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Original Research

Symmetry or Asymmetry of Lower Limb 3D-Mechanical Muscle Power in Female Athletes' Gait

Razieh Yousefian Molla[1*], Heydar Sadeghi[2,3], Amirreza Kiani[4]

1. Department of Physical Education and Sports Science, Islamic Azad University of Karaj Branch, Karaj, Iran. Email: Razieh.yousefianmolla@iau.ac.ir, ORCID: 0000-0002-1527-7737
2. Department of Biomechanics and Sports Injuries, Faculty of Physical Education and Sport Science, Kharazmi University, Tehran, Iran. Email: sadeghih@yahoo.com, ORCID: 0000-0001-6563-9882
3. Department of Sports Biomechanics, Kinesiology Research Center, Kharazmi University, Tehran, Iran. Email: sadeghih@yahoo.com, ORCID: 0000-0001-6563-9882
4. Computer Engineering Department, Shomal University, Amol, Iran. Email: ark13821389@gmail.com, ORCID: 0009-0009-6005-9833

ABSTRACT

The present study aimed to determine the extent to which female athletes display asymmetrical or symmetry patterns in lower limb three-dimensional mechanical muscle power during gait. Thirty healthy female professional bodybuilders participated in his study. Their three-dimensional data of both lower extremities during walking was collected using a ten-camera Vicon motion capture system and two Kistler force plates. The peak mechanical muscle power of lower limbs in all three planes was calculated ($P \leq 0.05$). The results showed that except in the ankle joint, there were significant differences in third mechanical muscle power peaks of the knee and hip joints in sagittal plane (H3S, K3S), first and second mechanical muscle power peaks of knee joint in frontal plane (K1F, K2F), and second mechanical muscle power peak of hip joint in horizontal plane (H2T). In addition, the findings confirmed approximately 25% local asymmetry in the mechanical muscle power in the hip and knee joints between the right and left limbs.

Keywords: Mechanical Muscle Power, Symmetry, Gait

Corresponding Author: Razieh Yousefian Molla, Department of Physical Education and Sports Science, Islamic Azad University of Karaj Branch, Karaj, Iran. Email: Razieh.yousefianmolla@iau.ac.ir. Tel: +989122022730

INTRODUCTION

Gait is a fundamental skill that forms a large part of human motor activity [1]. Therefore, many studies have tried to find information as a reference for the evaluation of gait in people with various musculoskeletal abnormalities [2] or to optimize rehabilitation interventions [3] As gait is a safe, easily accessible physical activity [4, 5], it can be an important indicator of healthy motor functioning in various groups.

The mechanical muscle power of the lower extremities, calculated by multiplying the joint moments and their respective angular velocities, allows for the assessment of energy flow in the limb and indicates how the muscles crossing each joint are utilized [6]. As such, it has many applications in gait analysis [7, 8], including the gait of healthy people [9, 10], persons with lower-limb amputations [8], joint replacements [11], etc. In addition, bilateral analyses have focused on comparing the lower limbs [12]. The study of the interaction between the mechanical muscle power parameters in the lower limbs can reflect specific control and propulsion strategies in healthy individuals [13].

The lower extremity muscle power is proved to increase from childhood to reach its peak between the ages of 20 to 30 [14, 15], then remaining constant until age 40, after which it decreases linearly until the end of life [5, 16]. In addition, it has been reported that mechanical muscle power among women is lower than men in whole life and all classifications [3, 11]. Joint moment and power play an important role in controlling the center of mass to create a stable gait cycle [17, 18]. In addition, some studies have shown that muscle power is more strongly associated with physical function and postural control than muscle strength [19, 20]. Some studies claim that joint power generated by muscle synergies can be used to determine the capacity of muscle groups to produce or inhibit movements [21, 22]. The positive mechanical power produced by concentric muscle contractions produces motion, while negative eccentric power controls joint motion against external forces [8]. Additionally, estimating the muscle power is proved to be a valid way to predict a person's ability to control limbs [23, 24] and the extent of their ability to perform sports activities [25]. For example, it has been shown that athletic performance during speed exercises, such as running and cycling, is strongly characterized by the ability to produce and maintain maximum muscle power [26]. O'Bryan et al. [26] claim that the production capacity of the three lower extremity joints during cycling and isokinetic movements decreases in the first 30 seconds.

