COLLEGIATE MALE SOCCER PLAYERS EXHIBIT BETWEEN-LIMB SYMMETRY IN BODY COMPOSITION, MUSCLE STRENGTH, AND RANGE OF MOTION

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ABSTRACT

Background: Functional and structural asymmetries attributed to limb dominance are equivocal in soccer players. Previous authors hypothesize the existence of between-limb asymmetry secondary to the repetitive unilateral nature of kicking. However, symmetry is often present, particularly in measures of muscle strength.

Purpose: The purpose of the present study was to determine if lateral dominance is accompanied by corresponding between-limb asymmetries in a comprehensive assessment of body composition, muscle strength, and range of motion in healthy soccer players.

Study Design: Cross-sectional, observational.

Methods: 17 healthy male NCAA Division One collegiate soccer players participated (age 19.6 ± 1.5 years; BMI 23.9 ± 1.4 kg/m²). Footedness was attained via participant self-report. Lower limb muscle strength (hand held dynamometry), range of motion (goniometry), and body composition (dual energy x-ray absorptiometry scan) were measured. Lower-leg symmetry was analyzed comparing the dominant versus non-dominant limb using paired t-tests.

Results: Comparisons revealed no statistically different differences in outcomes, indicating remarkable symmetry in all measures of body composition, muscle strength, and range of motion ($p > 0.05$) between the dominant and non-dominant lower limbs.

Conclusions: The authors speculate the prevalence of running versus kicking, the longitudinal effects of playing careers, and/or functional compensation attenuates the expected asymmetries in healthy male collegiate soccer players.

Level of Evidence: 2b

Key words: Bone density, footedness, lateral dominance, muscle strength, range of motion

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INTRODUCTION

Lateral dominance is the natural tendency for an individual to use one side of the body to complete tasks. In soccer, lateral dominance can be defined as footedness: the preferred foot for kicking the ball, and the limb that mobilizes through an open kinetic chain.¹⁻³ A number of researchers have assumed between-limb asymmetry in soccer players as a product of unilateral kicking and greater repetition with the dominant limb.⁴⁻⁷ These previous hypotheses of expected asymmetry are logical: as an asymmetrical skill with unipedal posture, the dominant limb in soccer kicking displays greater ball velocity values⁸ and greater forces produced throughout the motion: pelvic rotation increases with faster kicks, suggesting the dominant limb experiences greater torque around the pelvis.⁹ Coupled with the different internal demands of the dominant mobilizing versus the non-dominant stabilizing limbs, a force production disparity between limbs likely exists. These potential asymmetries have been further linked to increased lower extremity injury risk.¹⁰⁻¹¹

In cohorts of professional soccer players, Daneshjoo et al.¹² reported hip flexibility disparities between limbs while Oliveira et al.⁸ reported no differences in between-limb goniometric measures of hip flexion. Between-limb comparisons are most commonly measured by assessing muscle strength and torque. Idoate et al.¹³ reported non-dominant side hypertrophy of the rectus abdominis in professional players, which they speculate was stronger to provide for the stabilizing demands of the non-kicking limb. In elite soccer players, Aginsky and Neophytu¹⁴ reported greater hamstring strength and endurance in the dominant limb, agreeing with Blache and Monteil¹⁵ who concluded that greater dominant limb knee flexor and extensor strength existed at 40% and 60% maximal load in a sample of recreational players. On the contrary, Rahnema et al.² found soccer players' dominant limb knee flexors to be weaker than the non-dominant limb. Despite discrepancies in which limb exhibits greater muscle strength, the existence of between-limb differences seem logical: the action of soccer kicking produces different force production between limbs as the dominant limb mobilizes and the non-dominant limb stabilizes. The non-dominant, stabilizing limb provides the foundation for the kicking motion, demanding actions of

the postural musculature to enable the dominant, mobilizing limb to move forcefully to impact the ball. In addition to differing functions between the dominant and non-dominant limbs, the dominant limb is utilized more frequently and with improved coordination and intersegmental patterning for kicking tasks.¹⁶

