Biomechanical Loading of the Musculoskeletal System During Exercise

Sheng Kai Wong
Contact: shengkai.wong56@gmail.com | LinkedIn: linkedin.com/in/sheng-kai-wong

Supervisor: Prof. Richie Gill

Background: Osteoporosis*

1-in-2 Women

&

1-in-5 Men

Hip fractures have a

30% Mortality

[1]

Rate in the first year post-injury.

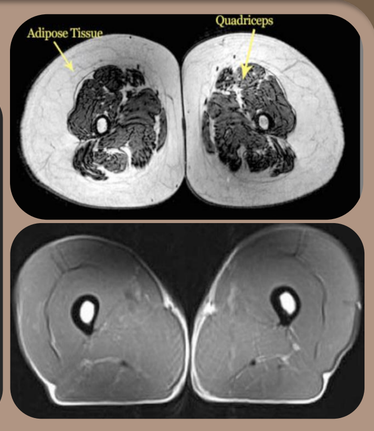
[2]

Above the age of 50 are expected to experience an osteoporotic fracture within their lifetime [2].

*A progressive disease where a person has a severely weakened skeleton [4].

Is Exercise Good For you?

Regular exercise is one of, if not *the* single best predictor for good musculoskeletal (MSK) health [3]. Bone is mechanoadaptive, and grows stronger the more often it is subject to biomechanical loads [4]. With osteoporotic fracture rates projected to increase with the ageing population, there is an interest in quantifying how different exercises interact with the skeleton through biomechanical loading.



(Yes.) *Cross-sectional X-Ray of the thigh a 74 year old sedentary man (Top) vs 70 year-old triathlete (Bottom) [5].*

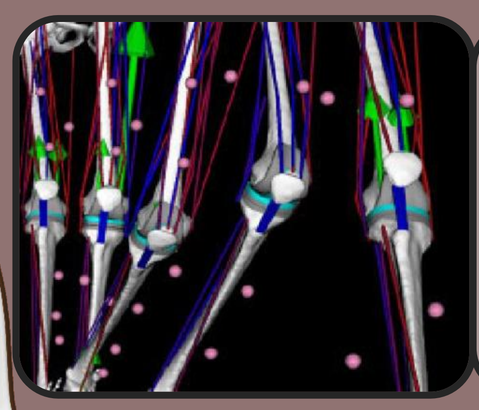
Methodology

Benedict Cumberbatch acting (amazingly) with the use of marker-based MoCap [6].

1. Raw Data
Motion Capture (MoCap) Data was taken from a previous project [7], including marker tracks, ground force-plate readings, and participant anthropometrics.

2. Simulation
This data was used to initiate biomechanical simulations within OpenSim (software) [8]. This included MSK model scaling, filtering, inverse kinematics, and inverse dynamics.

An example of an OpenSim Simulation [8].



3. Biomechanical Loads Estimation
Biomechanical joint moments were derived using multi-body dynamics analysis, representing the human skeleton system as a hierarchal set of spring-mass-damper units.

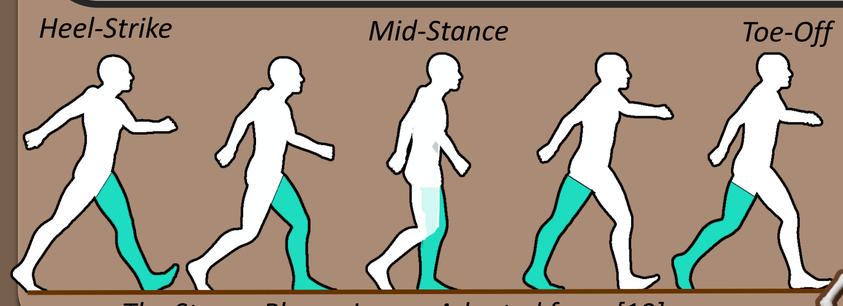
Joint reaction forces (green arrows) at the knee in a MSK model. Markers shown in pink [9].

