ORIGINAL ARTICLE

Neuromuscular activity differs between the inside and outside legs during bend sprinting

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ABSTRACT

This study aimed to clarify the characteristics of surface electromyograms during sprinting on a curved path. The participants were eighteen male track and field athletes including sprinters and hurdlers. Participants performed a 60-m sprint with maximal effort on straight and curved paths. Surface electromyogram signals were sampled from the biceps femoris, gluteus maximus, rectus femoris, vastus lateralis, medial head of gastrocnemius, and tibialis anterior, and kinematic variables and ground reaction forces were measured during sprinting. These variables were compared between straight and curved paths. Average rectified value of surface electromyograms for medial head of gastrocnemius in the inside leg on a curved path was greater than that on a straight path; however, there were no significant differences between the paths in the outside leg. In addition, there were no significant differences between paths. These results suggest that electromyographic strategies for performing curved sprinting with a large radius of curvature differ between the inside and outside legs and, that gastrocnemius muscle activity on inside leg contributes to force production during bend sprinting.
Keywords: Biomechanics, Sprint performance, Electromyography, Curved path.

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INTRODUCTION

It has been reported that the highest running speed that appears in the middle of a race greatly affects the performance of sprint events in athletics. (Hanon and Gajer,2009; Mackala, 2007). However, in 200 m and 400 m events, it is necessary to sprint on a curved path because of the design of the track and field stadium. That is, it is one of the tasks to acquire a high running speed on a curved path to improve the performance for 200 m and 400 m events.

To make curved sprinting possible, it is necessary to produce centripetal force; therefore, it is a general strategy to produce centripetal force by leaning the body toward the centre of curvature. It is generally accepted in previous studies that the running speed on curved paths tends to be slower than that on straight paths (Chang and Kram, 2007; Churchill et al., 2015; Churchill et al., 2016; Stoner and Ben-sira, 1979). Regarding the kinematics and ground reaction force during curved sprinting, there are reports of differences in the variables between the straight and curved paths in the frontal and sagittal planes (Churchill et al., 2015; Churchill et al., 2016) and only in the frontal plane (Alt et al., 2015; Hamill et al., 1987). There are a few reports on the characteristics of curved sprinting, and consistent knowledge has not yet been obtained.

Kinematic and kinetic characteristics during curved sprinting were reported by comparing movements on a straight path. However, only one report has investigated the surface electromyogram, which is one of the biomechanical characteristics. Smith et al. (2008) investigated the differences of the difference in lower limb muscle activities in inside and outside legs on straight and curved path with 5 m radius of curvature at 4.4 ms^{-1} and 5.4 ms^{-1} running speeds. The tibialis anterior muscle activity during the flight phase increased in the inner leg, and the tensor fasciae latae muscle during the flight phase and gluteus muscle during the running cycle increased in the outer leg on a curved path with increasing speed. However, there were no significant differences between straight and curved paths. The experimental setting mentioned in the previous study was slower and smaller in radius of curvature than conditions, such as sprinting events in athletics. Therefore, muscle activity during sprinting on a curved path shows characteristics different from those of the previous study. Many previous studies have reported the characteristics of surface electromyogram during sprinting on the straight path (Kuitunen et al., 2002; Mero and Komi, 1987; Nummela et al., 1994; Nummela et al., 1992; Slawinski et al.,2008), but it has been not clarified the characteristics on curved path. Centripetal force is added compared to sprinting on a straight path during sprinting on a curved path, so the total force exerted is greater. Therefore, we hypothesized that the surface electromyogram would also be greater during sprinting on a curved path, and that the areas affected would differ between the inside and outside leg.

This study aimed to clarify the characteristics of surface electromyograms during sprinting on curved paths, such as sprint events in athletes.

MATERIAL AND METHODS

Participants

Eighteen male track and field athletes (age 20 ± 1years, height 1.74 ± 0.06 m, weight 67.2 ± 4.9 kg) volunteered for this study. None of the participants reported musculoskeletal injuries at the time of testing. Approval to undertake the study was given by Japan Institute of Sports Sciences. Written informed consent was obtained from all the participants.

Measures

The trials involved 60 m sprint running on straight and curved paths. This experiment was conducted in a laboratory with all-weather pavement. The detrimental effects of curvature on running speed tend to be larger for smaller radii (Churchill et al., 2019; Greene, 1981; Quinn, 2009). The radius of curvature was 37.9 m, which corresponds to the most inside lane of a typical 400-m track. The participants performed 8 to 10 trials, two for each leg and path, during the same period. Between trials, participants rested for more than ten minutes to offset the effect of fatigue on running speed. The measurement section was 45 m from the start of both the paths.