In a two-dimensional analysis of the gait, the similarities and differences between the limbs are addressed explicitly by Sadhegi, et al. [12]. Also, Hannah et al. [27] showed significant motor and joint coordination between the pelvis on both lower limbs in all three planes and on the knee in the sagittal plane during normal gait. Hamil et al. [28] did not find significant differences between the forces in the two limbs during walking and running. Although these mentioned studies supported walking symmetry in general, it is not totally symmetric [29] in dominant and non-dominant limbs [30]. Hirasna [31], based on a well-known hypothesis of asymmetric functions [12], has shown that the left lower limb functions essentially in weight transfer during gait, while the right lower limb is responsible for propulsion [12]. Another study showed that these interactions could be disrupted in pathological gait and replaced by compensatory functions [12]. Therefore although these studies examine the biomechanical (kinetics and kinematics) symmetry or asymmetry of dominant and non-dominant legs, which showed not similarity in biomechanical maners, there is a shortage in investigation of a variable like mechanical muscle power wich consist of either kinetics and kinematics factors in symmetric or asymmetric manner of lower limbs.

Due to differences in previous study's results about the hypothesis of symmetry or asymmetry in the function of the lower limbs while walking [32], this issue is discussed with researchers in recognizing the differences in various dimensions between two lower limbs and they tried to answer the ambiguities that exist [12, 33, 34]. However, most surveys [12, 33, 34] focus on men or healthy people and consider asymmetry or symmetry in one dimension. Therefore there is no study on the symmetry or asymmetry of 3D mechanical muscle power among athlete women. This study aimed to determine the extent to which female athletes display asymmetrical or symmetry patterns in lower limb three-dimensional mechanical muscle power during gait.

MATERIAL AND METHODS

Participants

Thirty healthy female professional bodybuilders with a mean and standard deviation age of 29.5 ± 3.45 years, a BMI of 24.06 ±3 3.25 kg / m2, and a sports history of 8.96 ± 5.49 years participated in this study. The test protocol was approved by the Ethics Committee of the Kinesiology Research Center (No. 103/1000). Participants were informed about the testing process details and signed the informed consent form to participate in the research. Subjects were excluded from the study if any history of orthopedic, neurological, or surgical disorders could affect their gait pattern. All subjects had at least five years of sports participation and were right limb dominant.

Instruments and Examinations

To determine the dominant limb, the tests of throwing the ball, writing, opening the jam jar, hitting the ball, and jumping on one limb were used [34].

Three-dimensional data of both lower extremities while walking were collected using a ten-camera Vicon motion capture system (MX-T40-S, 120 Hz) and two Kistler force plates (50 x 60 cm and 50 x 30 cm models 9260AA3 and 9260AA6), located in a 10 m walkway. In addition, a three-dimensional marker model (PlugInGait) was used to identify the trunk and lower limb joints.

Before data collection, each subject walked several times along the determined walkway to familiarize the subjects with the laboratory environment and to ensure that they stepped on the force plates in the middle of the data collection path. The subjects were asked to walk barefoot at the selected speed. Each subject was tested three times, and during the tests, all the markers were seen by the cameras, and the limbs were placed correctly on two force plates were used for data analysis.

To calculate the kinematic varibles during walking, the coordinates of the studied joints through external markers and each subject's joint rotation centers were used. Nexus software filter (Woltring filter with MSE mode and level 10) was used to reduce camera noise and force plate data. The end of each toe-off phase in the both right and left legs, was determined by the information extracted from the vicon cameras and force plates. The lower extremity segments were marked on bony landmarks to calculate hip, knee, and ankle joint kinematics based on Plug in Gait marker set protocol. Also moments, and powers of lower limbs calculated according to ISB standards and Winter [6]. Instantaneous muscle power (P) in each joint (j) and in each plane (k) as a product of the joint moment (M) and also its angular velocity (ω) was calculated by the following equation:

$$P_{j,k} = M_{j,k} \, . \, \omega_{j,k} \quad [1]$$

The peak mechanical muscle power in all three planes was determined with the method mentioned by Winter et al. [6] and Sadeghi et al. [12]. Each peak was identified and labeled with the first letter of the joint and the plane under study. H1S, for example, was the first peak in the hip joint in the sagittal plane. Then, all moments and powers were normalized to the body weight of each subject. Also, local

Statistical Analysis

Mean, standard deviation, and coefficient of variation were used to perform statistical analyzes, and the Shapiro-Wilk test was used to check the normality of data distribution. Independent t-tests were also used to compare the values of mechanical muscle power variables of the right limb with the left limb at a significance level of $P \leq 0.05$.

