A Quantitative Evaluation of Running Injuries with Respect to Bilateral Dominance

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INTRODUCTION

The relationship between bilateral asymmetries involving anatomical, functional and kinematic features with running injuries has been widely accepted (Nigg, 1985; Subotnick, 1981). Orthopaedic surgeons, pediatrists and coaches all rely on the assumption of symmetry when doing corrective surgery, prescribing orthotics or correcting symmetric movement patterns.

Professionals also generally believe that bilateral asymmetries are fundamental in explaining running injuries (Clancy, 1980; Smart, 1980; McKenzie et al., 1985). It is thought that acute and chronic injuries originate from the misalignment of the skeleton, and are caused by mechanical overloading of the locomotor system (Nigg, 1985). The magnitude and the geometry of the acting forces, are critical to the load exerted on bones, cartilage and tendons. Given the plethora of functional and kinematic irregularities possessed by the runner, biomechanical symmetry is a form of reduced geometry in the acting forces, and may produce asymmetric accumulated loads with corresponding damage to the noncontractile tissue. Evidence has been presented to support associations between leg-length in equalities and running injuries (Coplin, 1971). The purpose of this study was to establish a systematic classification of running injuries with respect to bilateral dominance characteristics.

METHODS

The subject sample included 29 long distance male runners whose training patterns ranged from 2 to 12 years of running, from 6 to 12 months of consistent training per year, and from 20 to 160 km of training distance per week, at a pace of 3.67 to 4.92 min/km. They ranged in age from 21 to 31 years, from 1.64 to 1.89 m in height and from 55 to 79 kg of body mass. The preferred side for each runner was identified using the following questionnaire items: writing hand, drawing hand, throwing hand, kicking leg, high jumping leg, long jumping leg, hand grip strength, shoulder height and shoe wear. These data identified a clear cut superiority of the right side in upper limb dominance with a less defined yet distinct left side dominance for the lower limbs. The injury history of each runner was assessed with special emphasis on the identification of the body side affected as well as the severity of the symptoms. The degree of injury was recorded as either a minor disability representing occasional pain, moderate disability causing an alteration in running style or a major disability when the athlete is unable to run. The side of the injury was indicated by either a +1 or -1. A Cybex II was set at 60°/s in order to obtain isokinetic strength of the knee flexors and extensors. At the same time calcaneal flexibility was determined using a flexometer. Rearfoot kinematics were obtained using a Red Lake Locam II high speed camera during a treadmill run set at their personal training pace. After a 10 minute warm up, 10 trials were recorded at 150 frames per second. Five rearfoot body markers were digitized, superior calcaneal tuberocity, inferior calcaneal tuberocity, popliteal center, achilles tendon and gastrocnemius center. The points were smoothed at a cut off frequency of 6 Hz (Winter et al., 1974) and the following variables obtained, lower leg angle, subtalar joint angle, rearfoot angle, angular velocity and linear velocity (Figure 1). Foot angle was obtained using a VHS video system (Figure 1).

RESULTS

The multivariate statistical analysis presented in Table 1 identify statistically significant asymmetries for both talocalcaneal flexibility and isokinetic knee strength. A univariate analysis revealed the range of talocalcaneal flexibility as the only variable not statistically significant (Table 2). Ankle inversion, eversion and the eversion-inversion ratio were significantly asymmetrical in the subject sample. Isokinetic strength of the flexors, extensors, total strength and the flexor extensor ratio all proved to be asymmetrical in the investigative sample.

