Lower limbs muscle activation during instep kick in soccer: effects of dominance and ball condition

Journal:	*Science and Medicine in Football*
Manuscript ID	RSMF-2020-0260.R1
Manuscript Type:	Original Papers
Keywords:	kicking, EMG, moving ball, sports motion

Abstract:	Muscle activation during soccer kicking has been studied exclusively with players kicking stationary balls with the dominant foot. This study evaluated swinging and support limb muscle activation during the same kind of kick (instep) using different feet and ball approach conditions. Vastus medialis (VM), biceps femoris (BF), gastrocnemius medialis (GM) and tibialis anterior (TA) activations were evaluated during maximal instep kicks performed with both feet and with the ball in five conditions (n=18): stationary (STAT), approaching anteriorly (ANT), posteriorly (POST), laterally (LAT) and medially (MED). A repeated-measures two-way ANOVA compared muscle activations between feet and ball conditions throughout the kicking (0-100%) and follow-through phases (101-200%). Close to ball contact (81-124%), non-dominant support GM had greater activation compared to the dominant one. The LAT and MED conditions differed at certain points of the cycle in the swinging VM (0-21%; 191-200%), BF (13-70%; 121-161%), GM (22-82%; 121-143%) and TA (0-32%; 55-97%; 186-200%) and in support VM (0-81%), BF (6-24%; 121-161%) and GM (24-87%). Players require greater support GM activation to stabilize the ankle joint during non-dominant kicks. Furthermore, lower limb muscle activation differences between LAT and MED indicate that the kicking strategies are altered when kicking balls approaching from different conditions.

Lower limbs muscle activation during instep kick in soccer: effects of dominance and ball condition

MS RSMF-2020-0260 submitted to Science and Medicine in Football– R1 22 December 2020

Conflict of Interest Disclosure: The authors report no conflict of interest

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Abstract

Muscle activation during soccer kicking has been studied exclusively with players kicking stationary balls with the dominant foot. This study evaluated swinging and support limb muscle activation during the same kind of kick (instep) using different feet and ball approach conditions. Vastus medialis (VM), biceps femoris (BF), gastrocnemius medialis (GM) and tibialis anterior (TA) activations were evaluated during maximal instep kicks performed with both feet and with the ball in five conditions (n=18): stationary (STAT), approaching anteriorly (ANT), posteriorly (POST), laterally (LAT) and medially (MED). A repeated-measures two-way ANOVA compared muscle activations between feet and ball conditions throughout the kicking (0-100%) and follow-through phases (101-200%). Close to ball contact (81-124%), non-dominant support GM had greater activation compared to the dominant one. The LAT and MED conditions differed at certain points of the cycle in the swinging VM (0-21%; 191-200%), BF (13-70%; 121-161%), GM (22-82%; 121-143%) and TA (0-32%; 55-97%; 186-200%) and in support VM (0-81%), BF (6-24%; 121-161%) and GM (24-87%). Players require greater support GM activation to stabilize the ankle joint during non-dominant kicks. Furthermore, lower limb muscle activation differences between LAT and MED indicate that the kicking strategies are altered when kicking balls approaching from different conditions.

Keywords: kicking, EMG, moving ball, sports motion

Word count: 3477

Introduction

Kicking is among the most important actions in soccer, allowing players to move the ball with precision, passing to better-positioned teammates trying to score. However, it is a dynamic movement that requires high levels of power and coordination[1]. When kicking, players must position their support foot at an appropriate distance from the ball, accelerate the thigh and shank segments of the swinging leg and reach maximum foot speed near ball contact.[2,3] To be successful, all involved muscles must be activated with correct timing and magnitude. At the swinging limb, muscles acting at the knee and ankle joints must work together to accelerate the shank and efficiently contact the ball and then stop it during follow-through,[4,5] while the support limb muscles position the body's center of mass at an optimal point.

Although kicking is a multi-plane task, most of the movement occurs in the sagittal plane, with the vastus medialis (VM), biceps femoris (BF), gastrocnemius medialis (GM) and tibialis anterior (TA) muscles being often investigated during instep kicking through surface electromyography (EMG).[5–9] Particularly, Scurr et al.[6] found increased swinging VM activation when accurately instep kicking a ball (with the right foot) at the top-right corner compared to other corners, while Manolopoulos et al.[7] found increased VM activation after a period of training, observing no differences in swinging BF and support GM and BF. Kellis et al.[8] found increased support BF activation when starting the approach run from 90° or 45° compared to 0°. Meanwhile, Katis et al.[5] observed increased TA and BF and decreased gastrocnemius activation when kicking accurately at a high target (vs inaccurate kicks) and decreased TA activation when accurately kicking at a low target. Finally, Cerrah et al.[9] found a trend of positive correlations between ball velocity and VM activation when performing inside-foot kicks and a negative trend between ball velocity and BF and GM when outside-foot kicks were performed. Furthermore, since non-contact actions are responsible for more than half of soccer injuries,[10] and kicking represents a good portion of them,[11] other studies have used EMG to better understand the demands of this task on the involved muscles in both the swinging and the support limbs.[12–14] Particularly, the swinging thigh muscles play a role in protecting the joint from ligament injury and muscle strain,[14,15] while the support limb muscles deal with forces similar to those of running at 3.8 m/s, putting additional strain in those muscles and possibly leading to injuries when activation is inadequate.[8]

