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Original Article

Kinematic effects of different gait speeds during gait initiation movement

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Abstract. [Purpose] We investigated the influence of gait speed on the movement strategy during gait initiation. [Participants and Methods] This study included 21 young healthy individuals (11 males and 10 females; mean age, 21.7 ± 0.5 years; mean height, 166.1 ± 9.8 cm; and mean weight, 57.3 ± 11.2 kg). A three-dimensional motion analyzer and strain gauge force platform were used in this study. The measurement task consisted of gait initiation from the quiet stance; the two measurement conditions were normal gait and the highest speed. The analysis interval was from the start of the center of pressure migration to the heel contact at the first step of the swing limb. The center of gravity, center of pressure, joint movements, step length, and step time during the anticipatory postural control (from the start of center of pressure migration to swing leg-heel off) and swing (swing leg-heel off to swing leg-heel contact) phases were analyzed. [Results] Significant differences were observed in the center of gravity, center of pressure, hip flexion, abduction movement, stance-limb ankle dorsiflexion movement during the anticipatory postural control phase, and step time during the anticipatory postural control and swing phases. The stance-limb ankle plantar flexion movement and step length did not differ significantly in the swing phase. [Conclusion] When the gait speed increases, fluctuations in the joint movements increase as the center of pressure displacement increases, thus requiring complex control.

Key words: Gait speed, Anticipatory postural adjustment, Three-dimensional motion analysis

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INTRODUCTION

Gait initiation (GI) is a task to start walking from a quiet stance and is a movement that starts by breaking the equilibrium between the ground reaction force and gravity in the quiet stance. Movement strategies for GI include anticipatory postural control (APA), in which muscles are activated before the main movement and are important for controlling physical movement. APA is defined as the activity of the postural muscles that precedes the main movement[1)], which is extremely important for the stable execution of skilled movements. A typical example of APA in GI is the reverse reaction, which is the migration of the center of pressure (COP) to the swing limb and then to the stance limb that swings out the lower limb[2–4)]. Thereafter, the COP moves backward and generates a forward propulsion force for the center of gravity (COG), which initiates the gait.

Increased activity of the tibialis anterior and decreased activity of the triceps surae have been reported before GI[5, 6)]. It is usually maintained by ankle plantar flexor muscle activity during quiet stance, although the activity of the triceps surae muscle decreases, leading to an anterior rotation of the ankle axis, an anterior movement of the COG, and a posterior movement of the COP. In healthy individuals, the activity of the ankle plantar flexor muscle is weak, and the activity of the tibialis anterior muscle starts following the decrease in the activity of the plantar flexor muscle. When the tibialis anterior muscle contracts strongly, the COP moves back[4, 7)].

Previous studies have focused on the relationship between the COG and COP in GI and electromyography analysis, and

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*Corresponding author. Daisuke Sudo (E-mail: d.sudo@iuhw.ac.jp) few studies have reported on the resulting kinetic and kinematic changes[5–7]. However, there are only a few kinetic and kinematic studies in the APA phase, which is important for GI[2, 3]. In particular, GI is the movement from a quiet stance; sudden movements and accurate control of the COG are often required in daily life. Falls in older adults are reported indoors rather than outdoors. They often occur in environments that require sudden changes in movement and speed; falls occur when the COG is incorrectly moved[8].

In sudden movements, we will choose an advanced exercise strategy. Therefore, we aimed to clarify the kinetic and kinematic features of the APA phase in GI.

PARTICIPANTS AND METHODS

Twenty-one young healthy individuals (11 males and 10 females; mean age, 21.7 ± 0.5 years; mean height, 166.1 ± 9.8 cm; and mean weight, 57.3 ± 11.2 kg) with no serious neurological disease or orthopedic history on the trunk or lower limbs were included.

The purpose and methodology of the study were explained to the participants in advance, and consent was obtained. This study was approved by the Ethical Review Board of the International University of Health and Welfare (Approval No. 19-Io-228).

A three-dimensional motion analyzer (VICON, sampling frequency 100 Hz) and a strain gauge force platform (AMTI, sampling frequency 1,000 Hz) were used. Infrared reflective markers were attached to the following 34 locations throughout the body: left and right skull, occipital protuberance, suprasternal notch, seventh cervical spinous process, sternal xiphoid process, 10th thoracic spinous process, left and right acromion, lateral epicondyle of the left and right humerus, left and right radial styloid processes, left and right anterior superior iliac spine, left and right posterior superior iliac spine, distal one-third point connecting the left and right anterior superior iliac spine and the greater trochanter, lateral joint space in the left and right knees, medial joint space in the left and right knees, center of the lateral malleolus of the left and right ankles, center of the medial malleolus of the left and right ankles, left and right fifth metatarsal head, left and right first metatarsal head, left and right calcaneus, and right scapula. It was set according to the plug-in-gait model.

