Design and Evaluation of a Single-Sided Mobility Assistive Exoskeleton (SMAEXO) for Hemiplegia

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BACKGROUND

65% of stroke survivors have multi-joint hemiparesis, leading to unstable, inefficient gait. While exoskeletons aid rehab, most are bilateral, limiting unaffected side mobility, or unilateral with single-joint support, lacking comprehensive assistance. This highlights the need for unilateral, multi-joint exoskeletons with improved usability, comfort, and safety.

OBJECTIVE

- Develop SMAEXO, a unilateral multi-joint exoskeleton providing intuitive assist to the affected hip, knee, and ankle, while allowing natural movement of the unaffected side. The design optimizes force management and weight distribution for better stability, comfort, and usability.
- Validate SMAEXO's usability, comfort, safety, and effectiveness through an experimental user study involving eight participants, assessing its practical potential in enhancing gait rehabilitation for stroke survivors.

METHODOLOGY

- SMAEXO was co-developed with physiotherapists to meet hemiplegic users' needs, featuring a modular design with Back Module, Vest Harness, and Unaffected Module, and Affected-side Module.

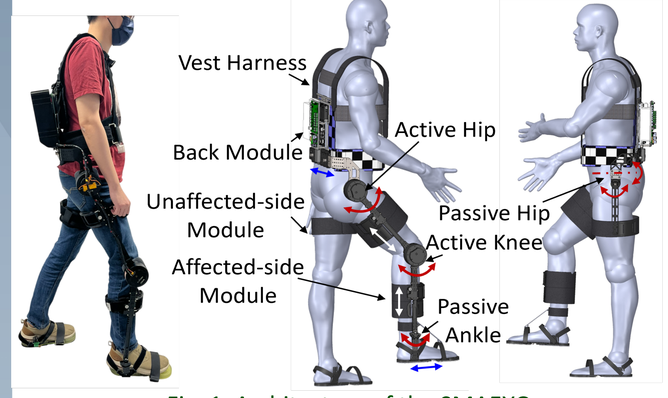


Fig. 1. Architecture of the SMAEXO.

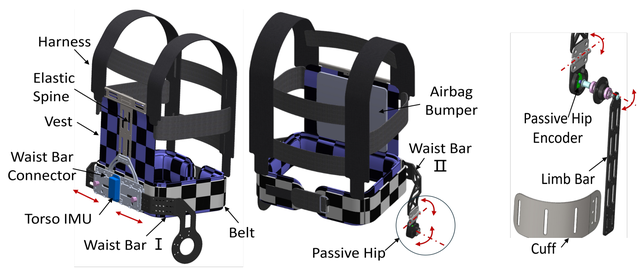


Fig. 2. Back Module with Vest Harness(left) and Unaffected-side Module (right).

Table I: Specifications of the SMAEXO

Items	Specifications
Motion Ranges (°)	Hip:(-20, 125); Knee:(0, 135); Ankle:(-40, 24)
Length Ranges (mm)	Upper Limb: 400–500 (Long), 300–400 (Short); Lower Limb: 380–480 (Long), 280–380 (Short); Hip Width: 335–435; Feet: 250–305
Hip/ Knee Motors	Rated Torque: 12Nm; Max Torque: 37Nm; Ratio: 1:6; Weight: 0.759kg
Battery	Lithium Battery Pack, 24V 6Ah, 0.82kg
Weight (kg)	Total: 7.5; Affected-side Module: 3.3; Vest Harness: 1.8; Unaffected-side Module: 0.3; Back Module: 2.1

KEY FEATURES

Comprehensive & Personalized Gait Assistance
- Active hip/knee, passive ankle for smooth gait assistance.
- Adjustable assistance tailored to gait phases, tasks, and impairments.
- Validated in 5 stroke survivors with variable gait deficits across sit-to-stand, walking and obstacle crossing.

Lightweight & Modular Design
- Rapid modular assemble/disassemble.
- Tool-free resizing to accommodate various body shapes.

Optimized Force & Weight Management
- Efficient load transfer to the core and ground via harness and footplates.
- Enhanced user comfort and stability over prolonged use.

Adjustable Ankle Joint & Realistic Ground Interaction
- Flexible footplate with force sensors for natural ground contact and gait detection.
- Angle-adjustable ankle joint enables free motion and controlled support for foot drop.

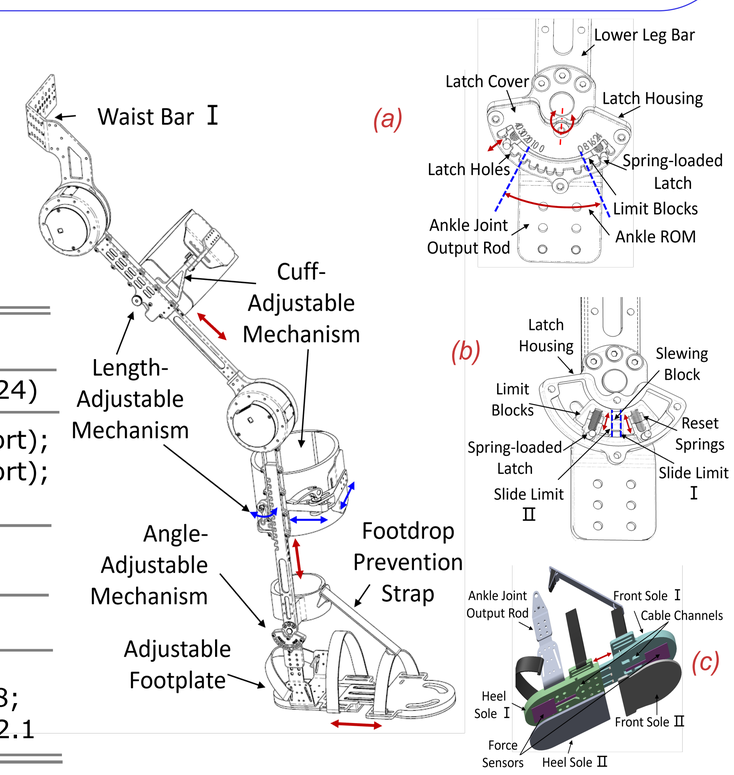
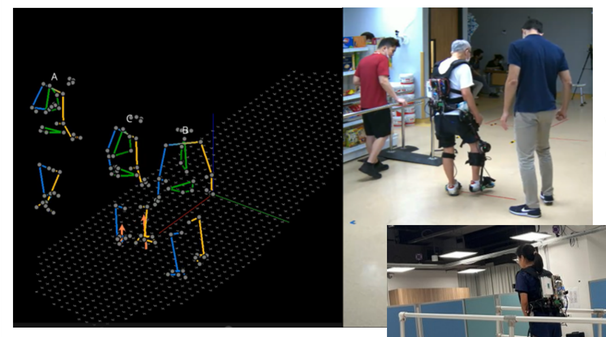


