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Anticipatory Phase of Gait Initiation on Horizontal, Upward and Downward Inclined Surfaces

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Abstract— **This paper presents a study of the center of pressure (COP) behavior during anticipatory postural adjustments phase (APA) of gait initiation in different conditions which are commonly required in daily activities. Twelve young subjects enrolled in this study and performed gait initiation in horizontal and upward and downward inclined surfaces. Significant differences were found only in the medial-lateral (ML) displacement and velocity of COP on both inclined surfaces. These results suggest a smaller transfer of the center of mass to the support foot in this phase on inclined surfaces. This should be taken in account in the design of bipedal robots once the ML COP control is an important aspect of gait initiation.**

I. Introduction

Daily activities often involve gait initiation, which consists of an intense neuromuscular activation due to the transition between the upright stance and the steady-state gait [1], [2]. Furthermore, gait initiation as a functional task is a challenge because it requires moving from a relatively static position to the cycling and unstable gait. The process of gait initiation requires the coordination of anticipatory adjustments in order to move the body center of mass (COM) to the support limb. The shift of COM is essential for the stability on a single support limb during gait initiation and is preceded by the shift of the center of pressure to opposite side.

Postural adjustments present in the gait initiation produce forces both vertical and horizontal to move the center of pressure (COP) from a position between the legs to backward and laterally toward the swing foot. This process is known as anticipatory postural adjustments (APA) phase, and it is characterized by adjustments in COP to move the COM toward to the support limb [8]. Next, while the swing foot loses contact from the floor, the COP moves medially toward the support foot resulting in the placement of COM on this limb. This phase is denominated the first step phase.

Nolan *and Kerrigan.* [10] studied the biomechanics of gait initiation of healthy subjects in two conditions: (i) from heel–toe standing and (ii) from toe-standing. They investigated the ground reaction force (GRF) and the COP in three pre-set speeds (slow, normal and fast). The authors found no differences in COP displacement or momentum generated in the medial-lateral (ML) direction, suggesting that in gait from toe-standing greater amounts of forward momentum are generated but not at the expense of generating excessive stance-side momentum.

This information can be useful in the design of bipedal robots with small feet and joints with only one degree of freedom in the sagittal plane in the lower limb, since gait initiation would be a challenge task in these robots. It can be noted that analyzing gait initiation is useful in several situations in respect to motor control [4, 5] and biological inspired system has the advantage of being more stable and low energy consuming [3]. This study attempts to contribute with insights for better understanding how humans react to inclined surfaces during gait initiation.

So, the motivation of the present study was to analyze the gait initiation in a relatively more challenging situation, because many falls in humans occur during the transition between standing and walking [9]. Thus this study aims to comparatively analyze the APA phase of gait initiation of young and healthy people in three situations: (a) horizontal, (b) downward and (c) upward surfaces (see Figure 1).

II. Materials and Methods

A. Sample/Population

The population is composed by 12 young subjects [9 men and 3 women; age: 22 ± 1.48 years (mean ± S.D.), range: 20-25; body mass: 76.14 ± 16 kg (mean ± S.D.), range: 49.25-110; height: 1.73 ± 0.10 m (mean ± S.D.), range: 1.56-1.92].

The inclusion criteria to select the subjects to this study considered the inexistence of neuromotor disorders or physiological problems and the age less than 30 years old.

B. Data Acquisition

One AMTI-Dual-Top AccuSway force plate which consists of two separate force transducer and six channels was used for data acquisition.

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Data were acquired at a sampling frequency of 100 Hz, during six seconds and filtered by a low-pass, fourth-order, zero-lag Butterworth filter with cutoff frequency set as 12.5 Hz using a custom MATLAB routine.

C. Procedures

The subjects were in orthostatic posture with each foot in one force plate. The examiner verified if the weight was equally distributed between the support limbs by visual inspection of the vertical GRF in both force plates. The subjects started walking a path three meter long with right foot. The same procedure was done in all three surfaces. The inclination of the inclined surface was 8%. Five trials were performed in each situation.

D. Data Analyses and Statistics

The COP for both force plates were calculated in relation to the force plate reference system. Then the resultant COP was calculated in relation to a global reference system located between the two force plates [6]. The identification of the beginning of the task was given by analysis of first and second derivate of the vertical GRF component of the support foot. The APA phase was identified from the beginning of the task until the instant at which the COP reached COP its maximum value in the ML direction [7].

The mean COP velocity was calculated as the length of trajectory for both direction anterior-posterior (AP) and medial-lateral (ML) divided by the duration of the APA phase. Three of five trials were selected, and the subjects were represented by the mean of each set of measures.

Since the data distribution was Gaussian (Shapiro-Wilk test, $p > 0.05$ in all cases), the parametric repeated measures ANOVA test was applied with surfaces conditions as repeated measure and post-hoc Bonferroni correction. All statistical analysis was performed with SPSS software (v17, SPSS Inc., Chicago, IL), with a significant level set at $p < 0.05$.

III. Results

Table I presents the values of COP displacement and velocity for APA phase. It was found significant differences in mean COP ML velocity and COP ML displacement (repeated measure ANOVA $p = 0.001$). Despite not having statically significant difference, it can be noticed that the mean COP AP velocity is higher in horizontal surface than in sloped surfaces.