However, despite reasonable inferences to suggest that between-limb asymmetry exists, other authors describe symmetry with regards to muscle strength between the dominant and non-dominant limbs.^{6,12,17-21} Despite the inherent force production differences between limbs and greater repetition of kicking with the dominant limb, perhaps underlying mechanisms exist that can explain between-limb symmetry in soccer players as previously reported. For example, the utility of running in soccer may overshadow the unilateral repetition of kicking. Fousekis et al.⁵ suggests between-limb asymmetry diminishes later in a player's career, attributed to the athlete adopting a more balanced use of the lower extremities to attain high-level play. Perhaps, other factors in the kinetic chain have not yet been assessed and lower limb symmetry measures do not capture the full scope of the function of soccer players. The present study examines collegiate soccer players in an effort to assess individuals between youth and professional soccer and further examine the effect of soccer on between-limb symmetry.

The purpose of the present study was to determine if lateral dominance is accompanied by corresponding between-limb asymmetries in a comprehensive assessment of body composition, muscle strength, and range of motion in healthy soccer players. Classifying a cohort of healthy soccer players as symmetrical or asymmetrical can assist in describing appropriate baselines for health professionals to attain in rehabilitation; if between-limb asymmetry is common, then achieving rehabilitation to match the contralateral limb is an insufficient measure of return-to-play criteria. The authors hypothesized that the asymmetrical nature of kicking would elicit between-limb asymmetry in the present sample. The authors wished to clarify the conflicting reports of symmetry versus asymmetry in soccer players by examining collegiate players via comprehensive testing of body composition, muscle strength, and range of motion.

MATERIALS AND METHODS

Seventeen healthy male collegiate soccer players (height = 1.82 ± 0.07 m; mass = 79.0 ± 6.1 kg) volunteered to participate from a NCAA Division One program. The athletes self-identified as single-sport athletes in college with primary positions yielding four defenders, five midfielders, five forwards, and three goalkeepers. The participants were chosen by convenience sampling from the team's pool of 29 players during preseason of the 2014 fall campaign and were all healthy by standard of availability for full participation in training. The Oakland University Institutional Review Board approved all methods and procedures and participants signed written informed consent before inclusion. All participants were tested for all measures in a single day in the university health building.

Footedness

The researchers explained to the athlete that footedness is the preferred limb to kick the ball during game play. Each participant verbally reported his dominant foot via personal preference to the researchers,^{3,6,17,22} herein referred to as self-reported footedness. Testers were blinded to participant footedness during data collection.

Symmetry measurements included body composition, muscle strength, and range of motion.

Body Composition

Body composition was measured via dual-energy X-ray absorptiometry (DXA; Hologic Discovery A, Boston, MA). All whole-body DXA scans were performed by a single technician following a standardized protocol procedure for a whole body scan.²³ Both total body and regional analyses were calculated by the DXA scanner, as per the default settings inherent to this device.

Muscle Strength

Lower limb isometric muscle torque to serve as an indirect measure of strength was assessed using a handheld dynamometer (Lafayette Instrument Company, Model 01163 Lafayette, IN). Two research assistants performed muscle strength assessments using dynamometer placements as described by Bohannon.²⁴ Ease of use with minimal training provides

practicality for handheld dynamometry, with good intra-rater (ICC = 0.77 to 0.97) reported.²⁵ One tester measured muscle strength at the hip (flexion/extension, adduction/abduction, internal/external rotation), while a second tester measured the knee (flexion/extension) and ankle (plantarflexion/dorsiflexion, pronation/supination). Three measurements were obtained, with the recorded value being the highest value of the three measurement attempts. All muscle strength values were recorded in kilograms.

Range of Motion

One research assistant performed testing using a manual goniometer and standard positions as recommended by Norkin and White.²⁶ The investigators were trained and supervised by a licensed physical therapist who ensured that there were no substitutions on standard positions or measurements. Three measurements were obtained, with the recorded value being the highest value of the three measurement attempts. Areas of focus included joint mobility at the hip (flexion/extension, adduction/abduction, internal/external rotation), knee (flexion/extension), and ankle (plantarflexion/dorsiflexion, inversion/eversion).

