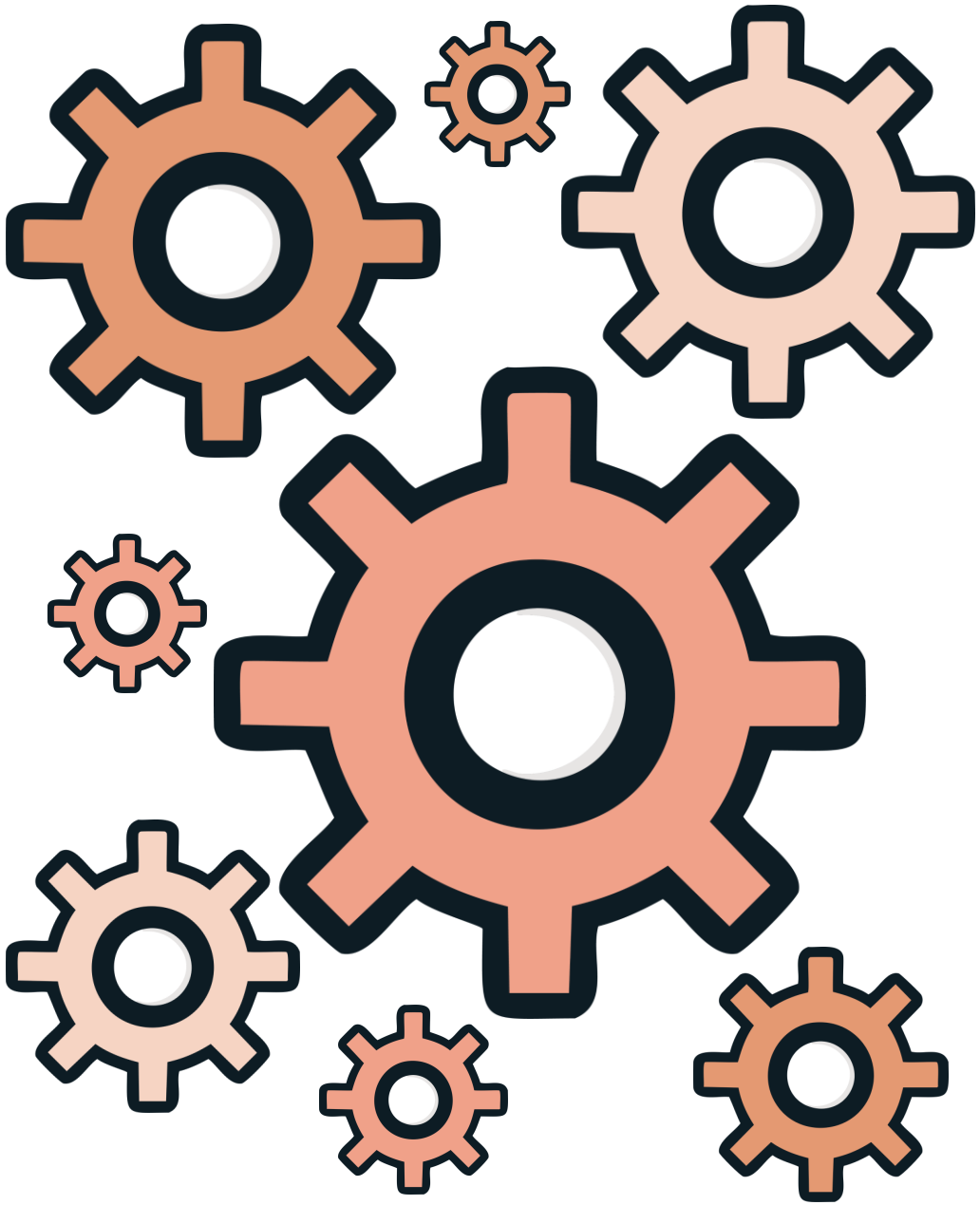


HARNESSING HUMAN NEUROMOTOR LEARNING IN EXOSKELETON DESIGN

MEGHAN E. HUBER, PH.D.