The stance limb position was marked on the strain gauge force platform, and the participant was in a quiet stance with a 10-cm distance inside the left and right feet and was instructed to walk at least five steps from GI (Fig. 1). The following was the procedure: after 5 s at rest standing, a right or left signal was given, the participant started to walk with the instructed limb, the measurement order was randomly set, and each task was measured three times, twelve times in total. The analysis range is from the point of displacement of ± 2 standard deviation (SD) or more from the average value of COP to the takeoff of the forefoot of the first step of the swing leg and from the time of displacement of ± 2 SD or more from the average value of COP to the takeoff of the free leg heel. In addition, the swinging period (playing foot heel takeoff-playing foot heel contact) was divided into two phases (Fig. 2). Heel takeoff was judged by the position of the marker from the measurement video.

The analysis items included COG displacement, COP displacement, change in stance limb hip flexion moment, change in stance limb hip abduction moment, change in swing leg hip flexion moment, change in swing leg hip abduction moment, change in swing leg hip dorsiflexion moment, step length, and step time. The coordinate data obtained from the three-dimensional motion analyzer was subjected to a low-pass filter (Butterworth filter) with a 10-Hz cutoff frequency using VICON Nexus 2.7.0.

For the COP and COG, the maximum displacement from the quiet stance was calculated (Fig. 3). Regarding the joint moment, the maximum displacement from the quiet stance in the APA phase and the difference between the maximum and minimum values in the swing phase were considered as the change in moment in each phase (Fig. 4).

Normality was confirmed by the Shapiro–Wilk test; the paired t-test between the two groups was used for those with normality, and the Mann–Whitney U test was used for those without normality (Fig. 5).

The significant level was set at $p<0.05$.

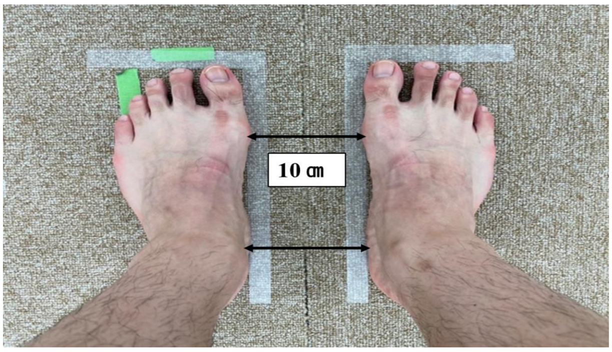
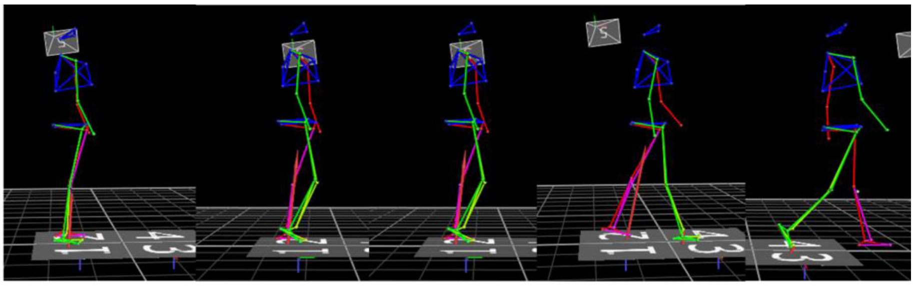


Fig. 1. Measured limb position: 10 cm in between both feet while standing.



① APA phase (start of COP movement to swing leg-heel off)

② Swing phase (swing leg-heel off to swing leg-heel off in the same side)

Fig. 2. Scope of analysis.

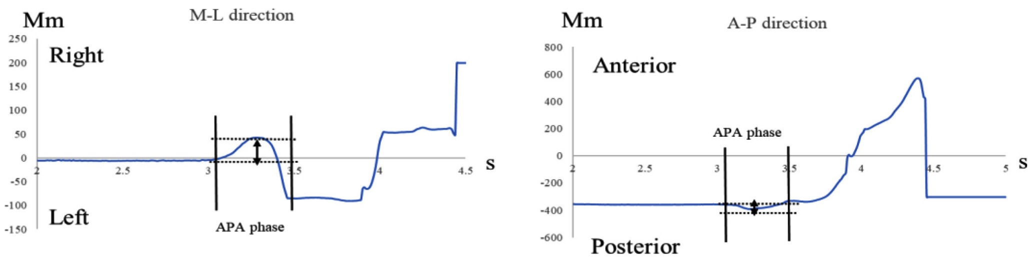


Fig. 3. Center of pressure calculation method.