Findings

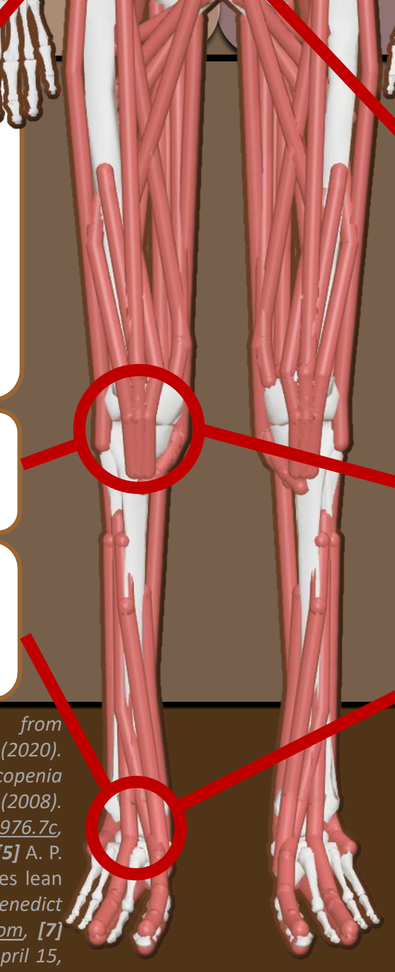
This research conducted gait moment analysis during the stance phase for running and walking for three participants (two male, one female). In total, three gait cycles, consisting of two stance phases each, were analysed.

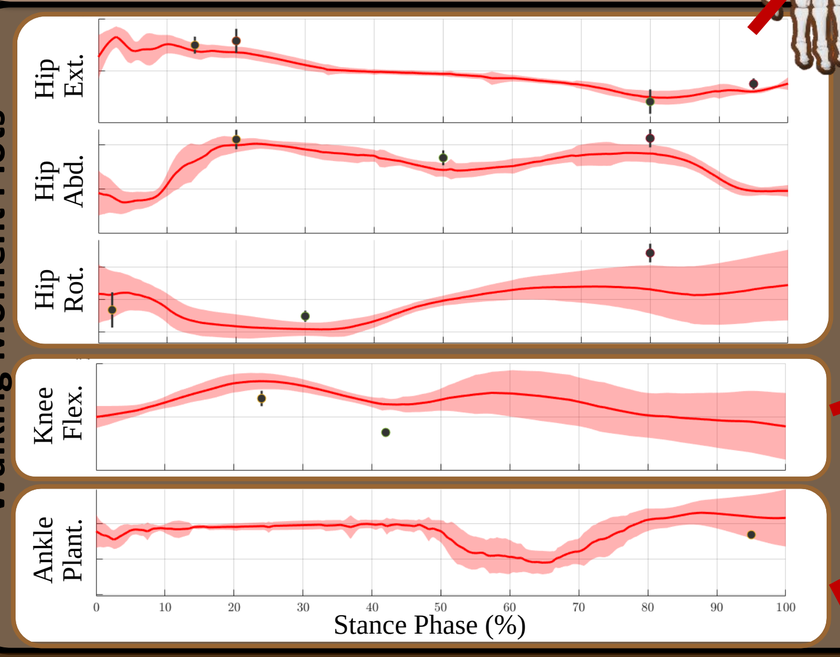
Compared to the existing literature, moment profiles for the hip joint were the most consistent (5-20% difference), followed by the knee (50-200%) and ankle joints (1000%+).