During matches, the situations in which a player kicks vary according to field location, position of other players and from where the ball is approaching. Players often find themselves in situations where the most appropriate kicking action is with the non-dominant foot. Therefore, being able to successfully kick with both feet is highly desirable in soccer.[16] Furthermore, players mostly kick moving balls. In fact, they rarely kick stationary balls outside of "set pieces" (corners, free kicks and penalties). Kicking a moving ball is more complex because it requires high levels of prospective control, where players must adjust the kicking motion's speed and timing to achieve optimal ball contact.[17]

Despite frequent occurrences of soccer kicks performed with the non-dominant foot and with moving balls, it is unknown how agonist and antagonist muscles activate while performing them. Greater understanding of this topic could help players and coaches to target training, seeking to improve performance and avoid injuries when performing these kicks. Therefore, our goal was to identify differences in activation patterns of selected lower limb muscles, in both swinging and support limbs, when kicking a stationary or a moving ball approaching from four different angles, with both dominant and non-dominant feet. We hypothesized that there would be different activation of the muscles investigated close to the moment of ball contact and immediately after ball contact, when kicking with the dominant limb and when kicking a stationary ball or approaching from the side, as these conditions seem to be the least challenging.

Methods

Subjects

Eighteen young male experienced non-professional soccer players volunteered (9 defenders, 6 midfielders, 3 forwards; 10 right-footed, 8 left-footed; Table 1). They participated weekly in at least two training sessions and a match with teams involved in competitions organized by the national federation. Subjects who experienced any severe lower limb injuries in the previous six-months or actual physical pain on the day of data collection were excluded. Dominance was assessed using the Waterloo Footedness Questionnaire-Revised.[18] Approval from the University's ethics committee was obtained (protocol number: 55/19) and all subjects gave informed written consent after having the protocol explained and any questions about the benefits and risks of the study answered.

<<TABLE 1>>

Experimental procedures

Subjects wore tight-fitting shorts and indoor soccer shoes. Passive reflective markers were positioned on the ball and on both shoes in correspondence to the calcaneus and the second and fifth metatarsal heads. After careful skin preparation (shaving and cleaning with alcohol), disc-shaped silver-silver chloride bipolar (diameter: 24mm; interelectrode distance: 2cm; Covidien, Dublin, Ireland) were placed over the muscle bellies and aligned with expected muscle fiber orientation of the VM, BF, GM and TA of both limbs.[19] FreeEMG 300 (BTS S.p.A, Garbagnate Milanese, Italy), with a sampling rate of 1000 Hz, 16bit resolution and differential amplifiers (bandwidth: 10-500 Hz) with common mode rejection ratio >110 dB at 50–60 Hz and an input impedance >10 GΩ was used to record muscle activation.

The laboratory was equipped with artificial turf and a nine-camera optoelectronic motion analyzer, sampling at 60 Hz (BTS S.p.A, Garbagnate Milanese, Italy). Players warmed-up for five minutes on a stationary bike and with ten minutes of soccer-specific exercises. After performing the desired amount of practice trials, subjects were instructed to kick a stationary ball (5-size FIFA approved) as fast as possible into a net to find the maximal functional activation of the selected muscles.[5,7] Three maximum trials were performed with each foot. All kicks were performed with the instep portion of the foot, to achieve maximal ball speed.[9,20]

<<FIGURE 1>>

Next, volunteers performed three kicks with the ball in each of the following conditions: (1) stationary (STAT), rolling ball approaching from the subject's (2) anterior side (ANT), (3) posterior side (POST), (4) perpendicular from the kicking foot's lateral side (LAT), (5) perpendicular from the kicking foot's medial side (MED). Participants were asked to kick the ball as fast as possible, starting the run at a 45° angle two meters from the kicking point, hitting a target (1.2 m x 1.2 m) in a net positioned three meters away. Figure 1 depicts the starting positions during the protocol. All kicks were performed with the dominant and non-dominant feet and the order of conditions and feet were randomized between subjects. Three valid trials (hitting the target and contacting ball with foot's instep portion) were recorded for each kick condition (30-second rest). During rolling ball trials, the ball was released from a small ramp positioned two meters away from the kicking point (average speed: 2 m/s).

Data processing

Kicks were divided into two phases based on three events: kicking phase (from swinging toe-off until ball contact) and follow-through phase (from ball contact until maximum foot height) (Figure 2). Events were manually identified through visual inspection of the video in which the position of the reflective markers placed on the shoes and on the ball could be observed during kicking, which was synchronized with EMG data. Average phases duration and total kick time were measured for all kicks.

<<FIGURE 2>>

Electromyographical data were rectified and filtered using a 4^{th} order Butterworth filter (high-pass: 20 Hz; low-pass: 6 Hz). Peak muscle activation for all the eight muscles was obtained from the maximum kicks and used for normalization. Normalization using peak EMG values during ballistic tasks has been shown to be highly reliable for all four muscles evaluated in this study[21] and has been previously used in kicking EMG studies.[5,7] Each phase was resampled on 100 time points, thus muscle activation during the kicking and follow-through phases was described by a 200-samples curve. These time series were averaged between the three trials of each condition.

Statistical analysis

G*Power (version 3.1.9.6; University of Trier, Trier, Germany) was used to calculate the appropriate *a priori* sample size. A repeated-measures ANOVA, within-between interaction (F tests family) was used, with significance level set at $p = .05$ and power set at 0.95 to detect medium effects ($f > 0.35$). A minimum of 18 subjects was required.

