Research Paper

Effect of Changing Arm Swing Speed on the Lower Limb 3D Maximum Mechanical Power While Walking

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ABSTRACT

Purpose: Walking is a complex activity that involves multiple parts of the body, including the lower limb, upper limb, trunk, head, and neck. Contrary to popular belief, walking is not solely related to the forward movement of the legs. Biomechanical analysis, especially in terms of mechanical power, is an essential aspect of gait studying. The study aims to explore how altering arm swing speed affects the 3D maximum mechanical power of the lower limb while walking.

Methods: In this study, 30 healthy women walked on a force plate path in front of cameras in three states of normal upper limb swing, fast upper limb swing, and slow upper limb swing. The calculation of muscle power in each lower limb joint and plane is based on the product of the joint moment and its angular velocity. The average mechanical power of the joints was compared using the repeated measurement test ($P \leq 0.05$).

Results: The results showed that changing the swing speed of the arm has a significant effect on all absorption and production parameters related to the mechanical power of the lower limb joints.

Conclusion: In conclusion, any change in arm movement during walking can affect movement, balance, and gait biomechanics.

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Highlights

• Biomechanical analysis, especially in terms of mechanical power, is an essential aspect of gait studying.

• The results showed that changing the speed of arm swings has a significant effect on all absorption parameters related to the mechanical power of the lower limb joints.

• The results showed that changing the speed of arm swings has a significant effect on all production parameters related to the mechanical power of the lower limb joints.

• Any change in arm movement during walking can affect movement, balance, and the biomechanics of movement.

Plain Language Summary

Although arm swings are a normal part of walking, the speed of this movement can vary depending on different conditions. Changes in the kinetic, kinematic, and spatial-temporal parameters of walking and the lower limbs can occur, along with a decrease in upper limb oscillation. Mechanical power is a crucial and intricate factor in biomechanics, calculated by multiplying a kinetic variable with a kinematic variable, making it a comprehensive measure for biomechanical analysis across various fields. This study found that changing the speed of arm swings had a significant effect on all absorption and production parameters related to the mechanical power of the lower limb joints. Therefore, any alteration in the swing of the shoulders and upper body during walking, which may occur due to various orthopedic and neurological conditions, can significantly affect the conditions of movement, balance, and walking.

Introduction

Walking is a critical human activity that enables us to fulfill many of our basic daily needs [1]. Biomechanical research on walking has received a lot of attention over the years due to its significance [2]. According to biomechanical analysis, walking consists of two phases for the lower limbs, stance and swing, which propels the body forward [2]. Although numerous studies have focused on the biomechanics of the lower limbs during gait, it is apparent that many other body parts, such as the trunk, head and neck, and upper limbs are also involved in the movement [3]. This means that walking is a complex activity that engages various parts of the body, not just the legs, and is not merely about moving the two legs forward [2]. Thus, it is essential to examine other body parts besides the lower limbs when walking.

It has been proven that the upper limb swings forward during walking with a movement that does not correspond to the lower limb [4]. Research has shown that this oscillation happens because the body needs to release energy due to the ground reaction force received after the foot hits the ground [4, 5]. In simpler terms, when the foot hits the ground, the ground, according to Newton's third law, applies a reaction force to the foot. This force then moves from the lower limb to the trunk and then to the upper limb, causing the oscillation [5, 6]. This oscillation helps to release the reaction force and makes the body consume less energy while walking [7].

Although arm swings in the upper limb are a normal part of walking, the speed of this movement can vary depending on different conditions. For example, research has shown that in some neurological diseases, such as Parkinson's and stroke, the speed of upper limb movement is greatly reduced or may even stop altogether [1, 8]. On the other hand, in some other pathological conditions like athetoid and cerebral palsy (CP), the speed of upper limb movement increases greatly during gait [9]. Furthermore, previous studies have indicated that following the occurrence of many of these diseases, there are changes in the kinetic, kinematic, and spatial-temporal parameters of walking and the lower limbs, along with a decrease in upper limb oscillation [2].

