INTRODUCTION

- Force feedback pathways are widely distributed and can be inter-joint and asymmetric.
- Proportional coordination (equal joint excursions) between the knee and ankle has been observed in cats over many behaviors despite the non-uniform mass distribution

Q: How does force-dependent feedback contribute to whole limb impedance and the coordination of multi-joint movement during yield?

H: Inhibitory intermuscular force-dependent feedback will reduce limb impedance and increase inter-joint coordination compared to a model with only uni-articular musculo-tendon representations

METHODS

\[ \begin{align*}
\mathbf{F} &= \mathbf{K}\mathbf{x} + \mathbf{B}\mathbf{x} + \mathbf{M}\ddot{\mathbf{x}} \\
\mathbf{K} &= \begin{pmatrix} K_{11} & K_{12} & \cdots & K_{1n} \\ K_{21} & K_{22} & \cdots & K_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ K_{n1} & K_{n2} & \cdots & K_{nn} \end{pmatrix} \\
\mathbf{B} &= \begin{pmatrix} B_{11} & B_{12} & \cdots & B_{1n} \\ B_{21} & B_{22} & \cdots & B_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ B_{n1} & B_{n2} & \cdots & B_{nn} \end{pmatrix} \\
\mathbf{M} &= \begin{pmatrix} M_{11} & M_{12} & \cdots & M_{1n} \\ M_{21} & M_{22} & \cdots & M_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ M_{n1} & M_{n2} & \cdots & M_{nn} \end{pmatrix}
\end{align*} \]

\[ \mathbf{F} = \begin{pmatrix} F_1 \\ F_2 \\ \vdots \\ F_n \end{pmatrix} \]

\[ \mathbf{x} = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} \]

\[ \mathbf{K} = \text{stiffness matrix} \]

\[ \mathbf{B} = \text{damping matrix} \]

\[ \mathbf{M} = \text{mass matrix} \]

\[ \tau_{\beta,j} = \begin{cases} \alpha_{hh} & \text{distal to proximal} \\ \alpha_{kk} & \text{proximal to distal} \end{cases} \]

\[ \tau_{\beta,j} = \begin{cases} \alpha_{hh} & \text{balanced} \\ \alpha_{kk} & \text{diagonal} \end{cases} \]

\[ \tau_{\beta,j} = \begin{cases} \alpha_{hh} & \text{no force feedback} \end{cases} \]

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CONCLUSIONS

- The impedance properties are frequency-dependent
- Impedance decreases with force feedback, as expected
- Feedback distributions from lowest to highest impedance (contrary to our hypothesis): distal to proximal, balanced, proximal to distal, diagonal only, and no force feedback
- Contrary to our hypothesis, proportionality between the hip and knee decreases with force feedback

FUTURE WORK

- Perform impedance analysis at the joint level
- Use the same procedure to study frequency dependent impedance properties in a three joint system
- Investigate the effect of changing the endpoint force direction on the impedance properties