Surface EMG signals were sampled from the biceps femoris (BF), gluteus maximus (GM), rectus femoris (RF), vastus lateralis (VL), medial head of the gastrocnemius (MG), and tibialis anterior (TA) on the inside and outside legs based on a previous study (Mero and Komi, 1987). The skin surface was cleaned with alcohol and rubbed with sand. Surface Ag/AgCl electrodes (Blue Sensor; Ambu, Copenhagen, Denmark) were used as the recording electrodes and were placed on the longitudinal axis of each muscle at an interelectrode distance of 30 mm. Bipolar surface electrodes were placed on individual muscles, in accordance with previous studies (Delagi*, 1981;* Higashihara *et al., 2010*). Signals were recorded using a portable data logger system (dimensions 34 × 77 × 132 mm, mass 300 g, BioLog DL 5000, S & ME Inc., Tokyo, Japan) attached to the waist at a sampling frequency of 1000 Hz. Electrode wired sensors (FA-DL 140, S & ME Inc., Tokyo, Japan) with an amplification amplifier of 12 × 7 × 23 mm were attached to the electrode, and connected to the electrodes were secured with tape to avoid movement-induced artifacts. The entire leg was covered with underlap tape (U 70 F; Nichiban Co., Tokyo, Japan) to fix the electrode. The presence or absence of abnormalities on each electrode was confirmed using measurement analysis software (m-BioLog 2, S & ME Inc., Tokyo, Japan).

Reflective markers were placed on body landmarks based on plug-in gait protocols (Davis et al.,1991; Kadaba et al.,1990). Three-dimensional positional data of the markers were recorded using a motion capture system operating at 250 Hz with 15 infrared cameras (Vicon MX; Oxford Metrics Ltd., Oxford, UK). Two force plate systems (Type 9286 B, Kistler Inc., Winterthur, Switzerland) were used to sample the ground reaction force (GRF) data at 1000 Hz. The positional data and GRF data were synchronized using Vicon Nexus software (ver. 1.7.1, Oxford Metrics Ltd., Oxford, UK.). In this study, we used only two force plate systems. Therefore, the kinematic and GRF data for each leg were obtained from separate trials. The global coordinate system directions were set as the X-axis for the medial-lateral direction, the Y-axis for the anterior–posterior direction, and the Z-axis for the vertical direction. On a curved path, the global coordinate system is translated to a local coordinate system, in which the X-axis is defined as a radial-to-curved path, and the Y-axis is a tangential-to-curved path.

Procedures

The recorded electromyogram data were loaded into the aforementioned software, and the data on each electromyogram were obtained. The EMG data were filtered with a band-pass of 20–500 Hz and rectified. Average Rectified Value (ARV) was performed during the analyse running cycle. The running cycle was divided by defining the onset-offset point of the MG at foot contact. The mean value of three cycles in total, including before and after the measured section that stepped the force plate systems, was set as a representative value in each trial. The ARVs at each straight path was normalized to 100% and a relative value was calculated for each curved path.

