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Lower Extremity Muscle Activation and Alignment During the Soccer Instep and Side-foot Kicks

Soccer is the most popular sport worldwide, with an estimated 200 million active players.[17] It is the fastest-growing sport in the United States with almost 20 million players[21] and an annual increase in soccer participation of greater than 20%.[2] Soccer players are at risk for injury, especially to the lower extremity and at the knee[1,3,7,12]; the incidence of soccer-related injuries is estimated to be 10 to 35 per 1000 playing hours in adult male players,[17] and often higher in younger and less-skilled players.[33] Approximately 60% to 80% of severe injuries to soccer players occur in the lower extremities,[12,18,24] most commonly at the knee (29%) or ankle (19%).[12] The most serious and frequent injuries occur to the anterior cruciate ligament, posterior cruciate ligament, and medial collateral ligament.[18,24]

STUDY DESIGN: Controlled laboratory study.

OBJECTIVES: To quantify phase duration and lower extremity muscle activation and alignment during the most common types of soccer kick—the instep kick and side-foot kick. A second purpose was to test the hypotheses that different patterns of lower extremity muscle activation occur between the 2 types of kicks and between the kicking limb compared to the support limb.

BACKGROUND: Soccer players are at risk for lower extremity injury, especially at the knee. Kicking the soccer ball is an essential, common, and distinctive part of a soccer player's activity that plays a role in soccer player injury. Regaining the ability to kick is also essential for soccer athletes to return to play after injury.

METHODS: Thirteen male soccer players underwent video motion analysis and electromyography (EMG) of 7 muscles in both the kicking and supporting lower extremity (iliacus, gluteus maximus, gluteus medius, vastus lateralis, vastus medialis, hamstrings, gastrocnemius) and 2 additional muscles in the kicking limb only (hip adductors, tibialis anterior). Five instep and 5 side-foot kicks were recorded for each player. Analysis-of-variance models were used to compare EMG activity between type of kicks and between the kicking and nonkicking lower extremity.

RESULTS: Five phases of kicking were identified: (1) preparation, (2) backswing, (3) limb cocking, (4) acceleration, and (5) follow-through. Comparing the kicking limb between the 2 types of kick, significant interaction effects were identified for the hamstrings ($P = .02$) and the tibialis anterior ($P<.01$). Greater activation of the kicking limb iliacus ($P<.01$), gastrocnemius ($P<.01$), vastus medialis ($P = .016$), and hip adductors ($P<.01$) occurred during the instep kick. Significant differences were seen between the kicking limb and the support limb for all muscles during both types of kick.

CONCLUSIONS: Certain lower extremity muscle groups face different demands during the soccer instep kick compared to the soccer side-foot kick. Similarly, the support limb muscles face different demands than the kicking limb during both kicks. Better definition of lower extremity function during kicking provides a basis for improved insight into soccer player performance, injury prevention, and rehabilitation. *J Orthop Sports Phys Ther 2007;37(5):260-268. doi:10.2519/jospt.2007.2255*

KEY WORDS: football, kicking, motion analysis

Kicking the soccer ball is an essential, common, and distinctive part of a soccer player's activity that plays a role in soccer injury. Regaining the ability to kick is essential for soccer athletes to return to play after injury. During an average 90-minute game, a player has 51 contacts with the ball, 26 with the foot.[39] An analysis of injury risk while playing soccer indicated that kicking accounted for 51% of potential actions that could lead to injury.[35]

The 2 main techniques of kicking are the side-foot kick, which strikes the ball with the medial aspect of the midfoot, and the instep kick, which strikes the ball with the dorsum of the foot. Both of these techniques enable a player to kick with power and accuracy. According to an analysis of goals in the 1998 Men's World Cup, the most common kicking techniques used to score were the instep and side-foot kick.[22]

While the instep soccer kick[5,15,28,32] and side-foot kick[28,32] have been the subject

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of extensive biomechanical analysis, only limited electromyographic (EMG) investigation has been reported.[13,14,38] Dorge et al[14] obtained EMG recordings from the gluteus maximus, vastus lateralis, rectus femoris, and biceps femoris of the kicking limb using surface electrodes, and from the iliopsoas of the kicking lower extremity using wire electrodes during an instep kick. They concluded that wire electrodes were applicable in the studies of fast movements and that the use of wire electrodes to record intramuscular EMG from the iliopsoas muscle during a maximum-velocity instep kick represents a highly recommendable method for future studies of kicking. No study has quantified EMG activation during the side-foot kick or compared EMG activation between the 2 types of kick.

Nunome et al[32] used video motion analysis data to describe the soccer kick with 3 phases defined by 4 events and compared the kinematics of the side-foot kick to the instep kick. They defined the backswing phase as beginning with toe-off of the kicking lower extremity. This phase ends at maximum hip extension, which marks the start of leg cocking. Leg cocking continues until maximum knee flexion, the event marking the transition to leg acceleration, which lasts until ball impact. This definition of the phases of kicking served as the starting point for this investigation described in the following section.

