Can Simulations Assist in Classification Development?

Marie Lund Ohlsson Jonas Danvind L. Joakim Holmberg

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The purpose of classification of impairments in sports is stated by the IPC classification code as (Tweedy and Vanlandewijck, 2011):

> *Classification is undertaken to ensure that an athlete's impairment is relevant to sports performance and to ensure that the athlete competes equitably with other athletes.*

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  - <u>the IPC choice!</u>

A problem with selective classification

Tweedy and Vanlandewijck (2011) state:

> *It is well recognised that the classification an athlete is assigned has significant impact on the degree of success they are likely to achieve. Unfortunately, however, Paralympic classification and classification research have not matured as rapidly as other areas of Paralympic sport and current Paralympic classification systems are still based on the judgement of a small number of experienced classifiers rather than on empirical evidence. As a consequence, the validity of the methods used in functional classification systems is questionable.*

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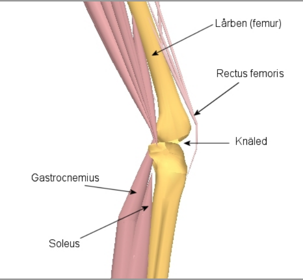
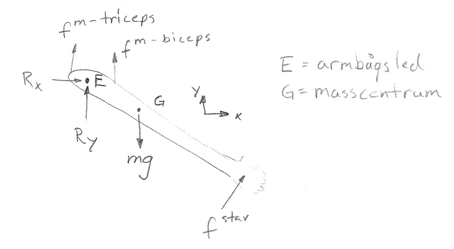
- With a musculoskeletal simulation, we can create two (or more) identical models of an athlete, impose a biomechanical impairment (or several similar/different impairments) and then compare the performance.
- Thus, we get quantitative data on the unbiased effect of different biomechanical impairments.

The concepts of a musculoskeletal model derives from 'basic' mechanics





Rigid body dynamics

The Newton–Euler equations of motion for an unconstrained segment i in three dimensions are

$$\begin{bmatrix} \boldsymbol{N}_i & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{J}'_i \end{bmatrix} \begin{bmatrix} \ddot{\boldsymbol{r}}_i \\ \dot{\boldsymbol{\omega}}'_i \end{bmatrix} + \begin{bmatrix} \boldsymbol{0} \\ \boldsymbol{\omega}'_i \times (\boldsymbol{J}'_i \boldsymbol{\omega}'_i) \end{bmatrix} = \begin{bmatrix} \boldsymbol{f}_i \\ \boldsymbol{n}'_i \end{bmatrix}$$

where $\boldsymbol{N}_i$ is the mass matrix and $\boldsymbol{J}'_i$ is the inertia tensor for segment i; $\boldsymbol{f}_i$ is the sum of all forces and $\boldsymbol{n}'_i$ is the sum of all moments acting on segment i. The translational acceleration of segment i is $\ddot{\boldsymbol{r}}_i$; $\boldsymbol{\omega}'_i$ and $\dot{\boldsymbol{\omega}}'_i$ are the angular velocity and angular acceleration of segment i, respectively, where the apostrophe indicates that the angular property refers to a segment-fixed local coordinate system.

Musculoskeletal inverse dynamics

The Newton–Euler equations of motion for a musculoskeletal system can be written as

$$\mathbf{C}\boldsymbol{f}^t = \boldsymbol{d}$$

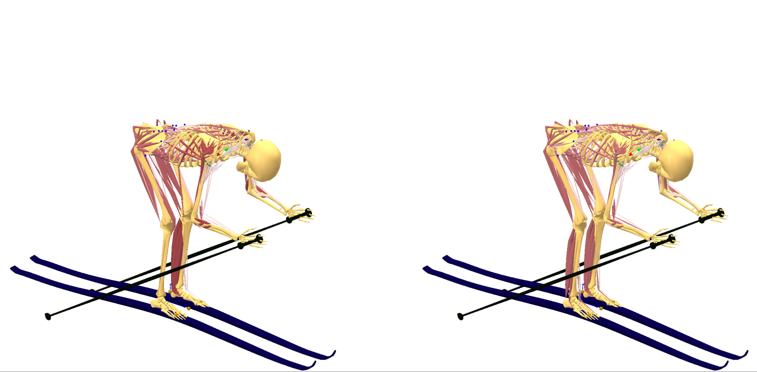
where

- $\boldsymbol{d} = \mathbf{M}\ddot{\boldsymbol{q}} + \boldsymbol{b} - \boldsymbol{g}^k$

and

- $\mathbf{C}$ is a geometry- and kinematics-dependant coefficient matrix
- $\boldsymbol{f}^t$ contains unknown muscle tendon forces
- $\mathbf{M}$ is the system inertia matrix
- $\ddot{\boldsymbol{q}}$ is the system acceleration vector
- $\boldsymbol{b}$ contains fictitious forces, such as Coriolis
- $\boldsymbol{g}^k$ contains the known applied forces, such as gravity

Cross-country skiing – pilot study (Holmberg et al., 2012)



Cross-country skiing – pilot study (Holmberg et al., 2012)

MEASURE (units)	NO MUSCLES BELOW RIGHT KNEE	ABLE-BODIED
Skiing work (Nm)	111	111
Metabolic muscle work, total (Nm)	3004	2463
Skiing efficiency (%)	3.7	4.5
Metabolic muscle work, lower-body (Nm)	1382	1192
Metabolic muscle work, lower-body (%)	46	48
Metabolic muscle work, upper-body (Nm)	1622	1271
Metabolic muscle work, upper-body (%)	54	52
Metabolic work, Rectus Femoris† (Nm)	6.73	1.24
Metabolic work, Gluteus Maximus† (Nm)	68.90	57.96

† Right leg.

The properties of the prosthetic device matters

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- decreasing stiffness to toe and heel minimized metabolic cost but increased knee joint contact forces
- increasing toe stiffness and decreasing heel stiffness reduced knee joint contact forces and yielded almost as low metabolic cost

Can simulations assist in classification development?

Musculoskeletal simulations yields quantitative data on the unbiased effect of different biomechanical impairments.

Thus, we suggest a research initiative to evaluate if musculoskeletal simulations can assist experimental methods in

- dividing impairments into classes
- assessment of weight factors in 'competition format' classification

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Affiliation of authors: Marie Lund Ohlsson[1,2], Jonas Danvind[2,3] and presenter L. Joakim Holmberg[1,†]

1. Mechanics, Department of Management and Engineering, The Institute of Technology, Linköping University, Sweden
2. Mid Sweden University, Östersund, Sweden
3. The Swedish Sports Organization for the Disabled and The Swedish Paralympic Committee

† Correspondence: joakim.holmberg@liu.se

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