Three Planar Symmetry of Hip, Knee and Ankle Joints' Moments during Running

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Submitted: 2021-03-12; **Accepted**: 2021-06-09; **Doi:** https://doi.org/10.22037/jcpr.v6i3.34315

Abstract

Introduction: Symmetry and asymmetry of the limbs' movement pattern during running are introduced as one of the main critical challenges of human locomotion. The aim of this study was to investigate three planar symmetry of hip, knee and ankle joints' moments during running at a fixed speed. **Methods and Materials**: 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 each 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. 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 between two limb's peak moments of lower joints in every three plane. Highest values of the dominant limb's peak moments in sagittal, frontal and transvers plane were derived in (knee, ankle, hip), (hip, knee, ankle) and (knee, ankle, hip) respectively. **Conclusion**: Symmetry exists in lower joints three planar moments during running at the constant speed. According to the results dominant and non- dominant lower joints play propulsive and absorbent roles cooperatively.

Keywords: Biomechanics; Joint's Moment; Running; Symmetry

Please cite this paper as: Fatahi A, Alizade R, Salehi M, Molavian R. Three Planar Symmetry of Hip, Knee and Ankle Joints' Moments during Running. J Clin Physio Res. 2021; 6(3): e40. Doi: https://doi.org/10.22037/jcpr.v6i3.34315

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 (1-4).The cyclical pattern of running requires a coordinated interaction of muscles, (5-9) a given range of motion (ROM) to optimize motor recruitment patterns, (10) and strength to influence propulsion ability(11). Ultimately, maintenance of lower extremity joints' kinetics, morphology and mechanical properties are perhaps essential in maintaining function during running.

Symmetry and asymmetry of the limb's movement pattern are 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 (12). 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 (13). When movement patterns become asymmetric, they can disrupt the natural rhythm of the performance (14, 15). Examples of this include running with uneven step lengths or with a lateral trunk lean. In theory, these asymmetries can lead to overloading certain musculoskeletal structures, increasing their risk for injury. Some investigations reported unpleasant effect of limb asymmetry during running performance (16-18). Zifchock *et al.* have shown that the injured limb of runners is associated with the side with the highest impact loading during running. It has been noted that some degree of asymmetry is normal in running (19). However, when asymmetry of performance is above expected differences, the goal of many interventions is to improve the symmetry to reduce injury risk (20-22).

Kinetic asymmetry can vary greatly among runners of different levels(23, 24), and asymmetry in stride time increases energy cost for runners depending on running velocity (25).Most of these evidences come from short bouts of running analyses, but

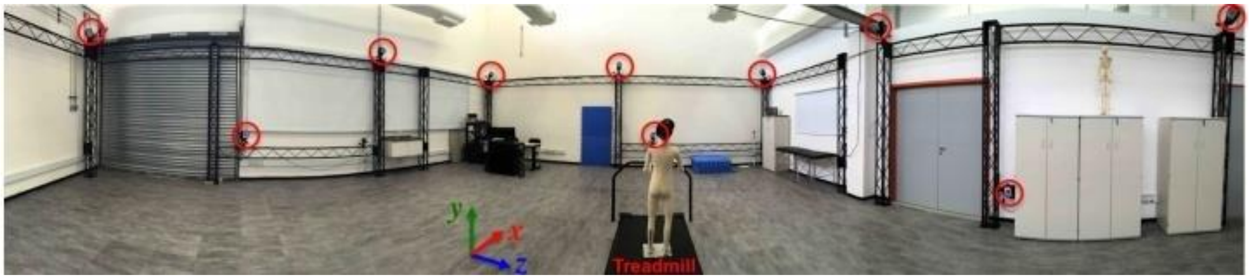

Figure 1. Overview of the Laboratory of Biomechanics and Motor Control. Expanded view of the Laboratory of Biomechanics and Motor Control (BMClab), showing 10 of the 12 motion-capture system cameras (marked with red circles), the instrumented treadmill, and the laboratory coordinate system

asymmetries may not be evident during the initial stages of an exercise (26). It has been suggested that asymmetries may arise, for example, in response to the development of muscle fatigue (27) and/or changes in exercise intensity (28). The increase in oxygen uptake and reduction in mechanical efficiency during prolonged running (29) may also influence asymmetric patterns. Some studies have computed torques, net powers, and/or work done at the lower limb joints during running (30-32). Both Glitsch and Baumann and McClay and Manal demonstrated that, during an almost planar movement such as running, the lower limb joints are associated with significant three-dimensional torques, especially in the frontal plane (5, 33-35). Furthermore, Stefanyshyn *et al*. found a relationship between frontal-plane knee joint dynamics during running and risk of injury in knee joint (30).

A review on the investigations performed on running symmetry with respect to joints kinetics reveals that there is a noticeable scientific lack in this criteria, especially in case of different planes of motions. 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 variables of hip, knee and ankle joints during running at fixed speed in sagittal, frontal and transverse planes

Methods and Materials

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), and written, informed consent was obtained from each subject prior to participation in the study.

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 that compromises its locomotion or the use of any assistive devices.

Equipment

The subjects performed running on the treadmill while kinematics data 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 GRF data were collected via an instrumented, dual-belt treadmill (FIT, Bertec, Columbus, OH, 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 (Figure 1). The instrumented treadmill was mounted over a pit, with the treadmill surface at the same level as the laboratory floor (Figure 1). 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 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 (36) 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.

