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Ccomparison of Methods for Calculating Symmetry in 3D Angular Kinematics of Lower Limb Joints During Athlete Walking

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ABSTRACT

Background: The lack of coordination in body movements while walking is known as asymmetry. Excessive asymmetry in movement can be used to diagnose various diseases among individuals with and without pathology. Despite the wide variety of equations and formulas used to estimate symmetry and asymmetry, it remains unclear which equation is the most effective. The present study aims to compare the equations to gain a better understanding of three-dimensional joint angle symmetry during walking and to select a more suitable equation for estimating symmetry in athletes.

Methods: 30 healthy female athletes walked barefoot in front of 10 Vicon motion analyzer cameras along a 10-meter walkway to record three-dimensional angles of both lower limb joints. Then by independent t-test, the results of two equations of calculating the symmetry of the three-dimensional angles of the hip, knee, and ankle joints of the lower limbs were compared.

Results: The study's results revealed that there was no statistically significant variance in the lower limb symmetry when comparing the two distinct symmetry equations.

Conclusions: Coaches and sports professionals can use these findings to analyze the symmetry of athletes' movements and develop tailored training programs. Moreover, these assessments can aid in identifying and correcting any asymmetries to prevent sports-related injuries, as symmetry and the dominant leg are crucial for maintaining proper technique across a wide range of sports.

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KEYWORDS

Assessment Kinematics, Athlete, Gait, Symmetry

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Introduction

Walking is a fundamental function in the neuro-skeletal-muscular system, involving the coordination of body movements from one place to another [1]. In healthy individuals, walking is efficient and does not require high energy consumption due to limb coordination. However, in asymmetry disorders, walking is associated with increased energy consumption and decreased speed [2-4]. Therefore, examining and analyzing human movement and walking symmetry is crucial for identifying various pathologies and planning for treatment and rehabilitation [5, 6].

The lack of coordination in body movements while walking is known as asymmetry. Whether a person exhibits symmetry or asymmetry during walking can indicate their overall performance and efficiency [7, 8]. Asymmetry refers to the differences between the right leg and the left leg. However, it's important to note that asymmetry in the lower limb is not always a sign of pathology and can be observed in healthy individuals and athletes [9]. Generally, the walking pattern of healthy individuals is smooth, and significant differences in movement between the two lower limbs may indicate a health issue [9]. Excessive asymmetry in movement can be used to diagnose various diseases among individuals with and without pathology [4, 10].

It is important to note that when asymmetry in movement is detected while walking, it can result in increased pressure on a limb and joints on the same side, raising the risk of arthritis and musculoskeletal injuries [11]. Research in this area has indicated that limb imbalances can also affect athletes' performance [9]. Therefore, keeping track of and identifying this asymmetry can aid in managing and enhancing an athlete's performance through appropriate interventions and also help in preventing injuries [9, 12, 13]. Consequently, calculating the symmetry index during activity, particularly in the joint angles of athletes, holds significant importance.

Understanding the differences in the coordination of movements between the upper and lower limbs during walking has long been a focus of clinical research [14]. A variety of parameters are used to measure the symmetry between the right and left legs and to assess a person's performance during the walking cycle. Common parameters include spatiotemporal measurements [15, 16], joint angle kinematics [17, 18], ground reaction forces, and foot progression angles [19]. In previous studies, analyzing the 3D angular kinematic symmetry of lower limb joints in athletes while walking has provided insights into the risk of falling in runners, correlations with knee injuries, and accurate examination of gait deviations in individuals with conditions such as stroke and multiple sclerosis [20, 21].

When estimating walking symmetry, two basic components are taken into account. The first component is the equation used to measure the degree of symmetry, which describes the calculation method. The second component is the variable used in the equation, and this also indicates how the degree of symmetry is calculated [22, 23].

Various studies have employed different equations to calculate and estimate the symmetry index during walking, with each aiming to achieve more accurate results [24-26]. Despite the wide variety of equations and formulas used to estimate symmetry and asymmetry, it remains unclear which equation is superior to the others. There is a scarcity of studies that compare the different equations for calculating the symmetry index and identify a superior equation [22]. Patterson et al. 2010, compared common methods of calculating gait symmetry in stroke patients, and no significant differences were observed between the results obtained using different equations [22]. Similarly, a study by Blazhkevich et al. (2014) compared four symmetry measurement equations in healthy individuals and found that all four equations produced similar results, with no clear differences between them [27]. However, no studies have considered determining the appropriate equation to estimate the three-dimensional symmetry of complex and simple activities performed by athletes.

