New simulation methods estimate metabolic cost of gait phases, but how consistent are those estimations?

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I. INTRODUCTION

Motion capture systems can measure at high framerates; however, with indirect calorimetry, we can only measure the average cost of a stride cycle. The inability to detect the cost of gait phases leads to suboptimal clinical decisions: e.g., if an orthosis reduces metabolic cost during one phase (push-off) but increases metabolic cost of another phase (swing cost due to distal mass), the effects cancel each other out, thereby hindering our capability to understand effects and design and prescribe improved interventions. Recent simulation methods and metabolic rate equations allow to estimate the time profile of metabolic cost within the stride cycle. In this abstract, we compare estimations of the cost of different gait phases using two simulation methods onto the same experimental dataset and a number of estimations from other studies.

II. METHODS

We estimated the metabolic time profiles using the muscle-level metabolic model of Umberger [1] by entering electromyography and kinematic data into a musculoskeletal simulation (OpenSim) [2]. We also estimated the metabolic time profile using the same experimental dataset based on the joint moments and joint angular velocities using the method of Roberts et al. [3]. Detailed methods are in Gonabadi et al. [4].

III. RESULTS AND DISCUSSION

Our estimations of the cost of the swing phase (22% according to the musculoskeletal method and 15% according to the joint-space method) were within a range from experimental studies with added mass, leg swinging, and leg swing assistance (1 to 24% [5]–[7]). The costs of phases appear similar to those from studies that used similar methods. e.g., our estimations with the musculoskeletal method were relatively close to those from [2], who used a similar EMG-driven method. However, there were also relatively large differences between different methods within our dataset and between different studies: e.g., estimations of the second double support phase ranged from 8 to 49%, estimations of the swing phase ranged from 15 to 31%. While we do not know the exact causes of these differences, it is known that assumptions such as simulation approaches or muscle-metabolic rate estimations can have vast influences on the resulting estimations [8].

IV. CONCLUSIONS

Even though estimations were in the ballpark of experimental estimations of swing cost, there were large differences between methods because of underlying assumptions. Advances estimations of the time profile of metabolic cost could lead to applications such as assistive devices or exercise therapies that target the costliest phases.

TABLE I ESTIMATED METABOLIC COST OF DIFFERENT GAIT PHASES

	1st double support	**Single support**	**2nd double support**	**Swing phase**
Own musculo-skeletal estimation	*17 ± 1.3*	*41 ± 2.7*	*19 ± 4.0*	*22 ± 1.8*
Jackson et al., [2]	10	39	27	24
Pimentel et al., [9]	18	27	24	31
Umberger [1]	27	40	8	25
Own joint-space estimation	*10 ± 0.7*	*26 ± 2.3*	*49 ± 2.7*	*15 ± 1.0*
Roberts et al., [3]	10	28	39	23
Max.	**27**	**41**	**49**	**31**
Min.	**10**	**26**	**8**	**15**

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