Mechanical power is a crucial and intricate factor in biomechanics. It is calculated by multiplying a kinetic variable with a kinematic variable, making it a comprehensive measure for biomechanical analysis across various fields [10].

Despite previous studies on the biomechanical changes in walking resulting from changes in upper limb swing, no study has yet been found that examines the changes in the mechanical power of the lower limb joints during gait with varying upper limb swing speeds. Therefore, this study was conducted to investigate the effect of changing arm swing speed on the 3D maximum mechanical power of the lower limb during walking, based on the materials presented in this context.

Materials and Methods

A quasi-experimental within-subjects and repeated-measures single-blinded crossover study was conducted to evaluate the walking patterns of 30 healthy women with a mean age of 29.5±3.45 years and a body mass index of 24.06±3.25 kg/m^2. The sample size was determined using G*Power software, version 3.1.9.7, analysis, and was deemed sufficient to detect at least a medium effect size with the following parameters, effect size of F=0.25, significance level α=0.05, and power of 1-β=0.80. All participants were informed about the test process and signed an informed consent form. The exclusion criteria included a history of orthopedic, neurological, or surgical disorders that can affect the walking pattern. The inclusion criteria included all subjects with right limb dominance identified using tests, such as throwing a ball, writing, opening a jar of jam, hitting a ball, and jumping on one limb [11, 12].

The Vicon motion recording system with ten cameras (MX-T40-S 120 Hz) and two force plates (Kistler 50×60 cm meters and 50 by 30 cm were used) were used to collect 3D data of both lower limbs while the subjects walked along a 10-meter path. The Plug-in-Gait 3D marker model was used to identify the joints.

To ensure that the subjects were comfortable with the laboratory environment and in the proper location on the force plates, they were asked to walk the designated path several times before data collection. During the test, each subject walked on the force plate path while being recorded by cameras. They walked in three different states, normal upper limb swing, fast upper limb swing, and slow upper limb swing. Each subject walked barefoot at their chosen speed, and the test was conducted three times to ensure accurate data analysis. To guarantee precise data analysis, the testing was performed in a way that allowed all lower limb markers to be seen by the cameras, and the lower limbs were positioned accurately on the two force plates.

External markers were used to evaluate joint coordinates for kinematic calculations, and the center of rotation for each subject's joint was estimated. The Nexus software filter (Woltring filter in MSE mode and level 10) was also applied to reduce camera noise and force plate information. At the end of each two-off stage, the cameras were used to extract information about the upper (right) leg of the subjects, and the ground reaction force of the upper limb was determined from the force plates. Bony landmarks were marked with markers to assess different parts of the lower limb for calculating the joint kinematics of the dominant leg, all of which were based on the standards of ISB and Winter [13, 14]. The instantaneous muscle power (P) in each joint (j) and in each plane (k) was calculated using the following equation (Equation 1) where M is the joint moment, and ω is the angular velocity of the dominant leg [11, 14]:

1. $P_{j,k}=M_{j,k}\cdot\omega_{j,k}$

Statistical analysis using Mean±SD, with data distribution normality was checked via the Shapiro-Wilk test. Furthermore, to compare the average 3-D mechanical muscle power of lower limb joints of the dominant leg in various swing states of the upper limb, a repeated measurement test was used (P≤0.05).

Results

Table 1 presents descriptive statistics related to the demographic variables of study participants.

The data distribution was normal based on the results of the Shapiro-Wilk test. Table 2 provides the output of descriptive and inferential statistics. The results in Table 2 indicated that the mechanical power of the joints in the upper and lower limbs show significant changes in absorption and propulsion parameters with varying speeds of the upper limb arm swing during gait.

Discussion

The current study was conducted to investigate how altering the speed of arm swinging affects the maximum mechanical power of the lower limb joints in three dimensions during walking. The results indicated that all the parameters related to the absorption and production of mechanical power in the lower limb joints displayed a significant difference as the arm swing speed changed.