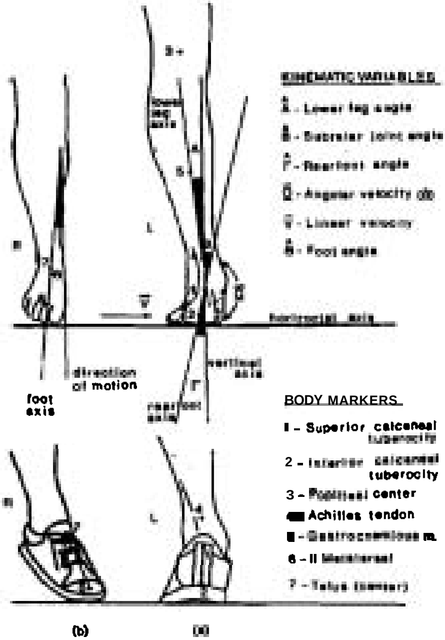

Figure 1: The kinematic reference system of the lower extremity (a. posterior surface; b. dorsal surface), and the kinematic parameters (angles A, B, Γ, and 0, Ω and V.

TABLE 1

Multivariate Test Statistics of the Functional Asymmetries of the Lower Limbs (n = 29)

Multivariate Component	Comparisons Set #	Wilk's Lambda	Exact F	DF H	DF E	Sign F
TCP Asymmetry	**1**	**0.25301**	**39.86**	**2**	**27**	**0.000**
	2	**0.23532**	**28.16**	**3**	**26**	**0.000**
IKS Asymmetry	**3**	**0.20492**	**52.38**	**2**	**27**	**0.000**
	4	**0.19832**	**35.03**	**3**	**26**	**0.000**
Overall Asymmetry	**5**	**0.13264**	**40.87**	**4**	**25**	**0.000**
	6	**0.13213**	**25.18**	**6**	**23**	**0.000**

#Variables included in each set are defined in Table 2.

TABLE 2

Descriptive and Univariate Statistics for the Functional Asymmetries of the Lower Limbs (n = 29)

Variable (unit)	Multiv. Sets#	Talocalcaneal Flexibility (TCF) Dominant Mean	SD	Nondominant Mean	SD	F Ratio	2-Tail P
EVE(deg)	1,2,5,6	10.21	3.94	6.17	3.97	82.11	0.000
INV(deg)	1,2,5,6	20.21	6.54	23.59	6.16	12.35	0.002
RAN(deg)	*	30.41	9.37	29.76	8.09	0.50	0.485
EIR	2,6	0.52	0.18	0.27	0.16	67.90	0.000

An analysis of the lower limb kinematics once again proved to reveal a distinct sidedness or asymmetry. Table 3 presents the following variables at touchdown, absolute rearfoot angle (r_t) touchdown, absolute lower leg angle (At) and frontal plane horizontal velocity of the foot (Vt), the following variables were measured at maximal pronation, absolute rear foot angle (r_p), absolute lower leg angle (A_p), angular velocity of the achilles tendon angle ($_{10}$), foot angle ($_m$) and time to maximal pronation (T_p), and the following variables were measured at maximal supination, angular velocity of the achilles tendon ($_{ms}$) and the frontal plane horizontal velocity of the foot (V_{ms}). In addition to the above basic variables the five following composite variables were also included, subtalar joint at touchdown (Bt), subtalar joint angle at maximal pronation (B_p), relative change in subtalar joint angle (B_p), relative change in rearfoot angle ($_p$) and time of foot fall (Table 3). An analysis of variance of the kinematic variables revealed 5 of the 10 basic variables significant with only one of the five composite variables significant (Table 3).

TABLE 3

Descriptive and **Univariate** Statistics for the Kinematic Asymmetries of the Lower Limbs in the "Running **Shoe" Condition** (n=29)