RESULTS

The results of descriptive statistics (mean and standard deviation and coefficient of variation) and inferential statistics of the three-dimensional mechanical power peaks for the 'subjects' right and left lower limbs are presented in Figure 1 and Table 1. This figure type of showing bilateral representation of the mechanical muscle power curve in lower limbs has been discussed and analyzed by Allard et al. (1997) [35] and Eng and Winter (2009) [6].

Table 1. The results of descriptive and independent t-test statistical analysis of the peaks of mechanical muscle power in different phases of a gait cycle in the right (R) and left (L) lower extremity in female athletes (W/kg)

Peak Power (W/kg)	Right Limb Mean ±SD (CV)	Left Limb Mean ±SD (CV)	Sig
H1S	0.533±0.426 (125%)	0.444±0.273 (162%)	0.347
H2S	-0.604±0.418 (144%)	-0.503±0.442 (113%)	0.377
H3S	0.949±0.396 (239%)	0.311±0.212 (146%)	**0.000***
H1F	-0.258±0.247 (104%)	-0.217±0.162 (133%)	0.464
H2F	0.1498±0.165 (90%)	0.1493±0.118 (126%)	0.990
H3F	0.297±0.273 (108%)	0.332±0.309 (107%)	0.655
H1T	-0.066±0.205 (32%)	-0.047±0.063 (74%)	0.636
H2T	0.024±0.035 (68%)	0.060±0.055 (109%)	**0.004***
H3T	-0.052±0.045 (115%)	-0.032±0.038 (84%)	0.076
K1S	-0.215±0.218 (98%)	-0.211±0.323 (65%)	0.956
K2S	0.217±0.175 (124%)	0.257±0.348 (73%)	0.582
K3S	-0.740±0.460 (160%)	-0.286±0.308 (92%)	**0.000***
K4S	-0.765±0.426 (179%)	-0.759±0.321 (236%)	0.946
K1F	0.030±0.049 (61%)	0.072±0.075 (96%)	**0.016***
K2F	0.281±0.508 (55%)	-0.077±0.068 (113%)	**0.038***
K1T	0.049±0.074 (66%)	0.046±0.047 (97%)	0.825
K2T	-0.024±0.040 (60%)	-0.020±0.047 (42%)	0.762
K3T	0.190±0.806 (23%)	0.068±0.085 (80%)	0.420
A1S	-0.831±0.280 (296%)	-0.792±0.287 (275%)	0.604
A2S	3.219±1.592 (202%)	3.182±0.953 (333%)	0.915
A2F	0.023±0.021 (109%)	0.034±0.041 (82%)	0.196
A1T	-0.140±0.124 (112%)	-0.156±0.157 (99%)	0.662

*Significant difference P≤ 0.05. H=Hip Joint, K= Knee Joint, A= Ankle Joint, 1 to 4= First to Forth Peaks, S=Sagital Plane, F=Frontal Plane, T=Transverse Plane