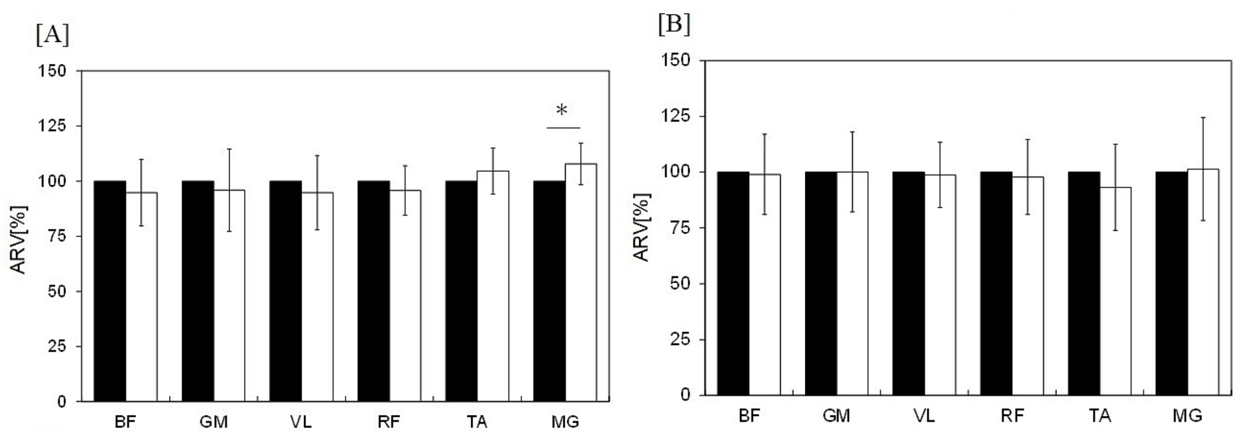
The Vicon Nexus software was used to reconstruct the positions of each reflective marker in a three-dimensional graphical environment. Each marker on the participant was labelled according to the body landmark to which it was attached or according to the cluster to which it belonged, based on the plug-in gait protocols. The positional data and GRF data were smoothed using a fourth-order Butterworth digital filter with cutoff frequencies of 12 and 50 Hz, respectively. The centre of gravity was calculated using body segment variables, which were based on Jensen's mathematical model for Japanese athletes (Ae, 1992). The lower-limb angle and angular velocity were calculated from the three-dimensional coordinate values. The spatiotemporal variables were calculated for the inside and outside steps on both paths. In accordance with previous studies (Churchill et al., 2015; Churchill et al., 2016; Stoner and Ben-sira, 1979), a right (outside) step was defined from outside foot touchdown to inside foot touchdown, and vice versa for a left (inside) step. The running speed for each path was calculated by averaging the running speeds of the inside and outside steps. Lower-limb movements in the sagittal plane during the stance phase were calculated for the inside and outside steps on both paths. The lower limb joint angles on foot touchdown and foot take-off, minimum knee and ankle joint angles, and maximum lower limb joint extension (plantarflexion) angular velocities were calculated. The maximum and minimum GRF and impulse for each coordinate were calculated for the inside and outside steps, respectively. The impulse of the anterior-posterior component is divided into eccentric and concentric phases (Mero and Komi, 1987). Kinematic, GRF, and EMG data of the fastest trial for each leg and path were used for detailed analyses. All data processing was performed using the MATLAB software (R2013a, The MathWorks Inc., Natick, MA, USA).

Statistical analysis

The Paired t-test was used to compare variables between the straight and curved paths for each leg. Statistical significance was set at $p < .05$. Cohen's d was used to describe the effect size (Cohen, 1992). All statistical analyses were performed using the IBM SPSS Statistics software (v. 22.0, SPSS Inc., Chicago, Illinois, USA).

RESULTS

Figure 1 shows that differences of the ARV in inside and outside each lower limb muscles on straight and curved path. ARV for MG in inside leg on curved path was greater than on straight path ($p = .03$, d = 0.82). However, there were no significant differences in the outside legs between paths. In addition, there were no significant differences between paths.



*Note. Values are presented as mean ± standard deviation (n = 18). * Significant difference between straight and curved paths (p < .05).*

Figure 1. Comparisons of ARVs in [A] inside and [B]outside legs between straight (black bar) and curved paths (white bar).

Table 1 shows the differences in the kinematic parameters in inside and outside the leg on straight and curved paths. The running speed on the curved path was slower than on the straight path ($p < .01$, d = 1.11). The mean percent difference of the running speed relative to straight path also was -3.10 % ± 1.51 (Range:-0.43 - -6.33%). There were no significant differences in the step frequency, stance time, or flight time for both legs between the paths. However, the step length ($p < .01$, d = 0.69) and flight distance ($p < .01$, d = 0.60) of the outer leg on the curved path were significantly shorter than those on the straight path. However, there were no significant differences in the step length and flight distance of the inside leg between paths. The minimum knee ($p = .01$, d = 0.52) and ankle ($p = .02$, d = 0.23) joint angles of the inside leg on the curved path were significantly smaller than those on the straight path; however, there was no significant difference in the outside leg. On the other hand, the knee joint angles at foot touchdown ($p = .02$, d = 0.44) and take-off ($p < .01$, d = 0.76) of the outside leg on the curved path were smaller and larger than those on the straight path, respectively, but there was no significant difference in the inside leg.

Table 1. Differences in the kinematic parameters in inside and outside the legs on straight and curved paths.