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

Table 2. Independent T test of dominant (D) and non-dominant (ND) lower limbs' three planar moments (N=28)

		Mean (SD)	t	sig.
Peak hip Moment (X) ($N.m.Kg^{-1}$)	D	1.63 (0.19)	1.180	0.243
	ND	1.54 (0.33)		
Peak hip Moment (Y) ($N.m.Kg^{-1}$)	D	0.03 (0.06)	1.544	0.128
	ND	0.01 (0.04)		
Peak hip Moment (Z) ($N.m.Kg^{-1}$)	D	0.59 (0.17)	0.868	0.389
	ND	0.55 (0.20)		
Peak knee Moment (X) ($N.m.Kg^{-1}$)	D	0.95 (0.25)	-0.690	0.493
	ND	0.99 (0.25)		
Peak knee Moment (Y) ($N.m.Kg^{-1}$)	D	0.15 (0.13)	1.467	0.148
	ND	0.10 (0.12)		
Peak knee Moment (Z) ($N.m.Kg^{-1}$)	D	2.84 (0.42)	0.210	0.835
	ND	2.81 (0.41)		
Peak ankle Moment (X) ($N.m.Kg^{-1}$)	D	0.12 (0.09)	0.245	0.807
	ND	0.11 (0.07)		
Peak ankle Moment(Y) ($N.m.Kg^{-1}$)	D	0.09 (0.08)	1.748	0.086
	ND	0.05 (0.07)		
Peak ankle Moment(Z) ($N.m.Kg^{-1}$)	D	2.07 (0.21)	-1.175	0.245
	ND	2.15 (0.26)		

D: dominant, ND: non dominant, X: frontal plane, Y: transverse plane, Z: sagittal plane

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. 48 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. b. 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.

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 between dominant and non-dominant joints during stance phase of running. The statistical calculations were performed in SPSS ver. 22 ($P<0.05$).

Results

Descriptive measures of demographic parameters are shown in Table 1. 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, frontal and transverse planes during stance phase ($P>0.05$).

Discussion

The aim of this study was to investigate the three planar Symmetry of Hip, knee and ankle joints moments during stance phase of running. Results of the present study showed no significant differences between all three planar 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 (34, 37-40). 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. This functional difference does not appear to be the consequence of abnormality, but rather relates to the contribution of each limb to propulsion and control tasks (41). Results of the present study is in agreement with Zhejiang Gao *et al.* which reported the symmetry characteristics of the hip joints specially when the subjects are susceptible to tiredness (42). 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. The data also suggest that aging may increase variability in some biomechanical measures such as symmetrical behavior of the lower limbs during various skills (43). Also, Chapman *et al.* reported that the able-bodied person walks with reasonable symmetry in the pelvis and knees (44). 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, frontal and transverse planes, it was shown that the peak of the hip joint moment of the dominant limb is greater than the non-dominant, insignificantly. Magnitude of the hip joint's moment peak in the frontal, transverse and sagittal planes of the dominant hip are 5.52%, 66.6%, and %6.77 greater than the non-dominant side, respectively. For the knee joint, in frontal plan, magnitude of the peak moment in the non-dominant knee is shown to be %4.04 greater comparing with the dominant knee but in transverse and sagittal planes, dominant knee showed %33.3 and %1.05 higher values than the non-dominant knee. Peak of the ankle joints' moments in frontal and transverse planes of the dominant one is %8.33 and %44.4 greater than the non-dominant ankle, and in sagittal plan, the non-dominant ankle showed 3.72% greater value comparing to the dominant limb.

The knee biomechanics in the frontal plane has been an area of debate centered on our ability to truly isolate abduction and adduction. This debate has been very much fuelled by the variance that is evident between individuals and the susceptibility of this plane to the effects of cross talk from other planes. These imply that in normal individuals there will be very little movement besides a slight deformation during loading and the opposite deformation during terminal stance. The direction of this deformation is based on the anatomical alignment of the knee adduction or abduction (varus or valgus).

The present study reveals that symmetrical behavior in moments exists in three plans of movement during stance phase of the running. The extensor muscle mass at the hip is the largest of the three major extensor muscle groups of the leg, yet mechanical measurements suggest that the hip musculature contributes little work during level running. Inverse dynamics measurements during jogging indicate that the net muscle moment developed at the hip are substantially lower than for the ankle and knee (3). The low hip moments relative to those at the knee or the ankle are associated with the favorable leverage, or mechanical advantage, for force production at this joint. Limb muscles operate across a skeletal system lever with a fulcrum at the center of rotation of the joint. Any given muscle's mechanical advantage for force production is set by the distance from the muscle line of action to this fulcrum (the in-moment arm) and by the distance from the fulcrum to the ground reaction force vector (30) Hip joint moments are low during ordinary running because the out-moment arm is small, i.e. the ground reaction force vector passes close to the joint center of rotation. Hip muscles must also produce force to overcome the inertia of the limb and to act against co-contracting muscle antagonists, but these forces are generally thought to be low relative to ground reaction based forces (31). The favorable mechanical advantage at the hip during running may reflect a mechanism for improving locomotors economy. The large extensor muscle mass at the hip must consume considerable metabolic energy when active; a favorable mechanical advantage at the hip may conserve metabolic energy by keeping hip extensor forces low.

The present study concentrated on the general symmetry comparison between dominant and non-dominant lower limbs. It seems that foot contact pattern as well as biomechanics of the lower limbs concerning foot pronation and supination or knee valgus still remained unidentified. It is proposed for further investigations to be studied in mentioned criteria. Also differences in gender would be another title proposed for future studies.

Conclusion

Joint's moments play an integrated cooperative role in propulsive movement of the runners and evidentially symmetry exists between lower limb's moments. Elite runner may find outstanding benefits regarding injury prevention as well as performance optimization as symmetry exists between all lower limb's joints in three directions.

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.

Conflict of interest:
None

Funding support:
None

Authors' contributions:
All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

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