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RESEARCH

Effects of Unstable Shoes on Lower Limbs with Different Speeds

Ze-ping Wang, Qin-er Qiu, Si-hui Chen, Bi-cheng Chen and Xiao-tong Lv
Faculty of Physical Education, Ningbo University, Ningbo, CN
Corresponding author: Qin-er Qiu (qiuqiner@nbu.edu.cn)

Purpose: The purpose of this study is to investigate the impact of walking at different speeds with wearing unstable shoes on the movement of the lower limbs, and to provide relevant biomechanical supports for fitness and injury prevention.
Methods: Twelve females volunteered to join the test. The walking speed was respectively 0.80 m/s, 1.20 m/s and 1.70 m/s. The kinematic parameters of the lower limb of ankle, knee and hip measured with Vicon motion analysis system. And univariate repeated measurements of variance analysis was used to measure the effect of unstable shoes in lower limbs joints in three differences speeds.
Results: The movement pattern of the hip joint is relatively stable and is less affected by the speed. It is mainly manifested in the extension, abduction and external rotation of the hip joint. The knee joint is affected by the walking speed, especially in the coronal plane and the horizontal plane. The angle range of motion of the ankle joint are larger than hip joint, there have increased of the dorsiflexion, inversion and internal rotation in ankle joint.
Conclusion: For the lower extremities of the hip, knee and ankle joints, with the increase of walking speed, joint angle and range of activities also showed varying degrees of increase; and joint angle peaks are in the pre-support period.

Keywords: Unstable shoes; Walking speed; Joint angle; Kinematics

1. Introduction

Walking is one of the most repetitive activities in people's daily life, and it is becoming one of the ways in which people in leisure and fitness because of un-limitation of time and place (Romkes, et al. 2006; Svenningsen et al. 2019). There are many benefits of walking, between the legs constantly changing to move and coordination, which not only can improve the function of the human brain around the hemisphere and brain cell reaction speed, delay brain cell aging, but also can strengthen the leg muscle and increase the flexibility of the joints (Song, 2008). In the course of walking, the support point from one leg to the other leg will produce a sense of instability; so in order to maintain a dynamic balance, people will exercise by changing the speed mode under the condition of rhythm and stability (Sadeghi et al. 2000; Taniguchi et al. 2012). The speed can affect the kinematic characteristics of gait-joint rotation, ground reaction force, joint union movement and power (Lelas et al. 2003). If people walking with high speed, it may reduce the body's shock absorption and increase the risks of lower limbs injuries.

In order to reduce the foot pressure and improve the foot comfort when walking, people will choose some different external objects to assist. During the movement of different speed, the body was always with the lower limb joints as a support point, then the type of soles or speed walking can cause the body posture, distribution of articular load, other physiological and pathological aspects to change through changing the angle of joint movement, joint torque, etc (Farzadi et al. 2107; Price et al. 2013). MBT shoes as a function of shoes, are used a similar type of arc design, so that the wearer in the process of standing and walking to produce a natural sense of instability. Compared with traditional shoes, it uses a high-performance compressible material to increase the thickness and curvature of the soles (Gu et al. 2014). Theoretically it can increase the ankle joint in the horizontal and sagittal range of activities.

There are a lot of studies on the kinematic parameters of the unstable shoes during walking. From the biomechanical point of the view, there are many differences between unstable shoes and ordinary shoes, which reflect the lower limbs of the joint movement amplitude, joint loads, muscle activities and so on. Therefore, it is necessary to study the lower limbs of the kinematic parameters of the joints to reduce joint damages, pains and provide reasonable fitness advice for the basis of exercise with unstable shoes.

2. Methods

2.1. Participants

Twelve healthy females volunteered to participate the experiment (**Table 1**). All subjects have understood the purpose and steps fully before the test, and without any lower limbs damage or disease history in the last six months, no neuromuscular system disorders and other factors that may affect the results of the experiment. Before the experience, the subjects singed a consent form, and this research was approved by the university Ethical Committee.