A significant aspect of our work is the inclusion of the support lower extremity as well as the kicking lower extremity in our EMG and motion analysis. One study looked at the ground reaction forces under the support foot and found the forces higher in skilled players than unskilled players.[16] While some studies have reported greater strength in the dominant lower extremity[19,30] or symmetry between players' dominant and nondominant limbs,[9,10] nondominant-limb peak knee extension torque was greater compared to the dominant side in 1 study.[31] The greater strength of nondominant quadriceps was attributed to the role of the nondominant lower extremity supporting the body during the kicking motion. Comparing the activity of the support lower extremity to the activity of the kicking lower extremity may help explain differences between performance and injury risk in these lower extremities.

The purpose of this study was to quantify and compare the phase duration and lower extremity muscle activation during the 2 most common types of soccer kick, the instep and side-foot kicks. Our initial aim was to demonstrate that the phase duration and muscle activation during kicking was measurable and consistent across individuals. Assuming this was the case, we sought to compare muscle activity during the side-foot kick with the muscle activity during the instep kick as well as compare the activity of the support limb musculature to the activity of the kicking limb musculature during these 2 types of soccer kicks. This information will better define lower extremity function during kicking in the sport of soccer and set the stage for further investigation into the role of kicking in player performance, injury, and return to play.

METHODS

Subjects

Approval of the Hospital for Special Surgery (New York, NY) Institutional Review Board was obtained prior to this investigation and all subjects provided informed consent before participating in this study. A cohort of 13 male NCAA Division I collegiate soccer players with no history of previous significant lower extremity injury were tested. Mean ± SD subject age (20.1 ± 1.6 years), height (178.5 ± 8.1 cm), and body mass (74.9 ± 8.8 kg) were recorded. All of the activity related to this study took place in the Motion Analysis Laboratory at the Hospital for Special Surgery.

Phase Definition and Duration

An 8-camera motion capture system was used. Three-dimensional kinematics (joint motion) of the ankle, knee, hip, pelvis, and torso was documented at 250 frames per second using standard joint definitions (EVA RealTime; Orthotrak Motion Analysis Corp, Santa Rosa, CA). A total of 21 retroreflective markers (Cleveland Clinic marker set) ranging from 7 to 25 mm in diameter were attached to the subject with double-sided tape, according to standard marker placement protocol for routine gait analysis of the lower extremities, pelvis, and shoulders (**FIGURE 1**).[34]

The video-based 3-dimensional motion analysis data were used as the basis for the phase definition of the 2 kicks. Previous work that was completed in the Motion Analysis Laboratory defining the phases of the overhead football throw, used changes in direction of motion (ie, from flexion to extension)[26] as transition events. This study builds on previous work describing the phases of kicking by Nunome.[32] Total time spent on the kick as well as the time spent in each phase was recorded.

The video-based motion analysis was also used to measure the following angles during each kick: maximum kicking knee flexion, maximum kicking hip extension, and maximum supporting knee valgus/varus alignment. The maximum kicking knee flexion and hip extension were collected to define transition points in the phase analysis. Supporting knee coronal alignment was collected as preliminary

FIGURE 1. Test subject with surface markers and electrodes.

data regarding potential relationships between kicking (for example, valgus alignment) and injury.

EMG

A total of 16 hip and lower extremity muscles were selected for EMG analysis using a combination of surface electrodes and fine-wire indwelling electrodes (MA-300; Motion Lab Systems, Inc, Baton Rouge, LA). Electrode placement was conducted in accordance with standard practice[23] (**FIGURE 1**).

Disposable solid gel silver/silver chloride surface electrodes with a 22 × 20-mm contact/recording area (Nicolet Biomedical, St Paul, MN) were placed on the gluteus maximus, gluteus medius, vastus lateralis, vastus medialis, medial hamstrings, and gastrocnemius of both the supporting and kicking limbs. In addition, surface electrodes were placed on the hip adductors and tibialis anterior of the kicking lower extremity. Based on the method used by Dorge,[14] bipolar fine-wire electrodes (Nicolet Biomedical, St Paul, MN) consisting of 0.025-mm-diameter insulated wires threaded through a 22-gauge needle were inserted into both iliaci in a sterile fashion just over the pelvic brim to an appropriate depth seating the wires in the muscle. The needle was withdrawn and the wires secured to the player's skin with tape, leaving several cm of exposed wire between the tape and the location of the wire exiting the skin to facilitate excursion during kicking.

Each set of bipolar recording electrodes from the 16 muscles was connected to a preamplifier and then hard-wired to an MA-300 multichannel EMG system. The signals from the device were then hardwired to an analog-to-digital converter (Motion Analysis Corp, Santa Rosa, CA) for simultaneous collection with the 3-dimensional motion analysis system. The sampling rate was at 1000 Hz, with a 350-Hz low-pass filter and a notch filter at 60 Hz.

