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Title: Soft Hip Exoskeleton Reduces Physiological Cost and Perceived Exertion in Older Adults During Uphill Walking

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes, all done**

3. Filming location: Will the filming need to take place in multiple locations? **No**

4. Testimonials (optional): Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **No**

Current Protocol Length

Number of Steps: 20

Number of Shots: 46 (4 SC)

Interviews

Videographer: Obtain headshots for all authors available at the filming location.

Authors: Please note that **the questions will not appear on screen**. Please answer in **stand-alone full sentence with sufficient context**

INTRODUCTION:

~~REQUIRED: Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Xiaohong Wu:** We test if a soft hip exoskeleton reduces physiological cost and fatigue in older adults walking uphill.
 - 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~Describe the research gap or limitation in existing methods and how this protocol addresses them.~~

- 1.2. **Xiaohong Wu:** Traditional rigid exoskeletons are too heavy, but our soft device offers lightweight and adaptive help.
 - 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

CONCLUSION:

~~What does this protocol allow researchers to study or measure?~~

- 1.3. **Xiaohong Wu:** This protocol evaluates physiological cost and muscle fatigue during uphill walking.
 - 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~Describe the most important consideration or challenge when performing this protocol.~~

- 1.4. **Xiaohong Wu:** The main challenge is putting the device on correctly and choosing the best setting for balance.
 - 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

- 1.5. **Xiaohong Wu**: Future studies can test real-world outdoor hills and include a larger group of diverse patients.

- 1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Videographer: Obtain headshots for all authors available at the filming location.

Ethics Title Card

This research has been approved by the Clinical Research Ethics Committee of the First Affiliated Hospital, Zhejiang University School of Medicine

Protocol

***Videographer:** Please always record an audio slate while filming each shot mentioned in the shotlist.*

2. Experimental Setup

Demonstrators: Xiaohong Wu and Zhao Yao

- 2.1. To begin, explain the study procedures to a participant aged 60 to 75 years and confirm that they can walk independently on a treadmill for at least 15 minutes [1].
 - 2.1.1. WIDE: Talent seated with an older adult participant in the laboratory, and explaining the procedure while pointing to the treadmill. ***Videographer:** Please obtain CU shot as well for this shot.*
- 2.2. Set the treadmill parameters to 3.5 kilometers per hour and a 15 percent incline [1]. Attach a magnetic safety lanyard from the participant's belt to the treadmill auto-stop switch [2], and keep a supervising researcher within continuous reach of the manual emergency stop button [3].
 - 2.2.1. Talent setting the treadmill to 3.5 kilometers per hour and a 15 percent incline.
 - 2.2.2. Talent attaching the magnetic safety lanyard from the participant's belt to the treadmill auto-stop switch.
 - 2.2.3. Talent asking another talent to stand beside the treadmill and showing the emergency stop button.
- 2.3. Prepare the exoskeleton device before testing [1]. Verify that the battery charge level is greater than 90 percent [2]. Manually inspect the drive units to confirm the absence of cable entanglement, mechanical binding, or excessive friction in the transmission mechanisms [3].
 - 2.3.1. Talent placing the exoskeleton on the setup table and opening/positioning the device for inspection.
 - 2.3.2. Talent verifying and pointing to the exoskeleton battery charge level greater than 90 percent.
 - 2.3.3. Talent manually inspecting the drive units.
- 2.4. Configure the exoskeleton to operate in the terrain-adaptive Climbing, Downhill, and Flat modes, with five assistance levels providing up to 18 newton-meters of torque [1].

In the **Climbing Mode**, enable the gait-learning algorithm and angle-triggered mechanism within the 0 to 90 degree range to synchronize hip flexion assistance with the participant's gait cycle [2]. Personalize the assistance magnitude, predominantly at levels 3 or 4, based on participative tolerance during adaptation [3].

- 2.4.1. CLOSE-UP: Talent pressing the physical buttons on the exoskeleton to switch terrain-adaptive assistance modes and intensity levels.
- 2.4.2. CLOSE-UP: Talent holding the button to set Climbing Mode and verifying the status via the device's physical indicator lights.
- 2.4.3. CLOSE-UP: Talent clicking the intensity buttons to personalize the assistance magnitude to level 3 or 4.