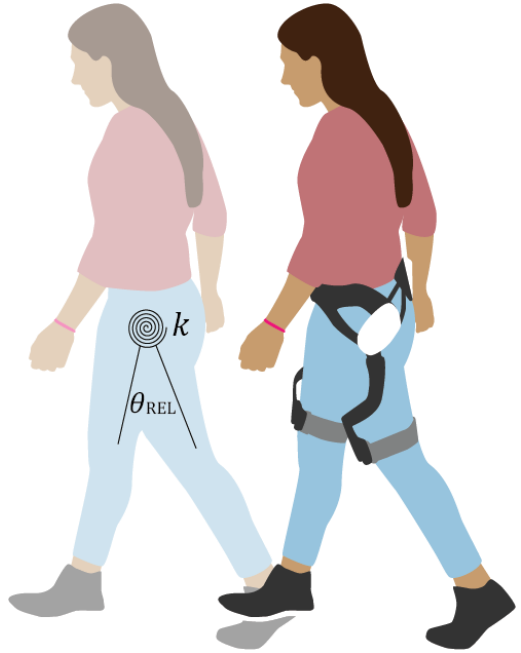
Assistant Professor

Department of Mechanical and Industrial Engineering

University of Massachusetts Amherst

HRSL

HUMAN ROBOT SYSTEMS LABORATORY
UMASS AMHERST

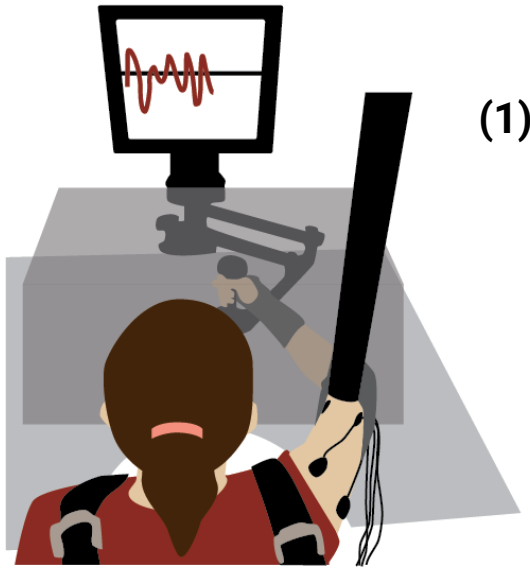


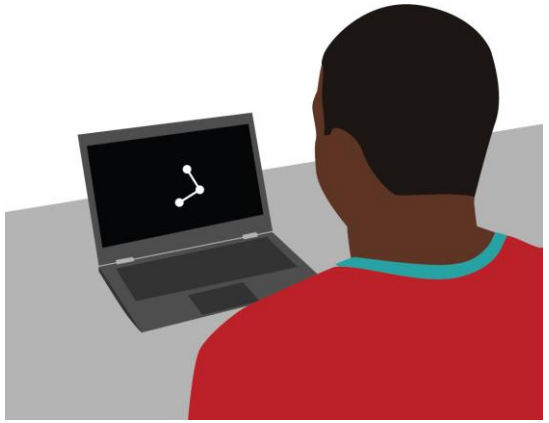
Our mission is to understand mechanisms of human interaction with the physical world, leveraging this understanding to

(1) enhance human complex skill learning with robotic systems (rehab exos),
(2) facilitate seamless human-robot collaboration (assistive exos), and
(3) improve the control of robot interactions

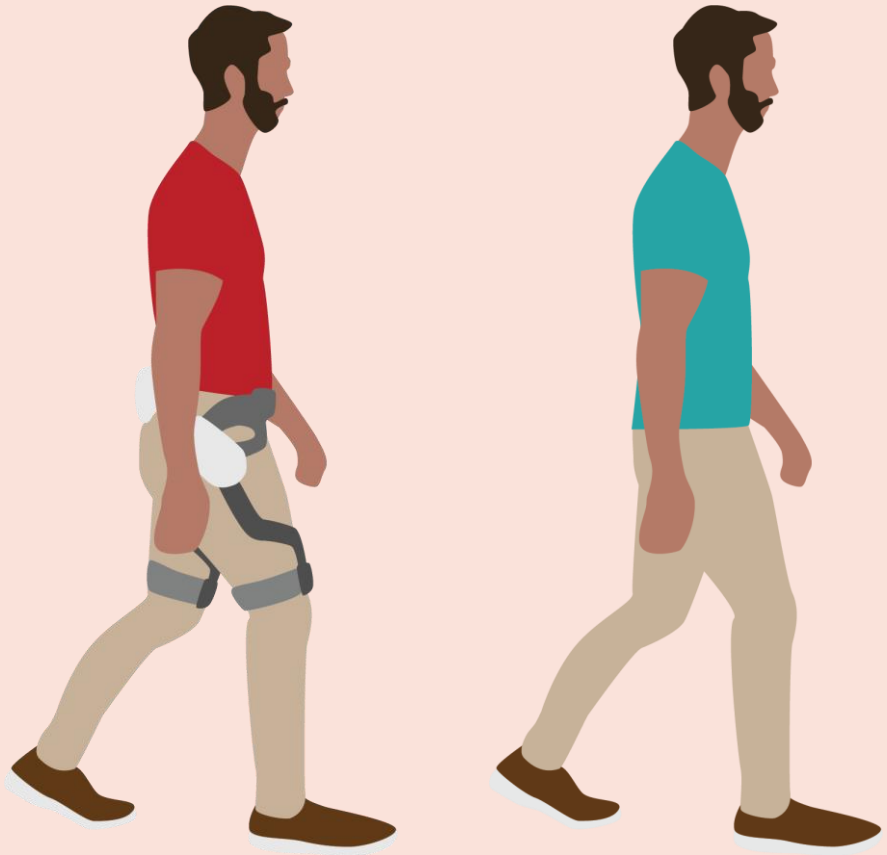
This highly interdisciplinary research lies at the intersection of robotics, dynamics, controls, human neuroscience, and biomechanics.