After the EMG electrodes and video markers were applied to the athlete, the electrodes were tested for appropriate connections and signal intensity. The athletes were then asked to complete a series of maximal voluntary isometric contractions (MVICs) to serve as a normalization factor for each muscle in accordance with usual practice when quantifying EMG. While testing positions were based on Kendall et al,[27] they were modified to accommodate for markers and electrode placement. With the subject in the seated position (hip in 80° of flexion), manually resisted knee flexion (medial hamstrings) and extension (vastus lateralis and medialis), hip adduction (hip adductors) and flexion (iliacus), and ankle dorsiflexion (anterior tibialis) were tested. Hip extension (gluteus maximus) and abduction (gluteus medius), and ankle plantar flexion (gastrocnemius) were tested in the standing position against resistance with the hip and knee in neutral. These trials were also used to confirm placement of both the surface and fine-wire electrodes via visualization on an oscilloscope.

The normalization MVIC consisted of 3-second isometric maximum muscle activation in each position. The highest signal averaged over 0.48 seconds from each MVIC was used as the normalization value. For each phase of the kick, the average EMG signal from each muscle as a percent of the MVIC signal for that muscle was calculated over the duration of the specific phase. This average signal as a percent of MVIC signal for a given muscle over a given phase is referred to as muscle activation.

Procedure

Following MVIC measurement, the players were allowed to warm up as needed prior to conducting the test kicks. The players were asked if they felt any discomfort from the electrodes or markers, or if they perceived any interference or alteration of their kicking motion from the instrumentation. The players kicked a standard-pressure size-5 soccer ball from a stationary position into a small goal 5 yards from the ball and were allowed a

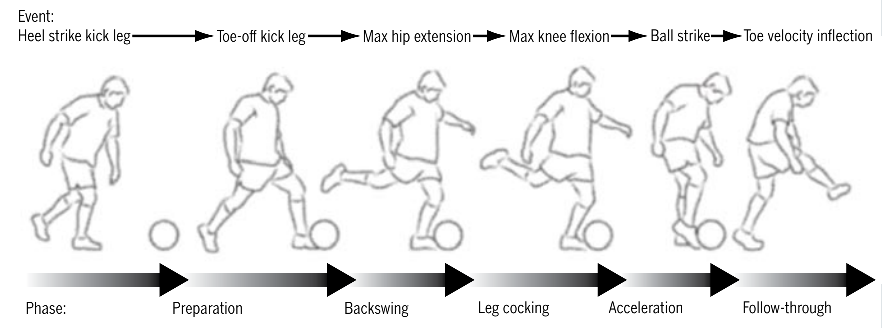

FIGURE 2. The instep kick is divided into 5 phases delimited by 6 events.

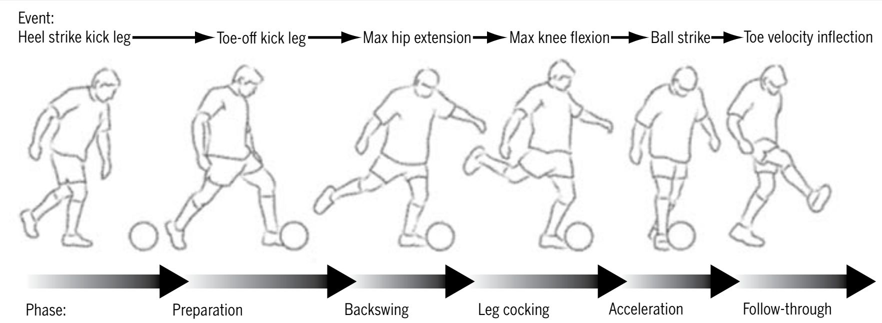

FIGURE 3. The side-foot kick is divided into 5 phases delimited by 6 events.

3- to 4-yard approach to the ball. Netting and drapes were placed behind the goal to capture any kicks that missed the goal. A single marker was placed on the ball to provide an estimate of the velocity of the kick. The ball marker was followed for its entire motion path and the highest measured velocity was used. Each player performed 5 recorded instep kicks and 5 recorded side-foot kicks with the preferred limb.

Data Analysis

Data were analyzed primarily with the use of descriptive statistics (measure of central tendency and variance). The mean and standard deviation of the kick duration was calculated in seconds for both types of kick. In addition, the mean and standard deviation of the duration of each of the phases of kicking was determined. For each kick, the phase as a percent of the total kick was also calculated. The actual time and the percent of the total kick were then compared between the instep kick and the side-foot kick for each phase using a repeated-measures, 2-by-5 (kick by phase) analysis of variance (ANOVA).

The average and standard deviation maximum kicking knee flexion, maximum kicking hip extension, and maximum supporting knee valgus/varus alignment were calculated. The values were then compared between the 2 types of kick using a paired *t* test.