Variable (unit)	Dominant Mean	Dominant SD	Nondominant Mean	Nondominant SD	F Ratio	2-Tail P
Touchdown						
T (deg)	-9.37	3.68	-7.47	4.27	8.35	0.0007
At (deg)	8.15	2.29	651	2.11	27.66	0.000
Vt (m/s)	0.27	0.14	0.26	0.16	0.67	0.417
Pronation						
p (deg)	-0.67	2.93	1.14	3.23	9.61	0.004
Ap (deg)	10.49	2.86	8.91	2.71	47.06	0.000
10 (r/s)	3.11	1.11	3.03	1.25	0.18	0.669
[illegible] (deg)	4.76	4.20	3.99	4.05	1.08	0.306
Tp (m/s)	915 7	13.16	88.25	17.60	1.88	0.183
Supination						
ms (r/s)	-3.25	1.21	-3.33	1.25	0.26	0.616
Vms (m/s)	-0.42	0.12	-0.36	0.14	-4.88	0.036
Composite Variables						
Bt (deg)	-1.21	4.25	-0.97	4.49	-0.09	0.768
Bp (deg)	10.83	3.64	10.04	356	1.49	0.232
Bp (deg)	12.05	2.86	11.02	3.46	454	0.042
P (deg)	8.71	2.40	8.62	2.94	-0.03	0.856
(ms)	222.44	16.91	223.27	18.00	-0.49	0.487

Negative values indicate supinated foot position.

An analysis of the running injuries as documented by our subjects revealed only 13 of 29 subjects (44.8%) had injuries or symptoms affecting one side of their body (SIDE): right side in eight and left side in five subjects. Based on the INJLR index, in 15 of the 46 reported injuries (32.6%) both sides of the body were affected, four of which the severity of the injury or the intensity of the symptom was greater on the right side. On the other hand, only four subjects were completely free of injury in their running careers. From the 25 remaining subjects, seven showed symmetric injury patterns, whereas 9 had the right side and 9 the left side affected more than the contralateral. From the 46 reported injuries, 13 were of minor (DIS=1) and 29 injuries were of moderated (DIS=2) degree of disability, while only four were classified as severe (DIS=3). Six subjects presented a high index of incidence (INJTOT =4-6), three of which also showed a high index of total disability (INJDIS=5-9). The mean scores for INJTOT and INJDIS were 2.40 (+1.75) and 2.86 (+1.99) respectively. This indicated that on average each subject in the sample was affected by approximately 2.5 different injuries (INJTOT) which resulted in a cumulative degree of disability of about 3 (INJDIS). In general, it appeared that the sample was rather highly affected by overuse running injuries.

The injury history data were cross-tabulated to reflect number of cases per injury add body side affected, and then grouped by major body regions (Table 4). The body regions mostly affected by the respective injuries were knee (n= 15) and foot (n= 10). Whereas thigh and shank had equal incidence (n= 7) and sidedness scores, knee and foot showed a trend of crossed laterality: the knee was mostly affected on the right side (left =7, right = 11) while the foot segment was mostly affected on the left side (left = 10, right = 6). Overall, the left and the right body sides in the sample were affected by a similar number of running injuries (left = 28, right = 29). However, taking functional laterality into consideration, these data can be interpreted as reflecting an overall pattern of compensation in terms of sites of injuries between the knee and the foot joints: with the knee more frequently injured on one side (right for this sample) and the foot most frequently injured on the contralateral side.

The injuries with high incidence included shin splints (n = 6), patellofemoral pain syndrome, hamstring strain, and plantar fasciitis (n= 5), and iliotibial band friction syndrome (n = 4). In general, the patterns of injury histories of the sample are compared to those of other samples of long distance runners (Brody, 1980; Clements et al., 1981; McKenzie et al., 1985). With respect to injurylateralization patterns, there are no available data to be compared to the results of this analysis.

The subjects were grouped into distinct categories for each of the three injury indices in accordance to the following manner. For INJLR three groups were established, the first including subjects with negative (right side), the second with zero (symmetry), and the third with positive (left side) scores. For INJTOT three groups were also made including subjects with scores from 0 to 1 in the first group (almost injury free), 2 in the second (moderate injury history), and from 3 to 6 in the third group (high injury history). The subjects were divided into two groups for INJDIS, with scores from 0 to 2 in the first group (low total disability) and from 3 to 9 in the second group (high total disability). A series of multivariate analyses of variance were then conducted in order to examine to what extent selected sets of functional and kinematic quantitative asymmetries differentiate significantly among the groups (levels) of each of the three injury factors (indices).

