Journal of Human Kinetics volume 80/2021, 309-316 DOI: 10.2478/hukin-2021-0111 309
Section III – Sports Training

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Comparison of Muscle Activity During 200 m Indoor Curve and Straight Sprinting in Elite Female Sprinters

by
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The purpose of this study was to assess whether peak surface electromyography (sEMG) amplitude of selected lower limb muscles differed during a) curve and straight sprinting, b) sprinting in inside and outside lanes between lower limbs. Eleven well-trained female sprinters (personal best: 24.1 ± 1.1 s) were included in a randomized within-subject design study, in which participants underwent two experimental conditions: all-out 200 m indoor sprints in the innermost and outermost lane. Peak sEMG amplitude was recorded bilaterally from gastrocnemius medialis, biceps femoris, gluteus maximus, tibialis anterior, and vastus lateralis muscles. Left gastrocnemius medialis peak sEMG amplitude was significantly higher than for the right leg muscle during curve ($p = 0.011$) and straight sprinting ($p < 0.001$) when sprinting in the inside lane, and also significantly higher when sprinting in the inside vs. outside lane for both curve and straight sprinting ($p = 0.037$ and $p = 0.027$, respectively). Moreover, left biceps femoris peak sEMG amplitude was significantly higher during straight sprinting in the inside vs. outside lane ($p = 0.006$). Furthermore, right and left vastus lateralis peak sEMG amplitude was significantly higher during curve sprinting in the inside lane ($p = 0.001$ and $p = 0.004$, respectively) and for the left leg muscle peak sEMG amplitude was significantly higher during curve compared to straight sprinting in the outside lane ($p = 0.024$). Results indicate that curve sprinting creates greater demands mainly for the gastrocnemius medialis of the inner than the outer leg, but the degree of these requirements seems to depend on the radius of the curve, thus significant changes were noted during sprinting in the inside lane, but not in the outside lane.

***Key words**: electromyography, activity pattern, lower limbs, biceps femoris, gastrocnemius.*

Introduction

Sprint running has been widely investigated in the literature mainly through kinematic and kinetic variables as well as muscle activity patterns while sprinting on both indoor and outdoor tracks (Howard et al., 2018; Jönhagen et al., 2007; Slawinski et al., 2008, 2010; Zabaloy et al., 2020). However, most of these studies examined straight, not curve sprinting (Morin et al., 2015; Nummela et al., 1992, 1994; Slawinski et al., 2008, 2010; Zabaloy et al., 2020), and those that focused on indoor curve sprinting concerned, above all, changes in velocity at particular sections of the race (Delecluse et al., 1998; Ferro and Floria, 2013) or differences in ground reaction forces (Chang and Kram, 2007; Luo and Stefanyshyn, 2012). According to our knowledge no studies have investigated lower limb muscle activity patterns in female sprinters during maximum-effort curve sprints.

Sprinting speed achieved on the curve is significantly lower than that registered on the straightaway, while times are significantly slower (Ferro and Floria, 2013). This is caused by the constant distribution of ground reaction forces which counter the centrifugal force and thus reduce the vertical and horizontal forces (Chang and Kram, 2007). Moreover, the lower limbs play different roles during curve sprinting (Chang and Kram, 2007; Filter et al., 2020). The left leg (inside) is responsible for stabilizing and managing the movement in the frontal plane by braking and

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Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 80/2021 in October 2021.

changing direction, whereas the right leg (outside) has a propulsive role and supports control of the motion in the horizontal plane during curve sprinting (Alt et al., 2015; Chang and Kram, 2007). This was confirmed in one of the recent studies considering surface electromyography activity (sEMG) during curve sprinting (Filter et al., 2020). Filter et al. (2020) showed that peak sEMG amplitude significantly differed between the outside and inside legs during curve sprinting among soccer players. Those authors noticed a higher peak sEMG amplitude of *biceps femoris* and *gluteus medius* in the inside leg, while in the outside leg, higher activity was noted in the *semitendinosus* and *adductor* muscles. However, participants were semiprofessional soccer players and a distance of the curve was equal to 17 m with a radius of 9.15 m, while on standard indoor tracks the minimum inner edge radius equals 17.2 m (International Association of Athletics Federations, 2008). Considering the characteristic construction of the indoor track, these results cannot be transferred to the 200 m sprint. Moreover, due to the differences in the radius, a significant change could be expected in lower limb muscle activity between sprinting in the outermost and innermost lanes (Churchill et al., 2015; Delecluse et al., 1998; Quinn, 2009), unlike, for example, in only straight movement (Stastny et al., 2015). Taking into account that the 200 m sprint in the indoor track is divided into four alternating curves and straight sections (and the start is on the curve), the athlete must demonstrate the ability to smoothly change from straight to curve sprinting (Ferro and Floria, 2013). This emerges in the differences in patterns of muscle activity between straight and curve sprints in the innermost and outermost lanes, especially between the lower limbs. Therefore, there is a special need to separately analyze each section of indoor track races, as well as the influence of the following sections on each other, to enhance the ability to effectively sprint in curvilinear trajectories. This will expand the knowledge of coaches and athletes and in combination with the available literature, enhance sprint performance and indicate the directions for further research.