The mean and standard deviation muscle activation as a percentage of MVIC were calculated for each muscle in each of the 5 phases of both types of kick. Four main analyses were performed. For each muscle of the kicking limb, a separate 2-by-5 (type of kick by phase of kick), 2-way ANOVA model was used to compare the level of muscle activation between the 2 types of kick and across the 5 phases of the kicking motion. A similar 2-by-5, 2-way, repeated-measures ANOVA was also performed for each muscle of the supporting limb. For the 7 muscles evaluated on both the kicking and supporting limb, a separate 2-by-5 (limb by phase of kick) repeated-measures ANOVA was performed for each muscle to compare activation of the muscles of the kicking limb to the activation of the corresponding muscle of the supporting limb for the instep kick. A similar analysis was finally performed to compare the muscle activation of the kicking limb versus the supporting limb during the side-foot kick. All statistical analyses were performed using SAS for Windows 9.1 (Cary, NC).

TABLE 1 PHASES OF KICKING*

Phase†	Instep Kick	Side-foot Kick
1. Preparation	0.18 ± 0.06 (22.3%)	0.19 ± 0.07 (23.4%)
2. Backswing	0.16 ± 0.02 (20.5%)	0.14 ± 0.03 (17.3%)
3. Cocking	0.04 ± 0.01 (5.2%)	0.05 ± 0.02 (6.5%)
4. Acceleration	0.06 ± 0.03 (7.3%)	0.04 ± 0.02 (4.8%)
5. Follow-through	0.35 ± 0.11 (44.7%)	0.40 ± 0.16 (48.0%)
Total	0.79 ± 0.12 (100.0%)	0.83 ± 0.20 (100.0%)

**Data expressed in mean ± SD seconds and percent of total kicking time.*
†No significant difference for the duration of each phase between kicks (P>.05).

TABLE 2 LOWER EXTREMITY ALIGNMENT DATA*

	Instep Kick	Side-foot Kick
Kicking limb		
Maximum knee flexion	82.4° ± 10.5°	84.0° ± 6.2°
Maximum hip extension†	9.3° ± 6.6°	5.1° ± 7.3°
Supporting limb knee		
Maximum varus (+)/valgus (–)	4.8° ± 6.8°	5.1° ± 5.7°

**Data expressed as mean ± SD.*
†Significant difference between type of kick (P = .02).

RESULTS

THIRTEEN MALE ATHLETES WERE recruited and completed the study. Twelve athletes preferred to kick with their right foot, the other athlete preferred to kick with his left foot. One of the players elected not to receive the iliacus wire electrodes just prior to their insertion; he otherwise fully participated in the study. None of the players reported any discomfort or disruption of their kicking due to the markers and electrodes. Data were captured for 5 instep kicks and 5 side-foot kicks for each player.

Phase Duration

We identified 5 phases of the kicking motion defined by 6 events (**FIGURES 2** and **3**). For the instep kick, the average length of time in the kicking motion was 0.79 seconds. For the side-foot kick, the average time of the kick was 0.83 seconds (**TABLE 1**). The mean duration of each phase, as well as the percent of total kicking time for each kick, are reported in **TABLE 1**. The longest phase of kicking was the follow-through (phase 5). Limb cocking and acceleration were a relatively small proportion of the kicking motion for both types of kicks. There was no statistically significant difference between the 2 kicks in terms of actual time or percent of the kick spent in each phase. The mean ± SD ball marker velocity for the instep kick was 17.1 ± 4.3 m/s (range, 11.5 to 28.4 m/s); the mean ± SD ball marker velocity for the side-foot kick was 16.1 ± 2.3 m/s (range, 12.2 to 19.5 m/s) ($P>.05$).

The lower extremity alignment data

TABLE 3 Kicking-Limb Muscle Activation Comparing Instep Kick to Side-foot Kick for Each Phase*

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5	
	Instep	Side-foot	Instep	Side-foot	Instep	Side-foot	Instep	Side-foot	Instep	Side-foot
Iliacus†	57 ± 90	28 ± 34	96 ± 97	65 ± 58	149 ± 112	128 ± 91	131 ± 117	106 ± 93	95 ± 170	82 ± 119
Gluteus medius‡	104 ± 68	100 ± 68	75 ± 60	63 ± 48	57 ± 46	72 ± 99	71 ± 61	80 ± 95	89 ± 78	82 ± 59
Gluteus maximus‡	148 ± 182	127 ± 113	74 ± 80	57 ± 55	73 ± 59	77 ± 69	114 ± 86	115 ± 79	129 ± 125	120 ± 109
Hamstrings§	63 ± 23	59 ± 28	39 ± 23	35 ± 34	26 ± 22	20 ± 13	33 ± 21	41 ± 26	50 ± 26	62 ± 34
Vastus lateralis‡	60 ± 33	48 ± 35	36 ± 36	24 ± 23	50 ± 21	58 ± 39	87 ± 66	90 ± 64	52 ± 43	47 ± 43
Vastus medialis‖	128 ± 103	115 ± 75	23 ± 20	15 ± 14	78 ± 52	50 ± 44	100 ± 57	99 ± 61	69 ± 62	71 ± 68
Gastrocnemius¶	99 ± 35	82 ± 36	33 ± 24	22 ± 18	42 ± 27	19 ± 13	57 ± 33	34 ± 52	67 ± 51	68 ± 68
Hip adductors#	60 ± 29	50 ± 27	68 ± 59	54 ± 34	75 ± 52	67 ± 38	81 ± 60	58 ± 31	75 ± 49	71 ± 46
Tibialis anterior**	25 ± 27	21 ± 25	19 ± 16	50 ± 26	40 ± 34	96 ± 36	44 ± 37	86 ± 29	39 ± 30	42 ± 23