hrs-lab.org

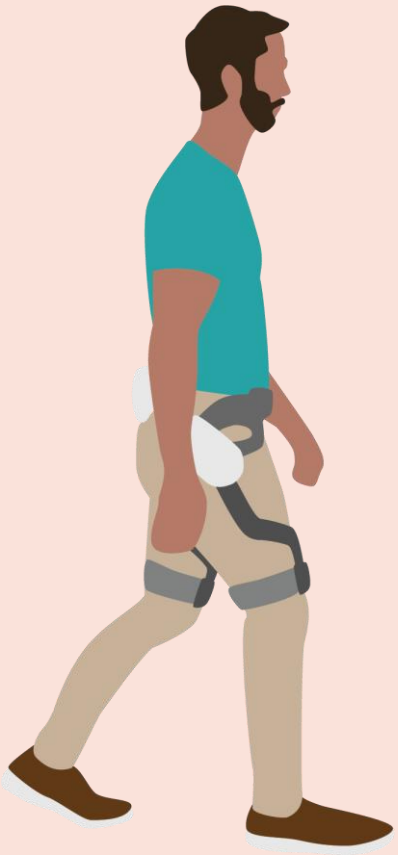




DIFFERENT EXOSKELETON GOALS

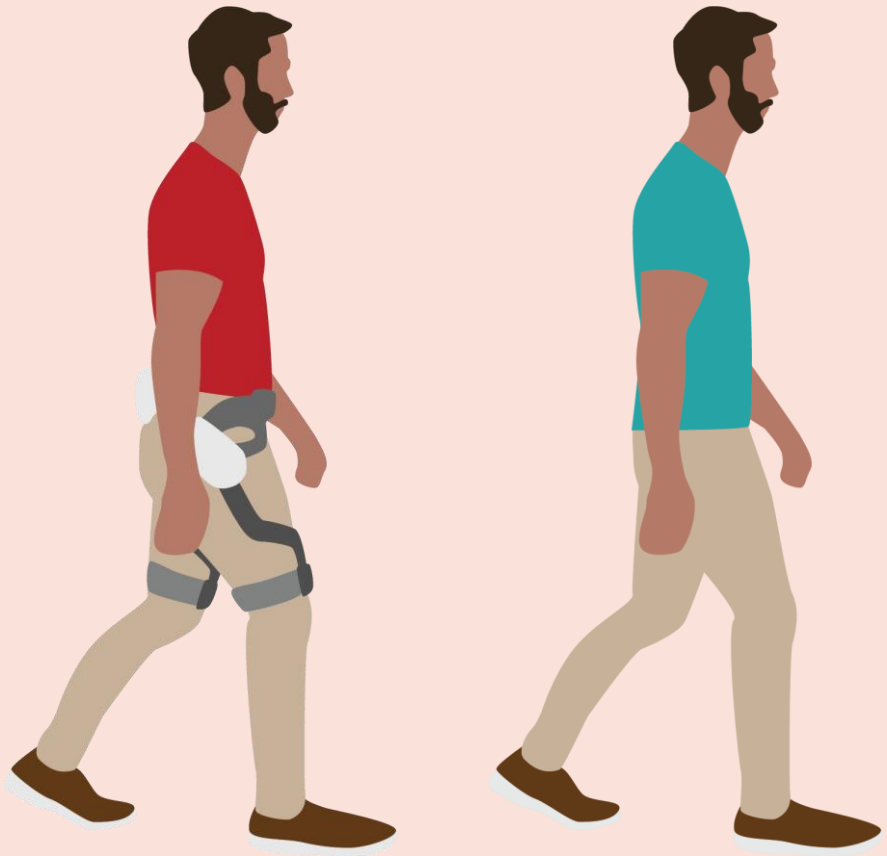


(RE)TRAIN/REHAB



ASSISTANCE

DIFFERENT EXOSKELETON GOALS



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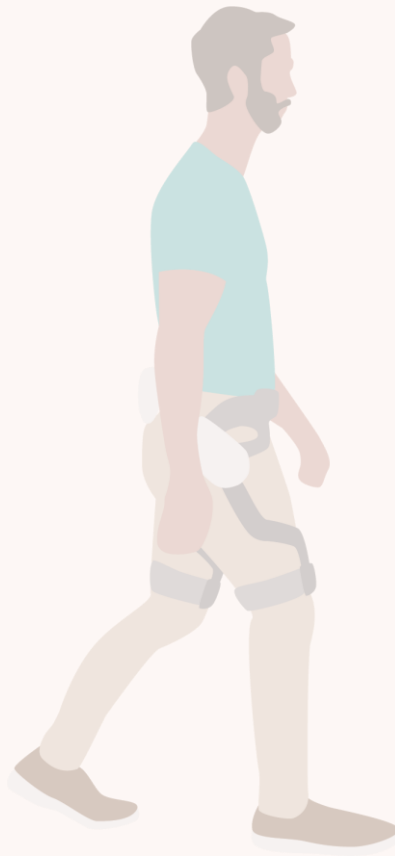
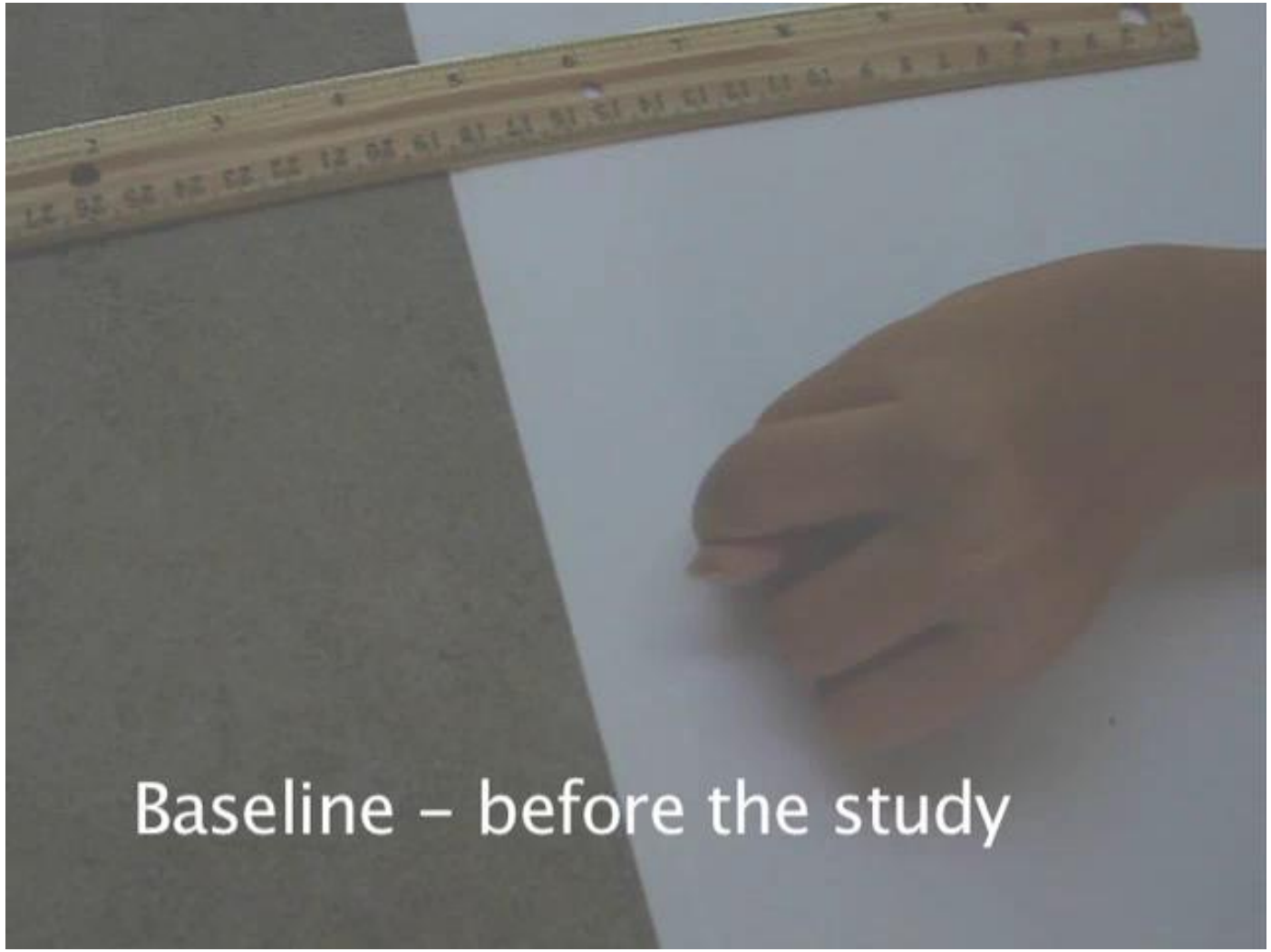


ASSISTANCE

VR-BASED TELEREHABILITATION

