LOWER-LIMB BIOMECHANICAL ASYMMETRY IN MAXIMAL VELOCITY SPRINT RUNNING

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Asymmetry analyses have provided valuable insight into submaximal running and walking gait. Knowledge of asymmetry in sprint running is limited due to traditional unilateral methods of data collection. The aims of the study were to develop asymmetry measures that included intra-limb variability and to investigate asymmetry of sprint running in an ecologically valid environment. Asymmetry was quantified for a group of sprint runners through the development of novel multifactorial asymmetry scores. The largest kinematic asymmetry values (7%) were smaller than the corresponding kinetic values (90%). The presence of significant athlete asymmetry suggested unilateral analyses may overlook important information. Information about individual athletes' asymmetry may also help to inform the coaching process.

KEYWORDS: variability, bilateral, symmetry angle, inverse dynamics analysis.

INTRODUCTION: The analysis of biomechanical asymmetry has proved to be useful from performance (Vagenas & Hoshizaki, 1991), injury (Jacobs et al., 2005) and sports technology (Buckley, 2000) perspectives. Significant differences have been reported between values for left and right sides of the body for kinematic (Vagenas & Hoshizaki, 1991) and kinetic (Munro et al., 1987) variables in submaximal running. However, limited information is available relating to asymmetry during sprint running. From a coaching perspective, knowledge of asymmetry may inform the nature of an athlete's training based on bilateral performance differences. Information about asymmetry in sprint running also has implications for biomechanical research. Previous biomechanical studies of sprint running have collected unilateral, spatio-temporal data due to constraints on data collection, such as the positioning of cameras or scanners (Gittoes & Wilson, 2010). In the event of a large amount of asymmetry being present during sprint running, a unilateral analysis may provide an incomplete description of technique and important kinematic and kinetic factors could be overlooked if occurring in the limb that was not chosen for analysis. Dufek et al. (1995) discussed potential problems with group-based analyses due to the creation of 'mythical average' performance data. If asymmetry exists in sprint running, similarly misleading 'mythical average' data could result from combining data of both sides of the body. Vagenas and Hoshizaki (1991) noted individual joint asymmetry varies within a limb and highlighted the need to include individual joint analyses when investigating asymmetry.

Zifchock et al. (2008) proposed the 'symmetry angle' (θ_{SYM}) as a method of quantifying asymmetry, which did not suffer from the artificial inflation associated with other methods such as the symmetry index (Robinson et al., 1987). The θ_{SYM} provides values ranging from 0% (no asymmetry) to 100% (perfect asymmetry) and allows quantification of the difference between left and right values. However, the θ_{SYM} does not include the important consideration of intra-limb variability. Giakas and Baltzopoulos (1997) noted that for asymmetry to be significant, the difference between values for left and right limbs must be larger than the intra-limb variability. Therefore, the aims of this investigation were to develop methods for quantifying kinematic and kinetic asymmetry that included the previously neglected intra-limb variability and to use these methods to gain understanding of asymmetry during sprint running.

METHODS: Data collection and processing: Ethical approval was gained from the University's Research Ethics Committee prior to commencement of the study. Eight male sprint trained athletes performed 9-12 maximal 60 m sprint runs (mean velocity = 9.03 $m \cdot s^{-1}$). Athletes mean age, mass and stature were 21.75 [±4.83] years, 73.99 [±8.72] kg and 1.79

[±0.07] m, respectively. Three-dimensional positional data were collected from an 8 m section of each run, centred on the 40 m mark, using an automated motion analysis system (CODA) operating at 200 Hz. Twelve active cx1 markers were connected in pairs to 'twin-marker drive boxes' and attached to athletes using adhesive tape. Markers were positioned lateral to the fifth metatarsal-phalangeal joint, lateral malleolus, lateral condyle of the tibia, greater trochanter, iliac crest and greater tubercle for both sides of the body. Kinetic data were collected via two piezoelectric force plates (Kistler 9287BA), mounted end to end along the direction of the running lane. Force plates were mounted in recessed customised housings and covered with running track identical to that covering the rest of the lane. Kinematic and kinetic data were filtered using a fourth-order Butterworth filter, with optimum cutoff frequencies determined using the autocorrelation method (Challis, 1999). Two-dimensional inverse dynamics analyses were performed to calculate net joint moments at the ankle, knee and hip joints. Eight kinematic variables were selected for analysis based on association with successful technique (Hunter et al., 2004) and identification by expert sprint coaches (Thompson et al., 2009). Following tests for normality, parametric statistics were used to test for significant ($p<0.05$) differences between left and right limbs for each variable. Significant differences were also tested for between the magnitude of asymmetry present in step velocity and the other kinematic variables. Seven discrete kinetic variables were selected for analysis due to their association with successful sprint running and the kinematic variables analysed. The inclusion of tests for significant differences between limbs meant that intra-limb variability was included in the asymmetry measures.

