Background
Neuromuscular modelling to describe balance behaviour
Various balance control model parameters included

Methods
Inverted Pendulum Balance Control Model

Closed-loop human balance control model with sensory & neuromuscular subsystems\(^2\). The neuromuscular controller processes motion- & force-related feedback to generate corrective torques. The human body is represented by a single-link inverted pendulum, pivoting around the ankle axis. Input of the system is the support surface rotations & output the body excursion.

Sensitivity Analysis
The sensitivity of each model parameter was determined for both the FRF gain & phase, through the analytically obtained partial derivative, using the Matlab symbolic toolbox (Mathworks).

Results
Each subplot represents the sensitivity of the gain & phase of the FRF to the model main feedback parameters. The particular subset of parameters can be considered as crucial for balance control, being closely related to major patient groups with balance disorders. The green area denotes positive relation (increased parameter value); the red area negative relation (decreased parameter value). Note that each parameter has a different effect on the FRF, influencing specific frequency bands.

- \( K \) & \( K_o \) shape the FRF in the lower frequencies [0.1-1] Hz
- \( W \) affects the overall gain of the FRF & does not affect the phase
- \( K_o \) shapes the peak & the slope of the FRF in the [0.5-0.9] Hz range
- the effect of \( \tau_d \) is hard to detect in the FRF gain, but becomes apparent in the phase above 0.6 Hz

Conclusion
It is possible to uniquely determine the value of the sensory weighting parameter, the time delay, the derivative gain & the lumped sum of passive & active stiffness, making the used balance control model suitable to determine differences in these parameters in different patient groups.

Acknowledgments

Dynamic balance behaviour → Frequency Response Functions: relationship between external perturbations & the response, in terms of amplitude & timing

<table>
<thead>
<tr>
<th>Model subsystem</th>
<th>Name</th>
<th>Value [( 10^x )]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human body</td>
<td>mass - ( m )</td>
<td>75 [kg]</td>
</tr>
<tr>
<td></td>
<td>moment of inertia - ( J )</td>
<td>66 [kg m(^2)]</td>
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<tr>
<td></td>
<td>centre-of-mass height - ( h )</td>
<td>0.83 [m]</td>
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<tr>
<td>Intrinsic muscle</td>
<td>stiffness - ( K )</td>
<td>40.5 [Nm/rad]</td>
</tr>
<tr>
<td>properties</td>
<td>damping - ( B )</td>
<td>68.8 [Nms/rad]</td>
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<tr>
<td>Neural controller</td>
<td>proportional feedback gain - ( K_o )</td>
<td>943.9 [-]</td>
</tr>
<tr>
<td></td>
<td>derivative feedback gain - ( K_o )</td>
<td>313.5 [-]</td>
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<tr>
<td></td>
<td>time delay - ( \tau_d )</td>
<td>0.097 [s]</td>
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<tr>
<td>Sensory systems</td>
<td>sensory weighting parameter - ( W )</td>
<td>0.8 [-]</td>
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<tr>
<td>Muscle activation</td>
<td>eigen-frequency - ( \omega )</td>
<td>16.8 [rad/s]</td>
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<tr>
<td>dynamics</td>
<td>relative damping - ( \beta )</td>
<td>0.99 [-]</td>
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<tr>
<td>Force feedback</td>
<td>gain - ( K_f )</td>
<td>0.0018 [-]</td>
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<tr>
<td></td>
<td>time constant - ( T_f )</td>
<td>17.4 [s]</td>
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