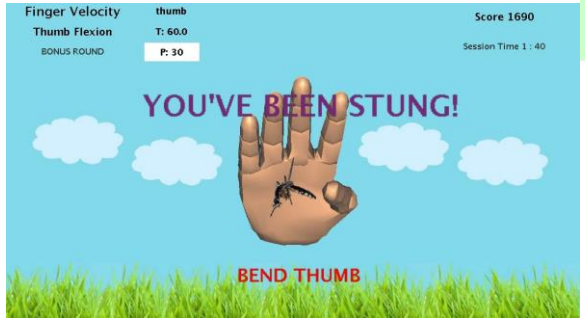


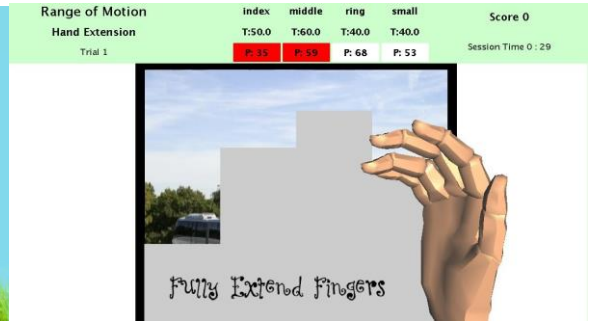
Huber, M.E., Rabin, B., Docan, C., Burdea, G., Abdelbaky, M., & Golomb, M.R. (2009) *TITB*
Golomb, M.R., McDonald, B.D., Warden, S.J., Yonkan, J., Saykin A.J., Shirley, B., Huber, M.E., et al. (2009) *APMR*
Huber, M.E., Rabin, B., Burdea, G., Docan, C., Nwosu, M.E., Abdelbaky, M., & Golomb, M.R. (2008) *ICVR*

