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NEW INSIGHTS INTO MUSCLE WORK ESTIMATION DURING GAIT

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INTRODUCTION

The estimation of muscle mechanical work (**MMW**) can be useful to assess movement efficiency (Fig. 1). Different methods to estimate MMW during walking have been presented in the literature:
external+internal *work* [1], ***segmental*** *work* [2], ***joint*** *work* [3].
Although attempts have been made to investigate differences among them [3, 4], all approaches are still used in research and clinical applications.
However, each method was originally based on different assumptions about i) between segments energy transfers, ii) interpretation of negative muscle work, iii) different meaning given to common terms as *internal* work.
A deeper understanding of theoretical differences and analogies would allow to know what is exactly computed by each method and help to make a more appropriate use of this information.

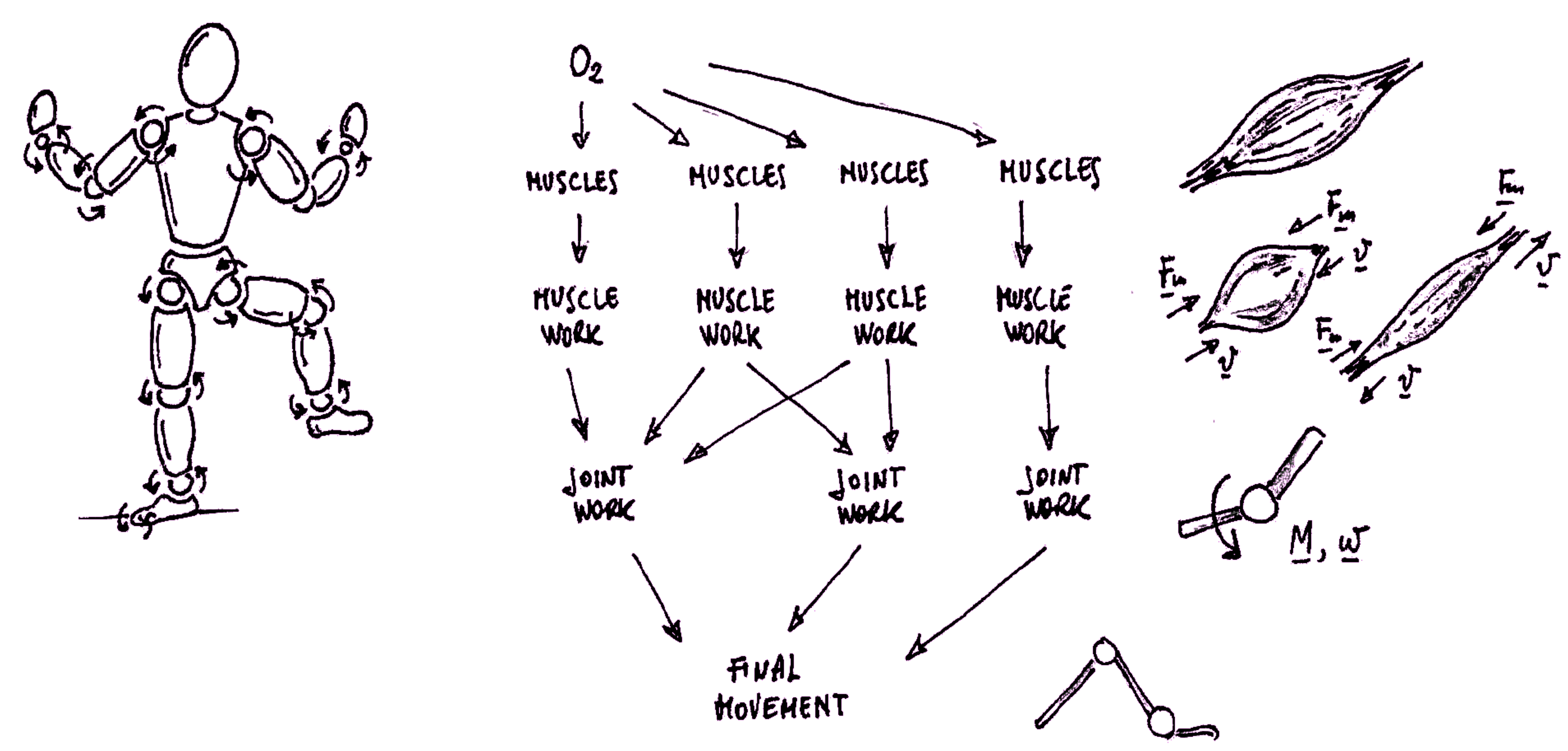


Fig. 1: Relationship between metabolic energy, muscle work and body movement.