The current investigations focus on the comparison of two commonly used equations for measuring symmetry in walking, highlighting the lack of investigation into the relationship between these two equations. These equations are highly accurate and comprehensive, commonly utilized in various studies without asserting the superiority of one over the other [14, 24]. It emphasizes the importance of understanding symmetry and asymmetry in athletes, as it significantly influences their performance in sports activities. The study aims to compare the equations to gain a better understanding of three-dimensional joint angle symmetry during walking and to select a more suitable equation for estimating symmetry in athletes.

Material and Methods

We selected 30 healthy female athletes through an available sampling method. They had a mean age of 29.5±3.45 years. The athletes had a body mass index of 24.06± 3.25. kg/m2. Additionally, their sports experience averaged 8.96 3.25±5.49 years. This study was conducted with the approval of the Ethics Committee of the Kinesiology Research Center of Kharazmi University with the code (IR-KHU.KRC.1000.103). The participants were fully informed about all aspects of the research protocol and willingly consented to participate in the study.

To be included in the study, participants had to have a minimum of five years of experience in bodybuilding exercises, and it was also required that the upper limb of each participant was their right limb. Any individuals with a history of orthopedic, neurological, or surgical diseases that could affect normal walking were excluded from the study. To determine the dominant side of the body, several tests were conducted including ball throwing, writing, opening a bottle, shooting a ball, and jumping with one leg [7]. Data was collected using 10 Vicon motion analyzer cameras, consisting of 6 MX T40s cameras and 4 Vero v2.2 cameras, with a frequency of 120 Hz. These cameras were positioned along a 10-meter walkway to record 3D data of both lower limbs during walking. Additionally, a plug-in-gate 3D marker system was utilized to identify and assess trunk and lower limb joints.

Before the data collection, the participants walked on the assigned path multiple times to become familiar with the laboratory environment. They were instructed to walk barefoot at their preferred pace. Each individual performed the test three times, and all markers were visible to the cameras throughout the test. The Nexus software filter (Woltring filter with Mean Square Error mode and level 10) was used to reduce camera output noise when analyzing the three-dimensional angular kinematics of the joints. We calculated the three-dimensional hip, knee, and ankle angles in the sagittal, frontal, and horizontal planes based on the ISB standards of the plug-in gait protocol during walking [5]. Subsequently, we used two equations (equation 1 and equation 2) to estimate the degree of symmetry and compare the two methods of symmetry and asymmetry of the three-dimensional angles of the hip, knee, and ankle joints of the lower limbs during walking [14]. In Equation 1, the difference between the values of the left and right legs is calculated and then divided by the average of the two values. This means that the smaller the difference between the left and right legs—and the more symmetrical they are—the smaller the symmetry index value will be, approaching zero. In Equation 2, we take the logarithm of the ratio of the value of the left leg to the value of the right leg. As symmetry increases, the difference between the left and right legs decreases, resulting in a value that is also closer to zero. We then compared the values and corresponding outputs of the two equations to determine the difference in their outputs.

The inertial sensors used in this study were manufactured by Shokofa Tavan Vira (Tehran University Science and Technology Park- ID 140084). Row data were captured at a 25 Hz sampling frequency on the 9 DOF, incorporating a three-axis accelerometer (±1.5 g), three-axis gyroscope (±250°/s), and three-axis magnetometer (±48 Gauss). The sensor weighs 21 g and has dimensions (48 × 41 × 18 mm) including the plastic frame. The sensor's raw data is downloadable via a USB output [15].

$$\text{SI}=abs\left(\frac{DR-DL}{0.5\times(DR+DL)}\times 100\right) \quad Equition1$$

(DL was considered as the average of each parameter of the left foot and DR of the right foot [14].)

$$SI_{ln} = abs\left(\ln\left(\frac{left}{right}\right) \times 100\right) \quad \text{Equation 2}$$

("Ln" represents the natural logarithm, and each of the parameters for the right and left leg is included in the formula [14].)

Statistical analysis of research variables was conducted using SPSS Model 21 software. Descriptive statistics, including mean and standard deviation, were calculated. The normal distribution of the variables was tested using the Shapiro-Wilk test. Ultimately, the independent t-test was used to compare the differences in symmetry of the three-dimensional angles of the lower limb joints between two different equations representing symmetry and asymmetry.

