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ESTIMATING LEAN ANGLE THROUGH APPLICATION OF THE GRAVITY LINE PROJECTION ALGORITHM

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INTRODUCTIONS

To understand the human postural control system, control models that represent the upright body as a single link inverted pendulum are frequently used. These models usually output the lean angle of the pendular body and use the desired lean angle as a reference input. Lean angle is defined as the angle between vertical and a line connecting the ankle and body center of mass (COM). In some experimental situations, it is not possible to collect kinematic data to estimate the location of the COM. In this study, we were interested in assessing the accuracy of estimating the location of the COM using only force plate data, rather than kinematic data from a motion capture system.

Numerous methods have been proposed to estimate the displacement of the COM (Lafond, 2004). Among those, we used zero-point to zero-point double integration, or gravity line projection, (GLP) method (Zatsiorsky and Duarte, 2000), which is robust and independent of standing conditions; furthermore, it only requires force plate data. In this study, we compared lean angles computed using either estimates of COM location based on (1) kinematic data from a motion capture system and (2) the GLP method.

METHOD

Subjects. Eight young adult subjects (7 males, 1 female; age 24±2.7 yrs, height 175±10 cm, and weight 77±15 kg) were tested.

Experimental Protocol

Subjects were tested in two conditions: 3 quiet standing trials, 3 voluntary sway trials in the AP direction, all 30s in duration. For both conditions, subjects were instructed to stand with arms at their side and eyes open, looking at a large stationary picture placed at eye level and 3m away. Ground reaction force and COP were recorded with a force plate (AMTI, BP600900). We collected kinematic data to compute the location of the body COM using a motion capture system (Vicon 460) with a 34-marker set placed on the head, torso, arms, and legs. All data were sampled at 120 Hz.

Data Processing

1. Lean angle from kinematic data via motion capture system (Gold-standard lean angle):
We estimated the location of the COM through the segmental method, where the body's COM was derived from a 12-segment model of the body (Vaughan et al., 1999). Lean angle was then calculated from the average of the ankle joint centers to this COM position. We used these data as the reference data for verification.

2. Lean angle from GLP algorithm:
We used the modified GLP algorithm (Zatsiorsky and Duarte, 2000) to compute the location of the COM. Since the GLP method

can only estimate the horizontal location of the COM, to calculate the body lean angle, we also needed the distance between the ankle and COM. We approximated this distance as 58.71% of body height for males and 57.48% of body height for females according to King and Zatsiorsky (1997).

Data Analysis

We used the root mean square error (RMSE) and cross-correlation between the two calculation methods to quantify how closely the GLP-derived lean angle compared to the gold standard lean angle derived from the kinematic motion capture data. We also checked robustness to the uncertainty generated due to estimating the ankle to COM distance by varying body height up to ± 20%.

RESULT AND DISCUSSION

Average RMSE for the eight subjects was 0.036±0.008 deg for quiet stance and 0.287±0.094 deg for voluntary AP sway (Fig 1). Average cross-correlation was 0.985± 0.014 for quiet stance and 0.992±0.006 for voluntary AP sway. Average RMSE and cross-correlation values for the cases when body height was varied ± 20% were 0.057±0.01 deg and 0.985±0.014, respectively, for quiet stance and 0.276±0.11 deg and 0.992±0.006, respectively, for voluntary AP sway. These results suggest that using the GLP method to compute the location of the COM along with approximating the length of the pendulum is a good method for estimating body lean angle.

SUMMARY AND CONCLUSIONS

In this study, we investigated whether it was possible to calculate lean angle with only force plate information. By applying the modified GLP algorithm to estimate the horizontal displacement of the body COM, the results suggest that estimating lean angle with only force plate data is a viable approach, especially when kinematic motion capture data are not available.

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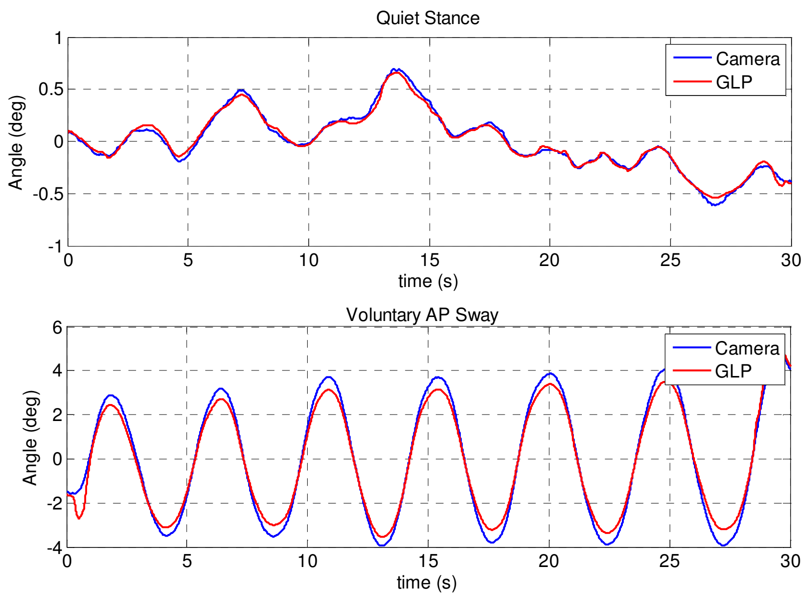

Figure 1. Sample body lean angles during quiet standing and voluntary sway. Lean angles were derived from kinematic data collected on a motion capture (camera) system versus application of the gravity line projection (GLP) method.

250 word summary:

To understand the human postural control system, control models that represent the upright body as a single link inverted pendulum are frequently used. These models usually output the lean angle of the pendular body and use the desired lean angle as a reference input. Lean angle is defined as the angle between vertical and a line connecting the ankle and body center of mass (COM). In some experimental situations, it is not possible to collect kinematic data to estimate the location of the COM. In this study, we were interested in assessing the accuracy of estimating the location of the COM using only force plate data, rather than kinematic data from a motion capture system. Specifically, we compared lean angles computed using either estimates of COM location based on (1) kinematic data from a motion capture system and (2) the zero-point to zero-point double integration, or gravity line projection, (GLP) method (Zatsiorsky and Duarte, 2000). Eight young adult subjects were tested in two conditions: 3 quiet standing trials, 3 voluntary sway trials in the AP direction, all 30s in duration. Root mean square error (RMSE) and cross-correlation between the two calculation methods were used to quantify how closely the GLP-derived lean angle compared to the gold standard lean angle derived from the kinematic motion capture data. The results suggest that using the GLP method to compute the location of the COM along with approximating the length of the pendulum is a good method for estimating body lean angle.