**Data are reported as the mean ± SD percent of maximal voluntary isometric contraction.*
†Main effect demonstrated greater activity during the instep kick ($P<.01$).
‡No significant difference in muscle activation between kicks for any phase ($P>.05$).
§Interaction effect ($P = .02$); greater activity for side-foot kick during phase 5 ($P = .03$).
‖Main effect demonstrated greater activity during the instep kick ($P = .016$).
¶Main effect demonstrated greater activity during the instep kick ($P<.01$).
#Main effect demonstrated greater activity during the instep kick ($P<.01$).
***Interaction effect ($P<.01$); greater activity for side-foot kick during phases 2-4 ($P<.01$).*

TABLE 4 Supporting-Limb Muscle Activation Comparing Instep Kick to Side-foot Kick for Each Phase*

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5	
	Instep	Side-foot	Instep	Side-foot	Instep	Side-foot	Instep	Side-foot	Instep	Side-foot
Iliacus†	46 ± 30	51 ± 31	17 ± 22	19 ± 27	30 ± 38	34 ± 39	36 ± 37	37 ± 31	30 ± 18	26 ± 14
Gluteus medius†	74 ± 67	73 ± 81	84 ± 61	70 ± 51	109 ± 109	103 ± 77	119 ± 121	114 ± 113	82 ± 74	79 ± 59
Gluteus maximus†	65 ± 57	59 ± 62	78 ± 57	59 ± 33	99 ± 60	109 ± 59	94 ± 72	96 ± 66	70 ± 60	69 ± 45
Hamstrings†	30 ± 61	26 ± 50	72 ± 65	78 ± 53	104 ± 104	108 ± 89	94 ± 134	74 ± 105	64 ± 111	55 ± 87
Vastus lateralis†	37 ± 39	34 ± 45	38 ± 27	28 ± 19	93 ± 49	87 ± 54	107 ± 66	96 ± 62	49 ± 29	57 ± 32
Vastus medialis†	37 ± 46	38 ± 47	60 ± 66	54 ± 59	202 ± 109	182 ± 79	228 ± 123	200 ± 83	90 ± 66	99 ± 44
Gastrocnemius‡	14 ± 11	12 ± 8	40 ± 24	32 ± 20	75 ± 34	84 ± 38	70 ± 37	56 ± 31	41 ± 34	37 ± 38

**Data expressed as mean ± SD percent of maximal voluntary isometric contraction.*
†No significant difference in muscle activation between kicks for any of the phases ($P>.05$).
‡Interaction effect ($P = .036$); greater activation for instep kick during phase 4 ($P = .02$).

are summarized in **TABLE 2**. The only significant difference between the 2 types of kick was greater hip extension with the instep kick ($P = .02$).

EMG

Kicking Lower Extremity: Instep Versus Side-foot Kick For the kicking lower extremity, comparing the instep kick to the side-foot kick, significant interaction effects were identified for the hamstrings ($P = .02$) and the tibialis anterior ($P<.01$) (**TABLE 3**). For the hamstrings, greater activity was noted for the side-foot kick during phase 5 ($P = .03$). The tibialis anterior demonstrated significantly greater activity during the side-foot kick in phases 2, 3, and 4 ($P<.01$).

Of the remaining muscles of interest, a significant main effect for kicking style was identified with greater activation during the instep kick in the iliacus ($P<.01$), vastus medialis ($P = .016$), gastrocnemius ($P<.01$), and hip adductors ($P<.01$). No significant main effect for kicking style was identified in the gluteus medius, gluteus maximus, and vastus lateralis.

Supporting Lower Extremity: Instep Versus Side-foot Kick For the support lower extremity, comparing the instep kick to the side-foot kick, the only significant interaction effect identified was for the gastrocnemius ($P = .036$) (**TABLE 4**). The only significant phase-specific difference was greater activation with the instep kick during phase 4 ($P = .02$). There were no significant main effects for muscle activation level between the 2 kicks ($P>.05$).

