ANALYSING HUMAN BALANCE RECOVERY ACTION USING CALCULATED TORQUES OF A DOUBLE PENDULUM MODEL

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1. Introduction

In clinical practice, assessment of balancing abilities aids the diagnostics of various fields such as orthopedics and neurology while researching balance can provide insight for control engineering. One test method uses a freely oscillating platform with a sudden perturbation to elicit balance recovery response motion [1]. Standing balance is recovered and maintained using dominantly the ankle or a mixed hip-ankle strategy for bipedal (BP) and unipedal (UP) stances, resp. In this proof of concept work, we demonstrate the utility of a 4 degrees-of-freedom (DoF), two-link double pendulum (DP) model of the human body according to the Denavit-Hartenberg convention [2] in calculating the estimated forward and sideways torques at the ankle and hip level based on actual position data from a motion capture system.

2. Materials and methodology

2.1 Participants and balance measurement

Eleven young, healthy collegiate participants (9M/2F; age: 22.8±1.7yrs, height: 179±11cm, body mass: 80.6±19.9 kg) were tested 10 times in three stances each: BP, right UP, left UP stance. The tests were authorized by the Science and Research Ethics Committee of Semmelweis University (174/2005) and written consent was obtained from all participants. Perturbation balance tests (Fig. 1) were performed on the PosturoMed® freely oscillating platform (Haider Bioswing, Weiden, Germany) as previously described in [1]. Briefly, the suspended platform is locked outside its resting position with the participant adopting a UP or BP stance; a sudden release delivers a ~20mm unidirectional perturbation. The task is to regain balance via stopping the oscillatory motion of the platform. Other than the standing support surface, no objects could be touched; foot contact with the platform had to be constant and rigid, and platform oscillation had to be decreased below ±2mm.

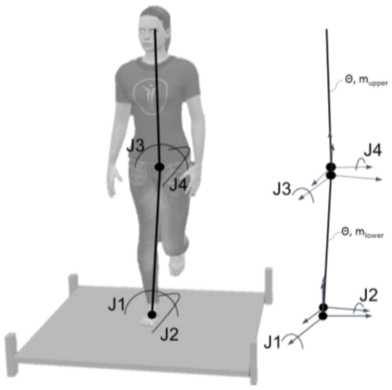

Fig. 1. Double pendulum model of balancing person on unstable platform.

2.2 Double pendulum model

The DP model (Fig. 1) consists of a lower body link (feet, shanks, thighs) and an upper body link (pelvis, trunk, arms, neck and head) with four single rotational DoF joints. Feet and arms were modeled as mass points; left and right shanks and thighs as two-two cylinders each; trunk-pelvis and neck-head as one-one cylinders each. Weight, inertia, center of mass values were based on proportional values [3] of total body mass and height. The respective body segments for the two DP links were then summed up to obtain the final inertial properties. Dynamics of the DP model were obtained through the Denavit-Hartenberg convention [2]. Joint1 and Joint2 allows lateral and frontal rotation in the ankle, resp.; Joint3 and Joint4 allows lateral and frontal rotation in the hips, resp. (Fig. 1). The four equations of motion give the calculated torque for each joint.

2.3 Data collection and analysis

Position data of platform, hip and head were collected using an 18 infra-red camera motion capture system OPTITRACK (NaturalPoint Inc., Oregon, USA) with passive reflecting marker sets at a sampling rate of 120Hz. Joint angles were calculated from position data. Angular velocity and acceleration were obtained by differentiation and values were low-pass filtered. Evaluating the equations of motion for these gave the joint torques.

Total joint work was calculated integrating torque multiplied by angular velocity.

3. Results

In order to provide a proof of concept of the model, the derived variables are explored to see if they can indicate the ankle or mixed strategies and if they are congruent with platform trajectory. Out of 330 attempts, 285 was successful and well recorded for the whole group. Here, results of a single participant are shown as an example.

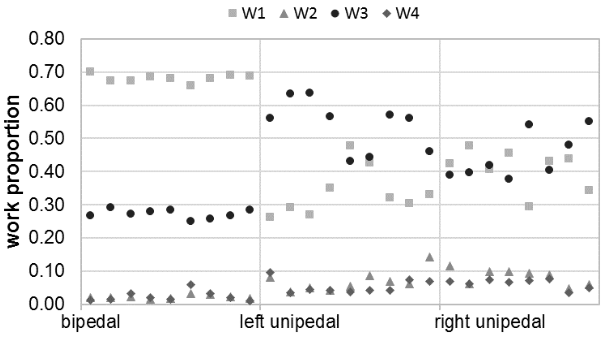

Fig. 3. Total joint work proportions of recovery motion.

Total work in the four joints can be analyzed in relative terms to identify if one or more is dominant (Fig. 3). The BP stance very consistently shows dominant and lower lateral torques at ankle (W1) and hip (W3) level, resp., with minimal frontal torques (Fig. 3). The dominance of lateral ankle torque (W1) over hip torque (W3) reverses for UP stances (Fig. 3). Left and right UP stances are also somewhat dissimilar in this regard. Frontal torques (W2, W4) also appear for UP stances (Fig. 3).

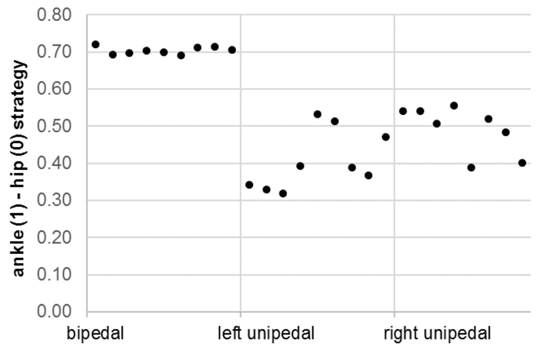

Fig. 4. Indication of ankle (1) and hip (0) strategies, based on joint work proportions.

Summation of ankle joint works (W1, W2) indicates joint dominance on a simple 0-1 (hip-ankle) scale; BP and UP stances are clearly distinct (Fig. 4). A lower directional ratio indicates more elliptical platform motion in response to the purely lateral perturbation, thus utilizing forward-backward motion to recover balance. The ratio of lateral (Q1, Q3) over frontal (Q2, Q4) joint works correspond well with platform motion (Fig. 5). For the total 11 participants, observations on the relative proportion of joint works were fairly consistent. However, the seemingly linear trend as depicted in Fig. 5 was similar only for 5 participants.

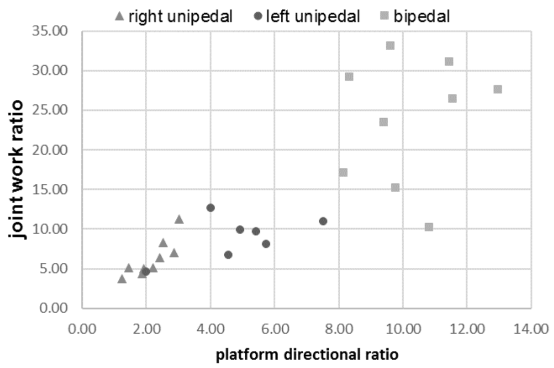

Fig. 5. More circular platform motion is elicited by antero-posterior torques.

Overall, the model allows to further analyze and better understand balance maintenance and the complex balance recovery action. In the future, the model could be evaluated for different types of balancing tests used in clinical practice.

4. Concluding remarks

- Measured position data were input to a double pendulum model to calculate joint torques.
- The model indicates dominance of ankle or hip joint strategies in different balance recovery conditions.
- Calculated torques relate to the trajectory shape of recovery motion.

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