A Comparison of Kinematic Symmetry of Lower Limbs during Running at Different Speeds

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Abstract

Introduction: Symmetry and asymmetry of lower limbs are introduced as main critical challenges of human movement. The aim of this study was to compare the kinematic symmetry of lower limbs during running at different speeds. **Material and Methods**: The study was conducted as a quasi-experimental design. Twenty-eight professional runners (aged: 34.75±6.63 years) voluntarily participated in this study. Running at three progressive speeds (2.5, 3.5 and 4.5 m/s) was conducted by each subject on a treadmill while kinematic data were captured at 150 Hz. Peak angle of hip, knee and ankle joints during flexion were derived in the stance phase of running. Independent T-test were performed to examine the symmetry of peak flexion angles of hip, knee and ankle joints during running at different speeds using SPSS ver. 22 ($P<0.05$). **Results**: Findings showed no significant difference between two limbs in peak flexion angles of lower joints at every speed. **Conclusions**: Symmetry exists in peak flexion angles of lower joints in stance phase during running at the different progressive speeds. Coaches and biomechanists would achieve benefits of kinematic symmetry of lower joints in order to prevent injuries and optimize athletes' running performance.

Key words: Biomechanics; Kinematics; Lower Joints; Running; Symmetry

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Introduction

According to easy performance and great accessibility, running is known as one of the most popular sports activities in the world. It is estimated that over 40 million people participate in running or jogging as a form of exercise around the world (1). Running promotes better cardiovascular health and also has positive effects on musculoskeletal system in older adults (2). That is also known as one of the sports and exercise activities with high injury rates, especially lower extremity musculoskeletal system injuries (3).

Researches on the various aspects of running would lead to performance optimization as well as injury prevention. In this filed, biomechanics plays an important role with respect to kinetics and kinematics. Associations of limbs kinematics and maximal speed sprinting performance have broadly been investigated previously (4-9). In most sprint running studies, the biomechanical variables have been measured on only one side of the body, with assumption of that similar results would be obtained for the contralateral side. However, investigations regarding the symmetry during submaximal-speed running (at 2.9–6.8 $m \cdot s^{-1}$) in young athletes have indicated that symmetry in biomechanical measures between opposing limbs cannot be automatically presumed (10, 11). Moreover, there are some evidences to suggest that limb dominance/preference can increase asymmetry during submaximal-speed running and walking, because the dominant limb may be more responsible for propulsion, whereas the non-dominant limb plays a stabilizing function (12).

Different parts of the lower limbs are expected to be fit to produce a rhythmic and smooth movement, especially during gait and running. Therefore, studying the symmetry of the related parameters of the mentioned activities is known to be important. On the other hand, asymmetry is frequently recognized among the pathological symptoms of running (13, 14).Therefore, any disturbance in running may affect symmetry among the lower limbs.

Among the various methods of the symmetry assessment, measuring the angle of hip- knee-ankle on a standing position is

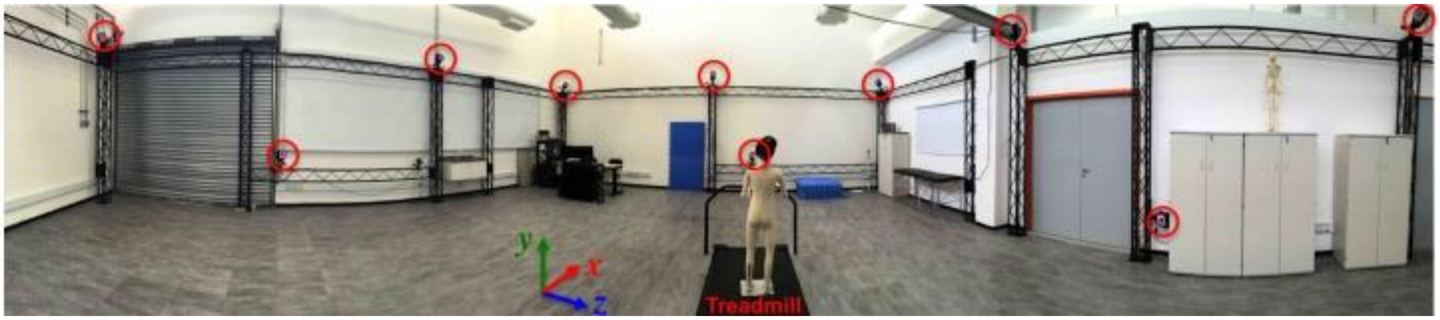

Figure 1. An overview of the Laboratory of Biomechanics and Motor Control. Expanded view of the Laboratory of Biomechanics and Motor Control (BMClab), showing 10 of the 12 motion-capture system cameras (marked with red circles), the instrumented treadmill, and the laboratory coordinate system

valid and commonly used by researchers (15). Ansari *et al.* (16) suggested that kinematic variables, such as the angle of knee, hip and ankle joints, and shoulder rotation and extension, are of key importance to the sprinting technique and have a vivid effect on sprinting performance. With the increase in the velocity of moving, the range of motion in the lower limbs becomes greater (17).