Fig. 3. Affected-side Module with adjustable ankle joint and flexible footplates. Ankle joint allows limited movement (a) or fixed angle (b) to prevent foot drop. Footplates (c) feature adjustable sizing, integrated force sensors for gait detection, and durable materials (PU, rubber, EVA) for enhanced comfort.

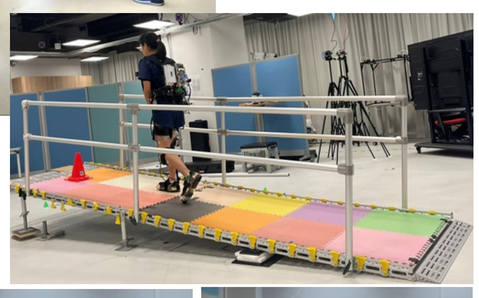
EXPERIMENTS & RESULTS

- 8 participants evaluated SMAEXO across level walking, slope walking, and obstacle crossing tasks with and without the device.
- After familiarization and testing, participants completed a questionnaire rating SMAEXO's usability, comfort, safety, and assistance on a 5-point scale.



Task 1: Level Walking with markerless Motion Capture System

Task 2: Slope Walking



Task 3: Obstacle Crossing



RESULTS

- SMAEXO was rated comfortable, safe, and effective in reducing effort, though balance issues during donning and weight on the unaffected limb were noted.
- Its modular, lightweight design and flexible footplates were appreciated; improvements in breathability are needed.
- SMAEXO offers good mobility and force management, with room for further weight reduction.

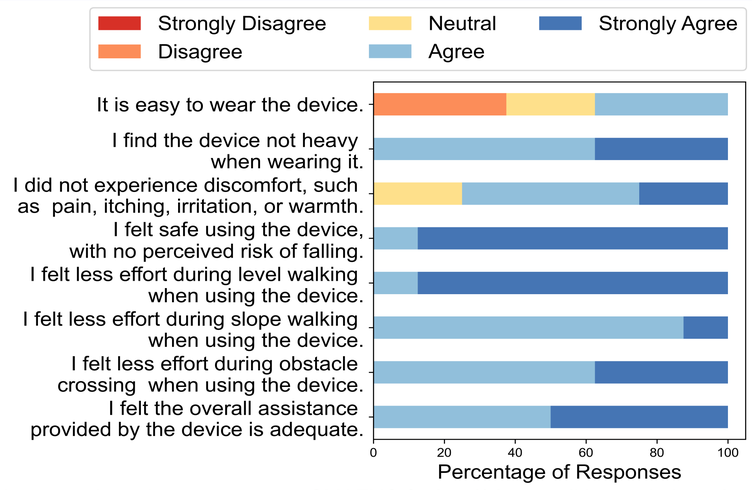
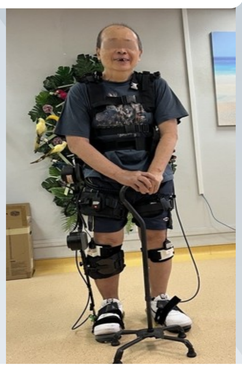


Fig. 4. User questionnaire responses on SMAEXO for level/slope walking and obstacle tasks.

CONCLUSION AND FUTURE WORK

Table II: Comparison of Unilateral Multi-Joint Exoskeletons

Devices	HAL(Cyberdyne)	LiteStepper(Angelexo)	SMAEXO(NTU)
Control Strategy	Model-based control (amplify muscle activities) or Predefined gait trajectory	Replicate gait trajectory of intact limb & Crutch handle to initiate walk	Hybrid model-based control for personalized assist
Actuators	2 Brushless DC motors	2 Brushless DC motors	2 QDD motors
Sensors Used	Kinematic Sensors Sole Pressure Sensors EMGs	Kinematic Sensors Sole Pressure Sensors Cane Pressure Sensor	Kinematic Sensors (4) Sole Pressure Sensors
Footplates Type	Customized shoes with rigid shoes insole	Mechanical footplates	Flexible & adjustable footplates
Weight Support	Rigid Sole (ground)	Vest (core) Footplate (ground)	Vest Harness (core) Footplate (ground)
Weight	9 kg	16.9 kg	7.5 kg



- This study introduced SMAEXO, a unilateral multi-joint exoskeleton providing effective hip and knee support with a passive ankle for dynamic gait assistance and user-friendly design.
- Eight participants reported it as safe, comfortable, and effective, with suggested improvements in cooling and donning.
- Future work includes larger-scale trials with post-stroke users to validate effectiveness and guide further refinements.

A collaboration between:

Catalysed by:

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