Paired t-tests were utilized to assess differences in laterality when all participants were categorized into dominant side versus non-dominant limb. All participants remained eligible throughout, and there is no missing data to report. Statistical significance was set at $p < 0.05$. All analyses performed using STATISTICA version 12 software (StatSoft Inc., Tulsa, OK, USA).

RESULTS

Table 1 presents demographic data organized by right- and left-footedness and exemplifies the total participant pool demographic information.

The limited number of left-footed participants ($n = 2$) prevented adequate analyses of right- versus left-footed between-limb differences. Post-hoc analyses

Table 1. Demographic data organized by dominant limb.

	Right (n=15)	Left (n=2)	Total
Age (years)	19.5 $\pm$ 1.6	20.5 $\pm$ 0.7	19.6 $\pm$ 1.5
Height (m)	1.82 $\pm$ 0.07	1.82 $\pm$ 0.08	1.82 $\pm$ 0.07
Weight (kg)	78.9 $\pm$ 6.3	79.4 $\pm$ 6.4	79.0 $\pm$ 6.1
BMI	24.0 $\pm$ 1.5	23.9 $\pm$ 0.2	23.9 $\pm$ 1.4
% Fat	10.8 $\pm$ 2.7	7.2 $\pm$ 0.8	10.4 $\pm$ 2.8
BMI = body mass index			

of dominant versus non-dominant limb were considered. There were no significant differences in body composition as measured via bone mineral content (BMC), lean mass, or fat mass when considering the dominant and non-dominant limb (Table 2). Muscle strength trended toward the dominant limb having marginally greater values, except for hip external rotation (dominant = 42.3 ± 8.1 kg; non-dominant = 43.7 ± 8.5 kg) and foot supination (dominant = 31.6 ± 8.7 kg; non-dominant = 36.2 ± 10.1 kg); however, none of the differences were statistically significant (Table 2). Range of motion scores across all participants in all measured movements were not statistically significantly different (Table 2).

DISCUSSION

Despite expected asymmetries, the results of the present study instead demonstrate symmetry

between limbs across all measures of body composition, muscle strength, and range of motion. Due to the symmetry found between limbs despite lower limb lateral dominance and the asymmetrical nature of soccer kicking, understanding why such symmetry may persist would be valuable to soccer research.

The present cohort is comparable to other studies on soccer players. Percent body fat reported for soccer players in prior research is consistent with $10.4 \pm 2.8\%$ from the present study: $10.5 \pm 4.3\%$ ²⁷ and $13.9 \pm 5.8\%$.²⁷ A study of NCAA Division One soccer players demonstrated similar height, weight, and body composition as the present study (presented as Silvestre et al.²⁸; present data): height (1.78 ± 0.06 m; 1.82 ± 0.07 m), body mass (77.5 ± 9.2 kg; 79.0 ± 6.1 kg), total lean body mass (63.2 ± 4.9 kg; 66.9 ± 4.7 kg), and total fat mass (10.6 ± 5.8 kg; 8.2 ± 2.5 kg). The 15 right-footed and two left-footed subjects in the current study are similar to previous studies in the ratio of right: left dominance: 11:1,²⁹ 6:1,¹⁶ 16:2 in youth players and 14:3 in professionals,⁶ and 13:2.¹³ Thus, the disproportionate participant pool of foot dominance in the current study is similar to most samples of soccer players, and is not a reason for the symmetry demonstrated. Further investigation into proposed theories as to why lower extremity symmetry exists in soccer players may be advantageous for organizing exercise protocols, injury rehabilitation, and performance enhancement.

Symmetry Theory #1) Running > Kicking

While high force production occurs during soccer kicking, it is not necessarily the primary movement throughout the course of a game or training session. Rampinini et al.³⁰ reported ball involvements per 90 minutes as ranging from 34.5-44.7 involvements depending on team success. This is remarkably low when compared to the high incidence of running in soccer, where total distances per field player range 10-12 km per match.³¹ In a study of elite European professional teams, “high-intensity running” and “very high-intensity running” accounted for 2.7 ± 0.7 km and 1.0 ± 0.3 km of total distance covered.³² Prevalent high-intensity running, a crucial element for performance, may effectively outweigh the repetitive unilateral motion created by kicking. If the bilateral running movement facilitates the foundation of

Table 2. Dominant versus non-dominant limb results for body composition, muscle strength, and range of motion.

