Subject-specific Surrogate Models of Task-level Human Movement

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How appropriate neural control inputs are selected to achieve a biomechanical movement task output is an open question. Experiments have exposed many aspects of human movement; however, simulations can complement experiments to help uncover task-level principles of coordinated and uncoordinated movements for predictions of functional outcomes. Predictions of subject-specific movements require full-body musculoskeletal modeling, accurate dynamic simulation, and robust control systems design. It is well known that human movement involves closed-loop control; therefore, a closed-loop blend of biomechanics and robotics approaches offers great potential for accelerating the study of human movement control and subject-specific outcome prediction.

For this blended closed-loop coordination, we have been combining biomechanical motions with surrogate response surfaces [1], developed using a second-order polynomial model ($\boldsymbol{y}_{\text{task}}^{\text{desired}} = b_0 + \sum_{i=1}^{2} b_i \boldsymbol{x}_i + b_{12}\boldsymbol{x}_1\boldsymbol{x}_2 + \sum_{i=1}^{2} b_{ii}\boldsymbol{x}_i^2$), of task-level neural control (Fig. 1a, 1b). Separate surfaces (Fig. 1b, 1c) are created for desired subtasks (e.g., swing foot position) as a function of a primary task (e.g., center of mass, CoM, balance). Each response surface finds a set of polynomial coefficients to best fit the subject's data. Desired tasks are computed from response surfaces as surrogate models for subject-specific motion coordination.

We created subject-specific surrogate models using three-dimensional (3D) motion capture data of balance recovery in unimpaired adults (female 25 yrs | 68.0 kg; male 25 yrs | 84.5 kg) and a range of walking speeds in unimpaired children (6 female | 2 male | 12.9±3.3 yrs | 51.8±19.2 kg) [2]. This data defined the high-level control relationships between tasks, where the response of a variable of interest ($\boldsymbol{y}$) is influenced by a set of predictors ($\boldsymbol{x}_i$). We related the 3D swing foot (Fig. 1c, $\boldsymbol{v}_2$) and torso ($\boldsymbol{v}_3$ *not shown*) positions to the CoM position in the transverse plane over the base of support (Fig. 1c, $\boldsymbol{v}_1$).

Surrogate models using quadratic surfaces accurately predict the responses for a range of adult and child movement data. These response surfaces advance our current understanding of the biomechanics and neural control of movement by establishing prioritized tasks for different motions and defining surrogates for these tasks; moreover, they may allow synthesis of a range of specific-subject motions without the need for additional prospective motion capture data (e.g., prediction of post-treatment outcome from pre-treatment motion).

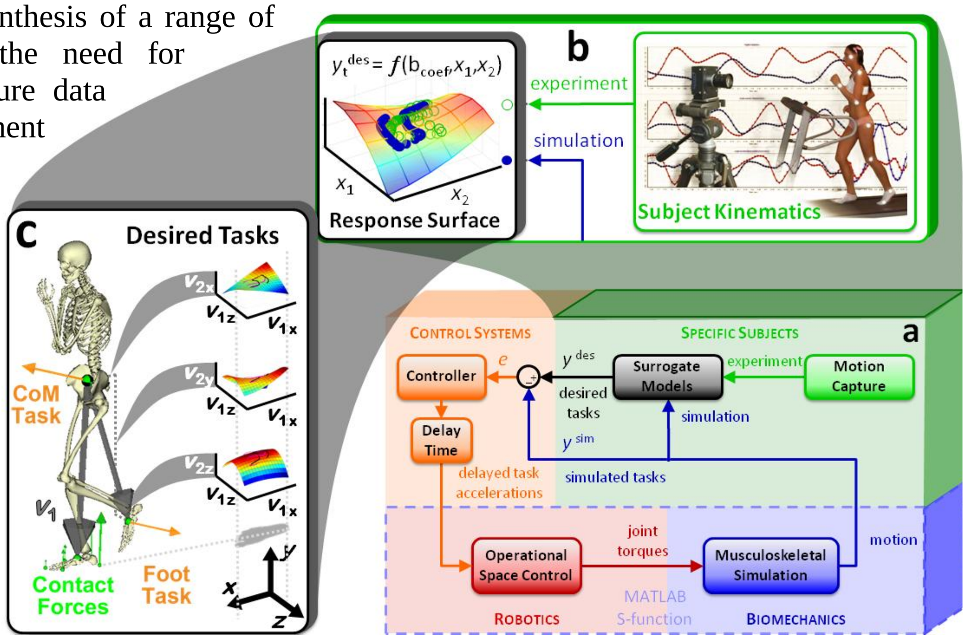

Figure 1: Subject-specific surrogate models created from experimental motion capture data and representing desired task-level coordination.

References

1. Box G E P (1951) On the experimental attainment of optimum conditions. *J R Stat Soc B* 13:1–45.
2. Liu M Q (2008) Muscle contributions to support and progression over a range of walking speeds. *J Biomech* 41: 3243-3252.

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