Results

The data distribution was found to be normal according to the results of the Shapiro-Wilk test. Table 1 presents the descriptive statistics for the angular kinematic variables of the lower limb joints in three dimensions and the results of independent t-tests. The table shows no significant differences in any values related to the three-dimensional symmetry of the lower limb joints when comparing the two symmetry equations used ($P \leq 0.05$).

Table 1. Comparison of 3D lower limb kinematic symmetry during walking in female athletes using descriptive and inferential statistics.

Joint (Axis)	Equation	SD±Mean	F	T	Sig
Hip (X)	1	6.751±9.217	0.001	-0.017	0.987
	2	6.792±9.409			
Hip (Y)	1	8.616±7.980	0.000	-0.011	0.992
	2	8.638±8.019			
Hip (Z)	1	33.921±28.667	0.112	-0. 158	0.875
	2	35.172±30.654			
Knee (X)	1	8.898±9.677	0.001	-0.16	0.987
	2	8.941±9.813			
Knee (Y)	1	50.587±34.450	0.170	-0307	0.760
	2	53.583±38.495			
Knee (Z)	1	24.897±17.445	0.019	-0.075	0.941
	2	25.250±17.978			
Ankle (X)	1	20.551±20.295	0.014	-0.074	0.941
	2	20.965±21.301			

Ankle (Y)	1	57.510±44.452	0.682	-0.462	0.646
	2	63.579±53.473			
Ankle (Z)	1	35.388±23.521	0.035	-0.107	0.915
	2	26.086±25.154			

Discussion

In athlete rehabilitation and injury prevention, a deep understanding and careful analysis of the symmetry in athletes' walking patterns is of utmost importance. A recent study delved into comparing and analyzing two prevalent methods used to assess symmetry in athletes' walking, which are based on joint angle kinematics in three dimensions. The study's results revealed that there was no statistically significant variance in the lower limb symmetry when comparing the two distinct symmetry equations. This suggests that both methods are equally proficient in evaluating sports symmetry and can be valuable tools for coaches and specialists in devising customized training regimens for athletes. These findings corroborate previous research, underscoring the high precision of both methods in quantifying joint angles and scrutinizing symmetry. In essence, both equations have consistently exhibited accurate performance across diverse conditions and have been validated by different researchers.

In a study conducted by Peterson et al (2008), researchers compared the second equation with other prevalent methods for measuring the symmetry of spatiotemporal parameters in individuals affected by stroke and in healthy individuals [4]. Their findings revealed that the data generated by the two equations used in the study did not exhibit significant differences. The researchers concluded that the walking parameter selected for the equation holds more significance in evaluating walking symmetry after a stroke than the specific formula used for calculating the symmetry. Additionally, a study conducted by Blazhkevich et al. (2014) compared four common equations for assessing symmetry in walking among healthy individuals and yielded similar results, indicating no significant difference between different methods of symmetry evaluation. Notably, there was a strong correlation and great similarity in the results obtained from the two equations used in the research [27].

The excerpt below explores several academic studies that employ diverse mathematical equations to quantify symmetry and asymmetry. In one particular study, researchers use a specific equation to measure symmetry and a different equation to evaluate asymmetry. Conversely, another study proposes a consistent methodology for assessing symmetry while disregarding asymmetry altogether [28-30]. Additionally, a study conducted by Siberz et al. (2021) investigates how certain movements affect joint angle symmetry and reveals findings that differ from those of the current research. Moreover, a comparison of three common symmetry assessment techniques highlights the significant impact of activities like ascending and descending stairs on joint angle symmetry [31]. Furthermore, a study from Gianco et al (2023) compares five prevalent methods for evaluating symmetry in the elderly and individuals with Parkinson's disease, showing notable differences between the results obtained from the first and second equations [32]. These disparities in the findings are ultimately attributed to variations in testing conditions, study populations, parameters, and the types of movements analyzed.