PATIENTS/MATERIALS AND METHODS

Kinematic and kinetic data from 10 healthy children (age 9.8±2.7 y, height 1.36±0.17 m, weight 33.9±11 Kg) walking at self-selected speed were acquired with a Vicon system and 2 force plates. 3 gait cycles were selected for each subject.
A 16 segments full-body 3D model was validated and used to compute *pi(t)* functions as ***joint,*** or ***external*** (associated to the centre of mass, COM) + ***internal*** (associated to the segments movement relative to the COM), or ***segmental*** powers, during the gait cycle. External work was computed from COM kinematics and also via the ***individual limbs*** method [5].
Inertia parameters were scaled for children.

For each method, different whole-body power curves, *P(t)*, were obtained by summation of the *pi(t)* functions depending on the energy transfers allowed between segments (i.e. introducing, or not, absolute values among power terms to be summed) (Fig. 2, 4). The same conditions were applied to all methods. By integrating *P(t)* curves, different values for MMW were obtained:

W+, W-: total positive/ negative work allowing no energy transfers;
Wnet: (W+) + (W-);
|W|: |W+| + |W-|;
Wabsnet: integration of |P(t)|, allowing all possible energy transfers between segments, but no energy recuperation during time.

$$(1)\quad Wnet = \int_{T0}^{T1} \sum p_i(t)\,dt$$

$$(2)\quad Wpos = \int_{T0}^{T1} \sum (p_i(t)>0)\,dt$$

$$(3)\quad Wneg = \int_{T0}^{T1} \sum (p_i(t)<0)\,dt$$

$$(4)\quad |W| = \int_{T0}^{T1} \sum |p_i(t)|\,dt$$

$$(5)\quad Wabsnet = \int_{T0}^{T1} \left|\sum p_i(t)\right|dt$$

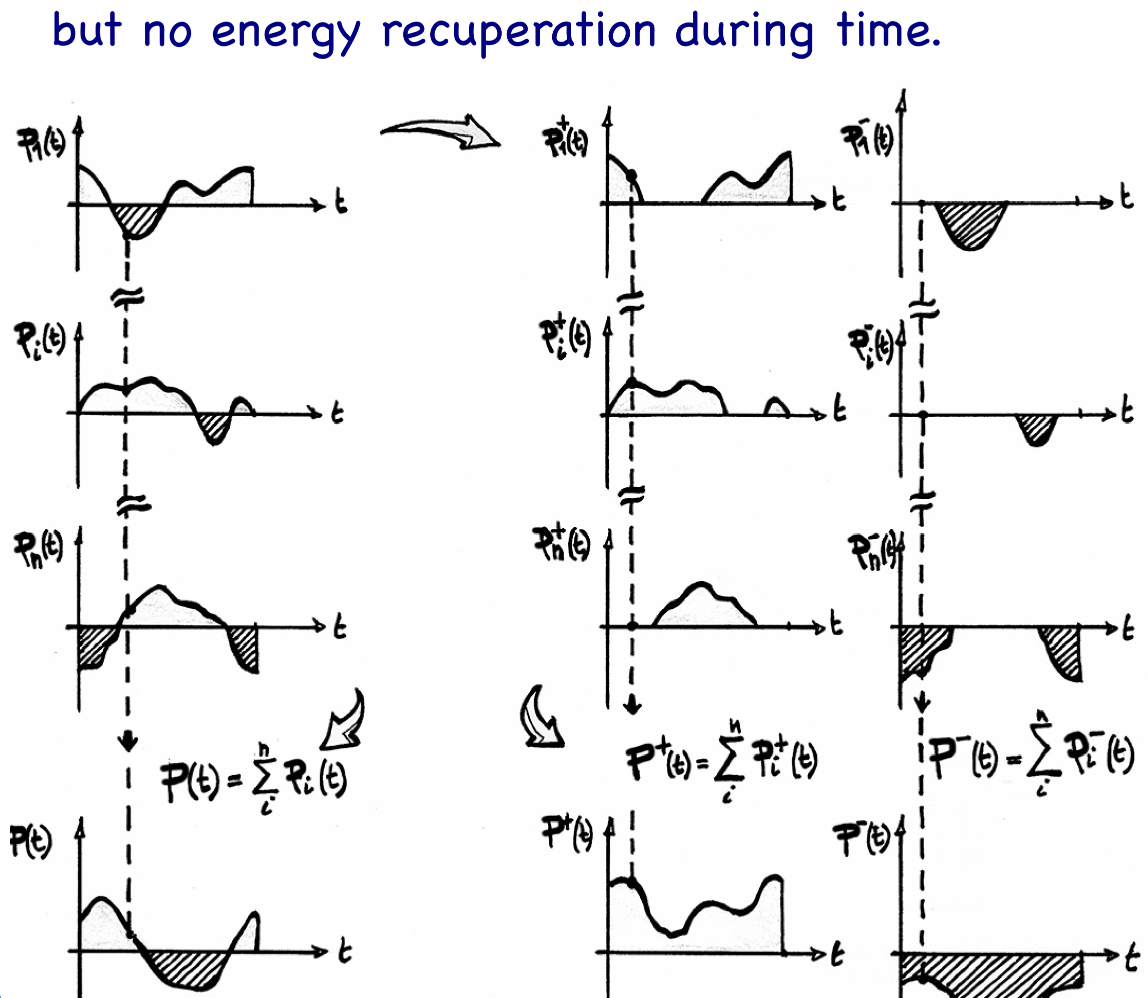
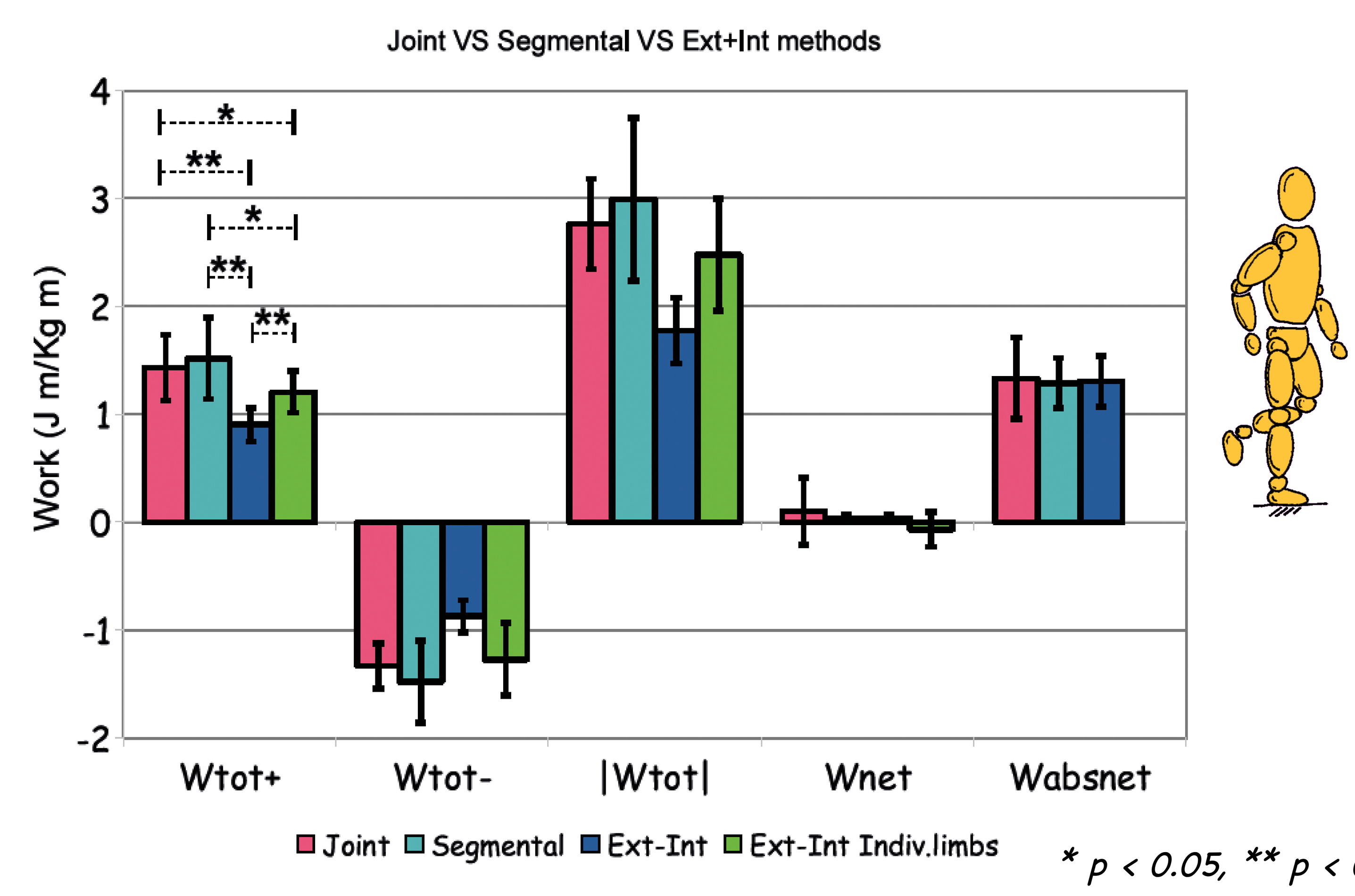