The movement of the upper limbs in a reciprocating and oscillatory motion while walking is a natural behavior [1, 13]. Mechanical power is a variable that results from the multiplication of a kinetic variable and a kinematic variable. Hence, any adjustments to this factor would impact the kinetic and kinematic aspects of walking. Therefore, rehabilitation programs, clinical biomechanics, and medical personnel need to consider this factor when dealing with different upper limb immobilizations during walking. Previous studies have shown that the movement in the upper limbs improves stability and balance during walking, reduces energy usage, and also impacts spatiotemporal variables [8].

It was discovered that no direct study has been conducted on the impact of upper limb speed on the mechanical power of the lower limb while walking. Studies related to the present topic have only examined other biomechanical parameters, as reported by Yousefian Molla [2]. Bahrili et al. (2022) [15] conducted a study to investigate the effect of removing the upper limb swing on the biomechanical parameters of walking. They concluded that removing the upper limb swing caused changes in some spatial variables during walking, while the principle of walking symmetry was still maintained. However, their results contradict the results of the current study, which may be attributed to the fact that their study only investigated spatial-temporal variables and only in the state of absolute immobility of the upper limb. In contrast, the current study examined the biomechanical variable of mechanical power comparison at different speeds of upper limb movement.

In a study conducted by Ortega et al. [16] and Bruijn et al. [17], the impact of reducing arm swing speed in elderly individuals was investigated. The study concluded that a reduction in upper limb swing movement leads to increased energy consumption and decreased stability during walking. These results are consistent with the results of the present study, indicating that changes in arm swing speed during walking significantly affect individuals' balance as a crucial biomechanical factor. In a similar study to the present research, Eke-Okoro et al. [18] examined the effect of different upper limb swing patterns on changes in gait biomechanics. Their results supported those of the present study, showing that changes in limb movement and arm swing affect kinematic parameters, such as walking speed and proper walking pattern, which are directly influenced by upper limb movement frequency and oscillation. In a study conducted by Navarro-López et al., the researchers examined how different placements of upper limb braces on the dominant and non-dominant arms affected walking parameters [8]. The study focused on spatiotemporal parameters of walking, and the results were consistent with the results of the present study. They found that brace placement above the elbow caused the greatest changes, while placement below the elbow or allowing natural arm oscillation caused the least changes. However, no consistency in terms of walking speed and cadence parameters was observed between the two studies, which may be due to differences in the age and exercise levels of the subjects.

Zampier et al. [19] conducted a study to analyze the effects of changing the speed and range of movement of the upper limb on the kinematic parameters of walking. They found that changing the arm swing caused kinematic changes in the subjects' walking, which is consistent with the results of the current study. In another clinical study, Weersink et al. [20] investigated the effect of increasing and encouraging upper limb swing on the biomechanical parameters of individuals with Parkinson's disease. They concluded that increasing upper limb swing in these individuals led to improvement in control and biomechanical parameters, which is also consistent with the results of the current study. In a study similar to the present one, Amberger investigated how upper limb immobility and arm oscillation affect kinetic, kinematic, and energy consumption parameters in the body [6]. He

Table 1. Participants' characteristics in the study

Variables	Mean±SD
Age (y)	29.5±3.45
Weight (kg)	64.6±2.92
Height (cm)	163.6±36.08
BMI (kg/m²)	24.06±3.25
Lower limb length (cm)	87.12±5.31

BMI: Body mass index.

