Effect of Timing of Hip Extension Assistance with IMU-based Iterative Control during Loaded Walking with a Soft Exosuit

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MOTIVATION
- Walking variability in joint kinematics and kinetics makes it harder for same effective external assistive force to provide metabolic benefits to all wearers.
- Understanding the effects of different hip assistive profiles is a fundamental step of designing assistive device that can provide higher metabolic benefits.
- Limited literature with studies exploring the effects of timing and magnitude of assistance on hip joint.

HYPOTHESIS
- Proposed controller can adapt different kinematics and kinetics and provide consistent hip joint assistance.
- Onset timing and peak force timing can regulate the amount of positive mechanical power delivered to the hip joint which is related to metabolic cost of walking.

AIM
- Model soft exosuit to determine how to appropriate apply the desired assistive force through a soft exosuit.
- Design and validate the performance of IMU-based iterative control across different subjects.
- Investigate the effect of onset and peak timings between hip assistive profiles by means of a soft exosuit.

MODELING
- Model soft exosuit to determine how to appropriate apply the desired assistive force through a soft exosuit.

CONTROLLER
- Detect the onset timing with maximum thigh flexion point from IMU

METHOD
- Eight male healthy participants (age 29.8 ± 5.0 yr, weight 82.6 ± 5.8 kg, height 1.79 ± 0.05 m, mean ± SD)
- A baseline condition: 23 kg loaded walking on treadmill at 1.5 m/s
- Four conditions: early-start-early-peak (ESEP), early-start-late-peak (ESLP), late-start-early-peak (LESP), late-start-late-peak (LSLP).
- Measurements: metabolic cost, kinematic data, ground reaction force, electromyographic signal (EMG).

RESULT

Force tracking performance
- Peak timing:
  Target: 23%
  Average: 22.7 ± 0.6%

- Peak magnitude:
  Target: 200N
  Average: 198.2 ± 1.6N

Different assistive force profiles:
- Onset timing (90%, 0%)
- Peak timing (13%, 17%)
- Peak force 200N

Delivered positive mechanical power & metabolic reduction:

\begin{tabular}{|c|c|c|c|c|}
\hline
 & ESEP & ESLP & LSEP & LSLP \\
\hline
Delivered positive power (W·kg\textsuperscript{-1}) & 0.198 & 0.219 & 0.185 & 0.198 \\
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Metabolic reduction (%) & 5.7 & 8.5 & 6.3 & 7.1 \\
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DISCUSSION & CONCLUSION
- Demonstrated IMU-based iterative controller can deliver robust hip extension assistive profiles across subjects.
- Different assistive conditions provided insight on how to manipulate actuation timing to regulate positive mechanical power to augment human walking.
- ESLP provided highest mechanical positive power and highest metabolic reduction, suggesting that starting the assistance at terminal swing with a later peak force may be the most beneficial strategy.

FUNDING ACKNOWLEDGMENT