2.5. Attach a heart rate monitor to the participant for continuous data recording [1]. Print the Borg rating of perceived exertion scale from 6 to 20 and the visual analog pain scale from 0 to 10 on A4 paper [2]. Position the printed scales within the participant's line of sight for easy access during testing [3].

- 2.5.1. Talent fitting the participant with a heart rate monitor.
- 2.5.2. Talent taking a printed sheet from the printer and showing the Borg rating of perceived exertion scale and visual analog pain scale on A4 paper.
- 2.5.3. Talent positioning the printed scales within the participant's clear line of sight.

3. Device Donning and Adaptation Session (Unblinded Phase)

3.1. Check the participant's height to select the appropriate device size [1]. Select Size L for a height greater than 165 centimeters and Size M for a height less than or equal to 165 centimeters [2]. Assist the participant in donning the shoulder straps [3].

- 3.1.1. Talent checking the participant's height using a tape fitted against the wall.
- 3.1.2. Talent selecting the appropriate device size based on participant height.
- 3.1.3. Talent assisting the participant in donning the shoulder straps.

3.2. Adjust the back module height so that the lateral hip motor units align with the participant's greater trochanter [1] and fasten the magnetic waist buckle [2]. Tighten the lateral adjustment straps above the iliac crest to anchor the device securely to the pelvis and prevent slippage [3].

- 3.2.1. Talent adjusting the back module height to align the lateral hip motor units with the greater trochanter.
- 3.2.2. Talent fastening the magnetic waist buckle.
- 3.2.3. Talent tightening the lateral adjustment straps above the iliac crest.
- 3.3. To secure the leg connection, align the thigh struts approximately 5 to 10 centimeters above the patella [1]. Secure the hooks [2], and rotate the Boa dial clockwise to tighten the thigh straps [3].
 - 3.3.1. Talent aligning the thigh struts approximately 5 to 10 centimeters above the patella.
 - 3.3.2. Talent securing the hooks.
 - 3.3.3. Talent rotating the Boa dial clockwise to tighten the thigh straps.
- 3.4. Verify proper strap tension by ensuring approximately 1 to 1.5 centimeters of clearance when the strap is pulled away from the skin [1]. Have the participant perform squats and high-leg lifts to confirm there is no mechanical interference or excessive cable tension [2].
 - 3.4.1. Talent checking and pointing to the clearance between the strap and the skin while pulling the strap perpendicular to the skin.
 - 3.4.2. Talent observing the participant performing squats and high leg lifts.
- 3.5. For the 15-minute adaptation session, remove the device [1] and ask the participant to walk on the treadmill at 3.5 kilometers per hour and a 15 percent incline for 5 minutes [2].
 - 3.5.1. Talent removing the device from the participant.
 - 3.5.2. Talent gesturing a thumbs up to the participant, and the participant begins to walk without the device on the treadmill.
- 3.6. Next, have the participant walk with the unpowered exoskeleton for 5 minutes [1]. Then turn on the device and let the participant walk with the powered exoskeleton for 5 minutes [2] while gradually increasing the assistance intensity from setting 1 to their preferred comfort level [3]. After adaptation, have the participant rest in a seated position for 20 minutes before the formal trials to ensure that heart rate and perceived exertion return to baseline [4].

- 3.6.1. Participant walking while wearing the unpowered exoskeleton.
- 3.6.2. Turning the device assistance on and participant walking with the powered exoskeleton.
- 3.6.3. Shot of adjusting the assistance intensity.
- 3.6.4. Talent asking the participant to take a seat and the participant taking a seat.

