COMPARING THEORETICALLY SCALED BIOMECHANICAL MODELS

F. N. Matari[1], (in memory of) R. K. Huffman[2], K. H. Lostroscio[3]
[1]CACI Inc., 2100 Space Park Dr., Houston, TX 77058
[2]METECS, Inc., 1030 Hercules Ave., Houston, TX 77058
[3]NASA Johnson Space Center, 2101 E NASA Parkway, Houston, TX 77058

BACKGROUND

An investigation into incorporating space suit aspects required a 50th-percentile male model which was not part of the existing dataset of models. Previously, theoretical models for 5th-percentile female and 95th-percentile male were created utilizing a scaled test subject as close as possible to the target height and weight. Scaling factors were created by taking the height ratio and applying it uniformly to the model body segments, then fine tuning to ensure the theoretical model's height is as expected. This study was initiated to examine the existing method of isometrically scaling in OpenSim [1,2] and to create alternative methods which do not rely on an existing subject being close in height and weight to the theoretical model of interest. Generating a theoretical biomechanical model provides additional abilities without the reliance on available OpenSim models or real subjects. Gained abilities include creating different percentile models and attaining representative anthropometry for any target height/weight, such as targeting specific crew populations or gaps within the current dataset.

METHODS AND RESULTS

This study includes 3 methods for generating the theoretical model; utilizing the modified unscaled OpenSim Full Body Rajagopal Model (FBRM) [3,4], a dataset of scaled OpenSim models, and existing scaling factors from Dumas et al. [5]. All methods use the Anthropometric Survey of US Army Personnel (ANSUR II) [6] as an input of necessary anthropometric measurements. The following measurements are retrieved from the ANSUR II collection: mass, stature, cervicale height, acromial height, axilla height, waist height, trochanterion height, lateral femoral epicondyle height, lateral malleolus height, acromion-radiale length, radiale-stylion length, palm length, ball of foot length, bicristal breadth, bimalleolar breadth. Some of the measurements are direct segment lengths and others are utilized to derive segment lengths. Height, weight, and age ranges are the required inputs to parse the collection for a mean value of the measurements. A simple iterative process may be necessary for the output of mean mass and stature consistent with the theoretical model of interest. In some cases, one may specify exact values instead of a range but that is dependent upon whether those exact values pertain to a single subject from the ANSUR II collection.

Equations from Dumas et al. were used to calculate scaling factors for the two methods that utilize OpenSim scaled and unscaled models. In the third method, Dumas' scaling factors were used directly instead of generating our own. After scaling factors are achieved, they are applied along with the mass and segment lengths retrieved from ANSUR II in order to calculate the segment mass, Center of Mass (CoM), mass Moment of Inertia (MoI), and the joint location in the parent frame. The theoretical models from the different methods were compared to the previous existing method of isometrically scaling in OpenSim, as well as the standards found in NASA STD-3000 [7] and the NASA Human Integration Design Handbook [8]. The whole-body center of mass is the main comparison performed between the models and the standards. The body segment mass properties were also compared when possible. In some cases, the standards do not provide complete data, or the center of mass location is not provided with respect to the appropriate joint coordinate system.

For a 50th-percentile male subject, results from isometric scaling in OpenSim and the method utilizing the unscaled FBRM were compared to the standards in NASA STD-3000. According to the standard, the whole-body vertical CoM location was taken from the head vertex to the CoM. The standards provide 80.2 cm for the CoM vertical component whereas isometric scaling in OpenSim and utilizing the unscaled FBRM provide 82.2 and 82.3 cm, respectively. Through definition, the whole-body CoM in the medial/lateral direction agreed across the models. Investigation is on-going to clearly identify the reference point pertaining to dorsal/ventral whole-body CoM position in standards and relate that to the theoretical models.

REFERENCES

[1] Delp, S.L., et al., "OpenSim: Open-source Software to Create and Analyze Dynamic Simulations of Movement", IEEE Transactions on Biomedical Engineering, (2007).
[2] Seth, A., Hicks J.L., Uchida, T.K., Habib, A., Dembia, C.L., Dunne, J.J., Ong, C.F., DeMers, M.S., Rajagopal, A., Millard, M., Hamner, S.R., Arnold, E.M., Yong, J.R., Lakshmikanth, S.K., Sherman,n M.A., Delp, S.L. OpenSim: Simulating musculoskeletal dynamics and neuromuscular control to study human and animal movement. Plos Computational Biology, 14(7). (2018)
[3] R. K. Huffman, W. K. Thompson, C. A. Gallo, L. J. Quiocho, "Improvement of Scaling and Inverse Kinematic Results with Additional Upper Body Joints Added to Opensim Rajagopal Model", NASA Human Research Program Investigator's Workshop, (2019).
[4] Huffman R.K., Thompson W., Gallo C., "Modified OpenSim Rajagopal Full Body Model", New Technology Report, MSC-26872-1. (August 2020).
[5] Dumas R., Cheze L. and Verriest J., 2007. "Adjustments to McConville et al. and Young et al. body segment inertial parameters". Journal of Biomechanics 40, pp. 543-553
[6] Gordon C.C., 2012 "Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics", US Army Natick Soldier RD&E Center.
[7] NASA STD-3000/REV-B, 1995. "The Man-System Integration Standards"
[8] NASA/SP-2010-3407/REV-1, 2014. "The Human Integration Design Handbook (HIDH)"