Prior to all analyses, a Shapiro-Wilk test confirmed that data were normally distributed. A two-way (5 x 2) ANOVA was performed to measure differences between the factors: condition and foot. For duration, average phases and total kick time were compared and partial eta squared (η_p^2) was calculated, while for muscle activation the kicking cycles time series was compared using Statistical Parametric Mapping (SPM). Bonferroni post-hoc tests explored eventual differences between conditions. SPM allows the analysis of the whole movement cycles, drawing conclusions based on the behavior of the variable through time, avoiding loss of information due to discretization.[22] All statistical analyses were performed using MATLAB (Version R2020a; Mathworks Inc., Natwick, USA).

Results

For phase durations, there were no differences in kicking phase, follow-through phase and total kick between feet, conditions or interaction between factors (all $p > 0.05$), with η_p^2 values between 0.019 and 0.166 (Table 2).

<<TABLE 2>>

In the swinging VM (Figure 3A), at the beginning of the kicking phase (from 0 to 21%) and at the end of follow-through (191 to 200%), MED condition had higher activation than LAT. Swinging BF (Figure 3B) activation was higher in MED than in LAT throughout most of the kicking phase (from 13 to 70%), while LAT was higher than MED during part of the follow-through phase (from 121 to 161%).

For swinging GM (Figure 4A), MED had higher activation than LAT for most of the kicking phase (from 22 to 82%), while it had lower activation during part of the follow-through (from 121 to 143%). Swinging TA activation (Figure 4B) was higher in MED than in LAT in both the kicking phase (from 0% to 32% and 55% to 97%) and at the end of follow-through (from 186% to 200%).

<<FIGURE 3>>

<<FIGURE 4>>

Support VM (Figure 5A) activation was lower in MED than in LAT for most of the kicking phase (from 0 to 81%), without differences at ball contact and follow-through. In the support BF (Figure 5B), there was lower MED activation in the kicking phase (from 6 to 74%) and higher MED activation during follow-through (from 121 to 161%) when compared to LAT.

In the support GM (Figure 6A), MED presented lower activation than LAT in the kicking phase (from 24 to 87%). Support TA presented no differences between conditions (Figure 6B).

Differences between feet were found exclusively in support GM, from 81% to 124% of the cycle (Figure 6A). When kicking with the dominant foot, support GM presented lower peak activation midway through the kicking phase, which rapidly decreased, plateauing in the beginning of follow-through. Meanwhile, non-dominant foot kicks presented a delay in peak activation, which was followed by a much slower decrease in activation throughout the kicking cycle. Furthermore, there was an interaction between the foot and condition factors close to ball contact (from 82 to 125%), where the MED condition did not seem to present differences between feet.

<<FIGURE 5>>

<<FIGURE 6>>

Discussion

Kicking balls approaching from different angles and with both feet are necessary skills in competitive soccer, and players may need to use different muscle activation strategies to perform them successfully. We found that soccer players presented significant differences in the activation of four swinging limb muscles (VM, BF, GM and TA) between LAT and MED conditions in both the kicking and the follow-through phase, while no differences were found between feet. In the support limb, significant differences were found between LAT and MED in the kicking phase for the VM, BF and GM muscles and in the follow-through phase for BF, while non-dominant GM activation was higher close to ball impact. These differences, however, did not seem to affect kicking phase durations.

The kicking duration results suggest that players didn't need to adjust speed to correctly execute different kicks. These findings agree with previous studies that found no differences in kicking duration between feet when performing a drive kick[23] and a side-foot kick.[24] However, our results contrast with Egan et al.,[17] who found that the duration of parts of the kicking movement was shorter when kicking a stationary compared to a moving ball. This difference can be explained by the different events chosen to define the kick and by the slower approaching ball speed used in our study (2 m/s vs 3 m/s).

Between conditions, differences were found in all muscles, except for support-side TA, occurring exclusively between MED and LAT. These results can probably be explained by the technique of the two kicks, which seem to be the most different between the five conditions. In MED, players let the ball pass through before landing the support foot, so that the ball does not hit it on its way to the kicking spot, while in LAT they can position the foot where they like and still hit the ball with good timing by altering the movement of the swinging limb. Changes in support foot position in relation to the ball are reportedly important when performing a more successful kick (with the dominant foot) compared to a less successful one (with the non-dominant foot).[23] Moreover, in LAT, players face the ball while it approaches, while in MED they must turn their head to follow it. These changes in gaze fixation may lead to postural changes between conditions,[25,26] affecting the kicking pattern. Although the other conditions also had differences in the movement, players didn't seem to require significantly different muscle activation patterns to perform them. In particular, the lack of differences involving the STAT condition is somewhat unexpected, since it is reportedly a more complex task.[17]

The swinging VM muscle, which extends the knee joint to accelerate the kicking foot, usually peaks shortly before ball contact.[27] Although this activation peak was similar between all conditions, we found in MED a higher activation at the beginning of the kicking phase (while the knee is flexing) and at the end of follow-through (when the foot decelerates) when compared to LAT. This behavior is not optimal since VM activation reduces the knee flexion torque which is required at those particular moments. Meanwhile, the swinging BF was more active in MED compared to LAT through most of the kicking phase, which may have resulted in greater knee flexion prior to the start of the leg forward motion, which occurs at approximately 75% of the kicking phase.[12] The BF muscle eccentrically decelerates the swinging foot after ball contact to prevent the knee from hyperextending. We found lower BF activation in the early stages of the follow-through in MED compared to LAT, which could suggest a decreased contribution of this muscle in decelerating the shank after ball contact. However, the other hamstring muscles also highly contribute to this task and the BF also performs other movements around the knee and hip joints, which could contribute to the differences found. These differences between conditions could have been the result of the different demands that each kick requires from the players, with the MED and LAT possibly being the most different among the conditions.

