BIOMECHANICAL CHARACTERISTICS OF THE LOWER EXTREMITY FROM GAIT INTIATION TO THE STEADY-STATE WALKING

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In this study, biomechanical characteristics during the whole process of gait initiation for twenty healthy volunteers were determined by the three dimension motion analysis. Gait initiation, a transitional movement phenomenon from quiet stance to steady-state walking, involves a series of muscular activities, GRFs, movements of COP and COM and joint motions. Results showed that the location of the net COP to be most lateral during double limb stance at the beginning of gait initiation. During gait initiation, changes in anteroposterior components of GRFs were first found and then changes in vertical components followed. Hip and knee motions were found before the ankle joint motion. Walking speed, step length and stride length gradually increased until the second step. The interaction between the COM and COP is tightly regulated to control the trajectory of the COM and thereby control total body balance.

KEY WORDS: gait initiation, movements of COP and COM, ground reaction force (GRF).

INTRODUCTION:

Gait initiation, a transient phase between standing and walking, is a complicated process with the neuromusculoskeletal systems to control the body against a perturbated situation (Mann, R.A. et al., 1979). There are many reports that falls occur most frequently in persons with poor score in clinical tests, emphasizing transfer for quasi-static to dynamic situations (Topper, A.K. et al., 1993).

Mann et al. (1979) measured ground reaction forces (GRFs) and electromyography (EMG) on eight muscles in the lower extremity during gait initiation experiment and reported that the center of pressure (COP) moved laterally and posteriorly toward the leading limb in the beginning. However, unfortunately, they regarded that the trajectory of COP during gait initiation was a projection of the anteroposterior and mediolataeral movements of the center of gravity (COG).

However, most of previous studies that analyzed GRF of the trailing limb and muscle activities include GRF and joint angles of the lower extremity only from the double limb upright standing position until toe off (TO) of the trailing limb.

Brenier et al.(1981) used a forceplate and studied movements of both COG and COP until TO of the leading limb, assuming that the steady-state walking is started from the second step. Thus, their results were different from others who assumed that at least 2~3 steps were required to reach the steady-state walking speed during gait initiation process. Later, Jian et al.(1993) used three forceplates to analyze COG movements for the whole process of gait initiation. They revealed that 90% of steady-state velocity was achieved during the first step and 100% by the second step. However, they did not analyze GRFs and joint moments and powers during the whole process of gait initiation.

In this study, the researchers tried to determine biomechanical characteristics such as spatial-temporal gait parameters, COP movements and joint angles during the whole process of gait initiation.

METHOD:

The arrangement of forceplates: Figure 1 shows the arrangement of four forceplates (Forceplate 1, 2, 3 and 4) for this study. Gait patterns in four gait periods (A, B, C and D) were compared with the steady-state walking of the same subject.

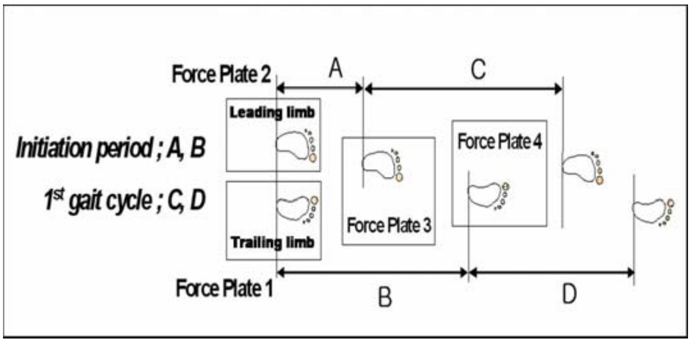


Figure 1: The arrangement of four forceplates

Experiment protocol: Twenty normal healthy male volunteers who had no history of neuromusculoskeletal disorders for walking were selected for the subjects in this study. Six near-infrared cameras (Vicon 612 Motion Analysis System, Oxford Metrics, UK) were used to determine joint motions during gait initiation. In addition, GRFs and muscle activities of the lower extremities were also synchronously measured using four forceplates (2 AMTI forceplates, Watertown, MA, USA, 2 Kistler forceplates, Switzerland).
For each subject, ten trials of the steady-state walking were performed first, then fifteen trials of the gait initiation experiments were followed. Upright standstill posture, defined by when there were less than 0.5% of the half of the subject's body weight for two seconds were regarded as the onset of the gait initiation. In this study, the left leg was decided as the leading limb, since there was no significant differences of the leading limb.

