**METHODS**

Simulation environment:
- Model used for simulation: OpenSim `gait2392` model
  - 23 degrees of freedom
  - 92 muscles
- Simulation type:
  - **Forward dynamic simulation**: motion produced by muscles acting across joints and accelerating limb segments
  - **Residual Reduction Analysis**: model is perturbed to increase dynamic consistency between kinematics and forces
  - **Computed Muscle Control**: muscle force profiles are optimized to match kinematics and boundary forces
- Kinematics and ground reaction forces:
  - **Kinematics and GRF supplied with model, one gait cycle**
- Simulation period:
  - **One full gait cycle**, starting at right heel strike, t=0.5s to 2.0s

Simulation of exoskeletal assistance:
- Equal & opposite torques were applied to segments connected by each joint, using OpenSim input files
- Torque profiles: half-sine functions; peak torque = 30 Nm

**RESULTS**

**Stance phase muscle work**
- **Stance phase baseline**
  - • Knee extensors working concentrically in mid stance to advance thigh
  - • Hip flexors working eccentrically to slow hip extension in terminal stance
- **Case 1 - stance phase knee extension assistance**
  - • Concentric work of knee extensors is lower than baseline; represents decreased knee extensor function that is compensated for by robotic assistance
  - • Eccentric work of hip flexors is higher than baseline
- **Case 2 - swing phase hip flexion assistance**
  - • Minor effects on stance phase muscle work

**Swing phase muscle work**
- **Swing phase baseline**
  - • Hip flexors working concentrically to accelerate limb forward
  - • Knee extensors working eccentrically to control knee flexion
- **Case 1 - stance phase knee extension assistance**
  - • Minimal effect on swing phase muscle work
- **Case 2 - swing phase hip flexion assistance**
  - • Concentric work of hip flexors is lower than baseline; represents decreased hip flexor function that is compensated for by robotic assistance
  - • Net eccentric work of knee extensors is lower than baseline. Additional concentric work occurs in late swing

**DISCUSSION**

- Two simulations of robotic joint torque assistance during walking were performed, by applying equal and opposite segmental torques to adjacent limb segments within a pre-existing modeling environment
- Differences in computed muscle powers consistent with expected effects were observed. When robotic torques were assistive to the effects of concentrically activated muscles, lower powers in muscles from those agonistic muscles were calculated.
- Utility of this method will be tested when using measured robotic torques, segmental kinematics, and ground reaction forces.
- Comprehensive simulations should also incorporate elements such as external forces from crutches, canes, or walkers, mass and inertia of the exoskeleton, as well as subject specific muscle architecture and skeletal scaling.
- This approach has the potential to aid the understanding of functional adaptation to robotic exoskeleton assistance.
  - Our group is currently performing several studies on the effects of intensive exoskeletal training.

**REFERENCES**


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