TABLE 5 Instep Kick Muscle Activation Comparing Kicking to Supporting Limb for Each Phase*

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5	
	Kick	Support	Kick	Support	Kick	Support	Kick	Support	Kick	Support
Iliacus†	57 ± 90	46 ± 30	96 ± 97	17 ± 22	149 ± 112	30 ± 38	131 ± 117	36 ± 37	95 ± 170	30 ± 18
Gluteus medius‡	104 ± 68	74 ± 67	75 ± 60	84 ± 61	57 ± 46	109 ± 109	71 ± 61	119 ± 121	89 ± 78	82 ± 74
Gluteus maximus§	148 ± 182	65 ± 57	74 ± 80	78 ± 57	73 ± 59	99 ± 60	114 ± 86	94 ± 72	129 ± 125	70 ± 60
Hamstrings‖	63 ± 23	30 ± 61	39 ± 23	72 ± 65	26 ± 22	104 ± 104	33 ± 21	94 ± 134	50 ± 26	64 ± 111
Vastus lateralis¶	60 ± 33	37 ± 39	36 ± 36	38 ± 27	50 ± 21	93 ± 49	87 ± 66	107 ± 66	52 ± 43	49 ± 29
Vastus medialis#	128 ± 103	37 ± 46	23 ± 20	60 ± 66	78 ± 52	202 ± 109	100 ± 57	228 ± 123	69 ± 62	90 ± 66
Gastrocnemius**	99 ± 35	14 ± 11	33 ± 24	40 ± 24	42 ± 27	75 ± 34	57 ± 33	70 ± 37	67 ± 51	41 ± 34

**Data are reported as the mean ± SD percent of maximal voluntary isometric contraction. All have interaction effect ($P<.01$).*
†Greater kicking-limb activity during phases 2-5 ($P<.01$).
‡Greater kicking-limb activity during phase 1 (P = .012); greater support-limb activity during phases 3 and 4 ($P<.01$).
§Greater kicking-limb activity during phases 1 and 5 ($P<.01$); greater support-limb activity during phase 3 (P = .017).
‖Greater kicking-limb activity during phase 1 ($P<.01$); greater support-limb activity during phases 2-4 ($P<.01$).
¶Greater kicking-limb activity during phase 1 ($P<.01$); greater support-limb activity during phase 3 ($P<.01$).
#Greater kicking-limb activity during phase 1 ($P<.01$); greater support-limb activity during phases 2-4 ($P<.01$).
***Greater kicking-limb activity during phases 1 and 5 ($P<.01$); greater support-limb activity during phases 3 ($P<.01$) and 4 (P = .034).*

TABLE 6 Side-foot Kick Muscle Activation Comparing Kicking to Supporting Limb for Each Phase*

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5	
	Kick	Support	Kick	Support	Kick	Support	Kick	Support	Kick	Support
Iliacus†	28 ± 34	51 ± 31	65 ± 58	19 ± 27	128 ± 91	34 ± 39	106 ± 93	37 ± 31	82 ± 119	26 ± 14
Gluteus medius‡	100 ± 68	73 ± 81	63 ± 48	70 ± 51	72 ± 99	103 ± 77	80 ± 95	114 ± 113	82 ± 59	79 ± 59
Gluteus maximus§	127 ± 113	59 ± 62	57 ± 55	59 ± 33	77 ± 69	109 ± 59	115 ± 79	96 ± 66	120 ± 109	69 ± 45
Hamstrings‖	59 ± 28	26 ± 50	35 ± 34	78 ± 53	20 ± 13	108 ± 89	41 ± 26	74 ± 105	62 ± 34	55 ± 87
Vastus lateralis¶	48 ± 35	34 ± 45	24 ± 23	28 ± 19	58 ± 39	87 ± 54	90 ± 64	96 ± 62	47 ± 43	57 ± 32
Vastus medialis#	115 ± 75	38 ± 47	15 ± 14	54 ± 59	50 ± 44	182 ± 79	99 ± 61	200 ± 83	71 ± 68	99 ± 44
Gastrocnemius**	82 ± 36	12 ± 8	22 ± 18	32 ± 20	19 ± 13	84 ± 38	34 ± 52	56 ± 31	68 ± 68	37 ± 38

**Data are reported as the mean ± SD percent of maximal voluntary isometric contraction. All have interaction effect ($P<.01$).*
†Greater kicking-limb activity during phases 2-5 ($P<.01$); greater support-limb activity during phase 1 ($P<.01$).
‡Greater kicking-limb activity during phase 1 (P = .038); greater support-limb activity during phase 3 (P = .046).
§Greater kicking-limb activity during phases 1 and 5 ($P<.01$); greater support-limb activity during phase 3 ($P<.01$).
‖Greater kicking-limb activity during phase 1 ($P<.01$); greater support-limb activity during phases 2-4 ($P<.01$; $P<.01$; P = .019).
¶Greater kicking-limb activity during phase 1 (P = .049); greater support-limb activity during phase 3 ($P<.01$).
#Greater kicking-limb activity during phase 1 ($P<.0001$); greater support-limb activity during phases 2-4 ($P<.01$).
***Greater kicking-limb activity during phases 1 and 5 ($P<.01$); greater support-limb activity during phases 2-4 ($P<.01$).*