	Straight		**Curve**	
	Inside	Outside	Inside	Outside
Spatiotemporal variables				
Running Speeds [m/s]	9.47 ± 0.28		9.17 ± 0.26*	
Step length [m]	2.03 ± 0.14	2.01 ± 0.13	2.00 ± 0.12	1.91 ± 0.16*
Stance distance [m]	0.99 ± 0.06	0.98 ± 0.08	0.99 ± 0.08	0.97 ± 0.08
Flight distance [m]	1.04 ± 0.12	1.02 ± 0.10	1.02 ± 0.12	0.95 ± 0.13*
Step frequency [Hz]	4.73 ± 0.34	4.63 ± 0.34	4.65 ± 0.32	4.68 ± 0.33
Stance time [ms]	105.6 ± 8.0	105.6 ± 9.9	109.1 ± 10.0	107.1 ± 9.8
Flight time [ms]	106.9 ± 12.3	107.1 ± 9.8	106.8 ± 12.1	107.8 ± 9.9
Joint angle [deg]				
Hip joint extension-flexion angle at TD	132.2 ± 4.1	132.7 ± 5.2	131.3 ± 3.2	131.0 ± 4.1
Knee joint angle at TD	151.8 ± 5.8	151.2 ± 6.4	150.7 ± 5.5	148.2 ± 7.3*
Ankle joint angle at TD	101.1 ± 4.6	100.5 ± 6.4	101.5 ± 3.7	100.6 ± 5.6
Minimum knee joint angle	138.4 ± 6.2	136.9 ± 8.6	134.9 ± 7.1*	138.2 ± 7.1
Minimum ankle joint angle	79.1 ± 4.5	79.3 ± 5.0	78.1 ± 4.2*	78.7 ± 4.3
Hip joint extension-flexion angle at TO	200.7 ± 5.4	200.8 ± 5.7	198.9 ± 4.8	201.2 ± 5.3
Knee joint angle at TO	161.1 ± 5.9	159.5 ± 7.7	157.6 ± 4.8	164.4 ± 4.8*
Ankle joint angle at TO	128.4 ± 8.4	126.9 ± 7.3	126.6 ± 8.8	126.3 ± 6.9
Joint angular velocity [deg/s]				
Maximum hip joint extension angular velocity	918.5 ± 87.2	912.8 ± 92.7	906.6 ± 83.2	924.8 ± 92.7
Maximum knee joint extension angular velocity	577.2 ± 138.9	570.4 ± 149.7	579.7 ± 137.4	585.2 ± 124.3
Maximum ankle joint plantar flexion angular velocity	1258.3 ± 163.6	1233.8 ± 148.8	1210.5 ± 172.7	1254.4 ± 119.4

*Note. Values are expressed as mean ± standard deviation. * Significant difference between straight and curved paths on each side. TD: Touch down, TO: Take-off.*

Table 2 shows the differences in the ground reaction force parameters in inside and outside the leg on straight and curved paths. The minimum (inside: $p < .01$, d = 1.32; outside: $p < .01$, d = 1.39) and maximum (inside: $p < .01$, d = 1.77; outside: $p < .01$, d = 1.56) medial-lateral GRF and the impulse (inside: $p < .01$, d = 1.61; outside: $p < .01$, d = 1.56) for both legs on the curved path were significantly greater than on the straight path. Additionally, the maximum posterior GRF ($p < .01$, d = 0.87) and impulse ($p < .01$, d = 0.81) for the outer leg on the curved path were significantly lower than those on the straight path, but there was no significant difference for the inside leg. However, there were no significant differences in the vertical component between groups or paths.

Table 2. Differences in Ground reaction forces parameters in inside and outside the legs on straight and curved paths.

	Straight		**Curve**	
	Inside	Outside	Inside	Outside
Minimum medial-lateral GRF [N]	-533.7 ± 133.6	-352.8 ± 211.3	-289.9 ± 224.2*	-104.3 ± 138.5*
Maximum medial-lateral GRF [N]	355.4 ± 186.1	496.5 ± 175.7	818.4 ± 320.1*	780.5 ± 188.6*
Medial-lateral impulse [Ns]	3.5 ± 13.2	-1.8 ± 12.0	33.1 ± 22.4*	26.4 ± 22.6*
Minimum anterior - posterior GRF [N]	-1624.5 ± 278.1	-1518.7 ± 364.8	-1566.2 ± 144.8	-1423.2 ± 255.8
Anterior impulse [Ns]	-30.6 ± 4.3	-30.9 ± 6.4	-30.0 ± 6.7	-29.5 ± 4.0
Maximum anterior - posterior GRF [N]	1164.3 ± 121.3	1184.4 ± 103.8	1142.4 ± 123.2	1093.8 ± 104.7*
Posterior impulse [Ns]	38.3 ± 5.4	37.0 ± 3.2	39.4 ± 5.3	33.8 ± 4.6*
Vertical peak GRF [N]	2592.3 ± 382.7	2772.1 ± 503.0	2474.9 ± 317.6	2589.8 ± 412.2
Vertical impulse [Ns]	150.8 ± 16.4	152.5 ± 18.5	152.3 ± 21.8	150.3 ± 15.6
Maximum total GRF [N]	2647.5 ± 361.4	2853.1 ± 520.8	2547.9 ± 411.0	2661.0 ± 394.5