2.2. Equipment

The study used a pair of common unstable shoes with front-rear direction, which the main feature is of the arc-shaped structure in foot arch (**Figure 1**). At the same time, treadmill (H/P/COSMED, Gaitway) was used to determine the speed and data collection before the experiment (**Figure 2**). An 8-camera Vicon motion analysis system (Oxford Metrics Ltd., Oxford, UK) was used to collect three-dimensional kinematic data at a frequency of 200 Hz (**Figure 3**).

Table 1: Subjects situation to participate testing (N = 12).

Age (years)	Mass (kg)	Height (cm)
24.00 ± 1.20	59.30 ± 4.70	165.57 ± 3.60

Figure 1: Unstable shoes.

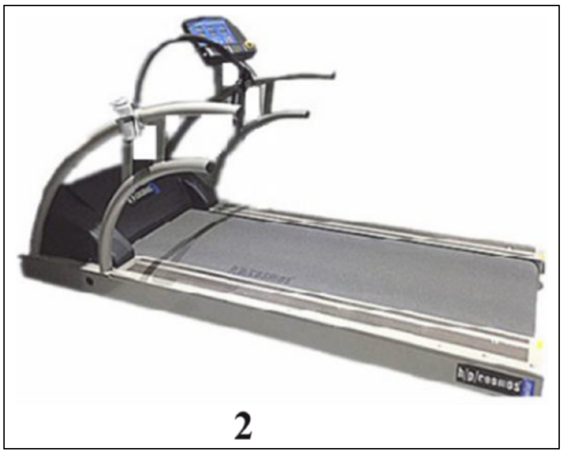

Figure 2: H/P/COSMED, Gaitway.

Figure 3: The 8-camera Vicon motion analysis system (Oxford Metrics Ltd., Oxford, UK).

2.3. Experiment protocol

Subjects wore unstable shoes to pass the test channel following the rhythm of the metronome at different speeds (0.80 m/s, 1.20 m/s, 1.70 m/s) and ensured their feet on the Kistler Force Platform simultaneously. During the experiment, let them wear the unstable shoes to be adaptive training for 1 hour before testing in order to ensure the stability of the pace and reduce the error of data. Each subject was asked to get on 5 tests, in which they have 3–5 minutes left to rest.

Statistical analysis

In the vertical direction of the ground reaction force, the threshold of the reaction force 20N was used to define the steady-period of right leg (from the right foot heel landing to the ipsilateral toe left), after selecting the data of joint angle in the lower limb during the stead-period. The SPSS19.0 software was used for statistical analysis with the univariate repeated measurements of variance analysis, and $P < 0.05$ was set for significant differences.

3. Results and discussion

3.1. Hip joints

According to the peak angle and ROM of hip, we found that in the sagittal plane, the peak angle of hip flexion was higher than that of normal speed when walking at slow speed, and the peak angle of extension was lower than that of normal speed. The peak angle of hip extension and ROM were significantly higher than that of normal and slow walking when walking at fast speed. In the coronal plane, the peak angle of the hip abduction was slower than that of the normal walking when the walking was slow. The peak angle of abduction and ROM were higher than those of the normal when walking quickly. In the horizontal plane, when walking slowly, the peak angle of the external rotation was significantly higher than that of the normal and fast walking. The peak angle of the internal rotation at normal speed was significantly lower than that of the slow and constant speed (**Table 2**).

According to the mean angle curve of right hip in three plates (**Figure 4**), we found that the movement trend was basically the same with three kinds of speed. The main differences performed in the hip extension, abduction and external rotation movement. Among them, the stretch of hip movement increased in the stance of late stage, when fast walking in the sagittal plane. The hip abduction was smaller in the stance of early during the slow walking, the latter part was increased, and the movement trends of normal and fast were similar in the coronal plane. In the horizontal plane, the angle of hip external rotation increased with the speed up in the stance of later.

Results showed that the angle curve of hip was sinusoidal variation, which was consistent with the previous study (Han & Wang 2011; Nigg et al. 2006). Research has found hip extension ROM and peak hip extension will increase with increasing speed. The results show that as the speed increases, the effect of unstable shoes on the hip joint is amplified (Zhang et al. 2012; Myers et al. 2006).

Table 2: Peak angle and ROM of hip in three planes while walking with different speeds (N = 12).

