# Evaluating and combining cost function criteria to predict healthy gait

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## I. Background

Predictive simulations of human gait rely on the optimization of criteria to handle system redundancy, yet these criteria are non-obvious. This study used different physiologically motivated criteria, and combined and weighted them in a stepwise manner to predict healthy gait.

## II. Methods

A generic planar OpenSim [1] model with 18 Hill-type musculotendon actuators and nine degrees of freedom was controlled based on the model by Geyer and Herr [2]. Muscle excitations were generated using a combination of constant motor signals and reflexes based on muscle length and force, and active phases of gait. The parameterized controller was optimized using SCONE [3]. Each simulation was 10 seconds and walking speed was free to vary. The initial pose and reflex gains were optimized for five cost function criteria: (1) cost of transport (CoT) using a muscle metabolic model [4], (2) muscle fatigue represented as activation squared, (3) head stability quantified by head acceleration per meter (HeadStab), (4) foot-ground impact quantified as the derivative of the ground reaction force per meter (FGImpact), and (5) extreme ranges of knee motion that minimized the use of knee ligaments (KneeInj). Coefficients of determination ($R^2$) quantified the agreements between simulated and experimental biomechanical variables, i.e., ground reaction forces (GRF); joint kinematics, moments and powers; and muscle activations. The average $R^2$ was calculated for each and across the variable categories.

## III. Results & Discussion

When optimizing for each criterion alone, the average $R^2$ was highest for FGImpact, followed by HeadStab, CoT, and MusAct (Figure 1). Average $R^2$ increased each step when combining the weighted criteria, yielding a combined cost function with an average $R^2$=0.70 (Figure 1 & 2). CoT had the highest normalized weighting in the combined cost function.

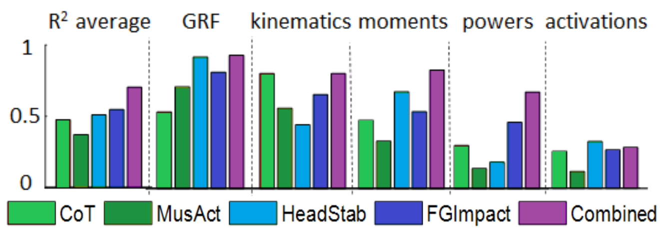


Figure 1: The agreement with experimental data (R2) for each of the criteria separately and for the combined cost function.

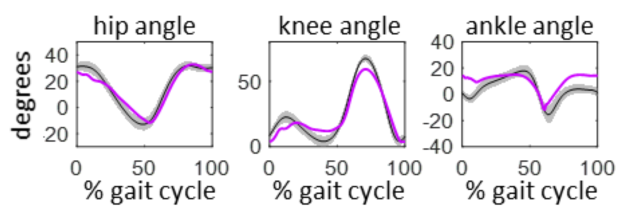


Figure 2: Kinematics predicted by the combined cost function (purple) compared to experimental data (black=mean; grey area=sd)

## IV. Conclusions

Stepwise tuning of the weightings in a cost function combining different criteria provided overall improved and acceptable agreement of the forward simulations of gait with experimental data. Interestingly, minimizing CoT alone yielded a low agreement, but it had the largest impact on the final tuned gait. A next step is to validate the framework for pathological gait by comparing it against patient data

## V. References

[1] Delp S. L., et al., IEEE Trans Biomed Eng 54, 1940-1950, 2007
[2] Geyer H. & Herr H., IEEE Trans Neural Syst Rehabil Eng 18, 263-273, 2010
[3] Geijtenbeek T., JOSS 4, 1421, 2019
[4] Uchida T. K., et al., PLoS One 11, 1-19, 2016