Sport Sciences and Health Research

University of Tehran
Faculty of
Physical Education and Sport Science

Comparison of kinematics and kinetics symmetry of lower limbs during running

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Article Info

Original Article

Article history:

Received: 14 January 2020

Revised: 28 January 2020

Accepted 1 February 2022

Published online: 1 July 2020

Keywords:
biomechanics,
joint's moment,
running,
symmetry.

Abstract

Introduction: Symmetry and asymmetry of the limbs' movement pattern during running is introduced as one of the main critical challenges of human locomotion. The aim of this study was to investigate kinematics and kinetics symmetry of lower limbs during running at a constant speed.

Martials and Methods: The present study was conducted as a quasi-experimental study. Elite runner (age: 34.75±6.63 years) participated in this study. Running at constant speed was conducted by each subject at 2/5 $m.s^{-1}$ on treadmill while kinematic (Raptor-4 motion analysis) and kinetic data (Force plate, Bertec) were captured at 150 Hz and 300 Hz, respectively. The internal joint moments in sagittal plane were represented in the joint-coordinate system and were calculated using a standard inverse-dynamics approach and were normalized by the subject's body mass as well as running cycle over 101 time points. The normality and homogeneity of variances assumptions of the dependent variables was tested using Bartlett and Leven's test. Independent t-tests were conducted to examine the symmetry of hip, knee and ankle moments between dominant and non-dominant joints during stance phase of running (P<0.05).

Results: Results of the present study showed no significant difference exists between dominant and non-dominant lower joints regarding the peak moments of hip, knee and ankle in sagittal plane during stance phase (P>0.05) as well as between peak flexion angle of dominant and non-dominant hip, knee and ankle joints during running.

Conclusion: Symmetry exists in lower joints sagittal moments and flexion angle during running at the constant speed. According to the results dominant and non- dominant lower joints play propulsive and absorbent roles cooperatively.

Cite this article: Fatahi A, Molavian R. "Comparison of kinematics and kinetics symmetry of lower limbs during running". *Sport Sciences and Health Research*. 2020, 12(2): 217-225. doi: 10.32598/JESM.12.2.10.

EISSN: 2717-2422 | Web site: https://sshr.ut.ac.ir/ | Email: sshr@ut.ac.ir

 Publisher: University of Tehran, Faculty of Sport Sciences and Health

1. Introduction

Running is known as one of the most popular sports and is not restricted by time or place. There is growing evidences that running provides many health benefits, such as preventing chronic diseases and reducing the rate of premature mortality [1, 2, 3, 4]. Running promotes better cardiovascular health and also has positive effects on musculoskeletal system in older adults [5] and is one of the sports and exercise activities with high injury rates, especially lower extremity musculoskeletal system injuries [6]. Research on the various aspects of running would lead to performance optimization as well as injury prevention. In this filed, biomechanics plays a significant role with respect to kinetics and kinematics.

Symmetry and asymmetry of the limb's movement pattern is introduced as main critical challenges of human movement. These terms are used interchangeably in literature in which asymmetry is associated with the amount of divergence between the left and right side of the body [7]. Asymmetry in the lower limbs is not only associated with the manifestation of a pathology but is also found to be present in able-bodies. Running, is considered relatively symmetric activity [8]. When movement patterns become asymmetric, they can disrupt the natural rhythm of the performance [9, 10].

Kinetic asymmetry can greatly vary among runners of different levels [11, 12], and asymmetry in stride time increases energy cost for runners depending on running velocity [13]. Most of these evidences come from short bouts of running analyses, but asymmetries may not be evident during the initial stages of an exercise [14]. It has been suggested that asymmetries may arise, for example, in response to the development of muscle fatigue [15] and/or changes in exercise intensity [16]. The increase in oxygen uptake and reduction in mechanical efficiency during prolonged running [17] may also influence asymmetric patterns. Some studies have computed torques, net powers, and/or work done at the lower limb joints during running [18, 19, 20].

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. Moreover, there are some evidences to suggest that leg dominance/preference can increase asymmetry during submaximal-speed running and walking, because the dominant leg may be more responsible for propulsion, whereas the non-dominant leg plays a stabilizing function [2].

Among the various methods of symmetry assessment, measuring angle of hip- knee-ankle on standing position is valid and commonly used by researchers [21]. Ansari et al. (2012) suggested that kinematic variables- such as knee, hip and ankle joints angle, shoulder rotation, and extension- are of key importance to the sprinting technique and have a vivid effect on sprinting performance [22]. The results of the study showed that the kinematic variables- i.e. knee, hip and ankle joints angles, shoulder rotation and extension- had a significant influence on sprinting style. With the increase in the velocity of moving, the range of motion in the lower limbs becomes greater [23].