The purpose of this study was to assess whether peak sEMG amplitude of selected lower limb muscles (*gastrocnemius medialis, biceps femoris, gluteus maximus, tibialis anterior, vastus lateralis*) differed during sprinting in a) a curve and a straightaway, b) an inside and an outside lane between lower limbs. It was hypothesized that the peak sEMG amplitude of all studied lower limb muscles would be higher in the left (inside) than the right leg (outside) during curve sprinting, and the magnitude of this difference would depend on the assigned lane. Additionally, it was expected that a higher peak sEMG amplitude would be recorded during curve compared to straight sprinting.

Methods

Participants

Eleven well-trained female sprinters participated in the study (age: 21 ± 4 yrs; body mass: 47 ± 5 kg; body height: 161 ± 7 cm; 200 m personal best: 24.1 ± 1.1 s). Athletes were in the pre-season phase of the season. The inclusion criteria were as follows: i) free from neuromuscular and musculoskeletal disorders as well as self-described satisfactory health status, ii) national team members for at least 2 years, iii) competing at national and international levels in the two previous seasons. All athletes were informed about the objectives and potential risks of the study before providing their written informed consent for participation. They were asked to maintain their normal dietary and sleep habits throughout the study and not to use any supplements or stimulants for 24 h prior to the testing session. The study received the approval of the Bioethical Committee of the Academy of Physical Education in Katowice (3/2021) and was performed according to the ethical standards of the Declaration of Helsinki, 2013.

Experimental sessions

This was a cross-sectional comparative study of running performance during the first curve and straightaway section of a 200 m indoor sprint between inside and outside lanes. The evaluations were carried out over three trials with a day of rest separating each session (Saturday, Monday and Wednesday) on an indoor synthetic four lanes track with IAAF certification (Certified Facility by World Athletics as Class 2). To avoid the influence of circadian rhythm on performance, both trials were performed at the same time of the day (between 9:00 and 11:00 a.m.). All sessions were preceded by a standardized, sprint specific

warm-up that was consistent with participants' normal training habits. During the familiarization session, each participant performed one run in the inside and the outside lane (in independently chosen order) with sEMG electrodes to exclude their influence on the quality of the run. Each experimental session consisted of two all-out sprints from a crouched start, with a 10-min rest interval in between. The test protocol for each day was identical, except for the lane in which the athlete sprinted (inside - 1st or outside - 4th lane). In both situations the 0- to 50-m section was considered as a curve, while the 50- to 100-m section as a straightaway. The radius of the curve of the inside lane was 17.2 m and of the outside lane it was 20.86 m. The order of the sprints was randomized. Participants used their track spikes during the sprint evaluations.

Electromyographic measurements procedure

The sEMG data were recorded bilaterally from the *gastrocnemius medialis, biceps femoris, gluteus maximus, tibialis anterior,* and *vastus lateralis.* After the warm-up, all participants performed three repetitions of 5 s maximal voluntary isometric contractions with a 1 min rest interval as described in Table 1. The eight-channel Noraxon TeleMyo 2400 Wireless system (Noraxon USA Inc., Scottsdale, AZ; 1500 Hz) was used for measurements and analysis of biopotentials from the studied muscles. After preparing the skin (skin overlaying the muscle belly was shaved, abraded and washed with alcohol), the electrodes (11 mm contact diameter and a 2 cm center-to-center distance) were placed along the presumed direction of the underlying muscle fibers according to the recommendations of SENIAM (Hermens et al., 2000) (Table 1). To ensure repeated electrode replacement between the experimental sessions, the locations were marked with a waterproof marker. Participants were instructed not to wash the markings off between particular sessions. The sEMG signals were demeaned, bandpass filtered between 8 and 450 Hz using a Butterworth 4th order recursive filter and subjected to a moving 100 ms root-mean-square (RMS) window and were normalized to the peak sEMG amplitude during the MVIC test to be expressed as a percentage of MVIC (%MVIC). The sEMG data were based on the average of the peak sEMG amplitude recorded across the trials for each muscle (Besomi et al., 2020).