*Note. Values are expressed as mean ± standard deviation. * Significant difference between straight and curved paths on each side.*

DISCUSSION

To enable curved running, it is necessary to produce a centripetal force with respect to the centre of curvature. The minimum and maximum medial-lateral GRF and impulse for both legs on the curved path were significantly greater than those on the straight path. These results indicate that the centripetal force is produced in the direction of the centre of curvature in the curved path. In addition, previous studies indicated that the running speeds in curved paths were slower than those in straight paths (Chang and Kram, 2007; Churchill et al., 2015; Churchill et al., 2016; Stoner and Ben-sira, 1979). The results of this study support those of many previous studies. Therefore, these results were reasonable in terms of the kinematics and kinetic characteristics during running on a curved path.

The ARV for the MG in the inside leg on the curved path was greater than that on the straight path, and there was no significant difference between the straight and curved paths in the maximum total GRF in this study. On the other hand, in the previous study which investigated EMG during running in curved path with a small radius of curvature (Smith et al.,1997), it was reported that there was no significant difference between straight and curved paths in EMG, and the maximum total GRF for the inside leg in curved path was smaller than that in straight path (Chang and Kram,2007; Smith et al.,2006). Therefore, in the inside leg, it is considered that the muscle activity for MG was involved in producing GRF equivalent to a straight path to enable sprinting in a curved path with a radius of curvature. Additionally, the minimum knee and ankle joint angles for the inside leg on the curved path were significantly smaller than those on the straight path. The results showed that the ankle joint angle for the inside leg was dorsiflexed in the curved path. Dorsiflexion of the ankle joint may cause a change in the muscle tendon complex length, and it is possible to perform concentric contraction at a high level by enhancing the activity level of eccentric contraction in the MG; consequently, it has been involved in producing greater force.

On the other hand, in the outer leg, it was inferred that the decrease in the anterior-posterior GRF and impulse for the outside leg could be caused by a decrease in running speed on a curved path, but there were no significant differences in the electromyogram between the paths for any muscle. In a study on electromyograms during sprinting, previous studies have reported that activity in the soleus muscle increases with running speed during the stance phase (Kuitunen et al., 2002), and that the semimembranosus and semitendinoid muscles were activated in the latter half of the stance phase (Schache et al.,2012). In addition, Tottori et al. (2016) investigated the relationship between running time on the curved path and cross-sectional area of the psoas major muscle using magnetic resonance imaging and showed that runners in whom the cross-sectional area of the psoas major muscle of the outer leg was larger than that of the inner leg were faster in curve sprinting. Therefore, it is considered that the activities of muscles that were not analysed in this study had an influence on the reduction of the ground reaction force for the outside leg and a decrease in running speed on the curved path. Otherwise, for the activities of muscles that were analysed in this study, it would have been an influence that these were not recruited more than in the straight path.

The muscles targeted in this study were limited to six points for each leg. Furthermore, these are the only points that can be derived from the surface. To investigate the muscle activities in curved sprinting in detail, it will be possible to evaluate the mobilization of muscle activity by analysing the T2 signals using MRI. In addition to examining only the amplitude of activity using ARV, an approach based on muscle synergies is also an issue that should be investigated in the future.

CONCLUSION

It was clarified that there were differences in the characteristics of surface electromyogram inside and outside the leg during curved sprinting between straight and curved paths, and ARV for MG in the inside leg on a curved path was greater than that on a straight path, but not in the outside leg. These results suggest that electromyographic strategies for performing curved sprinting with a large radius of curvature differ between the inside and outside legs.

AUTHOR CONTRIBUTIONS

Conceptualization: H.O. and A.K.; methodology: H.O.; software: H.O.; validation: H.O., Y.C. and T.Y.; formal analysis: H.O.; investigation: H.O. and T.Y.; resources: H.O. and Y.C.; data curation: H.O., Y.C. and T.Y.; writing—original draft preparation: H.O.; writing—review & editing: H.O., A.K., Y.C. and T.Y.; visualization: H.O.; supervision: H.O. and T.Y.; project administration: H.O. and Y.C.; funding acquisition: H.O. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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