A review on the investigations performed on running symmetry with respect to joints kinetics and kinematic reveals that there is a noticeable scientific lack in these criteria. According to the importance of running performance with respect to probable symmetry between two lower limbs, the aim of this study was to compare symmetry of kinetic and kinematics variables of hip, knee and ankle joints during running at fixed speed in sagittal plane.

2. Materials and Methods

The present study was conducted as a quasi-experimental study. The aim of this study was to compare symmetry of hip, knee and ankle joints moments during running. The study was conducted 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). The informed consent was obtained from each subject prior to participation in the study.

2.1. Participants

Twenty-eight elite runners participated in this study. The inclusion criteria included being a regular runner 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. Exclusion criteria of any neurological or musculoskeletal disorder compromises its locomotion or the use of any assistive devices.

2.2. 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. In order to capture kinetics data, 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, and (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 and kinetics data were set at 150 Hz and 300 Hz, respectively. The laboratory-coordinate system used for the study was the same as that proposed by the International Society of Biomechanics [24] 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.

2.3. Protocol

The data-collection protocol involved the following procedures:

Upon arrival, the participant was asked to provide written informed consent and undergo a brief interview regarding eligibility criteria, demographic data, and running habits. Forty-eight technical and anatomical reflective markers, and clusters with four technical markers were placed in a rigid shell, on the thigh and shank segments. These shells were securely fastened to the segments using a combination of elastic and Velcro straps. The force plates were zeroed, the subject was asked to step onto the treadmill, and the following protocol was followed:

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 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.

The net internal joint torques were represented in the joint-coordinate system and were calculated using a standard inverse-dynamics approach. Moments were normalized by the subject's body mass as well as running cycle over 101 time points. The Visual 3D software program (C-motion Inc., Germantown, MD, USA) was used to filter the marker and GRF data and to calculate joint moments.

Flexion angles of the hip, knee, and ankle joints during in 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 analysis.

2.4. Statistical analysis of the processed data

The normality and homogeneity of variances assumptions of the dependent variables was tested using Bartlett and Leven's test. Independent t-tests were conducted to examine the symmetry of hip, knee and ankle moments and peak flexion angles between dominant and non-dominant joints during stance phase of running. The statistical calculations were performed in SPSS ver. 22 (P<0.05).

3. Results

Descriptive measures of demographic parameters are shown in Table 1.

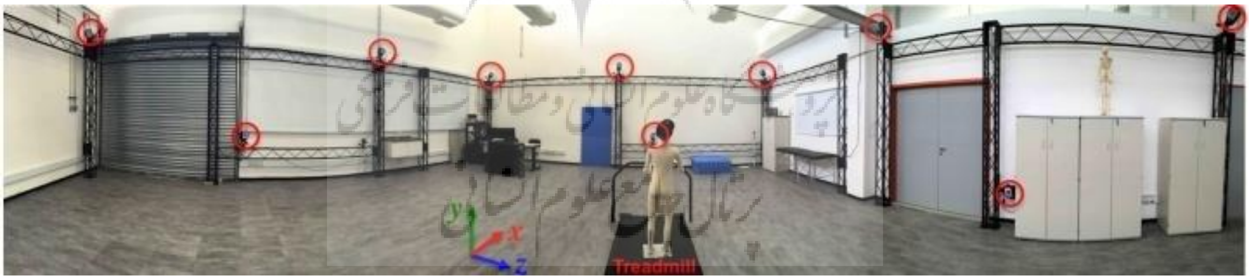

Figure 1. Overview of the Laboratory of Biomechanics and Motor Control. Expanded view of the Laboratory of Biomechanics and Motor Control (BMClab), showing 10 of the 12 motion-capture system cameras (marked with red circles), the instrumented treadmill, and the laboratory coordinate system.

Table 1. Descriptive measures of demographic parameters

	N	Minimum	Maximum	Mean	Std. Deviation
Body Mass (kg)	28	56.85	82.15	69.63	7.670
Age (year)	28	22.00	51.00	34.75	6.626
Height (cm)	28	162.70	187.20	175.96	6.74

Results of the independent t-test are presented in Table 2. According to the results, no significant difference exists between dominant and non-dominant lower joints regarding the peak moments of hip, knee and ankle in sagittal plane during stance phase (*P*>0.05) and showed no significant differences were observed between peak flexion angle of dominant and non-dominant hip and knee joints during running (Figures 2-7).