Statistical analysis

All statistical analyses were performed using SPSS (version 25.0; SPSS, Inc., Chicago, IL, USA). Results were expressed as means with standard deviations. Reliability was explored using intraclass correlation coefficients (ICCs) from the two-way mixed model for single measures and representing absolute agreement. ICCs were interpreted as poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90) (Koo and Li, 2016). The Shapiro-Wilk test was used to verify the normality of the sample data. Differences in %MVIC between the conditions were examined using repeated measures three-way ANOVA (2 conditions (outside vs. inside) × 2 paths (curve - CRV vs. straight - STR) × 2 side (right vs. left)). An independent analysis was performed for each muscle. Effect sizes for main effects and interactions were determined by partial eta squared (η2). Partial eta squared values were classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (>0.137). Post hoc comparisons using the Bonferroni correction were conducted to locate the differences between mean values when a main effect or interaction was found. For pairwise comparisons, effect sizes were determined by Hedges g which was interpreted as ≤0.20 small, 0.21-0.8 medium, and >0.80 as large. Statistical significance was set at $p < 0.05$.

Results

The changes in sEMG activity of the posterior and anterior thigh muscles are shown in Tables 2 and 3. The within-day ICC for normalized sEMG amplitude data from the studied muscles over the three MVIC trials ranged between 0.83 and 0.92. The normalized sEMG amplitude data from the studied muscles over the two inside lane trials ranged between 0.77 and 0.89, while for the outside lane trials they ranged between 0.78 and 0.92.

Gastrocnemius Medialis

The 3-way ANOVA revealed a significant condition × side interaction ($p < 0.0001$; $\eta^2 = 0.732$). Post-hoc tests for interaction indicated a significantly higher left *gastrocnemius medialis* peak sEMG amplitude compared to the right leg muscle during the CRV ($p = 0.011$, g = 1.08) and the STR ($p < 0.001$, g = 1.57) when sprinting in the inside lane. In addition, there was a significantly higher left *gastrocnemius medialis* peak sEMG

amplitude when sprinting in the inside vs. the outside lane for both CRV and STR (p = 0.037, g = 0.93; and p = 0.027, g = 1.19; respectively).

Biceps Femoris

The 3-way ANOVA showed a significant condition × path interaction (p = 0.01, η^2 = 0.501). Post-hoc tests for the interaction indicated a significantly higher left *biceps femoris* peak sEMG amplitude when sprinting in the inside vs. the outside lane (p = 0.006, g = 0.48).

Gluteus Maximus

The 3-way ANOVA did not show any significant interactions nor main effects for the *gluteus maximus* muscle.

Tibialis Anterior

The 3-way ANOVA did not show any significant interactions nor main effects for the *tibialis anterior* muscle.

Vastus Lateralis

The 3-way ANOVA did not show any significant interactions, but a main effect of the path (p < 0.0001, η^2 = 0.753). Post-hoc tests for the main effect of the path indicated a significantly higher right and left *vastus lateralis* peak sEMG amplitude during the CRV when sprinting in the inside lane (p = 0.001, g = 0.67 and p = 0.004, g = 0.48, respectively) and left *vastus lateralis* peak sEMG amplitude during the CRV when sprinting on the outside lane (p=0.024, g=0.26) in comparison to STR.

Table 1

Characteristics of electrode placement and maximal voluntary isometric contraction tests for each studied muscle group.