The muscles acting on the ankle joint (TA and GM) of the swinging limb control the foot's position in relation to the ball, with greater TA activation resulting in a higher ball trajectory.[28] During the kicking phase in the MED condition, both TA and GM were more active than in LAT, suggesting that players had a "stiffer" ankle joint when executing this kick.

The support limb plays a very important role in soccer kick performance, positioning the body in the right place to contact the ball at an optimal angle while supporting loads even higher than those of the swinging limb.[29] When kicking in the MED condition, players had lower support VM, BF and GM activation during most of the kicking phase when compared to LAT. All the differences found in the support limb between MED and LAT can be justified by the different strategies used by players to land the support foot at an optimal position during different kicks.

When comparing muscle activation between kicks with the dominant and non-dominant feet, the only muscle that presented any differences during the kicking cycle was the support GM, which had greater activation across the end of the kicking phase and the beginning of the follow-through when kicking with the non-dominant limb. It peaked at around 60% of the kicking phase, which corresponds to the moment when the support foot lands and the swinging hip has reached its maximal extension before starting to accelerate forward.[12] When kicking with the dominant foot, support GM activation decreased rapidly after its peak, reducing at the moment of ball contact. Meanwhile, when kicking with the non-dominant foot, the activation had a higher peak and decreased more slowly, still being high during ball contact and only reaching low values midway into the follow-through phase. This higher activation of the support GM close to ball contact when kicking with the non-dominant foot is probably a mechanism used by players to further stabilize the ankle joint when performing a more challenging movement, since this muscle plays an important stabilizer role in single-leg tasks.[30,31]

By knowing how lower limb muscles behave during different kicks or when kicking with different feet, coaches and athletes could develop training plans that improve kicking performance. Furthermore, we developed a protocol to evaluate muscle activation during kicking that is closer to the reality of competitive matches, possibly contributing to the development of normative data, which can ultimately allow sport scientists to compare their players' activation curves shape to those already found in different populations. This comparison can help identify players that have different patterns or activation asymmetries that can put them at risk of injury or result in worse kicking performance. Furthermore, since kicks performed with different feet and conditions result in distinct activation patterns, it could be advantageous to practice in a variety of situations, changing the stimulus as much as possible to adapt players to several in-game kicking situations.

We evaluated the activation of four lower limb muscles of experienced soccer players, both of the swinging and the support limbs, throughout the kicking cycle. To the best of our knowledge, no prior study has used EMG to measure the influence of dominance or ball condition on the kicking movement, having been limited to investigate kicks with a stationary ball performed with the dominant foot.

However, we must acknowledge some limitations. We evaluated only four muscles on each limb, but other muscles, particularly those that produce movement in other planes of movements, also contribute to kicking performance. Although normalization using maximum functional movement is reliable and more ecological than maximal isometric voluntary contractions,[5,7,21] for this study protocol, it might have mitigated eventual differences between limbs. In addition, activation of some muscles during surface EMG can be affected by crosstalk.[32] Furthermore, no performance indicators were measured, such as ball velocity, accuracy or perceived kicking difficulty, which could have helped determine if and how different activation patterns alter kicking quality. During competitive matches, an infinite number of combinations of ball angle of approach, distance and speed can be seen, however for this laboratory study, a limited number of conditions was defined. No kinematic measurements were performed during the kicks, which didn't allow us to divide the kicking phase in further sub-phases[12,33] and to associate the position of the subjects' lower limbs with the corresponding muscle activation at any given point. Finally, our sample was composed of adult male soccer players, however, different populations (females, younger subjects) may display different approaches to respond to the conditions presented.

In conclusion, we investigated the activation differences of the VM, BF, GM and TA muscles when the instep kick is performed in different conditions with both feet. We found that the support GM has an earlier activation peak and a lower activation magnitude near ball contact when kicking the ball with the dominant foot. We also found that all muscles investigated (except the support TA) had differences during the cycle when comparing the LAT to the MED conditions, but without any differences when comparing to the other conditions (STAT, ANT and POST).

Coaches should incorporate different angles of ball approach and kicks with the non-dominant foot in their practices, since there are several differences in muscle activation patterns between conditions and feet. Ultimately, this can lead to players being better prepared to perform these tasks during in-game situations. Future studies should perform similar protocols, measuring activation of more muscles combined with kinematic data in order to provide more specific recommendations to improve kicking performance.

