

Changes of kinematic parameters of lower extremities with gait speed: a 3D motion analysis study

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Abstract. [Purpose] The purpose of this study was to investigate the changes in hip, knee and ankle kinematic variables of the lower extremities at different gait speeds. [Subjects and Methods] Forty healthy subjects who had no previous history of neurological, musculo-skeletal or other medical conditions that could affect gait were recruited. The subjects were asked to walk 10 m down a walkway at three different gait speeds: normal gait speed, and self-selected fast, and slow speeds. The experimental order was randomly chosen across these gaits. The hip, knee and ankle kinematic data were evaluated using a VICON 3D motion analysis system and force plates. [Results] The flexion peak and external rotation peak of the knee joint significantly increased with the increase of gait speed. The plantarflexion peaks of the ankle joint significantly increased with increase of gait speed. However, none of the kinematic data of the hip joint were significantly dependent on increase of gait speed. [Conclusion] The relationship of the knee and ankle joint can be described as coupling motion which is dependent on gait speed. Our present findings suggest that coupling motion of the knee joint and plantarflexion of the ankle joint significantly increase with increase of gait speed. These results will provide important insight into gait mechanisms for the evaluation of pathological populations.

Key words: Gait speed, 3D motion analysis, Lower extremity

(This article was submitted Jul. 28, 2014, and was accepted Sep. 2, 2014)

INTRODUCTION

Human gait is important for efficient and safe locomotion¹⁾. Gait analysis provides us with important information on the functional capacity of patients when making disability assessments, and in intervention and treatment planning^{2, 3)}. The gait speed substantially influences the gait pattern, and kinematic and kinetic characteristics^{4, 5)}.

When quantifying human gait by kinematic and kinetic characteristics, subjects are typically asked to walk at what is called their normal gait speed^{6, 7)}. In general, normal gait speeds have been shown to range from 1.05 to 1.43 m/s in healthy adults^{8, 9)}. These subject-specific speeds of healthy subjects have been used to produce normative gait data that can be used as a reference when abnormal and/or pathological gait is assessed. A possible limitation of this procedure is that slower gait speeds may be associated with decreased joint movements and joint kinetics. At faster gait speeds, clinical evidence suggests that increased joint power is

responsible for certain types of overuse injuries of the musculoskeletal system^{10, 11)}. Thus, it is generally accepted that normal gait parameters follow a consistent pattern of change in response to changes in gait speed.

Many previous studies have investigated the relationship between kinematics of the lower limbs and gait speed^{7, 12, 13)}. In addition, gait speed has been shown to have a significant effect on gait kinematics and clinicians can provide normative kinematic data as goals for patients who walk slowly at their normal gait speed. Recent research has proposed the use of self-selected gait speeds to specify walking speed, because it offers the advantages of allowing comparisons between speeds, while concurrently allowing the subjects to act as their own control to normalize gait parameters^{10, 11)}. Thus, self-selected gait speeds are recognized as valid and sensitive measures of gait performance, and identifying kinematic profiles that relate to gait speed could provide guidance for intervention strategies aimed at improving normal gait. Recent studies have addressed gait movement patterns using three-dimensional (3D) motion analysis systems, but these have been limited to the sagittal plane and have neglected the frontal and transverse planes^{7, 14)}. Both the frontal and transverse planes are important because gait performance occurs in three-dimensional space. Therefore, we investigated the individual kinematic gait profiles of normal subjects in all three planes and identified frontal and transverse profiles in addition to the sagittal profile at self-

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Table 1. Comparison of Kinematic from gait speed on lower extremity joint (°)

Joint	Plane	Angle	SS	NS	FS	
Hip joint	Sagittal	Flexion peak	26.3±6.05	28.6±5.20	30.3±7.40	
		Extension peak	10.3±5.67	12.9±5.82	13.8±6.04	
	Frontal	Abduction peak	2.78±5.09	4.15±4.05	4.62±4.20	
		Adduction peak	5.69±8.02	8.62±3.21	7.66±8.56	
	Trans	External rotation peak	21.9±12.2	16.0±12.4	16.3±14.3	
		Internal rotation peak	-1.07±9.53	8.20±11.3	9.41±11.9	
Knee joint	Sagittal	Flexion peak [‡]	44.3±6.61	54.3±6.83	53.3±6.03	
		Extension peak	1.49±5.22	1.90±4.56	2.26±5.79	
	Frontal	Abduction peak	11.4±16.9	15.8±10.7	11.1±4.16	
		Adduction peak	-0.05±7.80	-2.35±4.45	-1.08±8.80	
	Trans	External rotation peak ^{†‡}	5.51±4.01	7.70±5.74	8.07±4.31	
		Internal rotation peak	3.39±12.1	3.58±8.58	7.70±8.73	
	Sagittal	Dorsiflexion peak	11.8±5.21	12.7±3.26	10.3±8.87	
		Plantarflexion peak ^{†‡}	7.85±7.82	12.9±9.11	16.1±6.83	
	Ankle joint	Frontal	Abduction peak	4.53±4.33	4.95±2.77	4.90±2.98
			Adduction peak	-0.42±3.53	-0.90±1.99	-1.36±2.37
Trans		External rotation peak	-4.40±11.7	-4.59±12.4	-3.65±9.84	
		Internal rotation peak	23.9±10.2	25.6±10.2	25.2±10.9	

[†]Significant difference between the SS and FS groups ($p<0.05$).