VR-BASED TELEREHABILITATION

30 MINS PER DAY, 5 TIMES PER WEEK

HOME





CLINICIAN

SERVER

Huber, M.E., Rabin, B., Docan, C., Burdea, G., Abdelbaky, M., & Golomb, M.R. (2009) *TITB*
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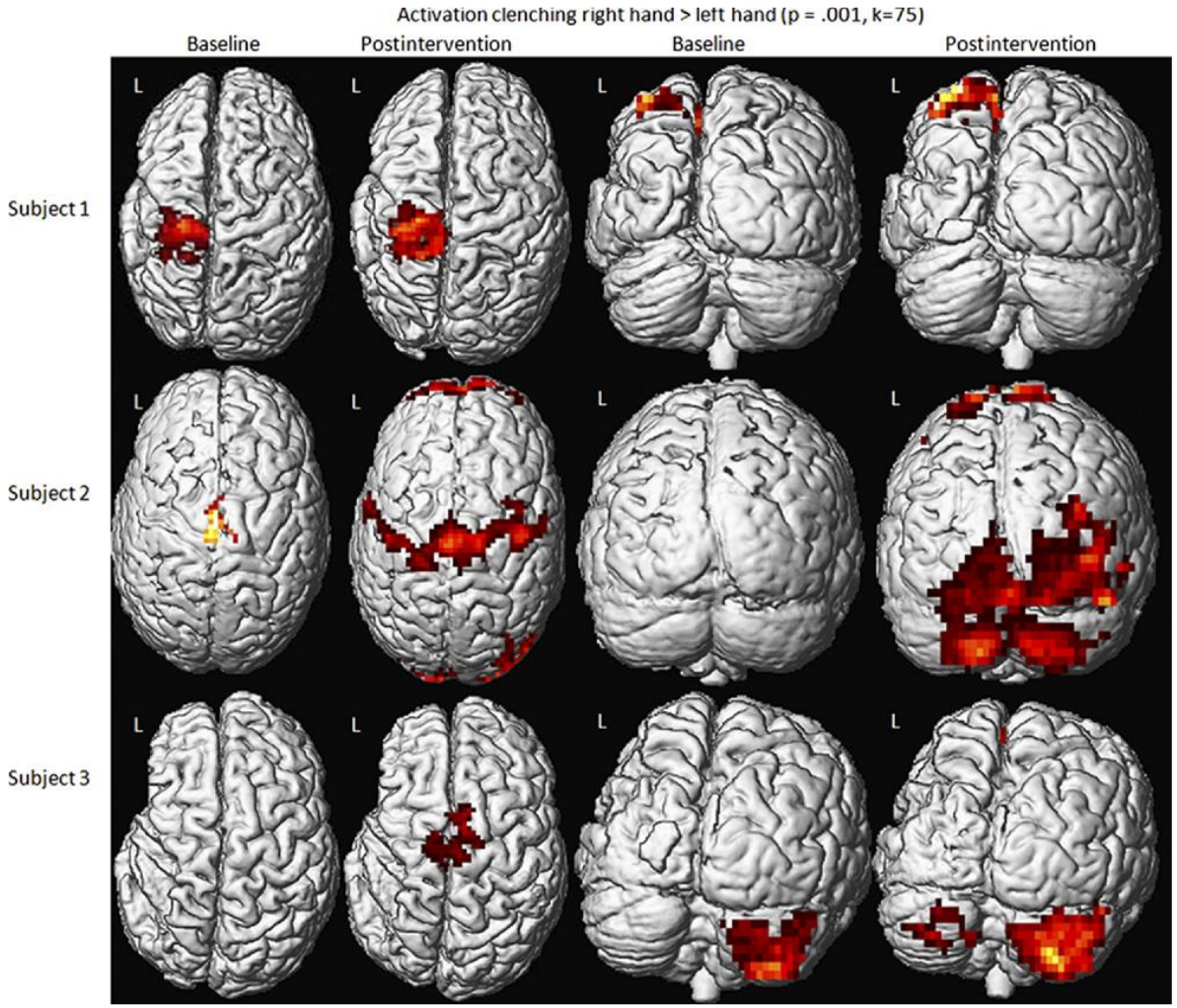
VR-BASED TELEREHABILITATION



Increased Hand Function

Increased Brain Activity

Increased Bone Health

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VR-BASED TELEREHABILITATION

Activity	Pre-Tele-rehab			At 3 months of home Tele-rehab			At 10 months of home Tele-rehab		
Participant	1	2	3	1	2	3	1	2	3
Brushing teeth					■			■	
Carrying grocery bag				■	■	■	■	■	■
HH shampooing					■			■	
Hold spoon				■	■		■	■	■
HH dressing				■	■		■	■	■
HH sports				■	■		■	■	■

Shaded areas represent activities participants were able to perform, either with the impaired hand alone or as a helper hand (hh) to aid the unimpaired hand. For each participant, this self-report refers to abilities before the telerehabilitation intervention, after three months of training and again after ten months (in part adapted from [25]).

