differences between the hip internal rotation range of motion of the DL and NDL in elite female soccer players [31]. The present study provides a new finding that the range of motion of hip internal rotation in female soccer players is greater in the DL than in the NDL. However, it is important to note that even if there were significant differences in joint range of motion, each effect size was small and the observed differences may not be relevant.

The present study also revealed differences between the DL and NDL in many other parameters. Leg dominance has been cited as a risk factor for several sports injuries, and such differences may strongly influence the association between DL and sports injuries. Further studies in other sports, age groups, and competition levels are needed to clarify these findings.

4.1. Limitations

This study has several limitations. First, the results may reflect team characteristics rather than differences due to gender because of the small number of teams evaluated. Second, the age of the soccer players included in this study is relatively young. As mentioned in the discussion, the difference between DLs and NDLs may be affected by years of experience and age, and the young age of the subjects may have affected the results of this study. Third, this study does not include kinematic analysis. Understanding the differences in kinematics between the DL and NDL lower extremities may bring us closer to understand how kinematic asymmetry is related to sports injuries.

5. Conclusion

The present study shows musculoskeletal asymmetry between the DL and NDL in young male and female soccer players. In particular, there was a clear difference between the DL and NDL in muscle strength tests, balance tests, and muscle flexibility tests. In male soccer players, DL's knee flexor strength and hip abductor strength were significantly stronger than in the NDL. In female soccer players, knee extension and knee flexion strength of the DL were significantly stronger than the NDL. In male soccer players, the hamstring-quadriceps ratio of the DL was significantly greater than NDL. DL demonstrated a significantly lesser COP excursion in the single-leg balance test in male and female soccer players. In both male and female soccer players, the quadriceps muscle of DL was significantly more flexible than those of the NDL. Normative data from this comprehensive study of DL and NDL characteristics in Japanese soccer players may prevent sports injuries in which leg dominance is considered a risk factor.

Acknowledgements

We would like to thank all the doctors, physical therapists, athletic trainers, and students who participated in the UTSSI project as volunteer examiners.

Funding

This study was funded by donations of scholarships from the East Japan Railway Company and Shimamura-Syoukai and a grant from the Nakatomi Foundation.

Conflict of Interest

The authors certify no conflicts of interest with any organization regarding the material discussed in this manuscript.

REFERENCES

[1] Beachy G, Akau CK, Martinson M, Olderr TF. "High school sports injuries. A longitudinal study at Punahou School: 1988 to 1996", *American Journal of Sports Medicine,* Vol. 25, pp. 675-681; 1997. doi: 10.1177/036354659702500515.

[2] Brophy R, Silvers HJ, Gonzales T, Mandelbaum BR. "Gender influences: the role of leg dominance in ACL injury among soccer players", British *Journal of Sports Medicine,* Vol. 44, pp. 694-697; 2010. doi: 10.1136/bjsm.2008.051243.

[3] Hägglund M, Waldén M. "Risk factors for acute knee injury in female youth football", Knee Surgery, Sports Traumatology, Arthroscopy, Vol. 24, pp. 737-746.; 2016. doi: 10.1007/s00167-015-3922-z.

[4] Ruedl G, Webhofer M, Helle K, Strobl M, Schranz A, Fink C, Gatterer H, Burtscher M. "Leg dominance is a risk factor for noncontact anterior cruciate ligament injuries in female recreational skiers", *American Journal of Sports Medicine,* Vol. 40, pp. 1269-1273; 2012. doi: 10.1177/0363546512439027.

[5] Takei S, Torii S, Taketomi S, Iwanuma S, Tojima M, Otomo M, Iizuka S, Tanaka S. "Is Increased Kicking Leg Iliopsoas Muscle Tightness a Predictive Factor for Developing Spondylolysis in Adolescent Male Soccer Players?", Clinical *Journal of Sports Medicine,* 2021. doi: 10.1097/JSM.0000000000000920.

[6] Saita Y, Nagao M, Kawasaki T, Kobayashi Y, Kobayashi K, Nakajima H, Takazawa Y, Kaneko K, Ikeda H. "Range limitation in hip internal rotation and fifth metatarsal stress fractures (Jones fracture) in professional football players", Knee Surgery, Sports Traumatology, Arthroscopy. Vol. 26, pp. 1943-1949; 2018 doi: 10.1007/s00167-017-4552-4.