Instep Kick: Kicking Limb Versus Supporting Limb For the instep kick, comparing the kicking limb to the supporting limb, all 7 muscles demonstrated significant interaction effects with $P<.01$ (**TABLE 5**). The iliacus demonstrated higher activation in the kicking limb during phases 2 through 5 ($P<.01$). The gluteus medius demonstrated higher activation of the support limb during phases 3 and 4 ($P<.01$), and greater activation of the kicking limb during phase 1 (P = .012). The gluteus maximus demonstrated higher activation of the kicking limb during phases 1 and 5 ($P<.01$) and higher activation of the support limb during phase 3 (P = .017). The hamstrings had greater activation in the support limb during phases 2 through 4 ($P<.01$) and greater activation in the kicking limb during phase 1 ($P<.01$). The support limb vastus lateralis achieved greater activation during phase 3 ($P<.01$), whereas the kicking limb achieved greater activation during phase 1 ($P<.01$). The vastus medialis achieved greater activation in the support limb during phases 2 through 4 ($P<.01$), while the kicking limb achieved greater activation during phase 1 ($P<.01$). The gastrocnemius demonstrated greater activity in the kicking leg during phases 1 and 5 ($P<.01$), and the support leg during phases 3 ($P<.01$) and 4 (P = .034).

Side-foot Kick: Kicking Limb Versus Supporting Limb The side-foot kick also demonstrated significant interaction effects for all 7 muscles comparing the kicking limb to the support limb ($P<.01$) (**TABLE 6**). Greater activation was seen in the kicking limb iliacus during phases 2 through 5 ($P<.01$), whereas the supporting limb iliacus was more active during phase 1 ($P<.01$). The gluteus medius demonstrated greater activation of the kicking limb during phase 1 ($P = .038$) and the support limb during phase 3 ($P = .046$). The gluteus maximus was more active in the kicking limb during phases 1 and 5 ($P<.01$), and more active in the support limb during phase 3 ($P<.01$). Medial hamstrings showed greater activation in the kicking limb during phase 1 ($P<.01$) and greater support limb activation during phases 2 ($P<.01$), 3 ($P<.01$), and 4 ($P = .019$). The vastus lateralis demonstrated greater activity in the kicking limb during phase 1 ($P = .049$) and the support limb during phase 3 ($P<.01$). The vastus medialis also reached greater activation in the kicking limb during phase 1 ($P<.01$), but greater activation in the support limb during phases 2 through 5 ($P<.01$). The gastrocnemius reached higher activation in the kicking limb during phases 1 and 5 ($P<.01$) and higher activation in the support limb during phases 2 through 4 ($P<.01$).

DISCUSSION

Nunome et al[32] described the soccer kick with 3 phases defined by 4 events. They defined the backswing phase as beginning with toe-off of the kicking limb. This phase ends at maximum hip extension, which marks the start of limb cocking. Limb cocking continues until maximum knee flexion, the event marking the transition to limb acceleration, which lasts until ball impact. Our results showed a longer backswing phase but shorter cocking phase compared with the previously published study for both types of kick. The acceleration phase was very similar between the 2 studies. Their reported initial ball velocities were higher than ours. Their instep average initial ball velocity was 28.0 ± 2.1 m/s, and for the side-foot kick they reported an average initial ball velocity of 23.4 ± 1.7 m/s versus our 16.1 ± 2.3 m/s. Other published studies of the soccer kick have reported faster velocities, in the range of 22.2 to 30.0 m/s for the instep kick.[4,15,28,29,41] One study reported an average velocity of 28.6 ± 2.2 m/s for the instep kick and 22.5 ± 1.8 m/s for the side-foot kick.[28] The difference in velocity probably reflects a difference in data capture methodology, as we measured the velocity of the marker sitting on the ball as a proxy for ball velocity. In retrospect, applying multiple markers to the ball may have eliminated the effect of ball spin, providing a more accurate representation of ball speed although precise measurement of ball speed was not an objective of this study.

The differences in muscle activation between kicks are consistent with gross qualitative differences in the kicking motion as demonstrated in **FIGURES 2** and **3**. For example, the position of the foot during the kick correlates with the relative activation of the tibialis anterior. During the instep kick, the tibialis anterior is relatively relaxed. By comparison, the kicking foot is held in neutral or slight dorsiflexion during phases 2 through 4 of the side-foot kick so the tibialis anterior is more active. While the greater hip extension achieved during the instep kick does not result in greater activation of the gluteus maximus, this may contribute to greater activation of the iliacus to flex the hip farther and faster compared to the side-foot kick.

