ASYMMETRIC CONTRIBUTION OF SUPPORT LEG TO CURVED RUNNING VELOCITY

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The purposes of this study were to show the support leg contributions in the curved sprinting, and to investigate the differences of contribution between inside and outside legs. Twenty athletes participated in the experiment and ran 60m with maximal effort on the curved path with 41 markers. The trials were recorded by motion capture systems. The relative momentum generated by the support leg and the generated forces were calculated. The asymmetric contributions were found in centrifugal-centripetal component. In the inside leg, the forces to the centripetal direction were generated by the thigh and foot. On the other hand, in the outside leg, the forces to the centripetal direction were generated by the shank and foot. However, the contributions of 3 segments in anterior-posterior and vertical components were similar to the straight sprinting in each leg.

KEY WORDS: curved running, sprinting, momentum generated, generated force.

INTRODUCTION: The outdoor track has 2 straight paths and 2 curved paths. These lengths are approximately 80m and 120m respectively (Quinn, 2009). The length of curved path is longer than straight path. Therefore the techniques of curved running are important for the running performance. In the curved running, the running direction is changed by the centripetal force. Some study reported the asymmetric function between legs during curved running (Alt, Heinrich, Funken, & Potthast, 2015; Chang & Kram, 2007; Churchill, Salo, & Trewartha, 2011; Churchill, Salo, Trewartha, & Bezodis, 2012; Hamill, Murphy, & Sussman, 1987; Ishimura & Sakurai, 2010; Ishimura, Tsukada, & Sakurai, 2013; Smith, Dyson, & Hale, 1997; Smith, Dyson, Hale, & Janaway, 2006; Stoner & Ben-Sira, 1978). The external force is not affect during flight phase except for acceleration due to gravity and air resistance, so the asymmetric functions must be generated during support phase. Therefore, the support phase may be key for curved running. Ae, Miyashita, Shibukawa, Yokoi, and Hashihara (1985) indicated that the support leg contributed most to the straight running velocity. The more detail function of support leg during the curved running would be shown by using their methods. Thus, this study aims to show the support leg contributions to the running velocity in curved sprinting, and to investigate the differences of contribution between sides.

METHODS: Twenty athletes (9 females; age: 19.2±0.4years, height: 1.64±0.06m, body mass: 55.5±3.0kg, 11 males; age: 20.8±1.9years, height: 1.75±0.06m, body mass: 68.4±7.5kg, mean±SD) volunteered in this study. Informed consent was obtained from all, and the protocol was approved by the institutional research ethics committee. Experiments were conducted on the curve path of outdoor track and lane 4 (average radius: 43.51m). The subjects wore lycra cap, shirts, tights and their own spike shoes. Forty-one retro-reflective markers (diameter: 14mm) were placed on body landmarks (Ishimura & Sakurai, 2013). The 3-D positional data of the markers were recorded using Vicon motion capture system (250Hz) with nineteen or twenty infrared cameras (ten Vicon-MX13 and nine or ten Vicon-MX-T20, Oxford Metrics Inc., Oxford, UK). Each subject ran 60m with maximal effort. The running time of the latter 30m was recorded with a photocell system (PhotoGate, BROWER Timing Systems Inc., Draper, USA). Three successful experimental trials were conducted with sufficient inter-trial intervals to prevent fatigue, and one of them with fastest running time was chosen for analysis. The 3-D raw positional data was smoothed using Singular

Spectrum Analysis techniques with window length *L* = *n*/10 and first 3 principal components for data reconstruction (Alonso, Castillo, & Pintado, 2005; Ishimura & Sakurai, 2012). The center of gravity (CG) of subject was calculated with Ae's body segment parameters (Ae, Tang, & Yokoi, 1992). The global coordinate system was rotated to match the anterior-posterior (A-P) axis and the direction of horizontal CG velocity vector at toe-off. The coordinate system was applied during step. Therefore, the CG velocity at toe-off in centrifugal-centripetal component was zero. The relative momentum generated by the lower extremity segments were calculated by Ae's equations (Ae et al., 1985).