Data analysis: COP during single-limb support period was calculated directly from GRFs acting on a force plate. In addition, the net COP during double-limb support period was determined from the coordinates of COP using the GRFs measured by the forceplates.

RESULTS:

Spatial-temporal gait parameters:

Table 1 Spatial-temporal parameters in gait initiation and in the normal steady-state walking (N=20)

		Cadence (steps/min)	Foot off (%)	Step length (m)	Step time (s)	Stride length (m)	Stride time (s)	Walking speed (m/s)
Gait initiation	LL	-	71.6±2.44	0.60±0.05	1.39±0.05	0.61±0.05	1.39±0.05	0.44±0.03
	TL	-	78.0±1.02	0.64±0.03	0.60±0.03	1.26±0.05	2.00±0.06	0.63±0.03
1st gait cycle	LL	105±4.83	62.8±1.38	0.69±0.05	0.54±0.03	1.35±0.07	1.15±0.05	1.18±0.07
	TL	112±5.10	60.6±1.48	0.69±0.04	0.53±0.03	1.38±0.07	1.08±0.05	1.28±0.08
steady-state walking		118±4.64	59.6±1.01	0.70±0.04	0.51±0.02	1.40±0.07	1.02±0.04	1.37±0.09

(Leading limb (LL), Trailing limb (TL)

Table 1 represents spatial-temporal parameters in gait initiation and in the normal steady-state walking respectively. After the gait initiation period, all parameters in the first gait cycle approached the ones in the normal steady-state walking, even though there were still significant differences in magnitudes.

Trajectory of the net COP: GRFs on both limbs affect the location of the net COP. Figure 2 represents the entire path of the net COP especially during the period from “A” to “D” and the trajectories of the net COP during gait initiation. At the onset of the gait initiation, COP moves laterally and posteriorly with a relatively slow speed. At the very beginning of gait initiation ("A" and "B"), GRFs on the leading limb relatively increase and become the local maximum, which causes the location of the net COP to be most lateral during the double limb stance.

Just after both GRFs become equal, the net COP moves quickly toward the trailing limb and heel off (HO) of the leading limb takes place. From HO to toe off (TO) of the leading limb, the net COP moves laterally and posteriorly with a relatively fast speed. During the single support period of the trailing limb, the net COP slowly moves laterally and anteriorly. At the very beginning of gait initiation the toe width is larger than that in the normal walking, the magnitude of mediolateral movements of the net COP decreases once gait initiates. The COP moves faster during double support period than during single limb support period.