References

1. Naito K, Fukui Y, Maruyama T. Multijoint kinetic chain analysis of knee extension during the soccer instep kick. *Hum Mov Sci*. 2010;29(2):259-276.
2. Nunome H, Ikegami Y, Kozakai R, Apriantono T, Sano S. Segmental dynamics of soccer instep kicking with the preferred and non-preferred leg. *J Sports Sci*. 2006;24(5):529-541.
3. Palucci Vieira LH, Barbieri FA, Kellis E, et al. Organisation of instep kicking in young U11 to U20 soccer players. *Sci Med Footb*. Published online 2020.
4. Severin AC, Mellifont DB, Sayers MGL. Influence of previous groin pain on hip and pelvic instep kick kinematics. *Sci Med Footb*. 2017;1(1):80-85.
5. Katis A, Giannadakis E, Kannas T, Amiridis I, Kellis E, Lees A. Mechanisms that influence accuracy of the soccer kick. *J Electromyogr Kinesiol*. 2013;23(1):125-131.
6. Scurr JC, Abbott V, Ball N. Quadriceps EMG muscle activation during accurate soccer instep kicking. *J Sports Sci*. 2011;29(3):247-251.
7. Manolopoulos E, Papadopoulos C, Kellis E. Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. *Scand J Med Sci Sport*. 2006;16(2):102-110.
8. Kellis E, Katis A, Gissis I. Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Med Sci Sports Exerc*. 2004;36(6):1017-1028.
9. Cerrah AO, Soylu AR, Ertan H, Lees A. The effect of kick type on the relationship between kicking leg muscle activation and ball velocity. *Montenegrin J Sport Sci Med*. 2018;7(1):39-44.
10. Hawkins RD, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. *Br J Sports Med*. 1999;33(3):196-203.
11. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. *Br J Sports Med*. 2002;36(5):354-359.
12. Brophy RH, Backus SI, Pansy BS, Lyman S, Williams RJ. Lower extremity muscle activation and alignment during the soccer instep and side-foot kicks. *J Orthop Sports Phys Ther*. 2007;37(5):260-268.
13. Brophy RH, Backus S, Kraszewski AP, et al. Differences between sexes in lower extremity alignment and muscle activation during soccer kick. *J Bone Jt Surg - Ser A*. 2010;92(11):2050-2058.

14. Cordeiro N, Cortes N, Fernandes O, Diniz A, Pezarat-Correia P. Dynamic knee stability and ballistic knee movement after ACL reconstruction: an application on instep soccer kick. *Knee Surgery, Sport Traumatol Arthrosc*. 2015;23(4):1100-1106.

15. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: Factors that Lead to injury and re-Injury. *Sport Med*. 2012;42(3):209-226.

16. Carey DP, Smith G, Smith DT, et al. Footedness in world soccer: An analysis of France '98. *J Sports Sci*. 2001;19(11):855-864.

17. Egan CD, Verheul MHG, Savelsbergh GJP. Effects of experience on the coordination of internally and externally timed soccer kicks. *J Mot Behav*. 2007;39(5):423-432.

18. Elias LJ, Bryden MP, Bulman-Fleming MB. Footedness is a better predictor than is handedness of emotional lateralization. *Neuropsychologia*. 1998;36(1):37-43.

19. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361-374.

20. Lees A, Nolan L. The biomechanics of soccer: A review. *J Sports Sci*. 1998;16(3):211-234.

21. Suydam SM, Manal K, Buchanan TS. The advantages of normalizing electromyography to ballistic rather than isometric or isokinetic tasks. *J Appl Biomech*. 2017;33(3):189–196.

22. Pataky TC. Generalized n-dimensional biomechanical field analysis using statistical parametric mapping. *J Biomech*. 2010;43(10):1976-1982.

23. McLean BD, Tumilty DMA. Left-right asymmetry in two types of soccer kick. *Br J Sports Med*. 1993;27(4):260-262.

24. Zago M, Motta AF, Mapelli A, Annoni I, Galvani C, Sforza C. Effect of Leg Dominance on The Center-of-Mass Kinematics During an Inside-of-the-Foot Kick in Amateur Soccer Players. *J Hum Kinet*. 2014;42(1):51-61.

25. Raffi M, Piras A, Persiani M, Perazzolo M, Squatrito S. Angle of gaze and optic flow direction modulate body sway. *J Electromyogr Kinesiol*. 2017;35:61-68.

26. Fiorelli CM, Polastri PF, Rodrigues ST, et al. Gaze position interferes in body sway in young adults. *Neurosci Lett*. 2017;660(November 2016):130-134.

27. Cerrah AO, Gungor EO, Soylu AR, Ertan H, Lees A, Bayrak C. Muscular activation patterns during the soccer in-step kick. *Isokinet Exerc Sci*. 2011;19(3):181-190.

28. Katis A, Giannadakis E, Kannas T, Amiridis I, Kellis E, Lees A. Mechanisms that influence

accuracy of the soccer kick. *J Electromyogr Kinesiol*. 2013;23(1):125-131.

29. Lees A, Asai T, Andersen TB, Nunome H, Sterzing T. The biomechanics of kicking in soccer: A review. *J Sports Sci*. 2010;28(8):805-817.

30. Delahunt E, Monaghan K, Caulfield B. Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the ankle joint during a single leg drop jump. *J Orthop Res*. 2006;24(10):1991-2000.

31. Kim H, Palmieri-Smith R, Kipp K. Time-frequency analysis of muscle activation patterns in people with chronic ankle instability during Landing and cutting tasks. *Gait Posture*. 2020;82:203-208.

32. Wong YM, Straub RK, Powers CM. The VMO: VL activation ratio while squatting with hip adduction is influenced by the choice of recording electrode. *J Electromyogr Kinesiol*. 2013;23(2):443-447.

33. Nunome H, Asai T, Ikegami Y, Sakurai S. Three-dimensional kinetic analysis of side-foot and instep soccer kicks. *Med Sci Sports Exerc*. 2002;34(12):2028-2036.