Table 2. Independent t-test of dominant (D) and non-dominant (ND) lower limbs sagittal plane kinetics (moments) and kinematics (flexion angle) (n=28)

Variables		Mean	SD	t	sig.
Peak hip moment (N.m.kg^{-1})	D	0.59	0.17	0.868	0.389
	ND	0.55	0.20		
Peak knee moment (N.m.kg^{-1})	D	2.84	0.42	0.210	0.835
	ND	2.81	0.41		
Peak ankle moment (N.m.kg^{-1})	D	2.07	0.21	-1.175	0.245
	ND	2.15	0.26		
Peak of hip flexion angle (Deg.)	D	33.63	4.94	0.16	0.87
	ND	33.43	4.47		
	D	43.16	5.77	-0.02	0.99
	ND	43.19	4.66		
	D	22.96	3.02	0.86	0.39
	ND	22.32	2.45		

D: dominant, ND: non dominant

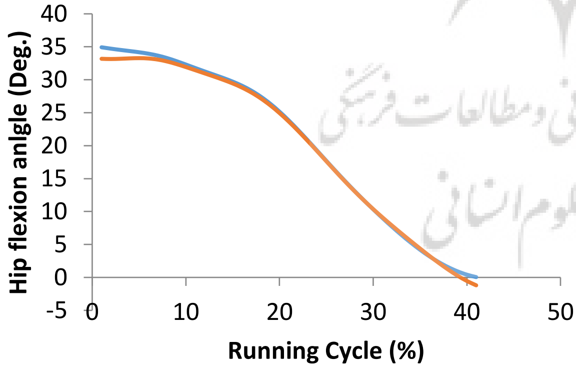

Figure 2. Hip flexion angles during stance phase of running
(blue line: dominant hip, red line: non-dominant hip)

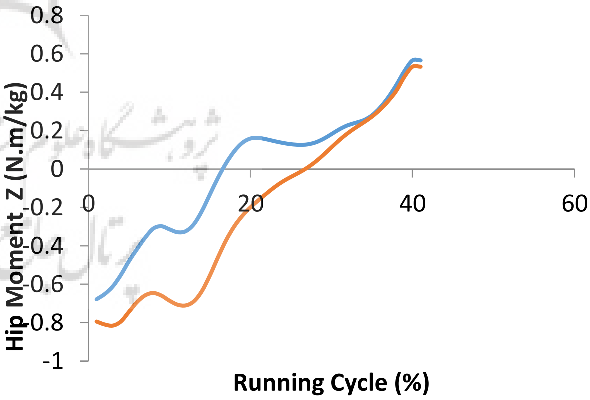

Figure 3. Hip flexion sagittal moments during stance phase of running
(blue line: dominant hip, red line: non-dominant hip)

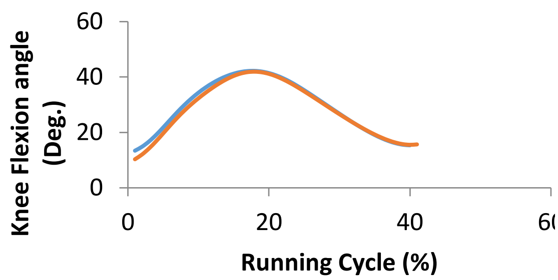

Figure 4. Knee flexion angles during stance phase of running
(blue line: dominant knee, red line: non-dominant knee)

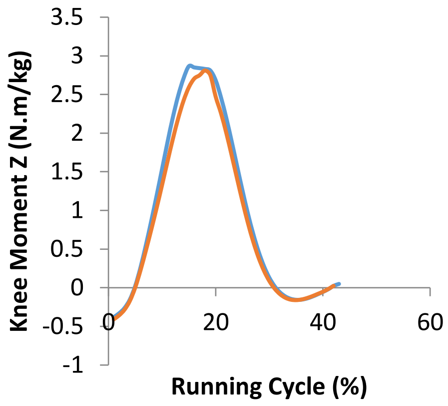

Figure 5. Knee flexion sagittal moments during stance phase of running
(blue line: dominant knee, red line: non-dominant knee)

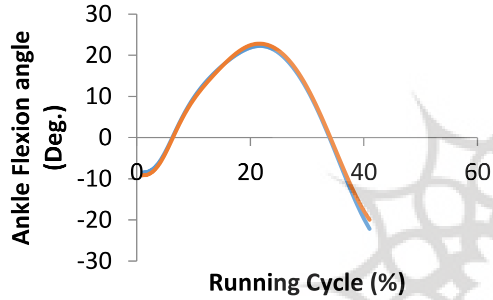

Figure 6. Ankle dorsi- flexion angles during stance phase of running
(blue line: dominant ankle, red line: non-dominant ankle)