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VR-BASED TELEREHABILITATION

- Practice is critical for learning

- Technology can increase the amount of practice
    - Increase accessibility to practice
    - Increase motivation

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Can we employ motor learning insights into our VR and robot solutions to accelerate learning?

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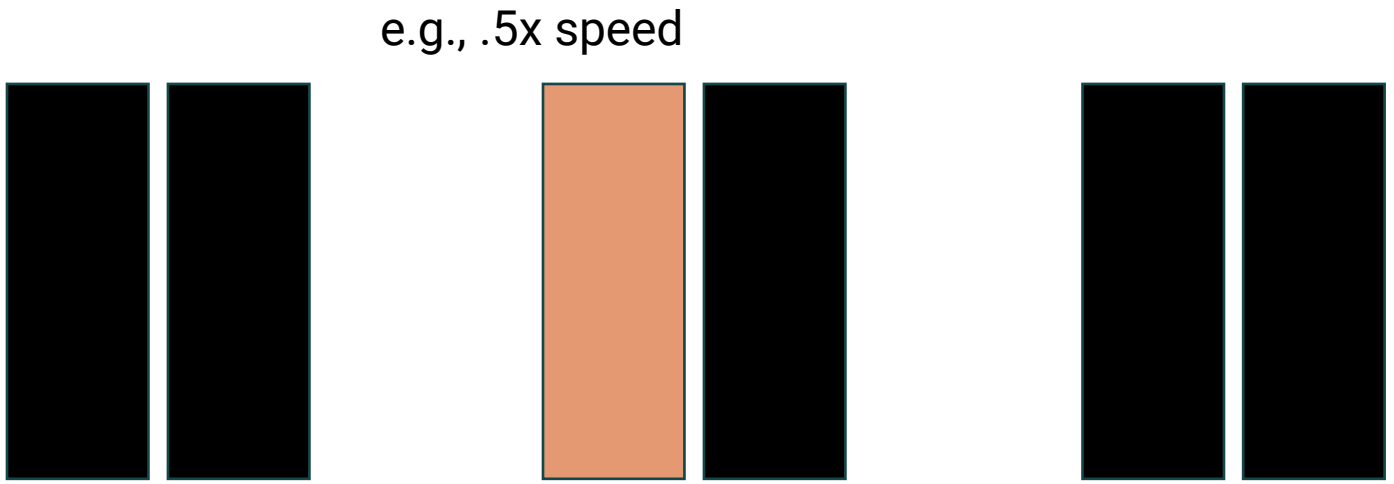
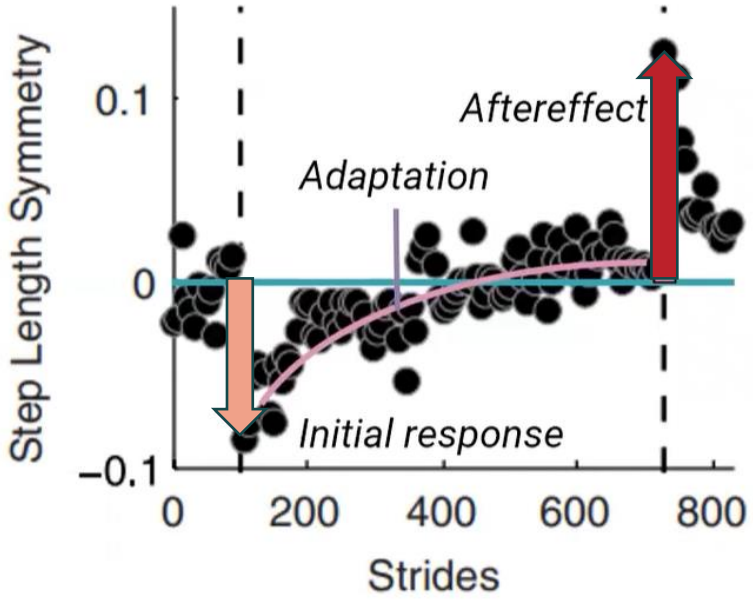
IMPROVING GAIT SYMMETRY

SPLIT-BELT TREADMILL TRAINING

- Dual belt treadmill with belts running at different speeds.
- With practice, humans adapt to restore gait symmetry.