Body Composition	Dominant (n=17)	Non-Dominant (n=17)	p-value
BMC - Arm (g)	228.5±18.4	220.0±23.7	0.25
BMC - Ribs (g)	92.9±23.2	98.8±24.8	0.48
BMC - Leg (g)	638.4±54.8	648.7±60.1	0.61
Lean - Arm (g)	4471.9±371.7	4301.7±491.3	0.26
Lean - Leg (g)	11727.5±1008.1	11605.2±896.0	0.71
Fat - Arm (g)	525.3±162.6	510.9±159.0	0.80
Fat - Leg (g)	1750.3±705.9	1709.5±699.6	0.87
Muscle Strength	Dominant (n=17)	Non-Dominant (n=17)	p-value
Hip Extension (kg)	66.6±14.4	63.8±11.7	0.55
Hip Abduction (kg)	71.9±20.5	67.0±13.5	0.43
Hip Adduction (kg)	53.0±11.7	48.8±9.3	0.26
Hip Int. Rotation (kg)	35.3±9.3	35.2±8.8	0.98
Hip Ext. Rotation (kg)	42.3±8.1	43.7±8.5	0.64
Hip Flexion (kg)	66.9±14.0	62.1±9.7	0.27
Knee Flexion (kg)	65.0±8.6	61.3±6.3	0.18
Knee Extension (kg)	61.0±11.5	57.4±11.2	0.37
Ankle Dorsiflexion (kg)	48.5±5.0	47.6±5.2	0.63
Ankle Plantarflexion (kg)	49.7±9.6	46.4±8.5	0.32
Foot Pronation (kg)	28.0±7.4	27.3±7.5	0.80
Foot Supination (kg)	31.6±8.7	36.2±10.1	0.18
Range of Motion	Dominant (n=17)	Non-Dominant (n=17)	p-value
Hip Abduction (°)	31.9±9.7	34.7±8.6	0.38
Hip Adduction (°)	19.1±4.9	17.6±4.3	0.38
Hip Int. Rotation (°)	33.2±10.8	30.2±10.4	0.41
Hip Ext. Rotation (°)	37.9±10.1	39.1±10.4	0.75
Hip Flexion (°)	96.3±6.2	99.4±6.9	0.18
Knee Flexion (°)	132.6±7.3	133.7±7.2	0.67
Knee Extension (°)	179.2±1.6	180.1±2.4	0.22
Ankle Dorsiflexion (°)	7.4±5.8	7.0±6.1	0.86
Ankle Plantarflexion (°)	47.0±8.1	48.2±5.2	0.60
Foot Inversion (°)	34.5±9.8	31.9±9.4	0.44
Foot Eversion (°)	12.2±4.6	13.6±5.9	0.44

BMC = bone mineral content

the sport, possible asymmetries created by kicking may be dominated and negated by running.

Asymmetries attributable to lateral dominance are apparent in athletes of other sports, but there have not been between-limb lower extremity studies outside of soccer. The authors citing asymmetries have primarily studied athletes in upper limb sports that do not contend with weight-bearing functions of standing and running. Volleyball players have reported with marked muscle and postural asymmetries, while tennis players have demonstrated skeletal asymmetry due to repetition of high intensity dominant limb motion.³³⁻³⁶ Without the responsibility of weight bearing, perhaps the upper limb is more susceptible to unilateral tissue adaptation. In soccer, running applies constant bilateral forces that may essentially negate lower limb asymmetry.