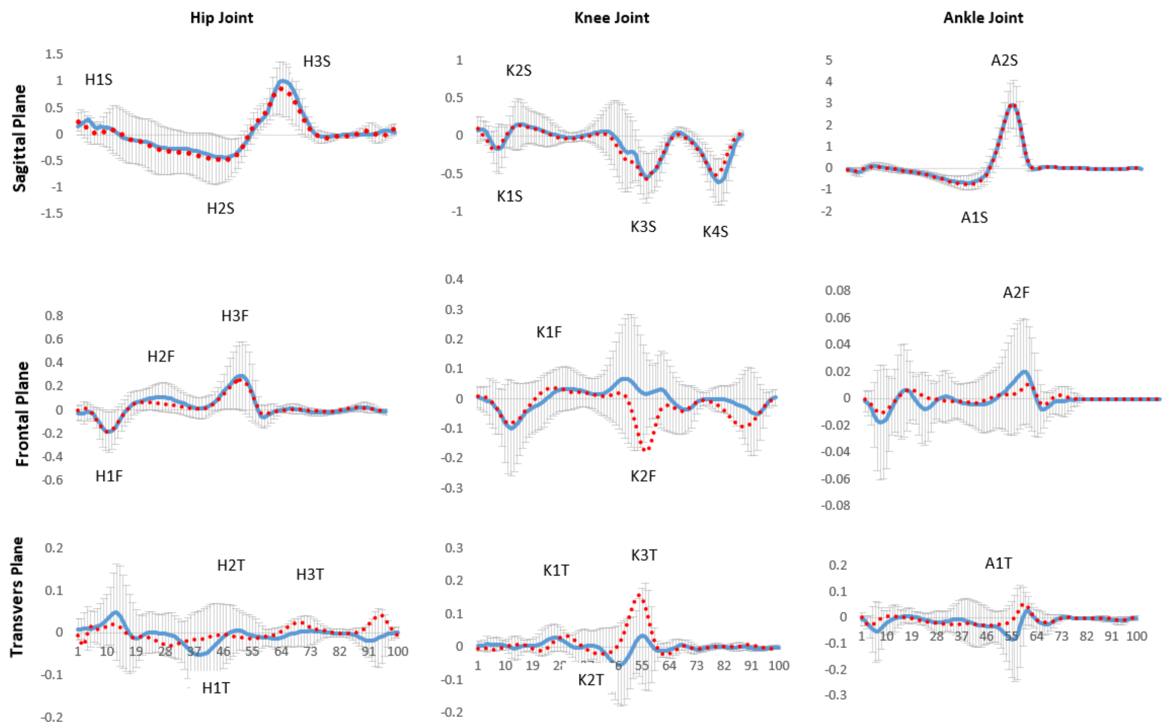

Figure 1. Mechanical muscle power in lower limb during gait of athlete women (W/kg). The continuous blue line shows left limb mechanical muscle power, and the red dotted line shows right limb mechanical muscle power. The standard deviation of the left limb is shown with grey lines (SD of the Right limb was removed to avoid confusion).(H=Hip Joint, K= Knee Joint, A= Ankle Joint, 1 to 4= First to Forth Peaks, S=Sagital Plane, F=Frontal Plane, T=Transverse Plane)

DISCUSSION

According to the collected data, 22 mechanical muscle power peaks were extracted, analyzed, and compared simultaneously in three anatomical planes of both right and left lower limb joints in different phases of the gait cycle. Specifically on the right and left limbs separately, 9 peaks of mechanical muscle power, corresponding to the hip joint (3 peaks per anatomical plane), 9 peaks related to the knee joint (3 peaks per anatomical plane), and 4 peaks related to the ankle joint (2 peaks on the sagittal plane and 2 peaks on the frontal plane) were observed (Figure 1). Also, based on statistical analysis and comparison of the mean of mechanical muscle power peaks between the right and left lower limbs, the results showed that except in the ankle joint, there were significant differences in some other mechanical muscle power peaks of the knee and hip joints in sagittal (H3S, K3S), frontal (K1F, K2F) and horizontal (H2T) planes.

Researchers in the field of biomechanics have considered the asymmetry issue, and several studies have been conducted in this field [1, 36, 37]. Reviewing the interpretations of previous research about symmetry or asymmetry, it is suggested that asymmetry in the gait should not be considered a sign of pathology in healthy people [38], but its main concept implies control tasks and or propulsion in each limb [31, 38]. Accordingly, the functional asymmetry hypothesis has been proposed by Sadeghi et al. (1996) as a claim based on which the function of the right and left limbs while walking is different. In this way, one limb takes the propulsion task and then controls the balance; the other limb first performs the task of controlling the balance and the next go-to propulsion. Following this theory, the idea of a dominant limb has been suggested by researchers as one of the possible reasons for the issue of asymmetry [32].

Different studies have used different methods and compared different lower extremity biomechanical factors (kinetics, kinematics, and EMG) to study the symmetry and asymmetry of the lower limbs [32], but since the mechanical power parameter as a variable in simultaneous inclusion of kinetic and kinematic variables [13], and is a suitable parameter to determine the ability to control and propel the lower limb [35], in this study is also used as a key variable. In the current investigation, asymmetry is considered if there is a significant difference in comparing the peak variables of mechanical muscle power of the right limb with its corresponding variable in the left limb of female athletes while walking.