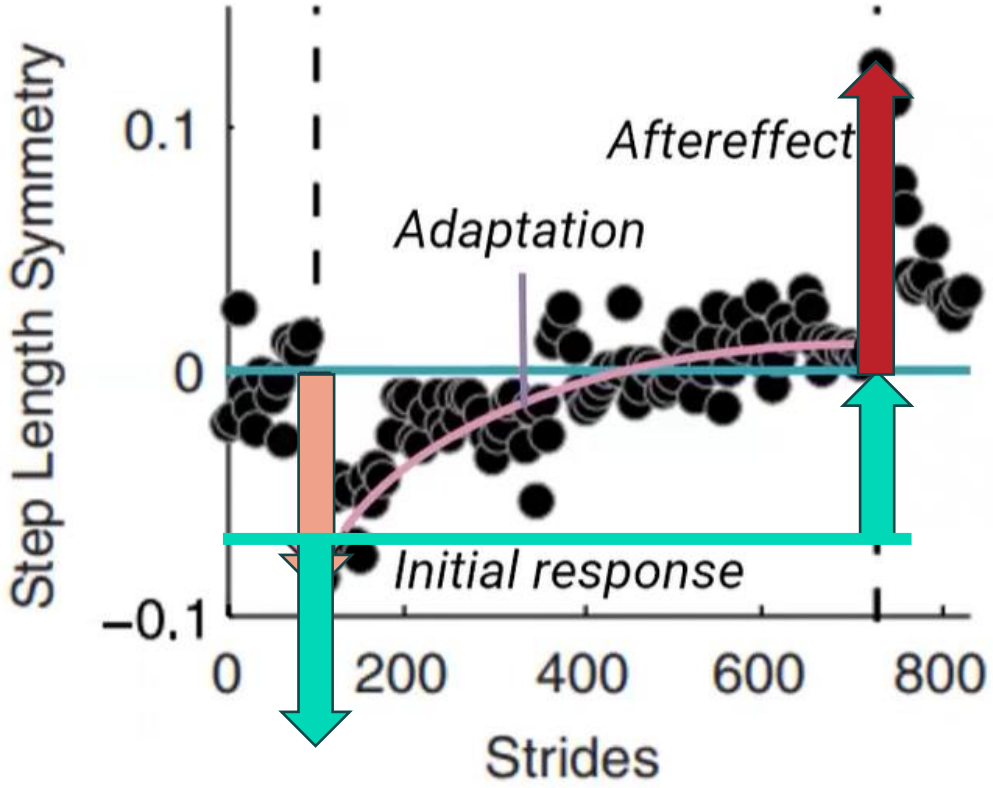


Adaptation to asymmetric belt speeds. (Finley et al. 2013)

SPLIT-BELT TREADMILL TRAINING

- Shown to improve gait symmetry in individuals with asymmetric gait after stroke. (Reisman et al. 2007, *Brain*)
- Repeated exposure can result in persistent improvements in gait symmetry for individuals post-stroke. (Reisman et al. 2013, *NNR*)

STROKE GAIT



Adaptation to asymmetric belt speeds. (Finley et al. 2013)

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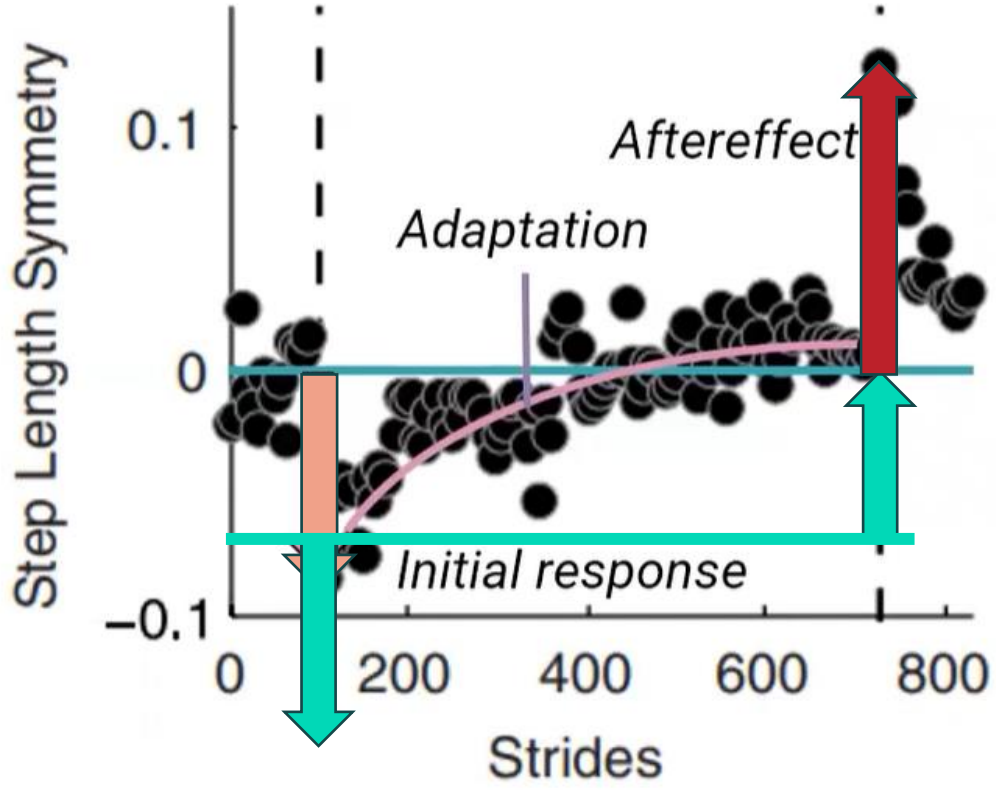
- Shown to improve gait symmetry in individuals with asymmetric gait after stroke. (Reisman et al. 2007, *Brain*)
- Repeated exposure can result in persistent improvements in gait symmetry for individuals post-stroke. (Reisman et al. 2013, *NNR*)

Can we use an exoskeleton to provide opportunities for EVEN MORE repeated exposure?