Calculation of asymmetry scores: Left and right values were combined to calculate the θ_{SYM} for each variable using the method of Zifchock et al. (2008). A composite kinematic asymmetry score (KMAS) was calculated for each athlete by multiplying each variable's θ_{SYM} by 0, 1 or 2 (representing neither, one or both tests indicating significance, respectively). A kinetic asymmetry score (KAS) was also calculated for each athlete by summing two values. The first was the event asymmetry score, calculated by summing the θ_{SYM} values for the discrete variables that displayed a significant difference between left and right limbs; the second was the profile asymmetry score, calculated from asymmetry present in the magnitude, phase, and duration of power profiles for the ankle, knee and hip joints.

RESULTS: Kinematic θ_{SYM} values (Table 1) were all <10%, with the largest value (6.68%) being touchdown distance for Athlete 4. Touchdown distance displayed the most frequent significant differences (7 athletes), while minimum hip height displayed the least (2 athletes).

Table 1
Kinematic variables contributing to the kinematic asymmetry score of eight athletes

Athlete	SV	SL	SF	zH_{MIN}	zK_{MAX}	θK_{FLEX}	θH_{EXT}	y_{TD}	KMAS
1	0.79*	1.28*	1.13	0.62	1.04*	3.72*#	0.69	2.63	10.53
2	0.62*	1.16*	1.68*#	0.43	0.92*	1.60	0.92*	3.76#	10.73
3	0.32*	0.79	0.81	0.69	0.81	1.81*#	0.69*	2.59#	7.22
4	0.18	1.33*#	1.44*#	0.34	0.66	4.15*#	0.41*	6.68*#	27.60
5	0.22	1.01	1.12#	0.47*	0.56	3.54*#	0.61#	1.79#	11.07
6	0.39*	1.04*	1.38*#	0.70*	1.44#	3.53#	0.55	2.56	9.86
7	0.25	0.62	0.65	0.23	0.81	1.39#	0.25	3.13#	4.52
8	0.25	0.58	0.65	0.58	1.78*#	1.52	1.24*#	2.60#	8.64

SV = step velocity, SL = step length, SF = step frequency, zH_{MIN} = minimum hip height during contact, zK_{MAX} = maximum knee lift during contact, θK_{FLEX} = minimum knee angle during swing, θH_{EXT} = maximum hip angle at end of contact, y_{TD} = touchdown distance, * = significant difference between left and right values, # = significantly larger asymmetry compared to SV for the other variables.

Kinetic θ_{SYM} values, shown in Table 2, ranged from 0.06% (net vertical impulse) to >90% (net ankle joint work). Net ankle joint work displayed the largest amount of significant differences (4 athletes), whilst net vertical impulse and mean support moment displayed the least (1 athlete). There did not appear to be any relationship between kinematic and kinetic asymmetry or between either kinematic or kinetic asymmetry and step velocity (Figure 1).

Table 2
Kinetic variables contributing to the kinetic asymmetry score of eight athletes

Athlete	IMP_H	IMP_V	Fz_{MAX}	M_{SUP}	WA_{NET}	WK_{NET}	WH_{NET}	PRO	KAS
1	25.07*	1.27	2.14	3.54	42.95*	8.48	5.47	124.89	193.50
2	2.99	0.73	0.38	4.59	11.64	76.94*	11.28	209.76	286.70
3	13.44*	1.97	2.32	3.48	6.07	23.23	21.63	159.17	173.16
4	9.38	0.79	3.01*	5.06	21.57*	42.67	3.42	49.04	73.62
5	1.55	0.06	1.12	5.30*	23.74	23.82*	24.25	40.49	69.61
6	0.18	0.83	0.90	2.68	14.54*	22.86	13.83	48.00	62.54
7	10.25	1.84	0.71	3.99	41.25*	56.43	66.43	28.00	69.25
8	2.39	5.95*	4.33*	7.47	93.23	79.56	44.99*	67.65	122.92

IMP_H = net horizontal impulse, IMP_V = net vertical impulse, Fz_{MAX} = maximum vertical force, M_{SUP} = mean support moment, WA_{NET}, WK_{NET} and WH_{NET} = net work around the ankle, knee and hip joints, * = significant difference between left and right values.