Symmetry Theory #2) Longitudinal Effect of Playing Time

Although expecting a longer playing career to result in the summation of asymmetrical kicking forces and subsequently greater lower limb asymmetries as proposed by Gur et al.,³⁷ other researchers suggest soccer players with longer professional careers presented with lesser lateral imbalances.⁵ This chronicity-dependent process is more sensible when considering the nature of high-level soccer: competence with the non-dominant limb is often necessary for success.³⁸ If professional soccer facilitates bilateralism, as most players become serviceable with the non-dominant limb to perform at the highest levels, then subsequent between-limb symmetry is sensible.^{29,38} As players' careers lengthen and the level of play heightens, the development of the non-dominant limb becomes more important. Furthermore, more qualified players display greater movement coordination and improved muscular activity differentiation in a sport that requires maximum efficiency of motor action.³⁹ Despite inherent dominance to one side, perhaps elite soccer players demonstrate symmetry.

The present cohort, however, is not comprised of professional players, however, these were amateurs playing at the highest level of university soccer in the United States. Fousekis et al.⁵ reported an absence of asymmetry in players whose professional careers had continued for more than 11 years, however the

present participants have not played professionally. Longitudinal information about length of playing careers was not obtained, but may have been useful; perhaps the youth careers of these players were in high-level environments, and the players developed non-dominant foot competence from an early age. Sport-specific development even from a young age can result in adaptations, greater psoas major cross-sectional area is displayed in early adolescent soccer players, while tennis players can develop structural asymmetries from a young age.^{3,35} Thus, the overall symmetry displayed by the present participants could coincide with the longitudinal effects of high level soccer extrapolated to the collegiate level. A longitudinal study of soccer athletes highlighting training logs and bilateral competence could help illuminate this theory of a chronicity-dependent soccer career working towards lower limb symmetry.

Symmetry Theory #3) Compensation for Dominant Limb Proficiency/Coordination

Functional compensation for lower limb differences in force production and function may allow symmetry to present itself despite underlying factors. While most literature on soccer kicking focuses on the lower limb, even noting hip flexion as the initiating motion, the entire kinetic chain is involved, including the spine and pelvis before moving the distal lower limb.^{16,40} The backswing phase requires lumbar spine rotation and extension to facilitate trunk rotation to the kicking leg; furthermore, the spine's functional mechanism both stabilizes and balances the body during upright activity while also transmitting forces to the pelvis and then throughout the lower extremities.⁴⁰⁻⁴¹ The spine, ever active in the weight-bearing lower limb, has even been acknowledged in a recent pilot study with kicking performance in soccer, demonstrating lumbar spine and sacroiliac joint manipulation provided short-term benefit for increased kicking speed.⁴⁰ The asymmetric force distribution created by soccer kicking may not be directly visible within the lower limb; rather, may be referred proximally up the kinetic chain, with the spine receiving the majority of the stress and strain. Functional spinal compensation for unilateral force production during soccer kicking may be a possible explanation for lower limb symmetry in soccer players.

Figure 1. Graphic depiction of speculative theories describing between-limb symmetry in soccer players. Despite factors hypothetically attributing to asymmetry (repetitive unilateral kicking and differing limb functions during a kick), the expected asymmetry does not match the presented symmetry. Thus, a number of theories are proposed as explanations for this symmetry, shown on the right side of the graphic.

Limitations and Future Research

The limited sample size and lack of longitudinal player injury data impact the generalizability of the current study; however, further research should expand on these concepts. Longitudinal information about length of playing careers or playing levels was not obtained, but may be useful for expanding on Theory #2. Addressing only lower limb adaptations may be insufficient in viewing soccer players; perhaps, additional research considering the trunk and spine could illuminate factors further up the kinetic chain that impact symmetry or asymmetry. Future research should explore why symmetry may be present in soccer players despite inherent lateral dominance and varying between-limb force disparities from the kicking motion.

Previous authors have proposed that asymmetries are a characteristic adaptation in experienced soccer players⁴⁻⁷ despite growing evidence supporting between-limb symmetry in healthy players.^{6,12,17-21} In some cases, asymmetries in soccer players have been linked to increased injury risk.¹⁰⁻¹¹ The growing evidence in favor of symmetry would solidify clinical advice that lower leg asymmetries are likely representative of a pathomechanical adaptation. Thus, sports medicine professionals should strive to preserve or achieve lower limb symmetry in range of motion, muscle strength, and body composition in male soccer players as a potential strategy to reduce

or prevent injuries. The authors further propose that the identification of asymmetries by researchers and health professionals should be addressed in injury prevention and exercise prescription. Rather than assuming the presence of lower limb asymmetry in soccer players, future research should seek to understand why symmetry exists by addressing the proposed theories above.