$$GM_{th} = (m_{ar} + m_t + m_{sw})V_{h/k} + m_{th}V_{th/k}$$
$$GM_{sh} = (m_{ar} + m_t + m_{th} + m_{sw})V_{k/a} + m_{sh}V_{sh/a}$$
$$GM_f = (m_{ar} + m_t + m_{th} + m_{sh} + m_{sw})V_a + m_f V_f$$
$$GM_{sl} = GM_{th} + GM_{sh} + GM_f$$

Here GM = momentum generated, m_i = segment mass, $V_{i/j}$ = velocity of segment I relative to joint j, ar = arm, t = trunk, th = thigh, sh = shank, f = foot, sw = swing leg, sl = support leg, h = hip, k = knee, a = ankle. The generated forces (GF) were calculated as the differential of GM. To compare the GM during inside foot contact and outside foot contact, paired t-test was conducted at 0, 20, 40, 60, 80, 100% of normalized support phase. Significance level was set at 5% in all statistical tests.

RESULTS: The mean of 30m time was 3.40 ± 0.25s (mean ± SD) and that average speed was 8.81m/s. The results of the CG velocity and GM_{sl} were illustrated in Figure1. The GM of inside leg changed from positive to negative, while the outside was always positive in the centrifugal-centripetal (CF-CP) component. In the A-P component, there were no significant differences in the GM_{sl} between sides. In the vertical component, the inside support leg contributed greater for upward than outside support leg from 0 to 60% (p value range: 0.00–0.01). The results of the GF of 3 segments were illustrated in Figure2. The GF curves of thigh, shank and foot were similar between sides in A-P and vertical components (Figure 2). In the CF-CP component, the GF curves indicated symmetric change between inside and outside.

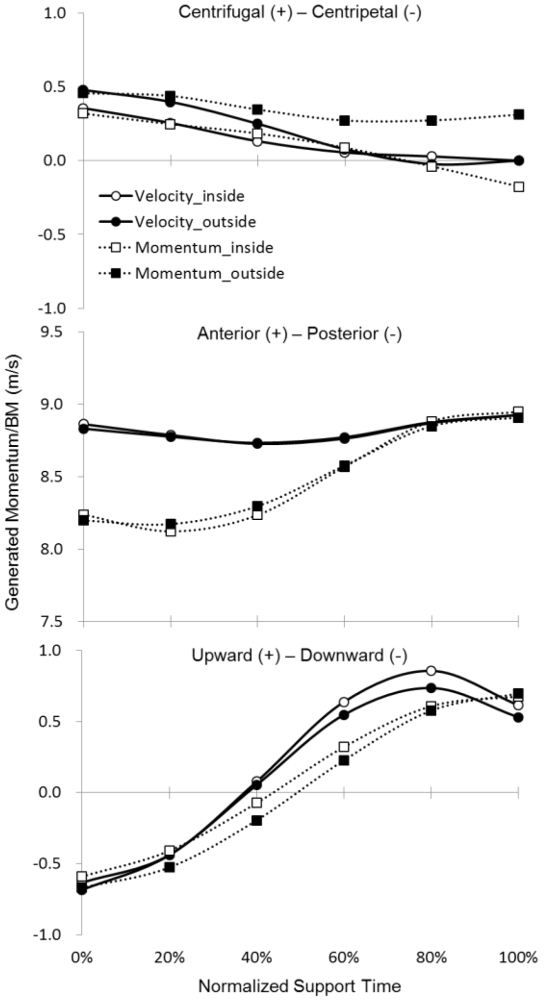

Figure 1: CG velocity and generated momenta of support leg. The support time was normalized at 100%

DISCUSSION: The GM_{sl} and GF curves in the A-P and vertical components were similar to the straight sprinting (Ae et al., 1985; Ogiso, Yasui, Aoyama, & Watanabe, 1998), although there were some statistically differences between inside and outside legs. The asymmetric contributions of support leg to the running velocity were found in the CF-CP component. The inside thigh generated the force to the centripetal direction during the first 20% and last 30% of support phase. The inside shank and foot generated the opposite forces. Thus, the inside thigh and foot contribute to accelerate the runner's body to centripetal direction at first and last support phase and at middle of support phase respectively. On the other hand, the outside thigh did not generate the forces to the centripetal direction during whole support phase. The inside foot and shank contributed to accelerate the runner's body to the centripetal direction during the first and last 20% of support phase and at the middle of support phase respectively.