The research findings highlight the exceptional accuracy of the tools employed in both evaluation methods, leading to minimal variation between the two approaches. State-of-the-art angular kinematic tools have demonstrated the capacity to precisely measure joint angles and evaluate symmetry, thereby bolstering the credibility of the results obtained. Furthermore, the meticulous selection of samples and stringent controls implemented in laboratory settings have significantly contributed to mitigating discrepancies and elevating the accuracy of the results. It is imperative to underscore the distinct advantages and robustness inherent in each symmetry assessment method, both of which yield highly precise and dependable insights into the three-dimensional movement symmetry of lower limb joints. However, it's crucial to acknowledge that the implementation of each method may necessitate specialized and sophisticated equipment, the acquisition and expense of which could pose potential constraints. These limitations should be carefully considered in the planning of future research initiatives. It is important to note that this study was conducted on a limited number of healthy female athletes, which may slightly restrict the generalizability of the results.

To enhance the quality of future research, it is recommended to conduct studies with a larger and more diverse sample size. This will help ensure that the results and conclusions drawn from the research can be applied to a wider range of scenarios and populations. Additionally, it would be beneficial to investigate how various specific factors, such as the types of sports exercises and the particular joint movements involved, influence movement symmetry. Understanding these nuances would provide deeper insights into the issue at hand. Furthermore, leveraging advanced tools and employing innovative kinematic analysis techniques can significantly improve the accuracy and efficacy of movement assessments, contributing to a more comprehensive understanding of the subject matter.

Conclusion

The results of the research demonstrate that both methods for assessing symmetry in the three-dimensional angular motion of the lower limb joints during walking by athletes are reliable and accurate. This means that coaches and sports professionals can use these findings to analyze the symmetry of athletes' movements and develop tailored training programs. Moreover, these assessments can aid in identifying and correcting any asymmetries to prevent sports-related injuries, as symmetry and the dominant leg are crucial for maintaining proper technique across a wide range of sports.

Ethical Considerations:

Compliance with ethical guidelines

This study was conducted with the approval of the Ethics Committee of the Kinesiology Research Center of Kharazmi University with the code (IR-KHU.KRC.1000.103).

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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«مقاله پژوهشی»

مقایسه روش های محاسبه تقارن در سینماتیک زاویه ای سه بعدی مفاصل اندام تحتانی در حین راه رفتن افراد ورزشکار

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چکیده

هدف: عدم هماهنگی حرکات بدن هنگام راه رفتن به عنوان عدم تقارن شناخته می شود. عدم تقارن بیش از حد در حرکت می تواند برای تشخیص بیماری های مختلف در بین افراد با و بدون آسیب شناسی استفاده شود. با وجود تنوع گسترده معادلات و فرمول های مورد استفاده برای تخمین تقارن و عدم تقارن، هنوز مشخص نیست که کدام معادله موثرتر است. هدف پژوهش حاضر مقایسه معادلات در این زمینه، برای درک بهتر تقارن زاویه ای سه بعدی مفاصل در حین راه رفتن و انتخاب معادله مناسب تر برای تخمین تقارن در ورزشکاران است.

روش شناسی: ۳۰ زن ورزشکار سالم با پای برهنه، در مقابل ۱۰ دوربین تحلیلگر حرکتی وایکون در امتداد مسیر پیاده روی ۱۰ متری راه رفتند، تا زوایای سه بعدی هر دو مفصل اندام تحتانی را ثبت کنند. سپس با آزمون تی مستقل، نتایج دو معادله محاسبه تقارن زوایای سه بعدی مفصل ران، زانو و مچ پا در اندام تحتانی مقایسه شد.

نتایج: نتایج این مطالعه نشان داد که در مقایسه دو معادله متمایز تقارن، واریانس آماری معنی‌داری در تقارن اندام تحتانی وجود ندارد.

نتیجه گیری: مربیان و متخصصان ورزشی می توانند از این یافته ها برای تجزیه و تحلیل تقارن حرکات ورزشکاران و توسعه برنامه های تمرینی مناسب استفاده کنند. علاوه بر این، این ارزیابی‌ها می‌توانند به شناسایی و اصلاح هرگونه عدم تقارن برای جلوگیری از آسیب‌های مرتبط با ورزش کمک کنند، زیرا تقارن و پای غالب برای حفظ تکنیک مناسب، در طیف گسترده‌ای از ورزش‌ها ضروری است.

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استناد به این مقاله:
یوسفیان ملا، راضیه؛ احمدی، مقدسه؛ و شجاعی فرد؛ محیا. مقایسه روش های محاسبه تقارن در سینماتیک زاویه ای سه بعدی مفاصل اندام تحتانی در حین راه رفتن افراد ورزشکار. نشریه فناوری ورزشی پیشرفته، (۱۴۰۳)؛ ۸(۳)، ۶۲-۷۰.
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