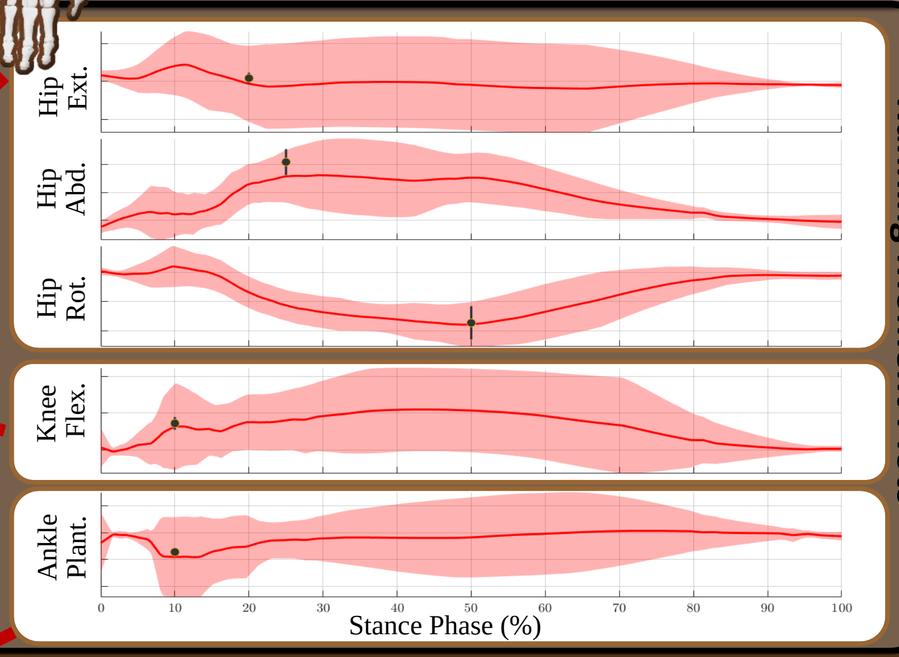
Walking simulations produced more consistent results than running, with cluster variability analysis revealing walking to be two times as stable. Simulation quality declined with distance from the pelvis, with hip moments displaying the least simulation noise, and the ankle moments the most.



The Stance Phase: Image Adapted from [10].







[1] Pelvis - Free healthcare and medical icons. (n.d.). Retrieved May 13, 2025, from https://www.flaticon.com/free-icon/pelvis_8855391, [2] Kirk, B., Zanker, J., & Duque, G. (2020). Osteosarcopenia: epidemiology, diagnosis, and treatment-facts and numbers. J Cachexia Sarcopenia Muscle, 11(3), 609–618. https://doi.org/10.1002/jcsm.12567, [3] Barry, D. W., & Kohrt, W. M. (2008). Exercise and the preservation of bone health. https://doi.org/10.1097/01.HCR.0000320065.50976.7c, [4] Porter JL, V. M. (2023). Osteoporosis. https://www.ncbi.nlm.nih.gov/books/NBK441901/, [5] A. P. Wroblewski, F. Amati, M. A. Smiley, B. Goodpaster, and V. Wright, "Chronic exercise preserves lean muscle mass in masters athletes,", doi: 10.3810/psm.2011.09.1933., [6] This is how Benedict Cumberbatch became a dragon in The Hobbit | LOTR Amino. (2015). https://aminoapps.com, [7] BioCV Motion Capture Dataset - University of Bath Research Data Archive. (n.d.). Retrieved April 15, 2025, from https://researchdata.bath.ac.uk/1258/

[8] Delp, S. L., Anderson, F. C., Arnold, A. S., Loan, P., Habib, A., John, C. T., Guendelman, E., & Thelen, D. G. (2007). OpenSim: Open-source software to create and analyze dynamic simulations of movement.. https://doi.org/10.1109/TBME.2007.901024, [9] Fregly, B. J., Besier, T. F., Lloyd, D. G., Delp, S. L., Banks, S. A., Pandy, M. G., & D'Lima, D. D. (2012). Comprehensive Data Sets for Evaluating Musculoskeletal Model Predictions of In Vivo Knee Loads. https://doi.org/10.1002/JOR.22023, [10] footbionics. (n.d.). The Gait Cycle. Retrieved May 13, 2025, from https://www.footbionics.com/For+Patients/gait_cycle.html

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