Fig.2: Different ways of summation of the power components

RESULTS

W+ and **Wabsnet** values were compared between methods through one-way ANOVA with posthoc Bonferroni correction.
The analysis demonstrated (Fig. 3) that all methods are equivalent when energy transfers between segments are allowed (**Wabsnet**). With no transfers, ***joint*** and ***segmental*** methods are equivalent while differing significantly from results of the ***external+internal*** method. The difference is reduced, but still significant, with ***external*** work computed via the individual limbs method. **Wnet** values are almost zero, as expected from walking at constant speed, and **|W|** is therefore close to 2*W+.

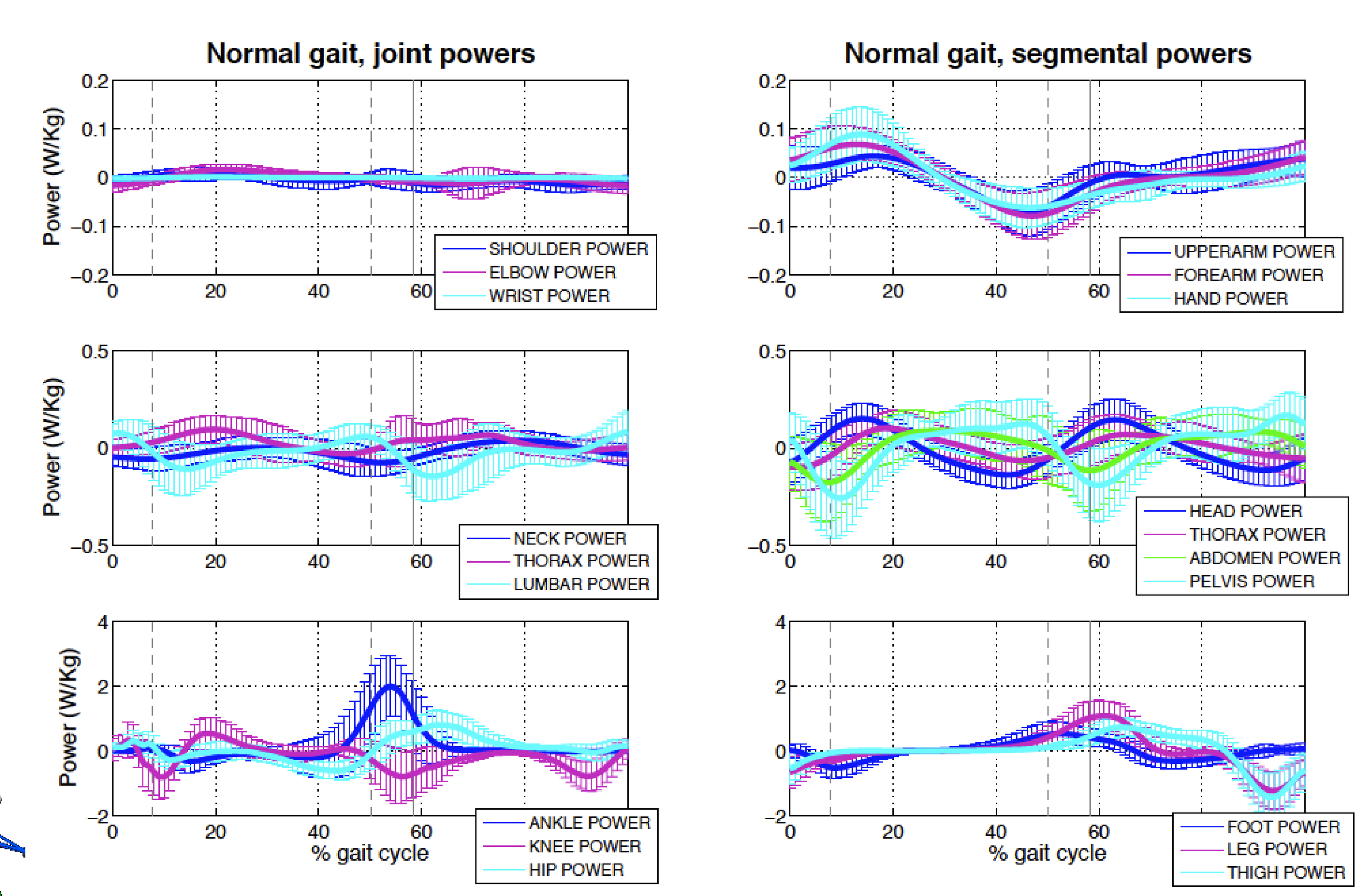


* p < 0.05, ** p < 0.01