To best of our knowledge, no distinct study has concentrated on the symmetry and asymmetry of the lower limbs during running at different speeds. So, the purpose of this study was to compare the symmetry kinematics of the lower limbs during running at different running speeds.

Material and Methods

The study was conducted as a quasi-experimental design at the Laboratory of Biomechanics and Motor Control (BMClab; http://demotu. org) at the federal University of ABC (UFABC). The data collection was performed by experienced physiotherapist researchers. This study was approved by the local ethics committee of the UFABC (CAAE: 53063315.7.0000.5594), and written, informed consent was obtained from each subject prior to participation in the study.

Participants

Twenty-eight professional runners with a weekly mileage greater than 20 km, a minimum average running pace of 1 km in 5 min during 10-km races, and familiarity and comfort with running on a treadmill participated in this study. The exclusion criteria were the presence of any neurological or musculoskeletal disorders which compromises its locomotion or the use of any assistive devices.

The participants were introduced to the laboratory and given a brief explanation of the experimental procedures. Then, they were asked to provide a brief interview regarding the eligibility criteria, demographic data, and running habits.

Equipment

The running kinematics were collected via a 3D motion-capture system with 12 cameras (4 Mb, resolution, the Cortex 6.0 software, Raptor-4, Motion Analysis, Santa Rosa, CA, USA). The cameras were distributed around the laboratory such that they aimed at the instrumented treadmill's motion-capture volume (Figure 1). The cameras were mounted in a metallic truss setup structure with a length of 11.5 m, a width of 9.3 m, and a height of 2.8 m. This structure allowed positioning some cameras with varying elevations. The instrumented treadmill was mounted over a pit, with the treadmill surface at the same level as the laboratory floor. The Cortex 6.0 software (Motion Analysis, Santa Rosa, CA, USA) was used to (1) calibrate the motion-capture volume; (2) capture and identify the reflective markers. The motion-capture volume consisted of an area 3.1 m long, 2.3 m wide, and 1.2 m high, and this volume was calibrated daily. The rates of acquisition of the kinematics data were set at 150 Hz. The laboratory-coordinate system used for the study was the same as that proposed by the International Society of Biomechanics (Wu & Cavanagh) and, as shown in Figure 1, contained the following:

- X-axis in the direction of gait progression and positive pointing forward.
- Y-axis in the vertical direction and positive pointing upward.
- Z-axis in the medial-lateral direction and positive pointing to the right.

Protocol

The study used 48 technical and anatomical reflective markers. Clusters with four technical markers placed in a rigid shell were used on the thigh and shank segments. These shells were securely fastened to the segments using a combination of elastic and Velcro straps.

The subject walked at 1.2 m/s for 1 min to become familiar with the treadmill. Next, the subject was asked to stay on the left belt of

Table 1. Descriptive measures of demographic parameters

	n	Min	Max	Mean (SD)
Body Mass (kg)	28	56.85	82.15	69.64 (7.67)
Age (year)	28	22.00	51.00	34.75 (6.626)
Height (cm)	28	162.70	187.20	175.96 (6.74)

the treadmill, the belt speed was incrementally increased to 2.5 m/s, and after a 3-min accommodation period at this velocity, the data were recorded for 30 s. This procedure was repeated at speeds of 3.5 m/sand 4.5 m/s, always in the same sequence. After the running trials, the treadmill speed was again set to 1.2 m/s for a 1-minute cool-down period prior to being stopped. Flexion angles of the hip, knee, and ankle joints during the stance phase for the dominant and non-dominant joints were calculated using Cardan angles, with the distal segment expressed relative to the proximal segment which defines the flexion-extension movement. Peak of calculated angles were considered for further analyses.

Statistical analysis of the processed data

The homogeneity of variances assumptions of the dependent variables were tested using the Leven's test. Independent T-test was conducted to examine the symmetry of peak hip, knee and ankle joints during running at various speeds. The statistical calculations were performed according to significance level of 0.05 using SPSS ver. 22.

Results

Descriptive statistics of the subjects are presented in Table 1. Results of study indicated no significant differences between peak flexion angle of dominant and non-dominant limbs in hip and knee joints during running of three progressive different speeds (Table 2).

Lower extremity joints angles concerning the dominant and non-dominant limbs are presented in Figures 2, 3 and 4.