			Slow walking (0.8 m/s)	Normal walking (1.2 m/s)	Fast walking (1.7 m/s)
Hip	Sagittal plane	Flexion	26.84 ± 0.27[a]	24.57 ± 0.78	25.79 ± 1.24
		Extension	–5.97 ± 0.33[a]	–7.25 ± 0.17[b]	–9.81 ± 0.52[c]
		ROM	32.81 ± 0.30	31.82 ± 0.84[b]	35.60 ± 1.25[c]
	Coronal plane	Abduction	14.03 ± 0.74[a]	15.69 ± 0.52	16.38 ± 0.31[c]
		Adduction	1.78 ± 0.81	2.37 ± 0.20	1.79 ± 0.67
		ROM	12.26 ± 1.23	13.32 ± 0.50	14.58 ± 0.84[c]
	Horizontal plane	Internal rotation	–22.63 ± 0.57	–20.42 ± 0.73[b]	–17.91 ± 1.38[c]
		External rotation	–48.93 ± 0.54[a]	–44.24 ± 1.78	–45.21 ± 1.26[c]
		ROM	26.30 ± 0.89	23.82 ± 1.37	27.30 ± 2.13

Note: unit: degree (°), [a,b,c] indicate significant difference, $p < 0.05$ ([a] represents slow and normal walking; [b] represents normal and fast walking; [c] represents slow and fast walking).

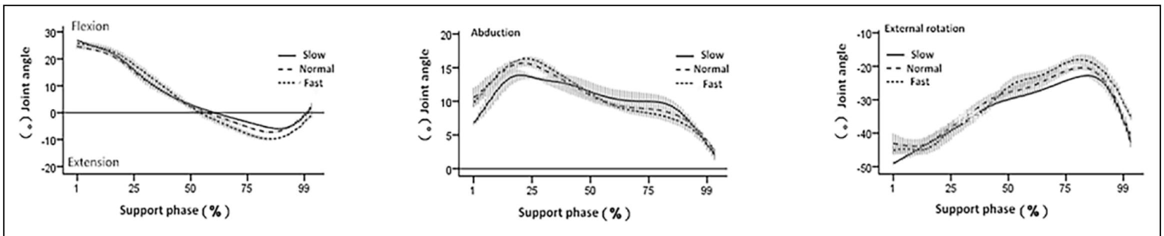

Figure 4: Mean joint angel curve of right hip in the stance of walking with different speeds (N = 12).

With the increase of walking speed, the overall movement amplitude of hip was not changed greatly; the hip may be the joint as a typical ball and socket joint, which the joint capsule was thick, tense and the joint fissure was deeper, so in the course of movement it was rugged and less flexible. At the same time, the movement of joint was proportional to the speed increasing in the sagittal and horizontal plane; it showed that when walking fast, the subjects increased the hip amplitude of movement in order to maintain the original balance (Zhang et al. 2012), especially the increasing of hip abduction throughout the stance phase.

3.2. Knee joints

According to the peak angle and ROM of knee, we found that in the sagittal plane, the peak angle of the knee flexion was significantly lower than that of the normal and fast walking when the walking was slow; the peak angle of extension at walking rapidly was lower than the slow walking; and at slow walking the ROM of flexion and extension was significantly lower than the normal. In the coronal plane, the peak angle of knee abduction at normal speed was significantly lower than that of fast walking, while the ROM was higher than that of fast walking. In the horizontal plane, the peak angle of the knee rotation and ROM were both significantly higher than those of the slow and normal speed. The peak angle of the external rotation was significantly higher than that of the slow and fast walking (**Table 3**).

The main differences were manifested in the adduction and internal rotation of the knee from the movement of knee at three speeds (**Figure 5**). In the sagittal plane, the knee movement of flexion and extension was basically the same at three speeds. When fast walking in the coronal plane, the knee performed for a larger angle of adduction; when slow and normal walking, the trend of movement was basically the same. During fast walking in the horizontal plane, the internal rotation angle of knee was the largest movement in the stance of early, and later gradually reduced.