[‡]Significant difference between the SS and NS groups ($p<0.05$).

selected gait speeds.

SUBJECTS AND METHODS

Forty healthy subjects who had no previous history of neurological, musculo-skeletal or other medical conditions that could have affected gait were recruited. All the subjects understood the purpose of this study and gave their written and informed consent prior to their participation. The study protocol was approved by the local Institutional Review Board and complied with the ethical principles of the Declaration of Helsinki.

The subjects were first asked to walk along a 10 m walkway at a comfortable pace. The procedure was repeated at two different gait speeds, performed in a random order, to give three sequences of data for each subject. The three gait speeds were as follows and were always performed at a self-selected speed: slow speed (SS): a gait somewhat slower than normal walking speed; normal speed (NS): a gait at a normal, comfortable speed; fast speed (FS): a gait somewhat faster than normal walking speed¹³. The experimental order of the self-selected gait speeds.

A twelve-camera video-based motion analysis system (Vicon, UK) was used to record joint angles. Sixteen reflecting markers were placed on specific anatomical landmarks on the hip (ASISs and PSISs) as well as on each mid-thigh (the lower lateral 1/3 of the thigh), knee (lateral epicondyle), mid-tibia (lower 1/3 of the shank and lateral malleolus), and foot (second metatarsal head and heel) for capturing joint motion. The marker protocol was based on the Plug-in-gait marker set. The motion capture rate was 120 fps. Two force plates (Advanced Mechanical Technology Inc., USA) were placed at the centre of the 10 m walkway to measure the gait

cycle. Data collected from the force plates were digitized at 500 Hz and low-pass filtered at 1,000 Hz. The system was capable of measuring separate repeated steps over successive strides for extended trials. Only trials that included three consecutive clean force platform data and complete data were considered.

The statistical analysis was performed using SPSS ver. 12.0. Demographic data such as age, height and weight were analyzed by one-way ANOVA. The values of the different gait speeds were compared using one-way ANOVA and least-squares difference as a post hoc test. Statistical significance was accepted for values of $p<0.05$.

RESULTS

The subjects had an average age of 23.16±3.76 years, an average body mass of 65.88±6.97 kg, and an average height of 171.04±3.52 cm.

The flexion peak and external rotation peak of the knee joint significantly increased with increase of gait speed ($p<0.05$). The results of the LSD posthoc test show that the flexion peak of the knee joint was significantly different between SS and NS ($p<0.05$) (Table 1). The external rotation peak of the knee joint was significantly different between SS and NS, SS and FS ($p<0.05$) (Table 1). Plantarflexion peaks of the ankle joint significantly increased with increase of gait speed ($p<0.05$). The results of the LSD posthoc test show that plantarflexion of the ankle joint was significantly different between SS and NS, and SS and FS ($p<0.05$) (Table 1).

DISCUSSION

In the current study, we found that between the pre-swing

and the mid-swing the flexion peak and the external rotation peak of the knee joint and the plantarflexion peak of the ankle joint significantly increased with the increase of the gait speed. These results imply that there is a need for greater power generation at higher gait speeds for propelling the body forward, and it is accompanied by coupling motion of the external rotation of the knee joint.

Gait speed has an important influence on the kinematic parameters of the lower extremity joints. In particular, the kinematic parameters of the knee and ankle joints have a positive relationship with gait speed^{13, 15, 16}. In this study, the knee flexion peak during pre-swing and mid-swing significantly increased with the increase of gait speed. The knee flexion angle in the gait cycle has a significant positive correlation with the gait speed, according to previous studies^{13, 16}, indicating that the angle of the knee flexion increases with increase of gait speed. It is possible that this is due to the need for greater shock absorption at higher speeds. In addition, our findings show that the external rotation peak of the knee joint significantly increased with increase of gait speed. Previous studies have reported that one joint segment of the lower extremities affects the others during the gait. These relationships are described as coupling motion^{16, 17}. Therefore, we think that gait speed is affected by coupling motion of the lower extremity. Our present findings support the findings of other studies of gait mechanism. The plantarflexion peak of the ankle joint significantly increased with increase of gait speed. This result is in agreement with other studies that have suggested that plantarflexion of the ankle joint is closely related to gait speed. In addition, the ankle joint plays an important role in changing gait speed, and it has been suggested that plantarflexion is a strong predictor of step length and gait speed^{18–20}.

In conclusion, we examined the changes in the lower extremity joints at different gait speeds using a 3-dimensional motion analysis system. Our results suggest that coupling motion of the knee joint and plantarflexion of the ankle joint significantly increase with increase of the gait speed. These results provide important insights into the gait mechanisms underlying speed regulation in walking and provide a foundation on which to investigate the influence of walking speed on various measures of interest in pathological populations. In this study, we restricted recruitment to males of standard height and weight to negate the effects of external factor. Therefore, further studies involving a larger population are suggested.

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