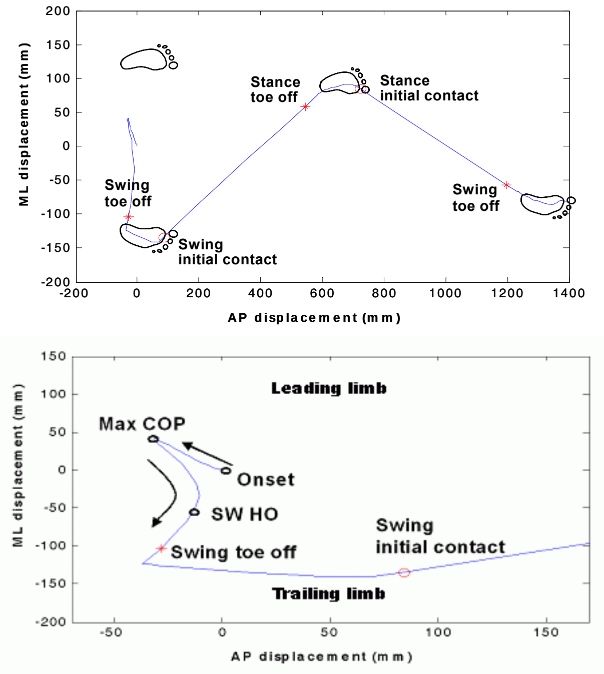
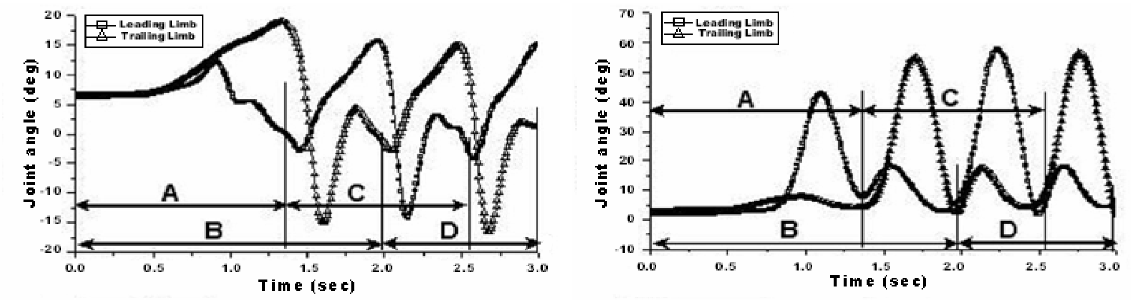
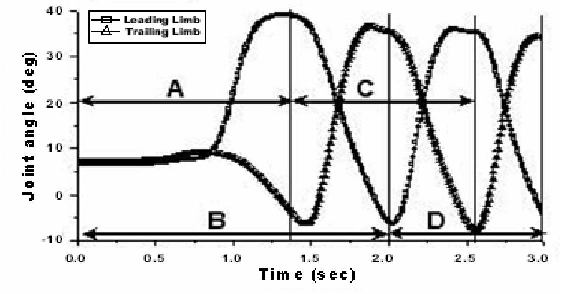


Figure 2: Movement if the net COP during gait initiation

Joint angle: Figure 3 represents sagittal plane angles of the ankle, knee and hip joints during gait initiation. At the onset of gait initiation (interval "A"), the ankle joint of the leading limb showed no plantarflexion until TO when it was dorsiflexed at 12.7°. There was no stance phase knee flexion in the leading limb, but the maximum swing phase flexion after TO was approximately 46.9°. The maximum knee flexion of the leading limb was considerably smaller, but the maximum hip flexion was larger than those in the normal walking. During the interval "B", the ankle joint of the trailing limb showed 19.8° dorsiflexion at HO without initial plantarflexion, which was significantly larger than that in the normal walking. There was a small knee flexion in stance and the maximum knee flexion in swing phase was approximately 56.8°, which was about 93.7% of the normal walking. A slight hip flexion (approximately 5°) was shown during stance and the maximum hip extension of the trailing limb was 8.9° which was about 88.1% of the normal walking. The maximum hip flexion during swing phase of the trailing limb was about 34.5°, which was larger than that in the normal walking. During the interval "C", the maximum dorsiflexion of the leading limb in stance significantly delayed compared with that in the normal walking. The knee joint was slightly flexed by 9.3° at IC of the leading limb and the stance phase knee flexion was about 18.2°. The Hip joint of the leading limb was also flexed by 9.3° at IC. The maximum hip extension was also delayed by approximately 4%. During the interval "D", joint angles of hip, knee and ankle looked similar to those in the normal walking.



(a) Ankle (b) Knee



(c) Hip

Figure 3: Sagittal plane angles of hip, knee and ankle joints

CONCLUSION:

In this study, we determined biomechanical characteristics such as spatial-temporal gait parameters, GRFs, COP movements and joint angles during the whole process from the gait initiation to the steady-state walking. Decreased walking speed, step length and stride length gradually increased until the second step. Compared with the normal walking, hip joint of the leading limb was more flexed at terminal swing and the ankle joint of the trailing limb also increased during terminal stance. All joint motions of the lower extremity slightly delayed. During gait initiation, anteroposterior GRFs of the leading limb changed first then vertical GRFs changed next. For the leading limb during gait initiation, changes in GRFs occurred earlier than those in joint angles. For the trailing limb during gait initiation, ankle motions were followed by knee and hip motions. The interaction between the COM and COP is tightly regulated to control the trajectory of the COM and thereby control total body balance.

Further studies on hemiplegic patients and amputees would differentiate many biomechanical parameters in the normal gait initiation process.

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