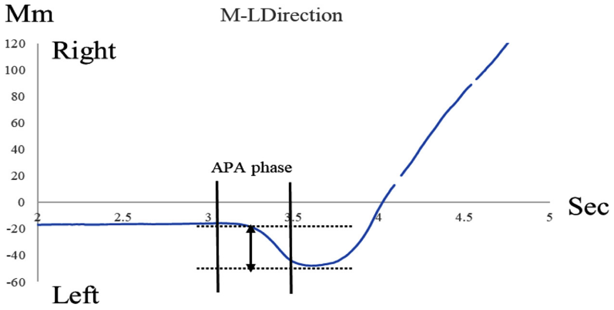


Fig. 4. Center of gravity calculation method.

RESULTS

The lateral displacement of the COG was significantly lower at a fast speed than that at a normal speed (p<0.01). COP displacement was significantly higher at a fast speed in the anterior-posterior direction than that in the left-right direction (p<0.01). The stance limb hip flexion moment was significantly higher at a fast speed than that at a normal speed (p<0.01).

The stance limp hip abduction moment was significantly higher at a fast speed than that at a normal speed (p<0.01). The stance limb hip abduction moment decreased once during the APA phase, and the fast speed showed a significant decrease (p<0.01).

The swing limb hip abduction moment was significantly higher at a fast speed than that at a normal speed (p<0.01). The stance limb ankle dorsiflexion moment during the APA phase was significantly higher at a fast speed (p<0.01) (Table 1). No significant difference was noted in step length, and step time was significantly shorter at a fast speed (Table 2).

DISCUSSION

Our study showed that when gait speed increased, fluctuations in joint moments increased as COP displacement increased, thus requiring complex control.

As the movement speed increased, the anterior-posterior and lateral displacement of the COP during the APA period increased, and the strategy of increasing the hip abduction moment on the swing limb side was selected to move the COP to

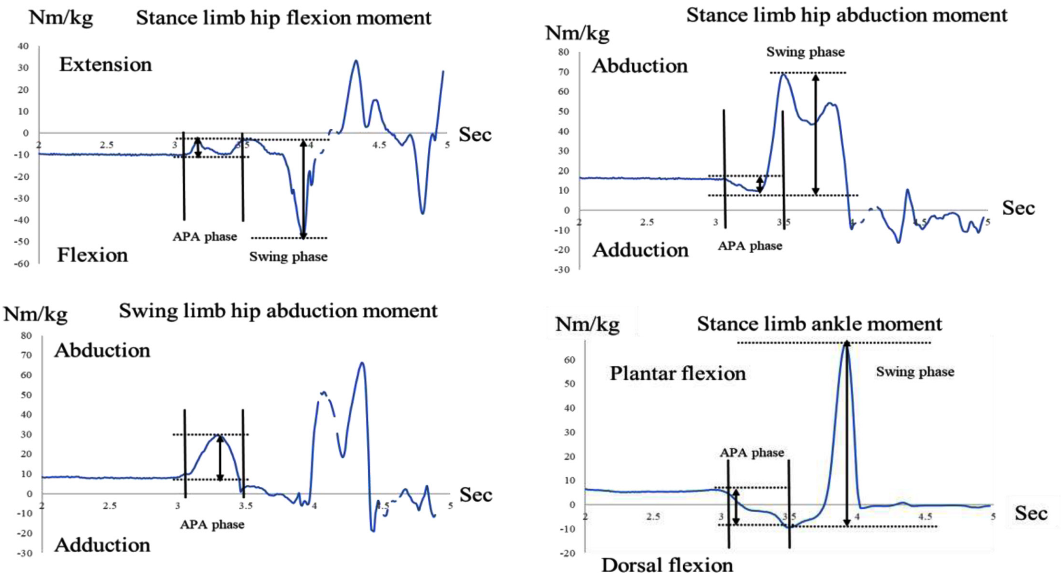


Fig. 5. Joint moment calculation method.

Table 1. COP, COG, floor reaction force, and joint moment in each condition

	Normal	Fast	Effect size
COG M-L displacement (mm/Ht)	0.03 ± 0.007	0.02 ± 0.008**	r=0.72
COP; APA M-L displacement (mm/Ht)	0.01 ± 0.004	0.03 ± 0.008**	r=0.83
COP; APA A-P displacement (mm/Ht)	0.02 ± 0.01	0.05 ± 0.01**	r=0.89
Stance limb hip flexion moment (Nm/kg)	0.53 ± 0.23	0.74 ± 0.29**	r=0.54
Stance limb hip flexion moment; APA (Nm/kg)	0.04 ± 0.04	0.15 ± 0.25**	r=0.45
Stance limb hip abduction moment (Nm/kg)	0.94 ± 0.11	1.02 ± 0.24**	r=0.6
Stance limb hip abduction moment; APA (Nm/kg)	0.05 ± 0.04	0.15 ± 0.10**	r=0.74
Stance limb ankle plantar-flexion moment (Nm/kg)	1.07 ± 0.16	1.08 ± 0.21	r=0.27
Stance limb ankle dorsal-flexion moment; APA (Nm/kg)	0.16 ± 0.10	0.34 ± 0.10**	r=0.96
Swing limb hip abduction moment; APA (Nm/kg)	0.15 ± 0.10	0.35 ± 0.14**	r=0.89