The results showed that the change of the knee angle was more obvious than that of the hip joint, especially in the coronal and horizontal plane. It was due to the special position of the knee in the human body, which made the flexibility more than the hip and more prone to injury during the exercise. The study found that the angle of the knee adduction, internal rotation increased significantly with the increase of speed and the maximum angle occurred in the pre-stance; indicated that with the impact of speed increasing in the initial landing, the knee increased the angle of internal rotation and adduction to maintain the stability of the

Table 3: Peak angle and ROM of knee in three planes while walking with different speeds (N = 12).

			Slow walking (0.8 m/s)	Normal walking (1.2 m/s)	Fast walking (1.7 m/s)
Knee	Sagittal	Flexion	29.93 ± 0.09[a]	33.85 ± 1.15	32.83 ± 1.34[c]
		Extension	–2.77 ± 0.13	–2.17 ± 0.62	–0.97 ± 0.55[c]
		ROM	32.70 ± 0.16[a]	36.01 ± 0.69	33.80 ± 1.54
	Coronal plane	Abduction	–2.21 ± 0.34	–0.40 ± 3.88[b]	–6.90 ± 0.80
		Adduction	–31.11 ± 2.33	–32.53 ± 0.84	–29.45 ± 0.43
		ROM	28.91 ± 2.02	32.13 ± 3.05[b]	22.55 ± 0.81[c]
	Horizontal plane	Internal rotation	12.84 ± 2.52	12.89 ± 0.54[b]	16.98 ± 0.73[c]
		External rotation	4.60 ± 0.66[a]	6.02 ± 0.50[b]	4.49 ± 0.45
		ROM	8.24 ± 1.88	6.88 ± 0.96[b]	12.49 ± 1.06[c]

Note: unit: degree (°), [a,b,c] indicate significant difference, $p < 0.05$ ([a] represents slow and normal walking; [b] represents normal and fast walking; [c] represents slow and fast walking).

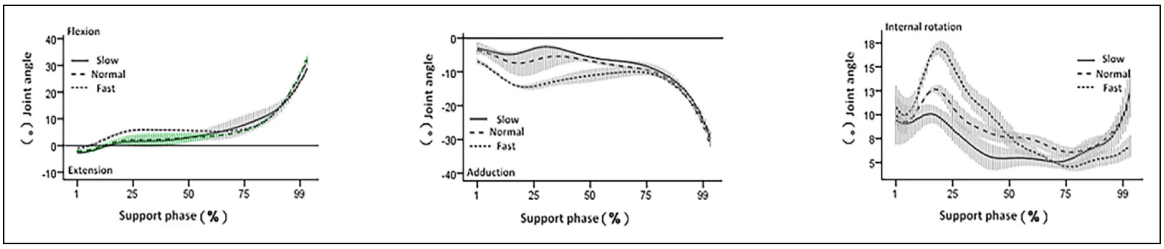

Figure 5: Mean joint angel curve of right knee in the stance of walking with different speeds (N = 12).

movement, but also increased the risk of injury (Landry et al. 2012). The greater the angle of adduction of the knee joint, the greater the load on the anterior cruciate ligament, the reaction force on the ground, and the forward shear force of the proximal tibia, resulting in damage to the anterior cruciate ligament (Yang 2017).

3.3. Ankle joints

According to the peak angle and ROM of hip, we found that in the sagittal plane, the peak angle of dorsiflexion was significantly lower than that of the normal and rapid walking during slow walking. The peak angle of the plantar flexion was significantly lower than that of the slow and fast while normal walking. In the coronal plane, the peak angle of the ankle inversion when walking quickly was significantly higher than that of the slow and normal walking. In the horizontal plane, the peak angle of the external rotation was significantly higher than that of the slow and normal when walking fast. There was no difference with the ROM in the corresponding articular surface (**Table 4**).

According to the movement of ankle at three speeds (**Figure 6**), the main differences were observed in the ankle of plantarflexion, dorsiflexion, inversion and internal rotation. In the sagittal plane, slow walking performed for the greater plantarflexion and smaller dorsiflexion, but the trend of slow and normal walking was consistent. With the increase of walking speed in the coronal and horizontal plane, the angle of ankle inversion, internal rotation was gradually increasing.