[7] Bourne MN, Opar DA, Williams MD, Shield AJ. "Eccentric Knee Flexor Strength and Risk of Hamstring Injuries in Rugby Union: A Prospective Study", *American Journal of Sports Medicine,* Vol. 43, pp. 2663-2670; 2015. doi: 10.1177/0363546515599633.

[8] Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. "Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players", Br J Sports Med, Vol. 45, pp. 709-714; 2011. doi: 10.1136/bjsm.2010.077560.

[9] Brumitt J, Mattocks A, Loew J, Lentz P. "Preseason Functional Performance Test Measures Are Associated With Injury in Female College Volleyball Players", J Sport Rehabil, Vol. 29, pp. 320-325; 2020. doi: 10.1123/jsr.2018-0179.

[10] Collings TJ, Bourne MN, Barrett RS, du Moulin W, Hickey JT, Diamond LE. "Risk Factors for Lower Limb Injury in Female Team Field and Court Sports: A Systematic Review, Meta-analysis, and Best Evidence Synthesis", Sports Med, Vol. 51, pp. 759-776; 2021. doi: 10.1007/s40279-020-01410-9.

[11] Augustsson J, Thomeé R, Karlsson J. "Ability of a new hop test to determine functional deficits after anterior cruciate ligament reconstruction", Knee Surg Sports Traumatol Arthrosc, Vol. 12, pp. 350-356; 2004. doi: 10.1007/s00167-004-0518-4.

[12] McCurdy K, Langford G. "Comparison of unilateral squat strength between the dominant and non-dominant leg in men and women", J Sports Sci Med, Vol. 4, pp. 153-159; 2005.

[13] Orchard J, Best TM, Verrall GM. "Return to play following muscle strains", Clin J Sport Med, Vol. 15, pp. 436-441; 2005. doi: 10.1097/01.jsm.0000188206.54984.65.

[14] Tol JL, Hamilton B, Eirale C, Muxart P, Jacobsen P, Whiteley R. "At return to play following hamstring injury the majority of professional football players have residual isokinetic deficits", Br J Sports Med, Vol. 48, pp. 1364-1369; 2014. doi: 10.1136/bjsports-2013-093016.

[15] Barber SD, Noyes FR, Mangine RE, McCloskey JW, Hartman W. "Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees", Clin Orthop Relat Res, Vol. 255, pp. 204-214; 1990.

[16] Creighton DW, Shrier I, Shultz R, Meeuwisse WH, Matheson GO. "Return-to-play in sport: a decision-based model", Clin J Sport Med, Vol. 20, pp. 379-385; 2010. doi: 10.1097/JSM.0b013e3181f3c0fe.

[17] Vaisman A, Guiloff R, Rojas J, Delgado I, Figueroa D, Calvo R. "Lower Limb Symmetry: Comparison of Muscular Power Between Dominant and Nondominant Legs in Healthy Young Adults Associated With Single-Leg-Dominant Sports", Orthop J Sports Med, Vol. 5, pp. 2325967117744240; 2017. doi: 10.1177/2325967117744240.

[18] Bahenský P, Marko D, Bunc V, Tlustý P. "Power, Muscle, and Take-Off Asymmetry in Young Soccer Players", *International Journal of Environmental Research* and *Public Health,* Vol. 17; 2020. doi: 10.3390/ijerph17176040.

[19] Ocarino JM, Resende RA, Bittencourt NFN, Correa RVA, Mendonça LM, Reis GF, Souza TR, Fonseca ST. "Normative data for hip strength, flexibility and stiffness in male soccer athletes and effect of age and limb dominance", *Physical Therapy* in *Sport,* Vol. 47, pp. 53-58; 2021. doi: 10.1016/j.ptsp.2020.11.022.

[20] Read PJ, Oliver JL, Myer GD, De Ste Croix MBA, Lloyd RS. "The Effects of Maturation on Measures of Asymmetry During Neuromuscular Control Tests in Elite Male Youth Soccer Players", *Pediatric Exercise Science,* Vol. 30, pp. 168-175; 2018. doi: 10.1123/pes.2017-0081.

[21] DeLang MD, Kondratek M, DiPace LJ, Hew-Butler T. "Collegiate male soccer players exhibit between-limb symmetry in body composition, muscle strength, and range of motion", Int J Sports Phys Ther, Vol. 12, pp. 1087-1094; 2017. doi: 10.26603/ijspt20171087.