TABLE 4

Incidence and Lateralization of Injury (n=25) according to Anatomic Regions

Body	Running Injury or Symptom	Incidence	Body n	Side LR
Trunk	Thoracic Strain	1	1	0
	Lumbar Spine Strain	2	-	-
	Subtotal 1	3	1	0
Pelvis	Iliopsoas Tendonitis	1	0	1
	Hip Strain	1	1	0
	Troachanteric Bursitis	2	1	2
	Subtotal 2	*4*	2	*3*
Thigh	Adductor Strain	1	1	0
	Hamstring Strain	5	1	4
	Hamstring Tendonitis	1	1	1
	Subtotal 3	7	3	*5*
Knee	Patellofemoral Pain Syndrome	5	2	3
	Iliotibial Band Friction Syndrome	4	0	4
	Torn Cruciate Ligament	2	1	1
	Osgwd Shlatters Disease	2	2	2
	Patellar Tendonitis	1	1	0
	Popliteus Tendonitis	1	1	1
	Subtotal *4*	15	7	11
Shank	Shin Splints	6	4	4
	Tibial Bone Bruise	1	1	0
	Subtotal 5	7	5	4
Foot	Achilles Tendonitis	4	4	2
	Plantar Fasciitis	5	5	3
	Metatarsalgia	1	1	1
	Subtotal 6	10	10	*6*
	Totals	*46*	*28*	29

Body side affected by the respective injury or symptom
n- Incidence; number of subjects
L- Left side
R- Right side

The **MANOVA** option of the **ANOVA** procedure of SAS was used to carry-out this analysis, the results of which are presented in the summary Table 5. No significant difference was found between any of the levels in any of the three classifications with respect to either functional or kinematic asymmetries. The selected sets of functional and kinematic asymmetries did not significantly diierentiate between the injury groups. This clearly indicated that functional **and/or** kinematics asymmetries did not present overall or grouped correlations with the laterality (INJLR), total injury (INJTOT), and total disability (NJDIS) aspects of running injuries. significant results were also not produced when angles T and A were replaced by their composite angle B in this analysis.

TABLE 5

Summary Statistics for the Multivariate Analysis of the Injury **History Classification** with Respect to the Functional and the Kinematic Asymmetries (n=29)

Injury Index	Level Values	N	Functional Asymmetries	Kinematic Asymmetries
INJLR	1 right (-)	8	W =0.6776	W =0.6414
	2 Symm (0)	12	F=1.24	F=0.42
	3 Left (+)	9	D=0.9093	D=0.9774
INJTOT	1 LOw (0-1)	10	W=0.8714	W=0.4528
	2 Moder(2)	10	F=0.41	F=0.83
	3 High(3-6)	9	p=0.9093	p=0.6685
INJDIS	1 Low(0-2)	14	W=0.8782	W=0.6769
	2 High	(3-9)	F=0.83	F=0.86
			p=05179	p=0.5840

Functional variables: EVE, INV, FLEX, & EXT.
Kinematicvariables: t, At, Vt, p, Ap, 10, Tp, m, ms, Vms.
W - Wilks' lambda.
F - F ratio; Roa's F approximation to W.
p - probability level.