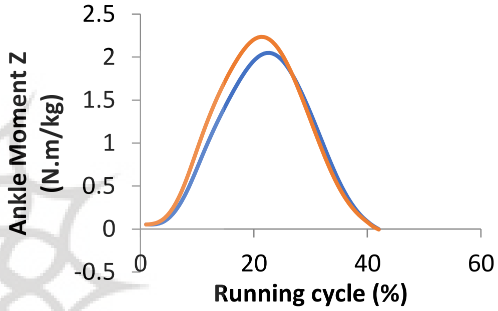

Figure 7. Ankle dorsi- flexion sagittal moments during stance phase of running
(blue line: dominant ankle, red line: non-dominant ankle)

4. Discussion

The aim of this study was to compare kinematic and kinetic symmetry of lower limbs during running. Results of the present study showed no significant difference between peak flexion angles of lower joints including hip and knee in running (2.5 m/s).

Results of the present study showed no significant differences between moments of hip, knee and ankle joints during running. In the other word, our hypothesis was accepted that symmetry exists between dominant and non-dominant lower limb's joints during stance phase of running. The majority of the similar studies have focused on the symmetry behavior of the walking gait as a challenging topic [25, 26, 27, 28]. In this case, symmetrical behavior of the lower limbs during gait has often been assumed, mainly for simplicity in data collection and analysis, while gait asymmetry seems to reflect a natural functional difference between the limbs [29].

Results of the present study is in agreement with Zhejiang Gao et al. (2020) who reported the symmetry characteristics of the hip joints specially when the subjects are susceptible to tiredness [30]. Marco et al. stated that the gait of only the selected operating system variables is sufficiently symmetric and reproducible that they can be used for comparison [31]. The data also suggest that aging may increase variability in some biomechanical measures such as symmetrical behavior of the lower limbs during various skills. Chapman et al. reported that the able-bodied person walks with reasonable symmetry in the pelvis and knees [32]. Results of the present study reveals the fact that symmetry exists between dominant and non-dominant lower joints of hip, knee and ankle in three movement planes.

According to the results of the peak of hip, knee and ankle joints' moments in sagittal planes, the peak of the hip joint moment of the dominant limb is greater than the non-dominant, insignificantly. Upon viewing a normal walking or running pattern with the naked eye, the typical observer would support the presence of the characteristic of symmetry in lower extremity function. Healthy individuals seem to exhibit smooth, uniform, harmonious interactions between right and left legs during most ambulatory states. These attributes have led many investigators to assume that right lower limb performance is typical of left lower limb performance and vice versa. There is, however, a lack of conclusive experimental evidence to support this assumption [33]. Normal walking gait patterns being evaluated for symmetry utilizing selected temporal and kinematic parameters produced positive results in studies conducted by Hannah, Chapman and Morrison (1984) who found high symmetry among kinematic variables during normal human locomotion [35]; and by Sawhill (1981) who reported symmetry in right and left limbs during an isokinetic exercise at several speeds of movement [36].

The symmetry between the preferred and non-preferred limbs in both locomotors' conditions indicated that both limbs were used equally in gait. These data are contrary to the findings of Singh (1970) [37] and Rosenrot (1980) [38]. Additionally, Singh (1970) concluded that upon evaluation of walking, there was not equal usage of the two lower limbs [37]. In both of these studies, one limb appeared dominant and resulted in a functional asymmetry between the limbs.

But some data in the available literature contrast with these findings. According to Table 2, the peak flexion angle of the hip joint of the dominant limb is greater than the non-dominant, insignificantly. For the knee joint, magnitude of the peak flexion angle in the non-dominant knee is shown to be greater comparing with the dominant knee. Magnitude of the ankle joint's peak flexion angle of the dominant ankle is greater than the non-dominant.

A review on the results in accordance with the previous researches confirm our findings, regarding the importance role of kinematic parameters including joint's angle.

5. Conclusion

Symmetry as one of the main biomechanics criteria, exists between lower limbs joint kinetically and kinematically during running at constant speed. Finding of the present study may be useful for athletes and coaches in order to design training programs as well as biomechanics specialist to promote researches concerning symmetry of human movement.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

Data availability

The data set generated and analyzed during the current study is available from the corresponding author on reasonable request.

Acknowledgment

The authors appreciate Reginaldo K. Fukuchi, Claudiane A. Fukuchiv and Marcos Duarte according to the providing of the public data set of running biomechanics.

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