Table 1. Demographics and anthropometrics of the participants.

	Mean	**SD**	**Range**
Age (years)	21.1	2.4	19 - 28
Weight (kg)	70.8	6.2	60 - 83
Height (cm)	177.4	5.5	167 - 186
Experience (years)	14.4	2.6	10 - 20
Training sessions/week (n)	2.6	0.8	2 - 5

376 Table 2. Kick phase duration and total kick time. Values are presented as mean and standard
377 deviation (mean ± SD).

	KICKING (s)	FOLLOW-THROUGH (s)	TOTAL (s)
CONDITION		**DOMINANT**	
STAT	0.23 ± 0.03	0.16 ± 0.02	0.39 ± 0.05
ANT	0.23 ± 0.03	0.16 ± 0.02	0.39 ± 0.05
POST	0.23 ± 0.02	0.18 ± 0.03	0.41 ± 0.03
LAT	0.23 ± 0.03	0.18 ± 0.06	0.41 ± 0.07
MED	0.23 ± 0.03	0.17 ± 0.04	0.40 ± 0.04
CONDITION		**NON-DOMINANT**	
STAT	0.24 ± 0.03	0.18 ± 0.04	0.41 ± 0.06
ANT	0.24 ± 0.02	0.17 ± 0.04	0.41 ± 0.05
POST	0.24 ± 0.02	0.18 ± 0.03	0.41 ± 0.03
LAT	0.23 ± 0.03	0.16 ± 0.04	0.39 ± 0.07
MED	0.23 ± 0.02	0.18 ± 0.04	0.41 ± 0.04
p values			
Condition	0.513	0.345	0.170
Feet	0.084	0.577	0.228
Interaction	0.328	0.068	0.122
Partial eta squared (η_p^2)			
Condition	0.041	0.061	0.098
Feet	0.166	0.019	0.084
Interaction	0.065	0.150	0.100

378 Ball approach: STAT: Stationary; ANT: Anterior; POST: Posterior; LAT: Lateral from kicking
379 foot; MED: Medial from kicking foot.
380

Figure 1 — Diagram showing the positions in which the ball and the subjects started in relation to the kicking point. When the ball comes from the sides the condition changes whether the subject is kicking with the right or left foot.

Figure 2 — Illustration of kicking events and relevant phases.

Figure 3 — Swinging vastus medialis (A) and biceps femoris (B) activation during kicking (1-100) and follow-through (101-200) phases. Curves are mean ± SD of all participants' trials.

Figure 4 — Swinging gastrocnemius medialis (A) and tibialis anterior (B) activation during kicking (1-100) and follow-through (1-100) phases. Curves are mean ± SD of all participants' trials.

Figure 5 — Support vastus medialis (A) and biceps femoris (B) activation during kicking (1-100) and follow-through (101-200) phases. Curves are mean ± SD of all participants' trials.

Figure 6 — Support gastrocnemius medialis (A) and tibialis anterior (B) activation during kicking (1-100) and follow-through (101-200) phases. Curves are mean ± SD of all participants' trials.

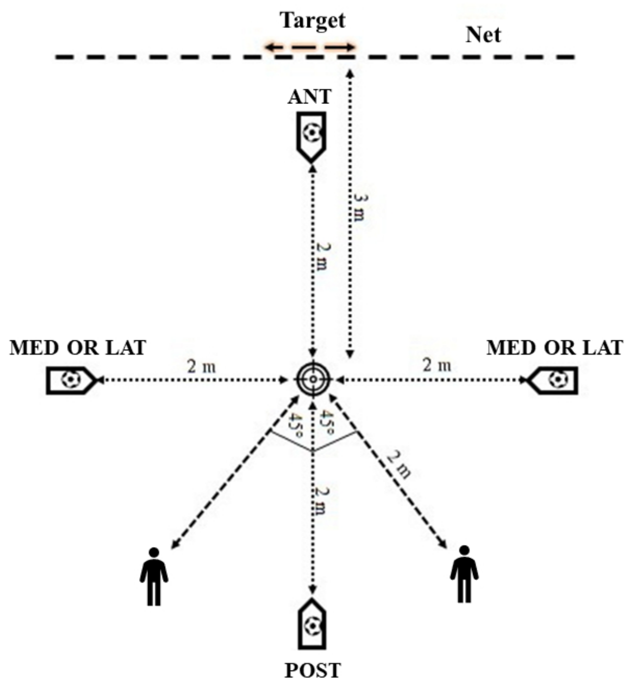

Figure 1 — Diagram showing the positions in which the ball and the subjects started in relation to the kicking point. When the ball comes from the sides the condition changes whether the subject is kicking with the right or left foot.

254x190mm (96 x 96 DPI)

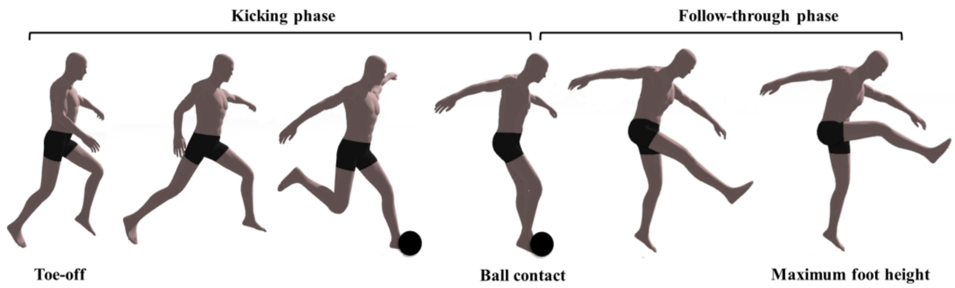

Figure 2 — Illustration of kicking events and relevant phases.