4. Intervention and Blinding

- 4.1. ~~Randomize the order of the three experimental conditions using a computer-generated sequence to minimize learning and fatigue effects [1].~~ Cover all light-emitting diode indicators, including power and mode lights, with black electrical tape to maintain visual blinding [2].
 - 4.1.1. Talent using a computer and generating/showing a randomized order list. **NOTE:**
Not filmed, VO moved as on-screen text
 - 4.1.2. Talent covering the device power and mode light-emitting diode indicators with black electrical tape.
- 4.2. In the NO_EXO (*no exo*) condition, have the participant walk in standard sportswear without the exoskeleton [1-TXT]. In the EXO_ON (*exo-on*) condition, activate the device in Climbing Mode with the assist intensity set to level 3 or 4 [2].
 - 4.2.1. Talent observing the participant walking in standard sportswear without the exoskeleton. **TXT: Randomize the order of the 3 experimental conditions**
 - 4.2.2. Talent activating the device in Climbing Mode and adjusting the assist intensity set to level 3 or 4.
- 4.3. Adjust the assistance level until the participant shows a stable gait pattern without postural instability, compensatory movements, or discomfort [1].
 - 4.3.1. Talent observing the participant's gait on the treadmill and Shot of adjusting the assistance level.
- 4.4. Provide a 40-minute seated rest period between trials to allow heart rate and fatigue levels to return to baseline [1].
 - 4.4.1. Talent asking the participant to take a seat.

5. Simulated Uphill Walking Task (Blinded Assessment)

- 5.1. Have the participant walk naturally on the treadmill for 15 minutes without holding the handrails unless required for safety [1]. Continuously record heart rate during the task [2].
 - 5.1.1. Talent observing and the participant walking naturally on the treadmill.
 - 5.1.2. Talent observing the participant's smartwatch to confirm continuous and normal heart rate recording during walking.
- 5.2. Average the data collected between minutes 12 and 15 at a sampling rate of 1 hertz to calculate the steady-state heart rate [1]. Define the absolute highest rate recorded during the task as the peak heart rate [2].
 - 5.2.1. SCREEN: 5.2.1..mov.
 - 5.2.2. SCREEN: 5.2.2..mov.
- 5.3. At minute 14, ask the participant to report the level of exertion using the Borg rating of perceived exertion scale [1].
 - 5.3.1. Talent asking and the participant reporting exertion.
- 5.4. Immediately after the task, visually inspect the skin contact areas for erythema, blisters, or pressure marks [1]. Record joint pain using a 0 to 10 centimeter visual analog scale, where 0 indicates no pain, and 10 indicates the worst imaginable pain [2]. Classify scores greater than or equal to 4 as clinically significant discomfort requiring further evaluation [3].
 - 5.4.1. Talent visually inspecting the participant's skin contact areas and pointing to any abnormalities.
 - 5.4.2. Talent recording joint pain using the 0 to 10 centimeter visual analog scale.
 - 5.4.3. SCREEN: 5.4.3.-.mov.
- 5.5. Finally, calculate the Physiological Cost Index by subtracting resting heart rate from walking heart rate and dividing the result by walking speed [1].
 - 5.5.1. SCREEN: 5.5.1..mov.