PHYSICAL TREATMENTS

Table 2. Descriptive statistics and repeated measure test results in the mechanical power of the lower limb joints during gait with different arm swing speeds

Dominant Lower Limb Mechanical Power	Mean±SD	F	Sig.	Dominant Lower Limb Mechanical Power	Mean±SD	F	Sig.
PTHXF	1.475±0.610			PJKYS	-0.210±0.176		
PTHXNO	1.114±0.522	160.378	0.00	PJKYF	-0.278±0.145	61.779	0.00
PTHXS	-0.482±0.378			PJKYNO	-0.215±0.161		
PJHXF	-1.036±1.709			PTKZS	0.066±0.049		
PTXS	0.907±0.711	35.593	0.00	PTKZF	0.127±0.091	50.023	0.00
PJHXNO	-0.566±0.423			PTKZNO	0.103±0.134		
PTHYNO	0.346±0.292			PJKZS	-0.074±0.057		
PTHYS	0.309±0.213	60.892	0.00	PJKZF	-0.124±0.114	47.204	0.00
PTHYF	0.363±0.264			PJKZNO	-0.104±0.107		
PJHYS	-0.215±0.172			PTAXS	2.431±1.248		
PJHYF	-0.348±0.274	77.967	0.00	PTAXF	3.624±1.353	254.198	0.00
PJHYNO	-0.231±0.151			PTAXNO	3.103±1.040		
PTHYS	0.131±0.164			PJAXS	0.355±0.349		
PTHZF	0.211±0.189	6.275	0.01	PJAXF	-0.947±0.526	164.595	0.00
PTHZNO	0.116±0.109			PTJAXNO	-0.794±0.269		
PJHZS	-0.098±0.110			PTAYS	0.028±0.040		
PJHZF	-0.167±0.146	52.198	0.00	PTAYF	0.057±0.072	29.60	0.00
PJHZNO	-0.112±0.099			PTAYN	0.0423±0.040		
PTKXS	0.372±0.290			PJAYS	-0.029±0.025		
PTKXF	0.660±0.417	84.366	0.00	PJAYF	-0.057±0.057	49.24	0.00
PTKXNO	0.439±0.384			PJAYNO	-0.043±0.037		
PJKXS	-0.698±0.467			PTAZS	0.0813±0.081		
PJKXF	0.209±0.126	150.82	0.00	PTAZF	0.142±0.092	70.627	0.00
PJKXNO	-0.827±0.359			PTAZNO	0.088±0.056		
PTKYS	0.172±0.135			PJAZS	-0.098±0.078		
PTKYF	0.209±0.126	116.963	0.00	PJAZF	-0.162±0.120	64.947	0.00
PTKYNO	0.193±0.165			PJAZNO	-0.162±0.149		

PHYSICAL TREATMENTS

Abbreviations: P: Muscle power; T: Propulsion; J: Absorption; X: Sagittal plane; Y: Frontal plane; Z: Horizontal plane; NO: Normal walking; F: Fast armswing; S: Slow armswing.

Sig. P≤0.05.

found no significant difference in kinetic and kinematic parameters of the lower limbs, except for ankle torque in two conditions, indicating a lack of consistency with the present study. The main reason for this inconsistency may be attributed to differences in the method of upper limb movement between the two studies. In Amberger's study, both upper limbs were immobilized during walking, while in the present study, the upper limb speed was changed [6].

Conclusion

When we alter the swinging motion and pace of the upper limb while walking, it leads to changes in the mechanical power parameters. These parameters are representative of important kinetic and kinematic variables. Therefore, it can be inferred that any modification in the swing of the shoulders and upper body while walking - which may occur due to various orthopedic and neurological conditions - can change the movement conditions, balance, and walking. Hence, it is crucial to pay special attention to it during rehabilitation programs.

The limitations of this study include the lack of access to other sexes and age groups, especially the elderly. The authors also did not have other biomechanical devices to measure other parameters, such as muscle activities. To improve future studies, we suggest investigating changes in biomechanical parameters during different conditions of the trunk, head, and neck while walking, and paying attention to other tasks like running in different types of subjects.

Ethical Considerations

Compliance with ethical guidelines

All procedures performed in the study were approved by the Ethics Committee of Kinesiology Research Center, Kharazmi University (Code: 103/1000).

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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