Muscle Group	Electrode placement	MVIC Description
Gastrocnemius medialis	on the most prominent bulge of the muscle	Lying on the belly with the face down, the knee extended and the foot projecting over the end of the table. Plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward. For maximum pressure in this position, it is necessary to apply pressure against the forefoot as well as against the calcaneus.
Biceps femoris	at 50% of the line between the ischial tuberosity and the lateral epicondyle of the tibia	Lying on the belly with the face down with the thigh down on the table and the knees flexed (to less than 90 degrees) with the thigh in slight lateral rotation and the leg in slight lateral rotation with respect to the thigh. Press against the leg proximal to the ankle in the direction of knee extension.
Gluteus maximus	at 50% of the line between the sacral vertebrae and the greater trochanter	Prone position, lying down on a table. Lifting the entire leg against manual resistance.
Tibialis anterior	at 1/3 of the line between the tip of the fibula and the tip of the medial malleolus	In the supine position. Support the leg just above the ankle joint with the ankle joint in dorsiflexion and the foot in inversion without extension of the great toe. Apply pressure against the medial side, dorsal surface of the foot in the direction of plantar flexion of the ankle joint and eversion of the foot.
Vastus lateralis	at 2/3 of the line from the anterior spina iliaca superior to the lateral side of the patella	Sitting on a table with the knees in slight flexion and the upper body slightly bent backward. Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.

Table 2

Comparison of peak sEMG amplitude (± standard deviation) of the selected posterior thigh muscles.

		sEMG activity of the posterior thigh muscles [%MVIC – maximum voluntary isometric contraction]			
		Inside Lane		Outside Lane	
Muscle Group	**Path**	**Right**	**Left**	**Right**	**Left**
Gastrocnemius Medialis	**CRV**	139 ± 29	166 ± 18*#	137 ± 30	142 ± 30
	STR	126 ± 22†	162 ± 22*#	128 ± 30	136 ± 20
Biceps Femoris	**CRV**	115 ± 21	129 ± 30	117 ± 17	127 ± 25
	STR	118 ± 27	132 ± 27*	113 ± 24	118 ± 29
Gluteus Maximus	**CRV**	100 ± 26	110 ± 31	99 ± 26	102 ± 29
	STR	105 ± 25	107 ± 33	101 ± 24	111 ± 44

** compared with the corresponding value to the outside lane condition;*
 # compared with the right limb; † compared with CRV

Table 3

Comparison of the peak sEMG amplitude (± standard deviation) of the selected anterior thigh muscles.

		sEMG activity of the Anterior Thigh Muscles [%MVIC - maximum voluntary isometric contraction]			
		Inside Lane		Outside Lane	
Muscle Group	**Path**	**Right**	**Left**	**Right**	**Left**
Tibialis Anterior	**CRV**	57 ± 22	55 ± 23	60 ± 24	64 ± 20
	STR	50 ± 22	51 ± 23	61 ± 24	56 ± 22
Vastus Lateralis	**CRV**	77 ± 22	76 ± 29	72 ± 25	73 ± 26
	STR	62 ± 21†	63 ± 23†	65 ± 25	66 ± 26†

† compared with CRV

Discussion

The main finding of this study was that the *gastrocnemius medialis* was the muscle in which peak sEMG amplitude varied the most depending on the conditions during the 200 m indoor sprint. Specifically, the peak sEMG amplitude of the left *gastrocnemius medialis* was significantly higher than that of the right one, during both curve and straight sprinting in the inside lane. Moreover, the peak sEMG amplitude of the left *gastrocnemius medialis*, as well as of the right one, was also significantly higher during sprinting in the inside lane compared to the outside lane. Considering the *biceps femoris*, a significantly higher peak sEMG amplitude was recorded in the left leg when running in the inside vs. the outside lane. Moreover, significantly lower peak sEMG amplitude of both *vastus lateralis* muscles was registered during the straightaway than curve sprinting in the inside lane, and only for the left *vastus lateralis* muscle in the outside lane.

As suggested by Alt et al. (2015) the inside leg is responsible for stabilizing the movement in the frontal plane, whereas the outside leg provides and controls the motion in the horizontal plane during curve sprinting. Indeed, our results showed that the left (inside) and the right

(outside) leg had different roles during curve sprinting, however, it concerned the *gastrocnemius medialis* muscle during sprinting in the inside lane. The left *gastrocnemius medialis* peak sEMG amplitude was significantly greater than of the right one during curve sprinting in the inside lane, which was not observed in the outside lane. This may be caused by the greater radius in the outside lane than in the inside one, thus the curve is milder (Taboga and Kram, 2019). This explanation is partially confirmed by results of Chang and Kram (2007) who found that the ground contact time increased to compensate a decrease in vertical ground reaction force as the radius of the curve diminished. During acceleration on the curve, athletes have to overcome not only gravity, but also the centrifugal force (Chang and Kram, 2007). Therefore, they have to produce vertical ground reaction force and part of it transforms to mediolateral force in order to stabilize and manage the movement in the frontal plane by braking and changing direction (Alt et al., 2015; Chang and Kram, 2007). As a result, it might be considered a limiting factor for the generation of maximal vertical force which hinders performance (Ohnuma et al., 2018).