CONCLUSION

No asymmetries existed in any of the measures tested in a cohort of Division I male soccer players including body composition, muscle strength, or range of motion. Thus, contrary to the authors' hypothesis and in agreement with much of the literature, healthy male collegiate soccer players demonstrate remarkable lower limb symmetry. This symmetry prompted three speculative theories on how lateral dominance may be attenuated by other factors within playing soccer that warrant further investigation.

REFERENCES

1. Luhtanen P. Kinematics and kinetics of maximal instep kicking in junior soccer players. In: *Science and Football*. London: E & FN Spon. 1988;449-455.
2. Rahnema N, Lees A, Bambaecichi E. A comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. *Ergonomics*. 2005;48:1568-1575.
3. Hoshikawa Y, Iida T, Ii N, et al. Cross-sectional area of psoas major muscle and hip flexion strength in youth soccer players. *Eur J Appl Physiol*. 2012;112:3487-3494.
4. Brady E, O'Regan M, McCormack B. Isokinetic assessment of uninjured soccer players. In: *Science and Football II*. London: E & FN Spon. 1993;351-356.
5. Fousekis K, Tsepis E, Vagenas G. Lower limb strength in professional soccer players: profile, asymmetry, and training age. *J Sports Sci Med*. 2010;9:354-373.
6. Kubo T, Muramatsu M, Hoshikawa Y, et al. Profiles of trunk and thigh muscularity in youth and professional soccer players. *J Strength Cond Res*. 2010;24:1472-1479.
7. Costa Silva JRL, Detanico D, Dal Pupo J, et al. Bilateral asymmetry of knee and ankle isokinetic torque in soccer players u20 category. *Braz J Kinathrop Hum Perform*. 2015;17:195-204.
8. Oliveira ASC, Barbieri FA, Gonçalves M. Flexibility, torque, and kick performance in soccer: Effect of dominance. *Sci Sport*. 2013;28:e65-e68.