Table 2. Results of the independent T-test between dominant (D) and non-dominant (ND) lower limbs during running at different speed in sagittal plane (n=28)

Joint	Running Speed (m/s)		Peak Angle (Deg.) Mean (SD)	t	Sig.
Hip	2.5	D	33.63 (4.94)	0.16	0.87
		ND	33.43 (4.47)		
	3.5	D	38.20 (4.94)	0.35	0.73
		ND	37.75 (4.64)		
	4.5	D	42.00 (5.44)	0.27	0.79
		ND	41.63 (5.03)		
Knee	2.5	D	43.16 (5.77)	-0.02	0.99
		ND	43.19 (4.66)		
	3.5	D	44.08 (4.80)	-0.05	0.95
		ND	44.15 (3.69)		
	4.5	D	44.92 (4.20)	0.08	0.94
		ND	44.83 (3.45)		
Ankle	2.5	D	22.96 (3.02)	0.86	0.39
		ND	22.32 (2.45)		
	3.5	D	23.12 (2.55)	1.23	0.22
		ND	22.33 (2.22)		
	4.5	D	23.32 (2.34)	1.56	0.12
		ND	22.29 (2.59)		

Discussion

The aim of this study was to compare the kinematic symmetry of lower limbs during running at different speeds. Findings demonstrated no significant difference between two limbs in peak flexion angles of lower joints including hip and knee at every speed (2.5, 3.5, and 4.5 m/s).

Upon viewing a normal walking or running pattern with the naked eye, the typical observer would support the presence of the symmetry characteristics in lower extremity function.

Healthy individuals seem to exhibit smooth, uniform, harmonious interactions between right and left limbs during most ambulatory states. These attributes have led many investigators to assume that right lower limb performance is typical than of left lower limb performance and vice versa. There is, however, a lack of conclusive experimental evidence to support this assumption (18). Normal walking gait patterns evaluated for symmetry utilizing selected temporal and kinematic parameters produced positive results in studies conducted by Hamill *et al.* (19) who found high symmetry among kinematic variables during normal human locomotion and by Sawhill who reported the symmetry in right and left limbs during an isokinetic exercise at several speeds of movement. It should be noted that right and left footfalls in both locomotors conditions were collected in separate trials and were not consecutive footfalls. Despite this limitation, the symmetry still remained high (19).

The studies reporting the asymmetry in lower limb function implied that asymmetry might have been a result of the presence of a dominant limb. On rearranging the data to reflect limb preference, no statistical differences emerged between the preferred limb and the contralateral limb. The symmetry between the preferred and non-preferred limbs in both locomotors conditions indicated that both limbs were equally used in gait cycle. These data are contrary to the findings of Singh (20). Additionally, Singh concluded that upon evaluation of walking, there was not equal usage of the two lower limbs. In both of these studies, one limb appeared dominant, thereby resulting in a functional asymmetry between the limbs. The data in that study indicated that, at a sub-maximal force effort, there was no evidence

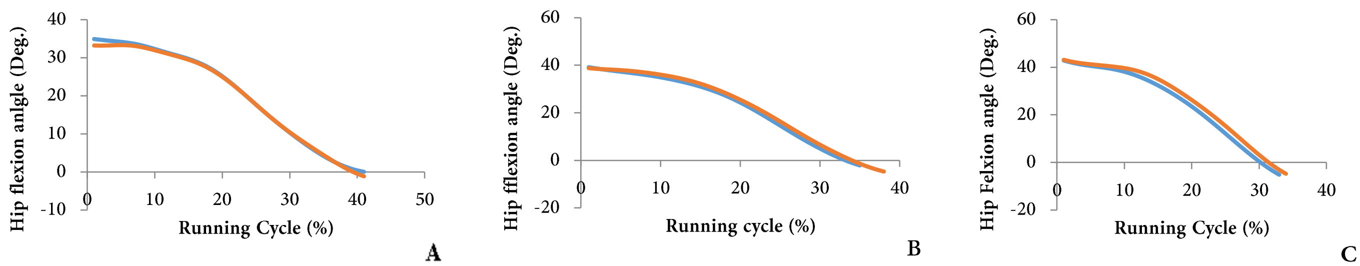

Figure 2*. A-C*) Hip flexion angles in three speeds (A: 2.5 m/s, B: 3.5 m/s, C: 4.5 m/s). Blue line: dominant hip, red line: non-dominant hip