Dorge et al[14] reported the EMG activity of the kicking-limb iliopsoas, rectus femoris, vastus lateralis, biceps femoris, and gluteus maximus in 7 skilled players, with 3 recorded kicks per subject. This study did not break the kick down into phases as part of the analysis or discussion and the EMG results are reported as average activity for "the period where the angular velocity of the thigh was positive until impact," which we believe roughly corresponds to our acceleration phase. In this phase, they reported mean kicking-limb iliopsoas activity of 79.4%, which is less than our data of 131%, and a mean vastus lateralis activity of 81.7%, which is consistent with our data of 87%. The mean kicking leg biceps femoris activity during this period was reported as 22.6% and a peak of 40.1%, which is comparable to our value of 33% for the hamstrings. However, they reported mean kicking limb gluteus maximus activity of 10.2% in this phase, with peak gluteus maximus activity before impact of 27.1%, both of which are significantly less than our 114%. With the exception of the gluteus maximus, given the differences in data collection, analysis, and reporting between the 2 studies, the results appear similar.

Comparing the 2 limbs during the kicking motion, the support limb faces different patterns of activation than the kicking limb. Studies comparing strength and power between the dominant and nondominant limb of soccer players have presented conflicting results,[9,10,16,19,30,31] perhaps reflecting the heavy stresses faced by the supporting limb during kicking. Obviously, the relative frequency of kicking with the nondominant limb and the heavy lower extremity demands of sprinting, cutting, and jumping also play a role in making it difficult to discern any physiological difference between the preferred and nonpreferred limbs.

The data in this study cannot be used to speculate about the relation of kicking to injury mechanism or rehabilitation. However, it raises a number of interesting questions with regard to soccer players. Muscle injury is a common occurrence in soccer, with 1 study[40] reporting hamstrings as the most common muscle involved followed by the quadriceps, adductors, and gastrocnemius. Groin injuries account for 5% of all soccer injuries and account for a disproportionate loss of time from the sport.[20] It has been suggested in the literature that chronic groin pain in the soccer player is related to the repetitive stress on the abdominal muscles and hip flexors and adductors during kicking.[11] Two findings in our study may have some clinical relevance to this injury pattern. First, the iliacus reached higher activation in the kicking limb, particularly during the instep kick. Second, the adductors of the kicking limb reached greater activation during the instep kick compared to the side-foot kick.

The methodologies of testing used here (3-dimensional motion analysis with passive markers and EMG) are standard techniques in the evaluation of gait and are becoming more standard as tools used to document sports activities. Although these techniques are used to measure a variety of movements, both of these methodologies have limitations. The motion analysis system, while calculating angular motion in all 3 planes, uses surface-mounted markers. Thus despite the use of high-resolution cameras, consistent and careful calibrations, and standardized models and joint coordinate systems, all calculations are influenced by underlying soft tissue movement.[6,25,37] It was not feasible or practical in this project (similar to most other reported studies) to use bone pins as a technique to directly measure the motion of the lower extremity. Thus, even with consistent marker placement and algorithms to calculate joint angles, the lower extremity alignment values have acceptable, but not perfect, agreement and validity.

The reliability of both surface and wire electrode EMG in gait has been documented by multiple authors, and recent work by Bogey[8] reports similar test-retest reliability between these 2 electrode types and a variance ratio (a measure of repeatability of waveforms with low values indicative of high repeatability) of less than 0.20 for both techniques.[25] We did not perform repeatability testing on these subjects. While we were able to demonstrate differences in selected muscles between type of kick and between limbs, the large standard deviations in activation values are an indication of the between-subject variability present and support the use of a repeated-measures design in data analysis.

The use of normalization with EMG data allows comparison between subjects (group and summary data) as well as within subjects (between the kicking and support limb) and is recommended in this case.[36] While placement of each electrode was confirmed and standardized, there is the possibility of crosstalk between adjacent muscles when using surface electrodes. To facilitate the ease of testing, maintain subject comfort, and minimize the impact that the electrodes would have, we opted to use surface electrodes where possible and fine-wire electrodes only for the deep muscles. In addition, EMG data, including the amplitude of the activation values, is not a direct measurement of force production or torque generation and should not be interpreted as such.

The authors recognized the presence of large standard deviations in the muscle activation data. Based on careful review of the data, this resulted largely from some players who demonstrated significantly greater muscle activation during the kick compared to the corresponding MVIC for some muscles. Different players demonstrated high activation for different muscles (ie, there was no discernible pattern of high muscles activation across the board for particular players). Furthermore, data within players was fairly consistent and there were no large trial specific outliers suggestive of a systematic source of variance such as a loose wire.

CONCLUSION

In summary, the soccer instep and side-foot kick occur with measurable phase timing and muscle activation by EMG. The different muscles can be grouped according to their activation pattern in a manner that appears logical. Overall, the 2 kicks are very similar with a few key differences in terms of the pattern and magnitude of muscle activation. The supporting limb musculature is activated with a different pattern compared to the kicking-limb musculature. This information may be helpful to investigate the role of kicking in injury risk, as well assessing the impact of a specific injury on a player's return to play. More significantly, this study sets the stage for further investigation into how, if at all, the kicking pattern changes in a variety of situations, including after injury or fatigue and in different player levels or gender. ◉

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