

Passive arm-leg coupling redistributes mechanical effort, increasing upper limb contribution while reducing lower limb demand – supporting coordinated movement during post-spaceflight rehabilitation.

BACKGROUND

- Human walking relies on coordinated arm-leg motion to maintain balance, efficiency, and smooth forward progression.
- Although arm swing contributes to whole-body coordination, it provides little direct propulsion, leaving upper-limb mechanical energy largely underutilized.
- In reduced-gravity environments, neuromuscular deconditioning can impair coordination, decrease lower-limb strength, and make efficient gait recovery more difficult.

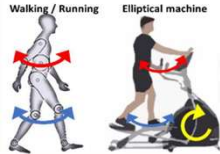


Figure 1. Natural arm-leg coordination patterns during gait.

BIO-INSPIRED PASSIVE COUPLING DESIGN (V2)

The exosuit mechanically couples upper and lower limb joints using biologically inspired coordination patterns to enable efficient energy redistribution.

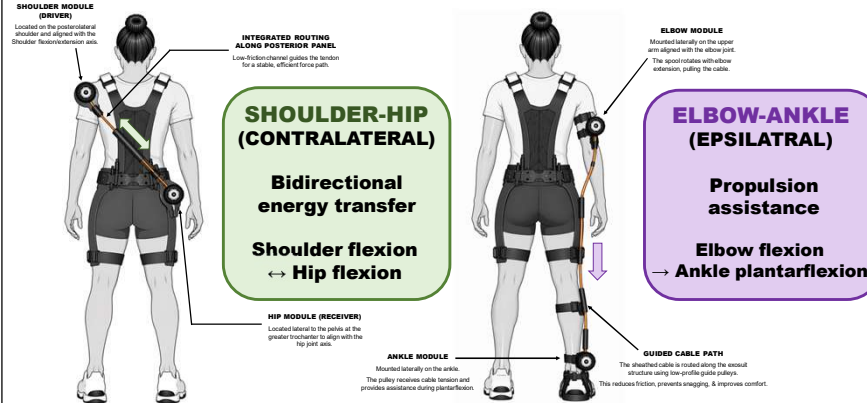


Figure 2. Contralateral shoulder-hip & ipsilateral elbow-ankle coupling configurations in the V2 exosuit.

EXPERIMENTAL PROTOTYPE (V1)

FRONT VIEW SIDE VIEW BACK VIEW

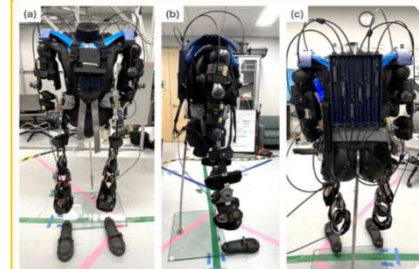


Figure 7. Full-body exosuit prototype used for human subject testing.

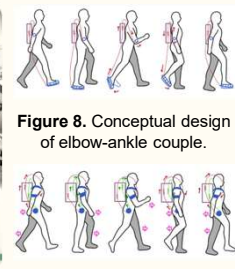


Figure 8. Conceptual design of elbow-ankle couple.

Figure 9. Conceptual design of shoulder-hip couple.

METHODS

PARTICIPANTS

15 healthy adults (18-30 y.o.)

CONDITIONS

- BL Baseline
- S1 Device worn, disengaged
- S2 Device worn, engaged

MEASUREMENTS

- EMG Muscle activity
- IMU Kinematics
- Metabolic Cost (VO₂, HR)

MECHANISM OVERVIEW

The exosuit uses a passive cable-driven transmission to transfer mechanical energy between upper and lower limb joints, as implemented in the experimental prototype and refined in the current design.

- Bowden cables** route forces along the body while allowing natural joint motion.
- Pulleys & gears** convert joint rotation into controlled cable displacement.
- Spring elements** store and release energy to assist movement.
- Passive system** redistributes existing energy without motors.

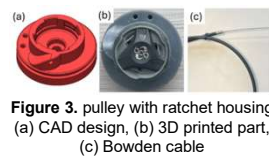


Figure 3. pulley with ratchet housing (a) CAD design, (b) 3D printed part, (c) Bowden cable

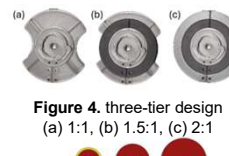


Figure 4. three-tier design (a) 1:1, (b) 1.5:1, (c) 2:1



Figure 5. tensional spring with cable crimped on each loop.

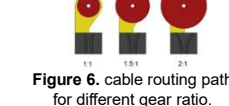


Figure 6. cable routing path for different gear ratio.

SPACE RELEVANCE

Long-duration spaceflight causes:

- Muscle atrophy (esp. lower limb)
- Degraded coordination & control
- Increased fatigue during re-adaptation

We need lightweight, low-power, systems that promote coordinated, whole-body movement.

OBJECTIVES

This work explores a passive arm-leg coupling exosuit (ALICE) to:

- Redistribute mechanical effort across limbs
- Reinforce natural gait coordination
- Reduce lower limb demand during walking
- Enable post-spaceflight rehabilitation

KEY FINDINGS

NATURAL GAIT PRESERVED

LOWER LIMB MUSCLE DEMAND DECREASED

UPPER LIMB CONTRIBUTION INCREASED (SUCCESSFUL ENERGY REDISTRIBUTION)

CONCLUSION

- Passive arm-leg coupling enables redistribution of mechanical effort across the body while preserving natural gait patterns.
- This approach presents a promising, low-power strategy for post-spaceflight neuromechanical rehabilitation.

RESULTS

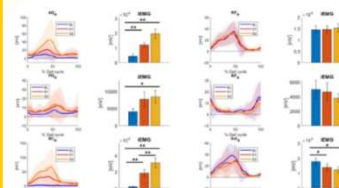


Figure 10. Group results for muscle activity data (*p<0.05, **p<0.01).

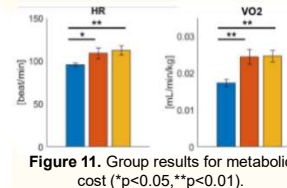


Figure 11. Group results for metabolic cost (*p<0.05, **p<0.01).

- Lower limb muscle activation decreased while upper limb activation increased.
- Joint kinematics and plantar pressure patterns were preserved, indicating minimal disruption to natural gait.
- Metabolic cost increased slightly, likely due to added system mass.

DISCUSSION

- Passive coupling enables whole-body coordination by leveraging natural arm-leg dynamics.
- Mechanical effort is redistributed rather than augmented, reducing reliance on lower limbs.
- This approach aligns with rehabilitation strategies focused on restoring coordinated movement.