Based on the results of the present study, the highest peak of mechanical muscle power in the left and right lower limbs was commonly observed in A2S (in the right limb higher than the left limb), but the lowest was observed in the right limb in A2F and the left limb in K2T. Therefore, the highest power is seen in the sagittal plane and the push-off stage, which is in line with the results of previous studies in this field [8, 38]; on the other hand, because the ankle joint according to the results of this study, has a high production capacity, so it can be concluded that this joint in the sagittal plane is more involved in propulsion and the rate of plantarflexion in is considered as a major intervention in propulsion. These results are consistent with previous ones [10, 35, 38] but are inconsistent with the results of Sdeghi (2001) [12], which states in a study that the ankle has a controlling role and is not a propellant. Because in this study, researchers believe that the hip and ankle synergistically play a controlling role while walking, but the knee has a propulsion role.

As mentioned earlier, 9 peaks in the left hip joint and 9 peaks in the right hip (H1S, H2S, H3S, H1F, H2F, H3F, H1T, H2T, and H3T) were examined and compared. Among these peaks, in general, except for the two peaks H3F and H2T, which had a higher mean on the left foot, the other peaks on the right foot (H1S, H2S, H3S, H1F, H2F, H1T, and H3T) had higher mean values. The results of inferential statistics also showed that among all these peaks, the two peaks H3S and H2T had a statistically significant difference between the two hips ($p = 0.000$ and $p = 0.004$, respectively) and showed asymmetry in this joint. As we know, H3S is one of the most important parts in push-ups, which perform by flexion in the hip, producing a relatively high production capacity in the pre-toe-off stage, and it is essential in propulsion [35, 38]. At this stage, which is at the end of the stance phase and accounts for 50 to 60 percent of the gait cycle [33, 39], the moment function of the muscles pushes the foot forward [40]. Since the values related to H3S have shown a significant difference between the right and left limbs and show asymmetry in both limbs and are in line with previous research in this field as Sadeghi et al. [38], it may be concluded that with considering the importance of this peak in propulsion and the productive power associated with both the knee and the hip, pushing forward in the right hip is stronger than in the left hip. In the left limb, this propulsion owes much to the moment function of the muscles in the knee (K2S). On the other hand, the results showed that H2T, which creates a production capacity in the mid-stance stage and is responsible for propelling the body forward, causes pelvic rotation, which has been described as one of the six main characteristics of the gait [41]. This peak causes the external rotation of the thigh in the second half of the mid stance to rotate the pelvis forward and guide the limb forward by creating propulsion in it. Since the H2T values are significantly different between the right and left limbs and its mean value in the left limb is higher than the right ones, and this result is consistent with other studies by Sadeghi (2001) [33] and Allard (1998) [35] and references, it is possible the reason for this asymmetry is that the left hip plays a more controlling role so that the weight transfer is completed well at this stage of gait and the limbs enter the push-off stage. Comparison of other peaks extracted in these joints from the two limbs showed symmetry and insignificance difference, which reveals that the behavior of the two limbs during different stages of walking is the same in other peaks and planes. So they act in harmony with the propulsion and control of the body forward while walking.

In the knee, 9 peaks were seen in each limb (K1S, K2S, K3S, K4S, K1F, K2F, K1T, K2T, and K3T), with which performance in the two limbs was compared. Among these peaks, only two peaks, K2S (significantly) and K1F (not significantly), had a higher mean value on the left knee, and the mean value of the other peaks (K1S, K3S, K4SK2F, K1T, K2T, and K3T) was higher (not significantly) on the right knee. The results of inferential statistics showed only a significant difference between the two peaks of K3S and K1F (p = 0.000 and p = 0.016, respectively), which can be called asymmetry in this joint. K3S occurs in the early stages of the mid-stance phase and causes flexion in the knee, compensating for weight acceptance in this phase and shock absorption [34, 42]. As a result, it plays an essential role in stabilizing the limb after gaining weight. These results are in line with the findings of previous studies [2, 40] but contradict the findings of Sadeghi (2001) [12] and Dellagrana (2015) [14], because they believe that K3S occurred at the end of the mid-stance and even push-off phase, and also causes extensor power in the knee. K1F occurs at the beginning of the stance phase, i.e., before entering the mid-stance, and indicates the production abduction and propulsion of the knee in the frontal plane. The mean value of this peak between the right and left limbs is significant, which considering the propulsion of the right limb and the stability of the left limb, can confirm the change in abduction values in both limbs based on their different tasks in weight-bearing, is different. These results are consistent with the study of [38] because, in the mentioned study, the K1F peak in the left limb was significantly higher, it occurred in the mid-stance stage, and according to the conclusion of its researchers, it describes a control or stable function in the left limb.