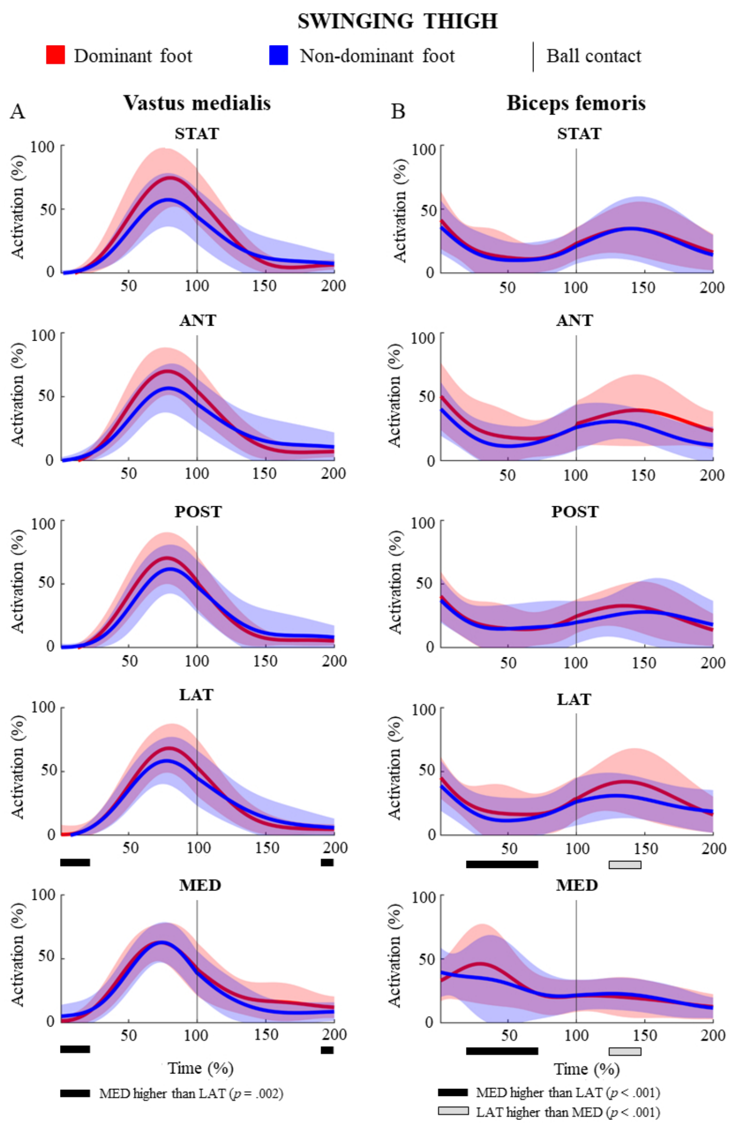

Figure 3 — Swinging vastus medialis (A) and biceps femoris (B) activation during kicking (1-100) and follow-through (101-200) phases. Curves are mean ± SD of all participants' trials.

228x338mm (96 x 96 DPI)

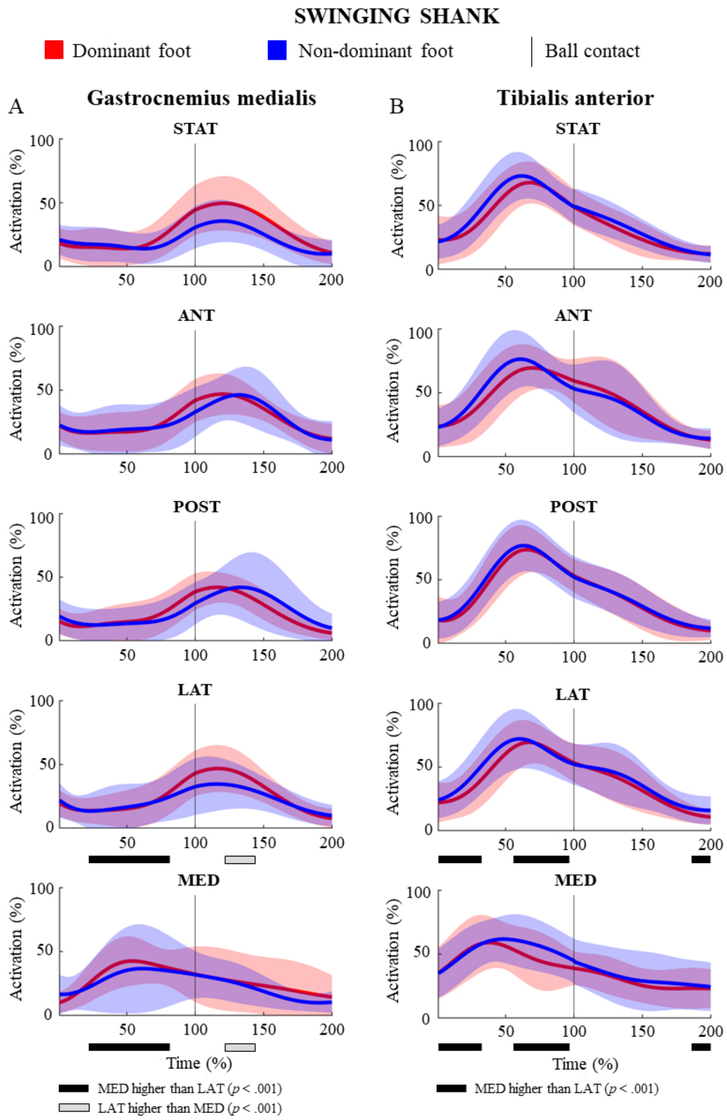

Figure 4 — Swinging gastrocnemius medialis (A) and tibialis anterior (B) activation during kicking (1-100) and follow-through (1-100) phases. Curves are mean ± SD of all participants' trials.