The above series of multivariate comparisons were performed to determine if groups of runners with distinctly different injury patterns were also different in terms of selected components of functional and kinematic asymmetries. Directional asymmetries (left-right) were used in this analysis since they consist of both the magnitude and the direction of asymmetry. It was initially hypothesized that if an interaction between selected functional or kinematic asymmetries takes place and results in the activation of injury mechanisms then this interaction would be detected by multivariate analysis. However, this analytic step was part of the exploratory nature of the study. Even though the notion of interplay between anatomic, functional, and/or **kinematic** factors is generally accepted as one of the underlying mechanisms for lower extremity biomechanical problems, the vast majority of the literature supports the importance of distinct biomechanical factors affecting running injury. These factors are leg length inequality (Subotnick, 1981; **Friberg**, 1982; **Klein, 1983),** excessive foot pronation during running (angles p and Bp) (Hlavac, 1977; Brody, 1980; Clements et al., 1981; **McKenzie,** 1985; Messier and Pittala, 1987; **Nigg, 1987),** angular velocity of foot pronation **( )** (Messier and **Pit**tala, 1987; Nigg, **19878), subtalar** joint functional irregularities (EIR) **(Jer**nick and **Heifitz,** 1979; Clancy, 1980; Brody, **1980),** and knee strength imbalances (FER) **(Coplin,** 1971; Knight, 1980; Subotnick, 1985; **Taunton** et at., 1987). However, the relationships of these variables to running injuries were not statistically documented. Therefore, additional analysis was undertaken to statistically assess the importance of each of these factors. A series of analyses of variance procedures were performed (Table 6) on the following asymmetry variables which were selected to represent the critical factors described above: talocalcaneal joint flexibility imbalance (EIR), **isokinetic** knee strength imbalance (FER), **rearfoot** angle at touchdown (0 t), subtalar joint angle at touchdown (Bt), **rearfoot** angle at maximum pronation (Ω p), subtalar joint angle at maximum pronation (Bp), and initial angular velocity of pronation (Ω 10)

Data presented in Table 6 revealed no significant differences for INJLR and INJDIS. The functional and kinematic asymmetry variables did not discriminate between the groups of each of these two classifications of running injuries. The initial angular velocity 010 presented the only significant effect for INJTOT (p=0.031).

TABLE 6

Summary Statistics for the Analysis of Variance of the Injury History Classification with Respect to Selected Functional and the Kinematic Assymetries
(n=29)

ASYMM DV'S	INJLR Model MS	Error Ms	F Value	INJTOT Model MS	Error MS	F Value	INJDIS Model MS	Error MS	F Value
Functional Asymmetries									
EIR	0.11	0.07	1.64	0.03	0.07	0.40	0.01	0.07	0.13
FER	0.01	0.0005	2.83	0.004	0.005	0.83	0.00009	0.005	0.02
Kinematic Asymmetries									
Running Shoe (RS)									
Γt	3.43	15.66	0.22	6.88	15.40	0.45	0.95	15.30	0.06
Bt	1157	19.03	0.61	2.61	19.72	0.13	1.66	19.12	0.09
Γp	0.46	10.81	0.04	1.01	10.77	0.09	0.07	10.44	0.01
Bp	11.20	12.81	0.87	1.64	13.54	0.12	17.98	12.49	1.44
Ω 10	0.70	0.71	0.99	2.31	0.58	4.00*	1.26	0.68	1.84

MS - Mean squares.
* $p < 0.05$.

To obtain an estimate of the extent of qualitative association existing between running asymmetries and injury patterns, the three injury indicies (INJLR INJTOT INJDIS) were subjected to nonparametric correlational analysis. Φ correlation coefficients were computed for the correlations between dichotomous data, whereas contingency coefficients were computed for the correlations between data expressed by trichotomous or higher classification values. Only a few significant correlations emerged. These were INJLR with φm (Φ =-0.39, $p=0.019$), INJDIS with FSW ($C=0.42$, $p=0.014$), and INJDIS with RAN ($C=0.41$, $p=0.012$). Therefore, it was clearly evident that injury patterns were independent of the laterality patterns characterizing the functional and the kinematic symmetries of the runners tested in this study. Given the possible limitations of the categorical groupings employed in this study for the classification of injury patterns did not present any significant multivariate or qualitative trend of relationship with the different functional and kinematic asymmetries possessed by the runners.

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