9. Lees A, Nolan L. The biomechanics of soccer: a review. *J Sports Sci.* 1998;16:211-234.
10. Soderman K, Alfredson H, Pietila T, et al. Risk factors for leg injuries in female soccer players: A prospective investigation during one out-door season. *Knee Surg Sports Traumatol Arthrosc.* 2001;9:313-321.
11. Croisier JL, Ganteaume S, Binet J, et al. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med.* 2008;36:1469-1475.
12. Daneshjoo A, Rahnama N, Mokhtar AH, et al. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional soccer players. *J Hum Kinet.* 2013;36:45-53.
13. Idoate F, Calbet JAL, Izquierdo M, et al. Soccer attenuates the asymmetry of rectus abdominis muscle observed in non-athletes. *PLoS ONE.* 2011;6(4).
14. Aginsky KD, Neophytu N. Isokinetic hamstring and quadriceps muscle strength profiles of elite South African football players. *Afr J Phys Health Educ Recr Dance.* 2014;20:1225-1236.
15. Blache Y, Monteil K. Contralateral strength imbalance between dominant and non-dominant lower limb in soccer players. *Sci Sport.* 2012;27:e1-e8.
16. Dörge HC, Bull Andersen T, Sorensen H, et al. Biomechanical differences in soccer kicking with the preferred and the non-preferred leg. *J Sports Sci.* 2002;20:293-299.
17. Costain R, Williams AK. Isokinetic quadriceps and hamstring torque levels of adolescent, female soccer players. *J Orthop Sports Phys Ther.* 1984;5:196-200.
18. Rochcongar P, Morvan R, Jan J, et al. Isokinetic investigation of knee extensors and knee flexors in young French soccer players. *Int J Sports Med.* 1988;9:448-450.
19. Capranica L, Cama, Fanton F, et al. Force and power of preferred and non-preferred leg in young soccer players. *J Sports Med Phys Fitness.* 1992;32:358-363.
20. Masuda K, Kikuhara N, Takahashi H, et al. The relationship between muscle cross-sectional area and strength in various isokinetic movements among soccer players. *J Sports Sci.* 2003;21:851-858.
21. Zakas A. Bilateral isokinetic peak torque of quadriceps and hamstring muscles in professional soccer players with dominance on one or both two sides. *J Sports Med Phys Fitness.* 2006;46:28-35.
22. Hides J, Fan T, Stanton W, et al. Psoas and quadratus lumborum muscle asymmetry among elite Australian Football League players. *Br J Sports Med.* 2010;44:563-567.
23. Tufts University, The Body Composition Analysis Center at Tufts University Standard Operating Procedures for Whole-Body DXA Scans Performed for Body Composition Measurements and Regional (Hip and Spine) DXA Scans Performed for Bone Mineral Density Studies. URL: <http://bcac.nutrition.tufts.edu/docs/DEXASOP.pdf>; accessed June 3, 2014.
24. Bohannon RW. Test-retest reliability of hand-held dynamometry during a single session of strength assessment. *Phys Ther.* 1986;66:206-209.
25. Kelln BM, McKeon PO, Gontkof LM, et al. Hand-held dynamometry: Reliability of lower extremity muscle testing healthy, physical active, young adults. *J Sport Rehabil.* 2008;17:160-170.
26. Norkin CC, White DJ. *Measurement of joint motion: a guide to goniometry (4th ed.)*. Philadelphia, PA: FA Davis Company; 2009.
27. Arnason A, Sigurdsson SB, Gudmundsson A, et al. Physical fitness, injuries, and team performance in soccer. *Med Sci Sports Exerc.* 2004;36:278-285.
28. Silvestre R, West C, Maresh CM, et al. Body composition and physical performance in men's soccer: a study of a National Collegiate Athletic Association Division I team. *J Strength Cond Res.* 2006;20:177-183.
29. McLean BD, Tumilty DM. Left-right asymmetry in two types of soccer kick. *Br J Sports Med.* 1993;27:260-262.
30. Rampinini E, Impellizzeri FM, Catagna C, et al. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *J Sci Med Sport.* 2009;12:227-233.
31. Stölen T, Chamari K, Castagna C, et al. Physiology of soccer: An update. *Sports Med.* 2005;35:501-536.
32. Bradley PS. High-intensity activity profiles of elite soccer players at different performance levels. *J Strength Cond Res.* 2010;24:2343-2351.
33. Krahl H, Michaelis U, Pieper H, et al. Stimulation of bone growth through sports. A radiologic investigation of the upper extremities in professional tennis players. *Am J Sports Med.* 1994;22:751-757.
34. Markou S, Vagenas G. Multivariate isokinetic asymmetry of the knee and shoulder in elite volleyball players. *Eur J Sport Sci.* 2006;6:71-80.
35. Bussey MD. Does the demand for asymmetric functional lower body postures in lateral sports relate to structural asymmetry of the pelvis? *J Sci Med Sport.* 2010;13:360-364.
36. Varekova R, Vareka I, Janura M, et al. Evaluation of postural asymmetry and gross joint mobility in elite female volleyball athletes. *J Hum Kinet.* 2011;29:5-13.
37. Gür H, Akova B, Pündük Z, et al. Effects of age on the reciprocal peak torque ratios during knee muscle

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- contractions in elite soccer players. *Scand J Med Sci Sports*. 1999;9:81-87.
38. Grouios G, Kollias N, Koidou I, et al. Excess of mixed-footedness among professional soccer players. *Percept Mot Skills*. 2002;94:695-699.
39. Koshelskaja EV, Kapilevich LV, Bajenov VN, et al. Physiological and biomechanical characteristics of the kick and goal techniques of football players. *Exp Biol Med*. 2012;153:266-268.
40. Deutschmann KC, Jones AD, Korpelaar CM. A non-randomised experimental feasibility study into the immediate effect of three different spinal manipulative protocols on kicking speed performance in soccer players. *Chiropr Man Ther*. 2015;23.
41. Gilchrist RV, Frey ME, Nadley SF. Muscular control of the lumbar spine. *Pain Physician*. 2003;6:361-368.