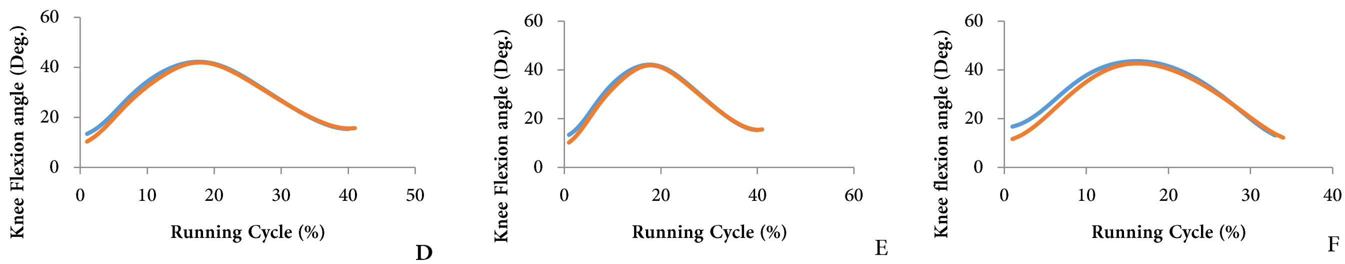

Figure 3*. D-F*) Knee flexion angles in three speeds (A: 2.5 m/s, B: 3.5 m/s, C: 4.5 m/s. Line blue: dominant hip, red line: non-dominant hip

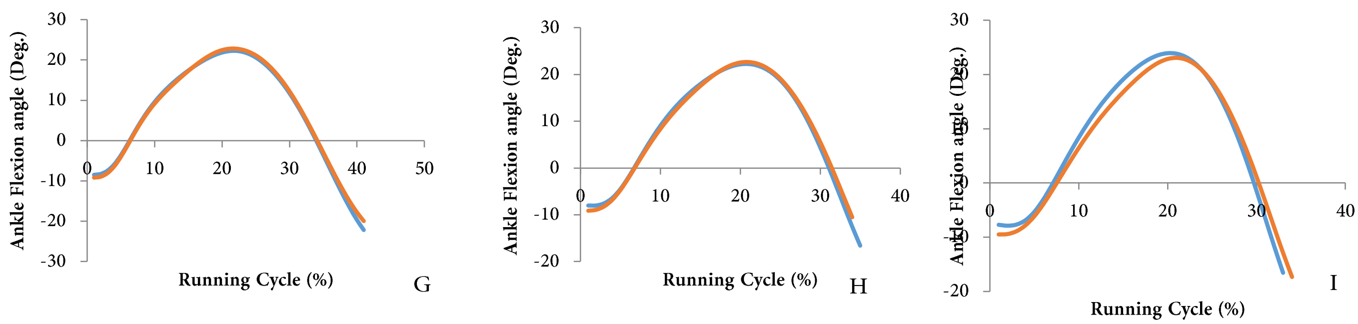

Figure 4. *G-I*) Knee flexion angles in three speeds (A: 2.5 m/s, B: 3.5 m/s, C: 4.5 m/s. Blue line: dominant hip, red line: non-dominant hip

of dominance in the lower limb (19). Roth *et al.* suggested that temporal symmetry measurement should be included in the comprehensive gait assessment because they found that speed had no significant relationship with symmetry .Power asymmetry is associated with slower walking speeds on the ground but does not affect basic gait parameters at standard or maximum speeds (21). However, Böhm *et al.* showed that asymmetry from walking to running is significantly increased. Increased asymmetry can be mainly due to disorders (spastic, contraction or weakness) of the affected limb. Asymmetries covered when walking may appear when running because running may put more strain on the musculoskeletal system (22).

But some data in the available literature contrasts with the findings of the present study. In this study, it was demonstrated that peak flexion angle of the hip joint at different speed of the dominant limb was greater than the non-dominant, but insignificantly. For the knee joint, in 2.5 and 3.5 m/s speed, magnitude of the peak flexion angle in the non-dominant knee was shown to be greater comparing with the dominant knee; but in 4.5 m/s speed, dominant knee had higher values than the non-dominant knee. Magnitude of the ankle peak flexion angle at the different speeds of the dominant ankle was greater than the non-dominant.

Given the functional connection between the joints within the lower limb, the interpretation of the results may provide some difficulties. During gait, ankle, knee, and hip angles undergo various changes to stabilize the upper body and to provide continual progression. It is natural that any changes in the ankle joint influence the knee and hip as the limb is a kinematic chain. One of the most spectacular forms of cooperation of these parts of the musculoskeletal system is a functional shortening of the lower limb during gait. Optimal performance of this task in the swing phase is possible only when the ankle plantar flexion occurs together with the knee and hip flexion. Therefore, it seems that greater asymmetry in the ankle than in the knee and hip movement may be a consequence of their location on the distal end of the aforementioned kinematic chain.

A review on the findings in accordance with the previous researches confirms our findings, regarding the importance role of kinematic parameters including joint's angle. Although increasing speed of running might affect different performance related parameters, kinematic symmetry of the lower joints will remain even by increasing magnitude of the peak angle in mentioned lower joints.

Conclusion

Kinematic symmetry in lower joints in the stance phase during running, as one the most challenges of human movement, exists in running performance at different speeds. Physical trainer and sports biomechanics may find great benefits concerning the symmetry during running.

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