Simulation of One-Handed Handstand

De Bock T. 1

1 Mechanical, Aerospace, and Biomedical Engineering, University of Tennessee, Knoxville, USA
tdebock@utk.edu

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1. INTRODUCTION

This study was motivated by the difficulty of achieving a controlled one-handed handstand and the goal was to create a simulation using Opensim to perform some analysis of the biomechanics behind the pose. There are several different ways to achieve a controlled one-handed handstand as shown in figure 1. The similarity between all three cases is that the center of mass of the entire body must stay within a small boundary above the contact points of the hand with the ground. A full body model was built upon in Opensim to use for analysis, and the moments about the wrist, elbow, and shoulder were analyzed.

Figure 1. Three different poses where the center of mass stays within the boundary of the contact between the hand and the ground.

2. METHODS

The first step of the study was to find an existing Opensim model that included the entire musculoskeletal system. The position vector to the center of mass, R, of the entire system needs to be computed via equation (1) where \( i \) is the number of bodies, \( m_i \) and \( r_i \) are the mass and position vector to the \( i \)'th body’s center of mass, and \( M \) is the total mass of all bodies. To get a realistic position for total center of mass, the entire body with realistic masses needs to be taken into account. Opensim has this function built in, so finding the center of mass of the entire system is found with the click of a button and updated as the individual bodies move around the global reference frame. A model developed by Menegolo Andrea was found on simtk.org which was built from other existing Opensim models [1-6]. The model, shown in figure 2, is comprised of 130 bodies, 53 degrees of freedom (DOF), and 156 muscles.

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R = \frac{1}{M} \sum m_i r_i.
\]  

One problem with the model was that some of the bones did not have any mass associated with them, so a Matlab script was written to find which bones needed mass. The mass of these bones was estimated using the masses from the other bones in the model. The total mass of the system was computed to be 98kg which is biologically feasible. The next step in creating the simulation was to add contact definitions between the hand and the ground. 6 contact spheres were defined on the hand as shown in figure 3. One sphere was created at each fingertip and one sphere at the palm. The contact force was modeled as an elastic force named the HuntCrossley Force which has been used in previous Opensim models with stiffness coefficient of 100,000,000, dissipation of 0.5, static and dynamic frictions of 0.9, and viscous friction of 0.6.
Once the full body model was ready with all masses assigned to bodies and contact forces defined, the body needed to be placed in the one-handed hand stand position to proceed with the analysis. The body was manually set in a position where the center of mass was within the boundary of the hand in both the sagittal and coronal planes, figure 4. The model was settled by locking all DOF except for vertical displacement, and forward dynamics was computed to let the body bounce until it settled in a resting position.
3. **RESULTS**

Once the body was settled in the position shown in figure 4, five additional DOF were unlocked to let the body translate and rotate about all three axes. Forward dynamics was run, and as can be seen from the center of mass location of figure 4 in the sagittal plane, the model started to fall frontwards and slightly to the right (in relation to the body). Static Optimization was run on this motion to see what kinds of muscle forces were necessary to hold this model in place. Unfortunately, the muscle isometric forces were not great enough to hold the model up, and the static optimization stated that the upper bounds of muscle activation were reached. Inverse dynamics was then run on the motion to see what kinds of moments were on the wrist, elbow, and shoulder joints. Figure 5 shows the graph of these moments for the body falling forward and figure 6 shows these moments when the model was locked in position.

![Figure 5](image1.png)

**Figure 5.** Moments about the shoulder, elbow, and wrist (flexion-extension) in N-m where time is in seconds for the falling motion.

![Figure 6](image2.png)

**Figure 6.** Moments about the shoulder, elbow, and wrist (flexion-extension) in N-m where time is in seconds for the static motion.

4. **DISCUSSION**

From the results shown in figure 5 and 6, the shoulder joint had the largest moment from gravity acting on the body’s total center of mass. Looking at the sagittal plane in figure 4, the body center of mass is directly above the wrist and elbow, so the moment arm is zero or very close to zero. The moment arm about the shoulder calculated above is in the coronal plane, and looking at figure 4 there is a small moment arm. The shoulder seems to have the largest moment arm from the body center of mass, but this may be due to some limitations in the model.
The first limitation of the model was that some of the masses of bones were estimated, and the total center of mass was computed based on these values. The total mass, 98kg, was too large for the muscles to hold, so this was a limitation for the static optimization. To improve this model, realistic masses should be used in all bones to compute the total center of mass, and the muscles’ maximum isometric forces should be increased to be strong enough to compute the static optimization. The present model lays the ground work for new simulations looking into gymnastic simulations and any upper body contact sport.

5. ACKNOWLEDGMENT
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6. REFERENCES