[22] Cheung RT, Smith AW, Wong dP. "H:q ratios and bilateral leg strength in college field and court sports players", J Hum Kinet, Vol. 33, pp. 63-71; 2012. doi: 10.2478/v10078-012-0045-1.

[23] Onofrei RR, Amaricai E, Petroman R, Surducan D, Suciu O. "Preseason Dynamic Balance Performance in Healthy Elite Male Soccer Players", Am J Mens Health, Vol. 13, pp. 1557988319831920; 2019. doi: 10.1177/15579883198319 20.

[24] Taketomi S, Kawaguchi K, Mizutani Y, Yamagami R, Sameshima S, Takei S, Kono K, Inui H, Tanaka S, Haga N.

"Anthropometric and musculoskeletal gender differences in young soccer players", *Journal* of *Sports* Medicine and *Physical Fitness*, Vol. 61, No. 9, pp. 1212-1218; 2021. doi: 10.23736/S0022-4707.21.11617-2.

[25] Watanabe H, Fujii M, Yoshimoto M, Abe H, Toda N, Higashiyama R, Takahira N. "Pathogenic Factors Associated With Osgood-Schlatter Disease in Adolescent Male Soccer Players: A Prospective Cohort Study", *Orthopaedic Journal* of *Sports Medicine,* Vol. 6, pp. 2325967118792192; 2018. doi: 10.1177/23259671187921 92.

[26] Lu YM, Lin JH, Hsiao SF, Liu MF, Chen SM, Lue YJ. "The relative and absolute reliability of leg muscle strength testing by a handheld dynamometer", *Journal* of *Strength* and *Conditioning Research*, Vol. 25, pp. 1065-1071; 2011. doi: 10.1519/JSC.0b013e3181d650a6.

[27] Scott DA, Bond EQ, Sisto SA, Nadler SF. "The intra- and interrater reliability of hip muscle strength assessments using a handheld versus a portable dynamometer anchoring station", *Archives* of *Physical Medicine* and *Rehabilitation,* Vol. 85. pp. 598-603; 2004. doi: 10.1016/j.apmr.2003.07.0 13.

[28] Brophy RH, Backus S, Kraszewski AP, Steele BC, Ma Y, Osei D, Williams RJ. "Differences between sexes in lower extremity alignment and muscle activation during soccer kick", *Journal* of *Bone* & *Joint Surgery,* Vol. 92, pp. 2050-2058; 2010. doi: 10.2106/JBJS.I.01547.

[29] Ireland ML. "The female ACL: why is it more prone to injury?", *Orthopedic Clinics of North America,* Vol. 33, pp. 637-651; 2002. doi: 10.1016/s0030-5898(02)00028-7.

[30] Śliwowski R, Marynowicz J, Grygorowicz M, Wieczorek A, Jadczak Ł. "Are There Differences in Concentric Isokinetic Strength Perfor-Mance Profiles between International and Non-International Elite Soccer Players?", *International Journal of Environmental Research* and *Public Health,* Vol. 18; 2020. doi: 10.3390/ijerph18010035.

[31] Chiaia TA, Maschi RA, Stuhr RM, Rogers JR, Sheridan MA, Callahan LR, Hannafin JA. "A musculoskeletal profile of elite female soccer players", Musculoskeletal Journal of Hospital for Special Surgery, Vol. 5, pp. 186-195; 2009. doi: 10.1007/s11420-009-9108-9.

[32] Cug M, Wikstrom EA, Golshaei B, Kirazci S. "The Effects of Sex, Limb Dominance, and Soccer Participation on Knee Proprioception and Dynamic Postural Control", *Journal* of *Sport Rehabilitation,* Vol. 25, pp. 31-39; 2016. doi: 10.1123/jsr.2014-0250.

[33] Stiffler MR, Sanfilippo JL, Brooks MA, Heiderscheit BC. "Star Excursion Balance Test Performance Varies by Sport in Healthy Division I Collegiate Athletes", *Journal of Orthopaedic* and *Sports Physical Therapy,* Vol. 45, pp. 772-780; 2015. doi: 10.2519/jospt.2015.5777.

[34] Mosler AB, Crossley KM, Thorborg K, Whiteley RJ, Weir A, Serner A, Hölmich P. "Hip strength and range of motion: Normal values from a professional football league". *Journal* of *Science* and *Medicine* in *Sport,* Vol. 20, pp. 339-343; 2017. doi: 10.1016/j.jsams.2016.05.010.