USE OF THE INVERTED PENDULUM MODEL IN POSTURAL STABILITY RESEARCH: NEW INSIGHTS

Nicholas Ali[1]; Gordon Robertson[1]; Gholamreza Rouhi[2]

[1]School of Human Kinetics, University of Ottawa, nali065@uottawa.ca

[2]Department of Mechanical Engineering, University of Ottawa, grouhi@uottawa.ca

INTRODUCTION

The ability to maintain the centre of mass (COM) in relation to the base of support (BOS) is termed postural stability (PS). For PS studies, the human body is often modeled as a single-segment inverted pendulum rotating about the ankle joint. Winter's model [1] utilized such an inverted pendulum to predict PS during quiet standing yielding the following equation:

$$COP - COM = k\,\ddot{x} \qquad (1)$$

where $k = I\ /\ Wh$. Here $\ddot{x}$ is the horizontal acceleration of the body's COM, I is the body's moment of inertia, W is the body's weight, and h is the height from COM to the ankle. A challenge with this model is that it requires motion capture data from very precise optical systems such as Optotrak [1]. The purpose of this paper is to present a more economical approach that requires only force platform and electrogoniometry data and thus might be more suitable for use in clinical applications.

PROPOSED APPROACH

The proposed approach is based on inverse dynamics analysis (IDA) and also work-energy theorem. This approach uses a two-segment inverted pendulum model (see Figure 1).

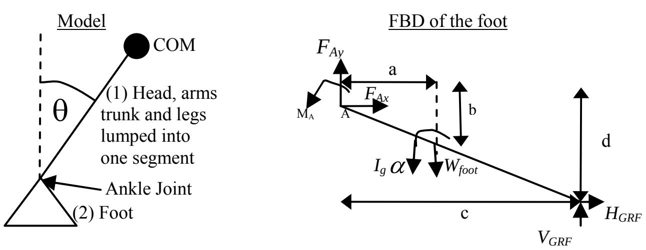

Figure 1: Two-segment inverted pendulum model

In Fig. 1, H_{GRF} and F_{Ax} are the horizontal forces at the ground and ankle; V_{GRF} and F_{Ay} are the vertical forces at the ground and ankle. M_A is the moment about the ankle, θ is the sway angle with respect to a fixed vertical axis, W_{foot} the foot weight, and I_g the foot's moment of inertia about its centre of mass and around the axis perpendicular to this plane. W_{foot}, a, b, c, and d can be measured or determined from Dempster's data [2].

Applying IDA equations of motion to segment 2:

$$\sum F_x = ma_x = H_{GRF} + F_{Ax} \qquad (2)$$

$$\sum F_y = ma_y = V_{GRF} + F_{Ay} - W_{foot} \qquad (3)$$

$$\sum M_A = I_g\alpha + ma_x b + ma_y a \qquad (4)$$

$$M_A - W_{foot}a + V_{GRF}c + H_{GRF}d = I_g\alpha + ma_x b + ma_y a \qquad (4a)$$

Since the foot is not accelerating during quiet standing α, a_x, and a_y can be approximated as 0. Therefore equation (4a) becomes:

$$M_A = W_{foot}a - V_{GRF}c - H_{GRF}d \qquad (5)$$

Values on the right-hand side of Eq.5 can be obtained using a force platform and anthropometrics. Thus, the work required to displace the COP to maintain the COM within the BOS is:

$$W = M_A\theta \qquad (6)$$

To validate this approach, θ was measured electronically and compared with data measured by motion capture. The findings from Winter's approach (Eq.1) are then compared to the present study's approach (Eq.6).

METHODS

A five-camera Vicon MX motion capture system sampling at 100 Hz recorded the three-dimensional marker trajectories of a male subject. Simultaneously an electrogoniometer measured θ and an AMTI force platform quantified the ground reaction forces and moments. The subject was requested to stand as still as possible, barefoot on a block that reduced the A/P BOS, chin parallel to the ground, and arms resting to the side. The postural sway in the A/P direction was recorded over a 60-s period for two conditions namely: normal quiet standing, eyes open (EO) and normal quiet standing, eyes closed (EC). A trial was recorded for each condition.

RESULTS

To improve the quality of the graphics only part of the trial is shown in Fig. 2. Fig. 2-A reveals that the COP—with higher amplitudes—moves on either side of the COM to maintain balance. Fig. 2-B demonstrates that COP-COM predicted using Eq.1 is highly correlated to $\ddot{x}$. Fig. 2-C shows that the work predicted by Eq.6 negatively correlates to $\ddot{x}$. Fig. 2-D shows that as body sway increases the work required increases linearly. Although not evident from Fig. 2, when $\ddot{x}$ is approximately zero, θ is typically a maximum and subsequently work is a maximum.

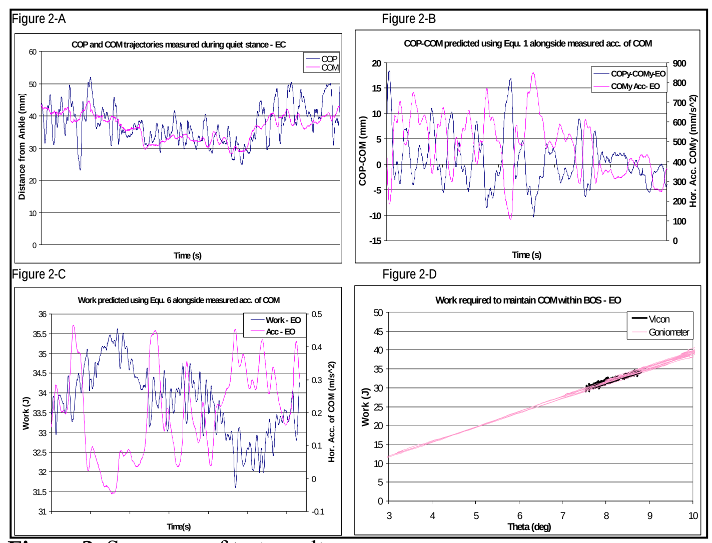

Figure 2: Summary of test results

SUMMARY AND DISCUSSION

Equations 1 and 6 yield similar results (Fig. 2-C & 2-D), so one can conclude that postural stability may very well be related to the work required to maintain balance. Compared to Eq.1's approach, the simplistic method proposed in this study reduces the amount of data to be processed and analyzed, as well as, the complexity of the computations required. More trials and varied subject population are required to illuminate and further validate the proposed approach.

REFERENCES

1. Winter DA. *Human balance and posture control during standing and walking.* Gait Posture **3**(4): p. 193-214, 1995.
2. Dempster WT. WADC-TR-55-159 1955, Wright-Patterson Air Force Base: Dayton, OH.