During the APA, the COP AP displacement is backward and it was higher in the downward inclined surface. The COP ML displacement is toward to the swing foot. The increase in the mean duration of the APA phase for both inclined surfaces is the reason why the COP velocity difference for those surfaces is larger than the COP displacement. Therefore, the COP ML velocity in inclined surfaces is significantly different from horizontal surface.

TABLE I. COP Displacement and Velocity During APA Phase

Measures	Surfaces		
	Horizontal	***Downward***	***Upward***
Duration (s)	0.281 (0.075)	0.352 (0.149)	0.338 (0.103)
ML Displacement (cm)*	5.91 (1.83) [a,b]	4.30 (1.09) [a]	4.09 (1.04) [b]
ML Trajectory Length (cm)	6.02 (1.93)	4.45 (1.24)	4.25 (1.08)
% Difference Between ML Displacement and Trajectory	≈ 1.8	≈ 3.4	≈ 3.8
ML Velocity* (cm/s)	23.65 (7.15) [c,d]	14.38 (5.42) [c]	13.58 (4.25) [d]
AP Displacement (cm)	4.36 (0.83)	4.77 (1.70)	4.46 (1.45)
AP Trajectory Length (cm)	4.73 (1.11)	4.89 (1.90)	4.77 (1.83)
% Difference Between AP Displacement and Trajectory	≈ 7.8	≈ 2.4	≈ 6.5
AP Velocity (cm/s)	18.36 (4.63)	15.17 (5.32)	15.15 (6.29)

* Repeated Measure ANOVA with post-hoc Bonferroni correction: p=0.001; a: p=0.002; b: p = 0.010; c: p = 0.001; d: p<0.001

IV. Discussion

Inclined surfaces were used to change proprioceptive input putting ankle flexor or extensor muscle spindles to different lengths, representing a common challenge in the daily activities of humans. Several authors have employed inclined surfaces to study the effects of trunk kinematics in lifting tasks [11], the postural strategies associated with walking on an inclined surface [12], or the action of the fusimotor system [13].

The first assumption that can be made about the results is that inclined surfaces put the ankle muscles in a different physiological condition. In the upward inclined surface, the ankle is in dorsiflexion position in which dorsi-flexor muscles (tibialis anterior, extensor digitorum longus and extensor hallucis longus) will be shortened and plantar-flexor muscles (soleus and gastrocnemius) will be elongated. In the downward inclined surface, this situation is reversed, the ankle is in plantar flexion position in which dorsi-flexor muscles will be elongated and the plantar-flexor muscles will be shortened. This should result in different steady state firing rates in spindle output (Ia and II afferents). Thereby, the peripheral reflex pathways will operate in a different manner in each condition. This may contribute to the observed differences in the COP behavior.

Significant differences in medial-lateral COP variables were found between horizontal surface and the two inclined surfaces. Both ML displacement and ML velocity were smaller in the inclined surfaces compared to horizontal surface. These results suggest that the COM transfer to the support foot during APA phase, in which there is dissociation between COM and COP displacement, is reduced in inclined surfaces. In upward inclined surface the main purpose is project the COM forward in order to overcome gravity, whereas in the downward inclined surface the dynamic stability is reached without the necessity to move the COM to support foot, because gravity helps the movement in this case and the stability will be reached with the next ground contact of the swing foot ahead of the support foot.

Another explanation to the differences found in the ML direction is the fact that the subjects commonly do not start walking on slopes, and possibly are more cautious, considering the friction condition between the force plate and feet was appropriate.

In inclined surfaces, the COM projection is nearer to the boundary of supporting base as it is shown in figure 1 [6]. Therefore, less or more effort is required in APA phase to move the COM forward. In the downward inclined surface, there is a decrease in the percent difference between AP trajectory length and AP displacement, which indicates fewer oscillations in AP COP movement. Besides, we would expect a larger AP COP displacement once the COM is located further back, but. However, neither the trajectory length nor the displacement was significantly different from the horizontal surface. Probably the gravity acts in favor of the intended movement reducing the AP COP displacement during APA phase that generates the necessary impulse to move the COM forward and toward the support foot.

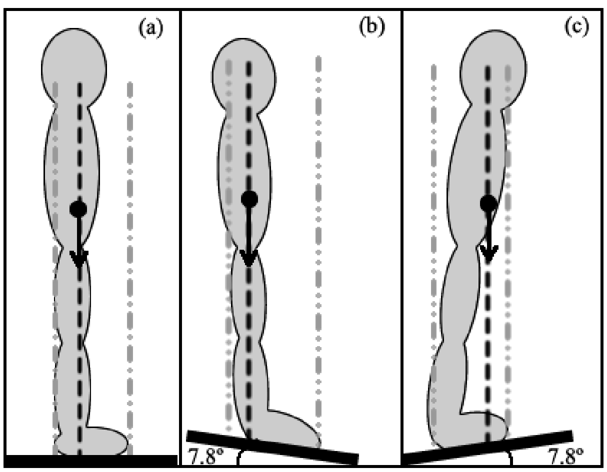

Figure 1 – Assumption about the projection of the COM on supporting base in the three different situations analyzed: a) horizontal surface, b) downward inclined surface and c) upward inclined surface.

V. CONCLUSION

This study indicates that there are COP behavior differences in the APA phase of gait initiation in inclined surfaces. These differences are mainly in the ML COP displacement and velocity suggesting that the COM transfer to the support foot during APA phase, in which there is dissociation between COM and COP displacement, is reduced in inclined surfaces. This should be taken in account in the design of bipedal robots once the ML COP control is an important aspect of gait initiation.

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