In the ankle, 4 peaks were seen in each limb (A1S, A2S, A2F, and A1T) and were compared in this study. Among these peaks, A2F and A1T had a higher mean on the left limb, and the mean of the A1S and A2S peaks were higher on the right. The results of inferential statistics showed that among all these peaks, there was no significant difference between the two limbs, which can be described as the symmetry of the function of mechanical muscle power in this joint. As mentioned earlier, of all the lower limb mechanical muscle power peaks, A2S, which occurs with plantarflexion in the push-off phase, causes the strongest forward propulsion in the right ankle and is consistent with Sadeghi (2000&2001) studies [12, 13], although, in some studies, this amount of power has been reported less, because the target group was nonathletic healthy people, and naturally the amount of propulsive power in the foot of the majority of these people was less than women athletes. Also, in relation to the only peak of mechanical muscle power of the ankle in the frontal plane (A2F), it should be considered that the power in this plane and this peak is entirely productive if in the article by Sadeghi (2002) [34] it was shown that the power generated on this plane can show in some people as a productive in some other as control function based on the initial position of hill strike in the push-off stage.

In the present study, we encountered some limitations. One of those limitations was the low number of samples and access only to the female athlete community. So lack of access to information on the mechanical muscle power in three planes and bilaterally in inactive men and women and men athletes in various sports, which could help in a more comprehensive study of the hypothesis of symmetry and asymmetry, was the most limitations of the present study.

CONCLUSION

The findings of this investigation confirmed around 25% local asymmetry in the function of mechanical muscle power in the hip and knee (H3S, H2T, K3S, and K1F) between the right and left limbs. Specifically showed asymmetry in the sagittal plane in the push-up stage in the thigh (H3S-propulsion function), and mid-stance in the knee (K3S-control function), also in the frontal plane in the knee (K1F-shock absorption), and in the transverse plane in the middle of the mid stance in the hip (H2T-propulsion function).

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سیمتری و آسیمتری توان مکانیکی عضلانی سه بعدی در زنان ورزشکار حین راه رفتن

راضیه یوسفیان ملا[۱*]، حیدر صادقی[۲،۳]، امیررضا کیانی[۴]
۱. گروه تربیت بدنی و علوم ورزشی، دانشکده تربیت بدنی و علوم ورزشی، دانشگاه آزاد اسلامی واحد کرج، کرج، ایران.
۲. گروه آسیب شناسی و بیومکانیک ورزشی، دانشکده تربیت بدنی و علوم ورزشی، دانشگاه خوارزمی، تهران، ایران.
۳. گروه بیومکانیک ورزشی، مرکز تحقیقات علوم حرکتی، دانشگاه خوارزمی، تهران، ایران.
۴. گروه مهندسی کامپیوتر، دانشکده فنی و مهندسی، دانشگاه شمال، آمل، ایران.

چکیده:

هدف از پژوهش حاضر تعیین الگوهای متقارن و نامتقارن در توان مکانیکی عضلانی سه بعدی اندام تحتانی در ورزشکاران زن در حین راه رفتن بود. ۳۰ زن سالم بدنساز حرفه ای در این مطالعه شرکت کردند و داده های سه بعدی آنها از هر دو اندام تحتانی در طول راه رفتن با استفاده از سیستم آنالیز حرکت Vi con و با ده دوربین و دو صفحه نیروی کیستلر جمع آوری شد. با استفاده از این ابزارها، حداکثر توان مکانیکی عضلانی اندام تحتانی در هر سه صفحه محاسبه شد ($p < ۰/۰۵$). نتایج نشان داد که به جز در مفصل مچ پا، در پیک‌های سوم توان مکانیکی مفصل زانو و مفصل ران در صفحه ساجیتال (H3S, K3S)، پیک اول و دوم توان مکانیکی مفصل زانو در صفحه فرونتال (K1F, K2F) و دومین پیک توان مکانیکی مفصل ران در صفحه افقی (H2T) تفاوت معنی‌داری وجود دارد. علاوه بر این، یافته ها تقریباً ۲۵٪ عدم تقارن موضعی را در توان مکانیکی عضلانی را در مفاصل ران و زانو بین اندام راست و چپ تأیید کردند.

واژه های کلیدی: توان مکانیکی عضلانی، سیمتری، راه رفتن