228x338mm (96 x 96 DPI)

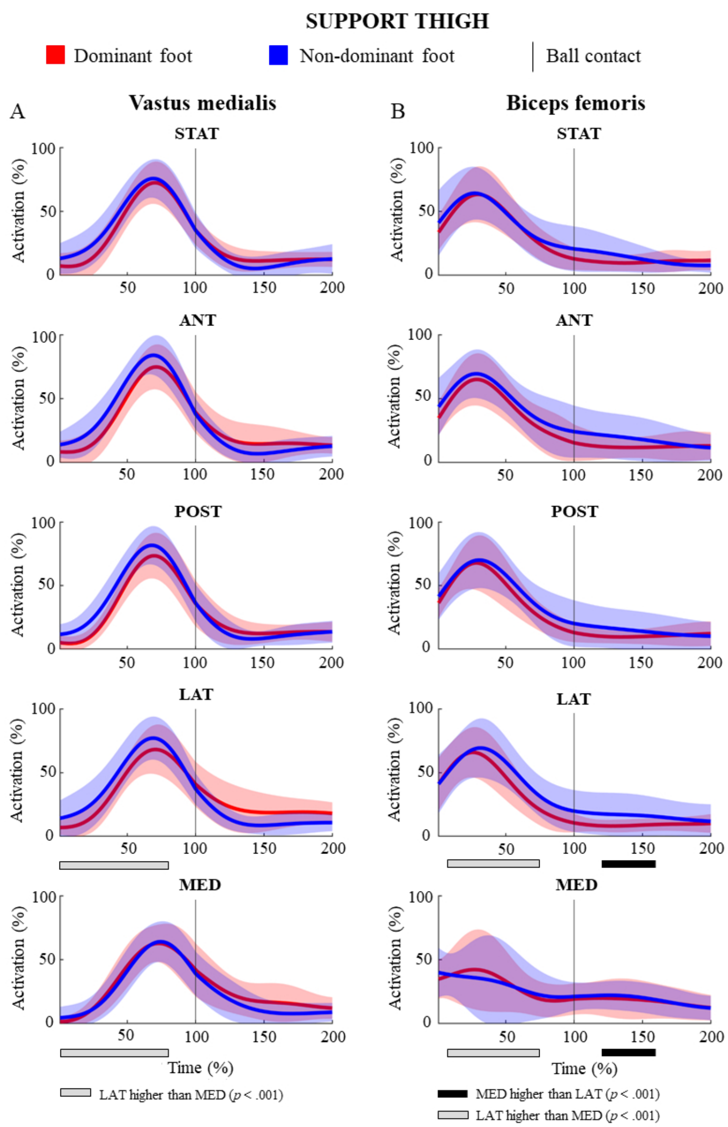

Figure 5 — Support vastus medialis (A) and biceps femoris (B) activation during kicking (1-100) and follow-through (101-200) phases. Curves are mean ± SD of all participants' trials.

228x338mm (96 x 96 DPI)

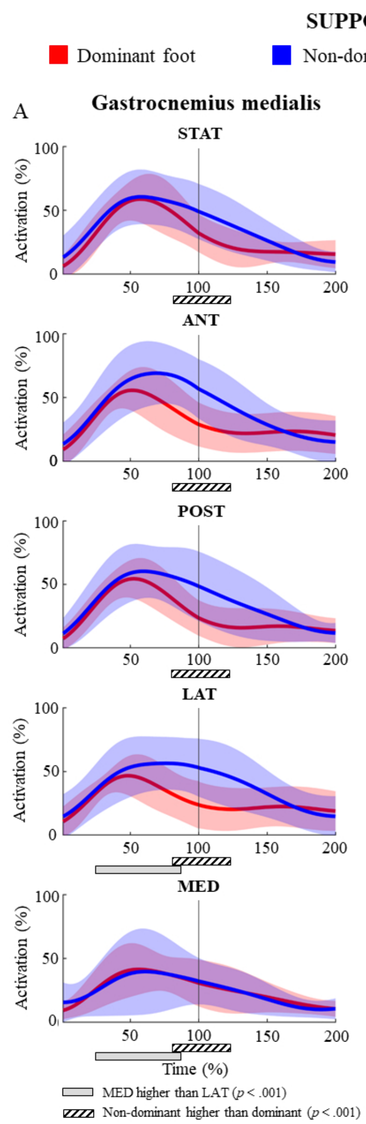

Figure 6 — Support gastrocnemius medialis (A) and tibialis anterior (B) activation during kicking (1-100) and follow-through (101-200) phases. Curves are mean ± SD of all participants' trials.

228x338mm (96 x 96 DPI)