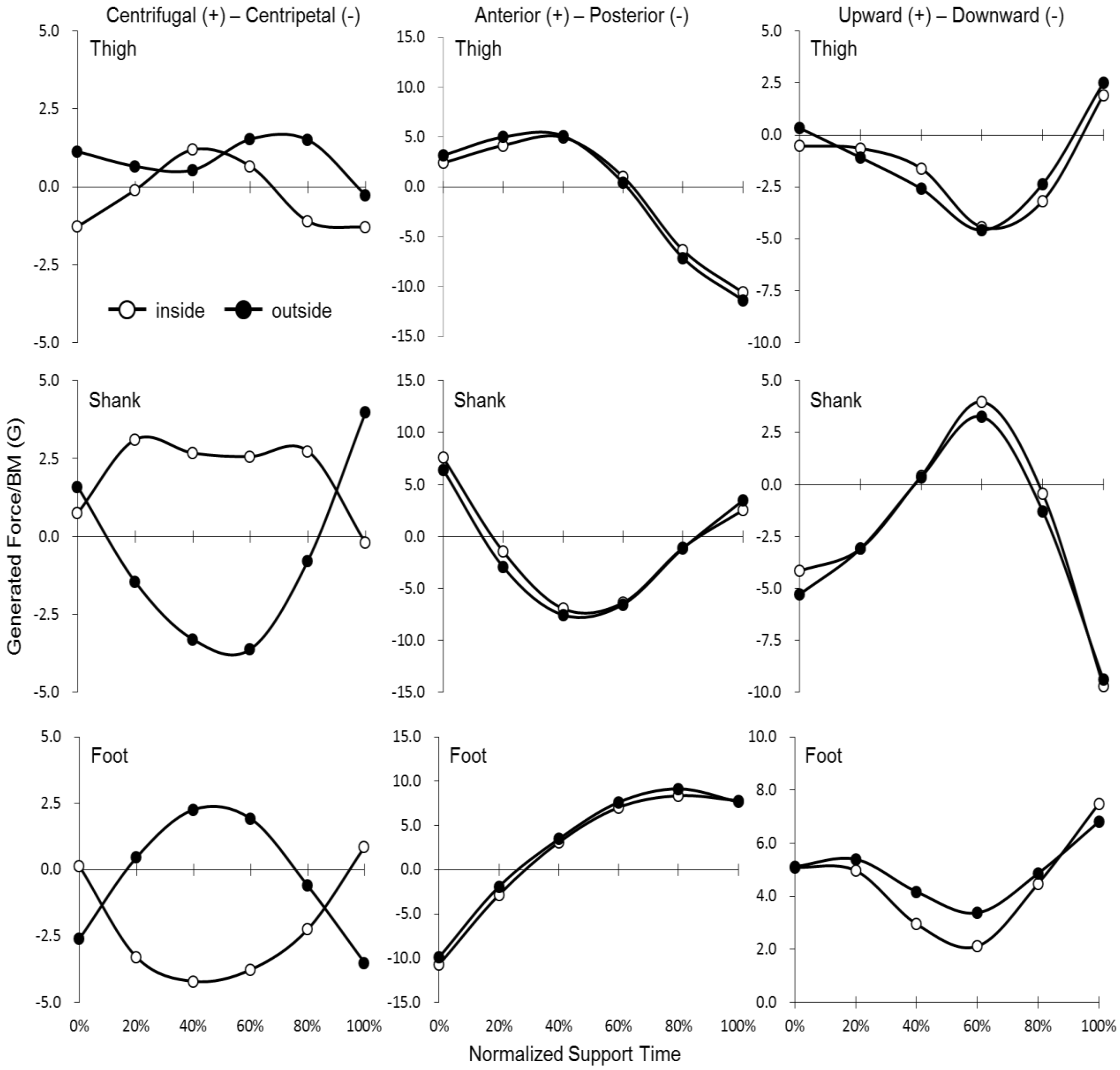

Figure 2: Generated forces of thigh, shank and foot. The open and filled symbols indicate inside and outside support respectively. The support time was normalized at 100%

CONCLUSION: The purpose of this study was 1) to show the support leg contributions in curved sprinting, and 2) to investigate the differences of contribution between inside and outside. The contributions of thigh, shank and foot in A-P and vertical component were similar to straight running in each leg. The asymmetric contributions were found in CF-CP component.

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