Interestingly, the increased peak sEMG amplitude of the left *gastrocnemius medialis* also persisted during the straight sprint section in the inside lane. Therefore, despite different demands in force distribution between sections, sprinters maintain a constant peak sEMG amplitude. Presumably, this could be due to the slope of the indoor track and that the acceleration phase starts at the curve (Bezodis et al., 2014; Cai et al., 2010). It has to be mentioned that the position of the starting blocks differs significantly between the inside and outside lanes. In the outside lane, the uphill sprinting part of the first curve is almost avoided and athletes take advantage of the downhill part at the end of the acceleration phase, whereas athletes starting from the inside lane have to cope with the very small radius of their curve and uphill running part. Hence, it could be speculated that the previous task affects muscle patterns during the subsequent phase of sprinting (in this case uphill running part on the curve section affects *gastrocnemius medialis* peak sEMG amplitude across the straight sprint section), perhaps due to an increasing level of muscle fatigue (Enoka et al., 2011; Enoka and Duchateau, 2008). This phenomenon might be manifested by an increase in the peak sEMG amplitude in an attempt to maintain ground reaction force, as it was observed in the *gastrocnemius medialis* muscle in the present study. A similar trend of increasing peak sEMG amplitude of the left *gastrocnemius medialis* muscle in comparison to the right one was also noticed when sprinting in the outside lane, however, it did not reach statistical significance, which also indicates that the present findings may be explained by different demands during sprinting in the inside lane.

Surprisingly, our initial hypothesis was not confirmed and these differences in the peak sEMG amplitude pattern were not found in the other studied muscles (*biceps femoris, gluteus maximus, tibialis anterior, vastus lateralis*). Indeed, the expected trend of change could be seen in posterior thigh muscles, but it was not significant. Thus, it seems that the *gastrocnemius medialis* manages the force produced by them, but the magnitude of this phenomenon increases with the degree of the curve radius. It is also interesting that the *vastus lateralis* peak sEMG amplitude decreases during straight sprinting in comparison to curve sprinting under both conditions. Therefore, it seems that the effect of the slope and the radius can be dismissed. The peak sEMG amplitude of the *vastus lateralis* is significantly higher during the acceleration phase (curve sprinting), and then significantly decreases with increasing speed (straight sprinting). This is partially consistent with Cai et al. (2010) that when running uphill, lower limb muscles increase their activity, but knee extensors and the *gastrocnemius* exert even more effort compared to the knee flexors and the *tibialis anterior*. In contrast, during downhill running they are activated to a lesser degree due to the undergoing eccentric movement. This also may explain the lower right *gastrocnemius medialis* peak sEMG amplitude during straight sprinting in comparison to curve sprinting (Cai et al., 2010).

Nonetheless, this study has several limitations which should be addressed. First of all, only the first two sections of the indoor sprint (first curve and first straightaway section of the 200-m indoor sprint) were considered. In addition, the external structure of the movement (i.e., ground reaction forces and motion analysis)

was not investigated. Furthermore, the sEMG amplitude was analyzed only on the basis of peak values and our analysis did not consider adductor muscles and *gluteus medius* (main lateral stabilizer of the hip), *gastrocnemius lateralis*, and abdominal muscles. Future research should investigate a whole 200-m sprint (both curve and straightaway sections) as well as other distances among both females and males.

Conclusions

It can be concluded that curve sprinting creates greater demands for the inner than the outer leg, but the degree of these requirements seems to depend on the radius of the curve, thus significant changes were noted during sprinting in the inside lane, but not in the outside lane. However, this concerned the *gastrocnemius medialis* muscle only, which seems to manage the work of the rest of the lower limb muscles. Consequently, coaches and athletes should be aware that the *gastrocnemius medialis* of the inner leg is highly activated during curve sprinting in the inside lane, therefore, during training involving large volume of this type of activity, it may be exposed to overloading, and consequently increased risk of injury.

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