A NEW FRONTAL PLANE FOOT MODEL SHOWS THE EFFECT OF NARROWED BASE OF SUPPORT ON UNIPDEDAL BALANCE

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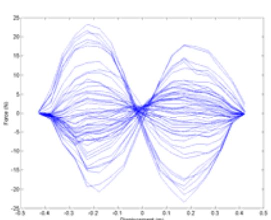
INTRODUCTION

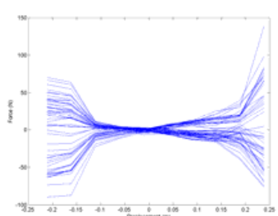
Despite balancing on one leg being widely used as a clinical test of frontal plane balance, comparatively little is known about the biomechanics of this task. The foot is generally described as a ground-attached pivot that transfers the ankle torque to the ground 'transparently' and this assumption forms the basis for using an inverted pendulum to model balancing on one foot. Two common ways to increase the difficulty of balancing tasks are to ask the subject to stand on a compliant surface or on a narrowed base of support. In the latter case, balancing on a narrow beam limits the transmission of ankle torque to the support surface. In this paper we will show that a narrowed base of support also changes the effective compliance of the foot-ground interface, an effect that is often neglected in the simple inverted pendulum model.

METHODS

Let us first posit that the compliance of the foot-ground interface changes the passive dynamics of balancing on one foot. To prove this, we developed an analysis method called *ground pressure decomposition (GPD)* whereby the ground pressure profile is decomposed into pure force (P_f) and pure moment (P_m) components.



(b) P_m for a compliant surface



(c) P_m for a narrow beam

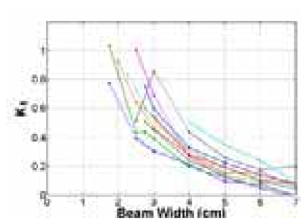
Figure 1: Profile of pure moment component (P_m)

We assume that the frontal plane motion of the foot can be modeled as the sum of a deflection and a rolling component ($\Delta X_{ankle} = K_1\Delta COP + K_2\Delta\varphi_{limb}$) [where COP denotes center-of-pressure]. In this we hypothesize that the deflection coefficient (or effective stiffness) K_1 is inversely proportional to the square of beam width (**H1**). The existence of the deflection suggests that there exists a critical beam width (CBW) at which it is no longer possible to balance upon: a base of support narrower than CBW (**H2**).

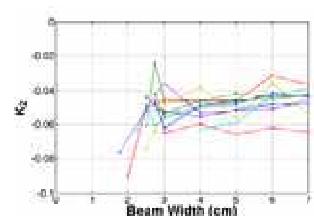
To test above hypotheses (**H1** & **2**), 11 healthy young adults (ages 23-32 yrs., 5 females) were recruited. They were asked to balance for 30s on one foot placed on one of six beams of increasing widths (1.75 cm to 7 cm) presented in a randomized order (total 15 trials for each subject). The kinematics and the ground reaction force were measured at 100 Hz using three Optotrak® markers and two AMTI® force plates and filtered with a 4^{th}-order bidirectional low-pass (7-Hz cut-off) Butterworth filter.

RESULTS AND DISCUSSION

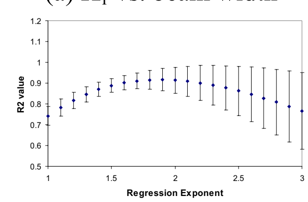
Of a total of 165 trials from the 11 subjects, 141 trials exceeded 20 s and analyzed. In Figure 1a & b we see that the deflection component gain, K_1, increased while the rolling component gain, K_2, remained constant. Figure 1c shows that the change of K1 has an optimal regression exponent, n=1.9, close to our expected value of n=2.0, thereby supporting **H1**. Figure 1(d) shows the change of K1 against beam width normalized about CBW. No subject could stand on beams narrower than CBW, supporting **H2**.



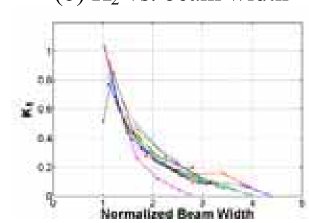
(a) K_1 vs. beam width



(b) K_2 vs. beam width



(c) Regression Exponent vs. R^2



(d) K_1 vs. normalized BW

Figure 1: Least square regression result result using $\Delta X_{ankle} = K_1\Delta COP + K_2\Delta\varphi_{limb}$.

So, balancing on a narrow beam has two characteristics: COP saturation and a compliant interface. As the compliance increases, the axis of the torque source (i.e., ankle jt.) is translated laterally causing relative system instability.

CONCLUSIONS

1) The foot has both compliance and rolling characteristics in the frontal plane.
2) This compliance reduces the transmission of the ankle torque to the ground, and defines a critical beam width (CBW) that limits balancing in a pure ankle mode.