Studies have shown that when walking fast, unstable shoes increase the angle of the ankle dorsiflexion and the movement of the spine that make the pressure center forward; and it can increase the muscles of ankle and back (Armand et al. 2014). That is similar to the flexion and extension activities of ankle in the sagittal plane in this study. Indicating that the increase of speed increased the range of dorsiflexion and the degree of knee flexion which that may be associated with the strengthening of the rear leg and fast-twitch muscle of legs (Yin 2014).

Boyer et al. found significant changes found at the ankle and hip joints may be a coordinated and coupled effort to stabilise the body's centre of mass displacement in the frontal-plane (Boyer & Andriacchi 2009).

Table 4: Peak angle and ROM of ankle in three planes while walking with different speeds (N = 12).

			Slow walking (0.8 m/s)	Normal walking (1.2 m/s)	Fast walking (1.7 m/s)
Ankle	Sagittal plane	Dorsiflexion	15.78 ± 1.32[a]	20.05 ± 1.67	19.00 ± 0.31[c]
		Plantarflexion	–9.96 ± 0.77[a]	–6.73 ± 0.90[b]	–9.02 ± 0.51
		ROM	25.74 ± 2.04	26.78 ± 2.17	28.14 ± 0.06
	Coronal plane	Eversion	–2.05 ± 1.89	–3.52 ± 0.29	–3.91 ± 0.15
		Inversion	–6.70 ± 0.22	–6.50 ± 0.23[b]	–7.31 ± 0.14[c]
		ROM	4.65 ± 1.84	2.99 ± 0.31	3.28 ± 0.28
	Horizontal plane	Internal rotation	33.86 ± 1.02	33.61 ± 1.78	36.64 ± 0.61
		External rotation	13.89 ± 0.50	15.29 ± 0.36[b]	18.68 ± 0.95[c]
		ROM	19.97 ± 0.64	18.31 ± 1.42	17.96 ± 1.54

Note: unit: degree(°), [a,b,c] indicate significant difference, $p < 0.05$ ([a] represents slow and normal walking; [b] represents normal and fast walking; [c] represents slow and fast walking).

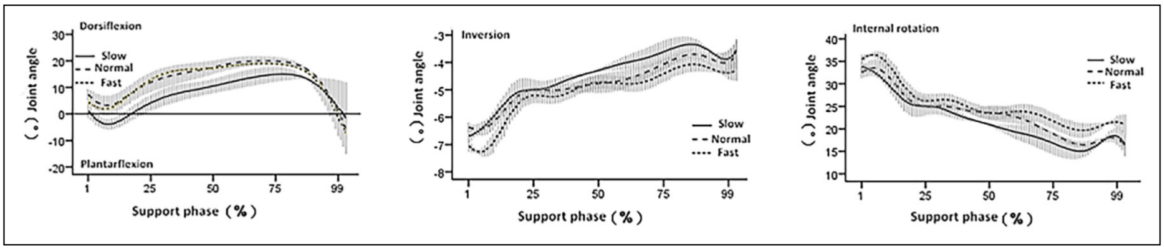

Figure 6: Mean joint angel curve of right ankle in the stance of walking with different speeds (N = 12).

It is not advisable to take too fast speed when walking. It is best to walk at your own preferred speed to prevent sports injuries. Because During walking exercise, as the speed increases, the range of Ankle dorsiflexion increases, increasing the forward driving force, which causes the ankle joint's movement pattern to change, adversely affecting the ankle joint, and then affecting the knee joint (Zhao & Lu 2017).

4. Conclusions

For the hip, knee, ankle joints, with the increase of walking speed, joint angles and ROM were increasing in varying degrees; and peak of joint angles was in the pre-support period.

The movement pattern of hip joint is relatively stable, which is less affected by the speed; it mainly showed in the hip of extension, abduction and external rotation. Walking speed had a greater affect on the knee joint, especially in the coronal plane and the horizontal plane of the adduction, internal rotation movement. Ankle joint angle and ROM was bigger than the hip joint, mainly for the increase of dorsiflexion, inversion, internal rotation. Because of the special arcuate sole structure, MBT shoes increase the connection between soles and the ground. So in our daily life, it is best to walk slowly that will not cause excessive movement of the lower limbs joints and lead to dislocation and injury.

Competing interests

The authors have no competing interests to declare.

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