Results

6. Results

- 6.1. A total of 20 healthy older adults, including 10 male and 10 female participants, completed all 3 walking conditions without any reported adverse events [1].
 - 6.1.1. LAB MEDIA: Table 1. *Video editor: Highlight the rows showing "Gender," with "10 male" and "10 female,"*
- 6.2. The EXO_ON condition resulted in a significantly lower physiological cost index [1] than the NO_EXO (*no exo*) condition [2] and the EXO_OFF (*exo off*) condition [3]. The NO_EXO index was also significantly lower [4] than EXO_OFF [5].
 - 6.2.1. LAB MEDIA: Figure 2. *Video editor: Highlight the EXO_ON box plot .*
 - 6.2.2. LAB MEDIA: Figure 2. *Video editor: Highlight the NO_EXO box plot .*
 - 6.2.3. LAB MEDIA: Figure 2. *Video editor: Highlight the EXO_OFF Boxplot.*
 - 6.2.4. LAB MEDIA: Figure 2. *Video editor: Highlight the NO_EXO box plot .*
 - 6.2.5. LAB MEDIA: Figure 2. *Video editor: Highlight the EXO_OFF Boxplot.*
- 6.3. Exploratory paired comparisons showed lower peak heart rates in the EXO_ON condition (*exo on*) [1] than the NO_EXO [2] and EXO_OFF conditions [3].
 - 6.3.1. LAB MEDIA: Figure 3. *Video editor: Highlight the EXO_ON box plot .*
 - 6.3.2. LAB MEDIA: Figure 3. *Video editor: Highlight the NO_EXO box plot .*
 - 6.3.3. LAB MEDIA: Figure 3. *Video editor: Highlight the EXO_OFF Boxplot.*
- 6.4. Participative fatigue measured by the Borg Rating of Perceived Exertion scale was significantly lower in EXO_ON [1] than in EXO_OFF [2], but was not significantly different from NO_EXO [3].
 - 6.4.1. LAB MEDIA: Figure 4. *Video editor: Highlight EXO_ON boxplot*
 - 6.4.2. LAB MEDIA: Figure 4. *Video editor: Highlight EXO_OFF boxplot*
 - 6.4.3. LAB MEDIA: Figure 4. *Video editor: Highlight NO_EXO boxplot*

1. Exoskeleton
Pronunciation link: <https://www.merriam-webster.com/dictionary/exoskeleton>
IPA: /ˌɛk-so-ˈske-lə-tən/
Phonetic Spelling: ek·soh·skel·uh·tuhn
2. Treadmill
Pronunciation link: <https://www.merriam-webster.com/dictionary/treadmill>
IPA: /ˈtred-ˌmil/
Phonetic Spelling: tred·mil
3. Lanyard
Pronunciation link: <https://www.merriam-webster.com/dictionary/lanyard>
IPA: /ˈlan-yərd/
Phonetic Spelling: lan·yerd
4. Torque
Pronunciation link: <https://www.merriam-webster.com/dictionary/torque>
IPA: /ˈtɔrk/
Phonetic Spelling: tork
5. Terrain
Pronunciation link: <https://www.merriam-webster.com/dictionary/terrain>
IPA: /tə-ˈrān/
Phonetic Spelling: tuh·rayn
6. Gait
Pronunciation link: <https://www.merriam-webster.com/dictionary/gait>
IPA: /ˈgāt/
Phonetic Spelling: gayt
7. Flexion
Pronunciation link: <https://www.merriam-webster.com/dictionary/flexion>
IPA: /ˈflek-shən/
Phonetic Spelling: flek·shuhn
8. Trochanter
Pronunciation link: <https://www.merriam-webster.com/dictionary/trochanter>
IPA: /trō-ˈkan-tər/
Phonetic Spelling: troh·kan·ter
9. Iliac
Pronunciation link: <https://www.merriam-webster.com/dictionary/iliac>
IPA: /ˈi-lē-ˌak/
Phonetic Spelling: il·ee·ak
10. Patella
Pronunciation link: <https://www.merriam-webster.com/dictionary/patella>
IPA: /pə-ˈte-lə/
Phonetic Spelling: puh·tel·uh
11. Pelvis
Pronunciation link: <https://www.merriam-webster.com/dictionary/pelvis>
IPA: /ˈpel-vəs/
Phonetic Spelling: pel·vis

12. Erythema

Pronunciation link: <https://www.merriam-webster.com/dictionary/erythema>

IPA: /,er-ə-'thē-mə/

Phonetic Spelling: air·uh·thee·muh

13. Physiological

Pronunciation link: <https://www.merriam-webster.com/dictionary/physiological>

IPA: /,fī-zē-ə-'lä-ji-kəl/

Phonetic Spelling: fiz·ee·uh·loj·i·kuhl

14. Exertion

Pronunciation link: <https://www.merriam-webster.com/dictionary/exertion>

IPA: /ig-'zər-shən/

Phonetic Spelling: ig·zer·shuhn

15. Adaptation

Pronunciation link: <https://www.merriam-webster.com/dictionary/adaptation>

IPA: /,a-dap-'tā-shən/

Phonetic Spelling: uh·dap·tay·shuhn