Ht: height; COG: center of gravity; COP: center of pressure; APA: anticipatory postural control; M-L: Medio-Lateral; A-P: Anterior-Posterior.
**p<0.01.

Table 2. Step length and step time in each condition

	Normal	Fast	Effect size
Step length (mm/Ht)	0.37 ± 0.04	0.38 ± 0.06	r=0.22
Step time (s)	0.54 ± 0.11	0.46 ± 0.11**	r=0.83

Ht: height.
**p<0.01.

the stance limb side. Furthermore, when the gait speed increased, to obtain forward propulsive force, the ankle dorsiflexion moment increased and the COP was displaced backward to generate rotational force forward and start the step. This is because it is known that in GI, the COP moves backward and to the stance leg during normal gait, the positional relationship with COG breaks down, and walking starts so that the pendulum falls[9)]. The displacement increased further depending on the difference in speed[10)]. Regarding the lateral displacement of the COP, at a fast speed, the COP was largely displaced toward the swing limb side in the APA phase. It seems that because the load on the stance limb decreased with COP displacement, the equilibrium of the abduction moment in both hips broke down, the stance limb hip abduction moment decreased, and then the swing limb hip abduction moment was used to create a source of force to move the COP to the stance limb. Furthermore, in GI, the swinging limb transfers weight to the stance limb[4, 11)], and we believe that the swing limb hip abduction moment increased because the swinging leg increased COP movement to the stance leg. Therefore, the COP moved to the support leg, which is why the stance leg hip abduction moment showed a significantly higher value at a fast speed than that at a normal speed. For the COG, left-right movement decreased as gait speed increased; however, COP posterior displacement increased, and to increase forward propulsive force, we believe that the same result as in normal gait was obtained in GI. Furthermore, we believe that the COG deviated forward with the posterior movement of the COP, resulting in a higher stance limb hip flexion moment. Similar conclusions can be drawn for the APA phase; we believe the hip flexion moment increased because the stance limb was involved in anterior propulsion11).

Previous studies have reported that, in GI, the swinging limb transfers weight to the stance limb, and the stance limb moves forward11, 12). Furthermore, we believe that the hip flexion moment of the swing limb increases to assist forward propulsion of the stance limb by increasing the speed.

In the swing phase, the stance limb hip flexion moment was significantly larger at a fast speed than that at a normal speed. At a fast speed, the posterior movement of the COP is large, requiring a higher than the normal anterior propulsive force of the support limb and increasing the stance limb hip flexion moment. To significantly disrupt the equilibrium between the COG and COP, the support leg ankle dorsiflexion moment was larger in the APA phase than that in the normal phase, and the stance leg ankle dorsiflexion moment was larger at a fast speed than that at a normal speed during the APA phase. Previous studies have shown that triceps surae muscle activity decreases during normal gait, causing the COP to move posteriorly9). We believe that when gait speed increases, the activity of the triceps surae muscle decreases, consequently increasing the dorsiflexion moment and resulting in the significant backward movement of the COP.

Previous studies have reported that the hip joint angle and muscle activity increase, thereby increasing step length13); however, we found no significant differences in step length. Furthermore, no significant difference was noted in the ankle plantar flexion moment of the stance limb in the swing phase; therefore, we believe that no significant difference was noted in step length.

As a limitation, this study only involved the comparison of healthy individuals; as such, it is necessary to analyze the movement strategy of older adults in the future. Regarding the condition setting, it is necessary to control speed; therefore, the method should also be evaluated in a future study.

Regarding the clinical application, we consider investigating the effects of the training that can improve APA for older adults. Jagdhane et al. reported that the exercise with the medicine ball could improve the performance of older adults14). Moreover, we consider effective training for older adults by using GI owing to its safety and convenience.

In conclusion, as the movement speed increased, the left-right and anterior-posterior COP displacement during the APA phase increased, and the strategy of increasing the hip abduction moment on the swing limb side was selected to move the COP to the support leg side. We clarified that as the movement speed increased, the fluctuation of the joint moment increased as the COP movement increased, thus requiring more complicated control.

Conflict of interest

None.

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