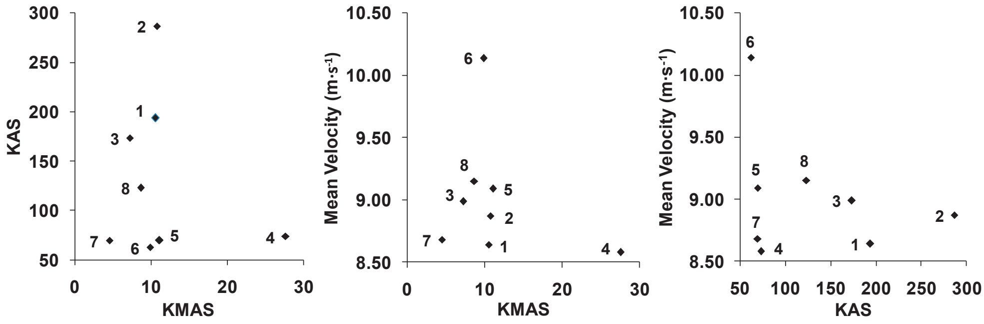

Figure 1: Comparisons of KMAS and KAS (a), KMAS and mean velocity (b) and KAS and mean velocity (c) for Athletes 1-8.

DISCUSSION: The aims of this study were to develop methods for quantifying kinematic and kinetic asymmetry that included intra-limb variability and to use these methods to gain understanding of asymmetry during sprint running. Novel composite asymmetry scores were developed that included intra-limb variability when quantifying the difference between limbs. Calculating overall scores along with detailed kinematic and kinetic measures of asymmetry allowed identification of the specific mechanisms underpinning an athlete's asymmetry, whilst providing a method that allowed inter-athlete comparisons to be made. Largest kinetic θ_{SYM} values were more than nine times larger than the largest kinematic θ_{SYM} values. The inclusion of measures that incorporated values close to zero (e.g. net joint work) reinforced the use of θ_{SYM} as a successful measure of asymmetry, due to the artificially inflated results characteristic of other methods, such as the symmetry index (Zifchock et al., 2008). Comparing KMAS and KAS between athletes indicated that there was no relationship between the two scores. Athlete 7 displayed similarly low scores for KMAS and KAS in relation to the other athletes, whereas Athlete 2 displayed a large KAS and a moderate KMAS in comparison to the other athletes. No relationship was apparent between kinematic or kinetic asymmetry and sprint performance. Athletes 1 and 4 displayed similar mean velocities (8.64 & 8.58 $m \cdot s^{-1}$) but the KMAS calculated for Athlete 1 (10.53%) was less than half the magnitude of Athlete 4 (27.60%). Athletes 6 and 7 displayed similar KAS values (62.54 & 69.25%) whilst having large differences in mean step velocity (10.14 & 8.68 $m \cdot s^{-1}$). The variables displaying significant asymmetry were different for all athletes. Step velocity asymmetry was low (<1%) for all athletes, indicating that asymmetry present in other kinematic and kinetic variables may serve to compensate for a strength imbalance or asymmetry in another variable (Vagenas & Hoshizaki, 1991).

From a coaching perspective, asymmetry evident in kinematics and kinetics of sprint running could influence sprint training by informing the coaching-biomechanics interface (Kerwin & Irwin, 2008). Asymmetry present in some kinetic variables was associated with asymmetry in corresponding kinematic variables. For example, the asymmetrical mean support moment shown by Athlete 5 was linked with asymmetry in mimumum hip height. Inter-athlete differences in KMAS and KAS and the contributing variables reinforced the importance of individual analyses, as discussed by Dufek et al. (1995). Asymmetry was present in the kinetics of all joints analysed; however, net joint work was only significantly different between limbs for one of the three joints for each athlete, supporting the need for individual joint asymmetry analyses (Vagenas & Hoshizaki, 1991).
From a data collection perspective, asymmetry was found to be inconsistent between variables and between athletes. For example, if touchdown distance data were collected unilaterally from Athlete 4, the difference of 0.06 m observed between left and right legs would have been lost. Conversely, touchdown distance was not significantly asymmetrical for Athlete 1; however, maximum knee lift, which was not significantly different between sides for Athlete 4, displayed a significant difference of 0.04 m for Athlete 1. The inconsistency of asymmetry between athletes indicated that bilateral analyses may be required to ensure athlete-specific bilateral differences are not overlooked.

CONCLUSION: The New asymmetry scores have highlighted bilateral differences that exist in sprint runners, which could provide coaches with information about individual athletes' asymmetry and inform future methods of data collection. Future research could investigate the robustness of the new asymmetry scores for a wider population and extend the new scores to investigate asymmetry in other forms of running, such as amputee sprinting.

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