Fig.3: Whole-body positive, negative, absolute, net and absnet muscle mechanical work, computed with all methods during normal gait as mean values ± 1 SD.

DISCUSSION AND CONCLUSIONS

Allowing for all possible energy transfers, all methods are equivalent. Significant differences appear when transfers are prevented, ignoring negative work or adding it as absolute value. However, all the computed quantities rely on artificial hypothesis and is therefore important to be aware of which method is being used, which conditions have been defined regarding energy transfers, and what kind or movements are being investigated.



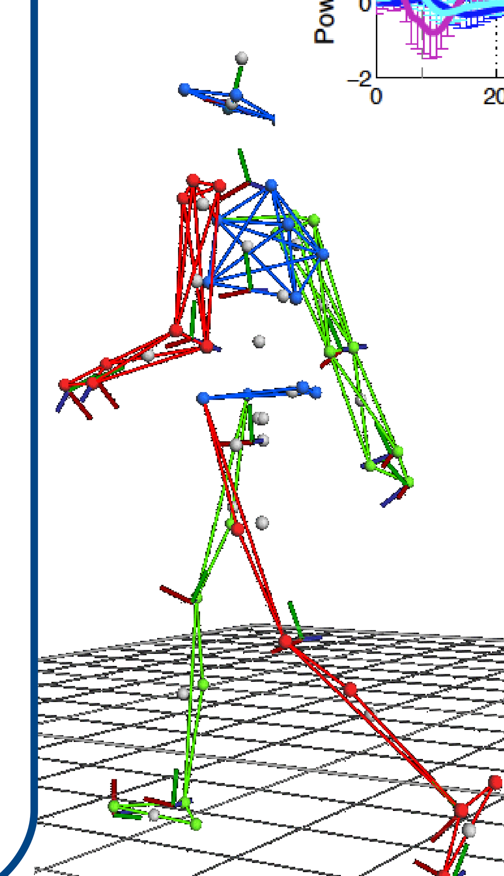


Fig.4: Power curves for the right upper limb, trunk, right lower limb computed as joint powers and segmental powers during normal gait

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