STROKE GAIT



Adaptation to asymmetric belt speeds. (Finley et al. 2013)

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Photo credit: Derrick Zellman UMassAmherst

BACKDRIVEABLE ACTUATORS
AK-80s with 6:1 or 9:1 gear ratio

LIGHTWEIGHT AND SIZE INCLUSIVE
3/3.8kg with off/onboard power

RIGID ANT/POST THIGH ATTACHMENT
Reduce relative motion during flex/ext

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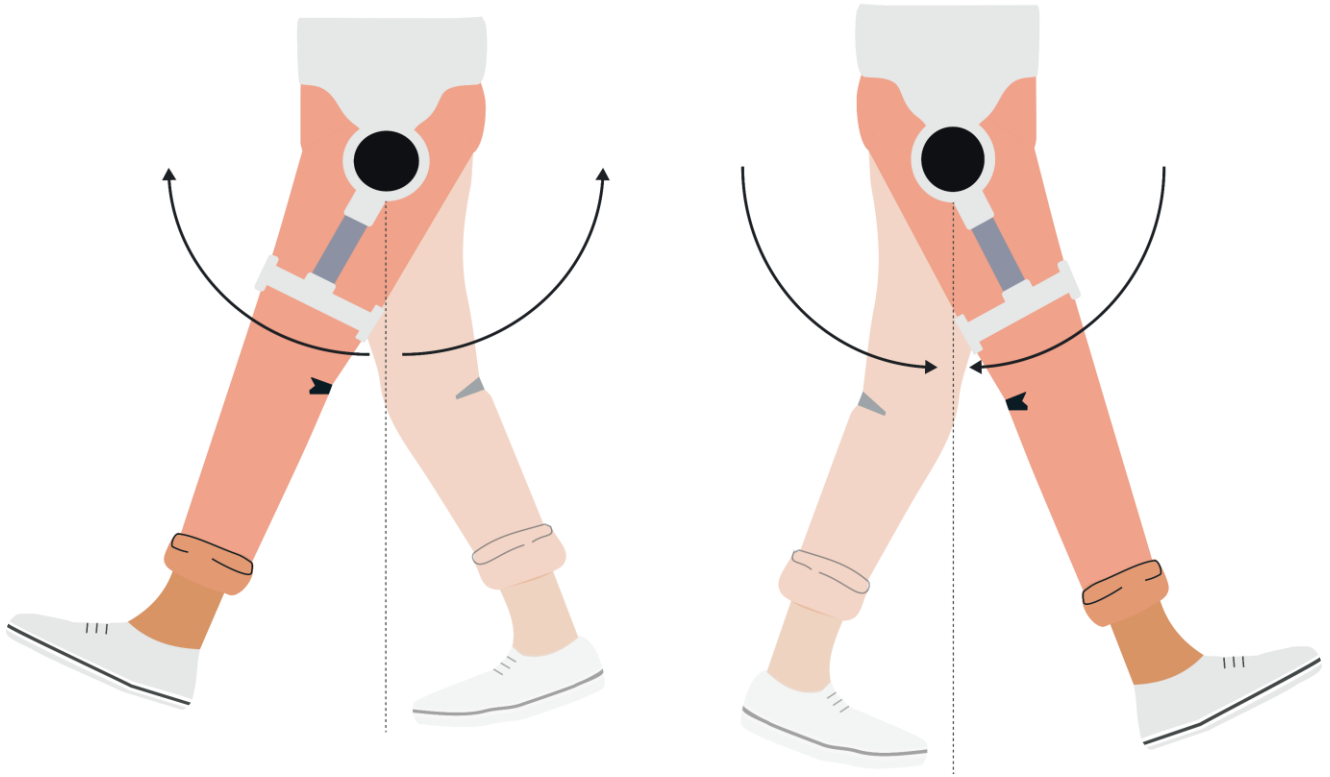
Photo credit: Derrick Zellman UMassAmherst

ASYMMETRIC STIFFNESS ADAPTATION

Left
k = -1Nm/rad

Right
k = 3Nm/rad



Price, M., Abdikadirova, B., Locurto, D., Moreno Jaramillo, J., Cline, N., Hoogkamer, W., & Huber, M.E. (2022) *IROS*
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Abdikadirova, B., Price, ., Moreno Jaramillo, J., Hoogkamer, W., & Huber, M.E. (2024) *TNSRE*

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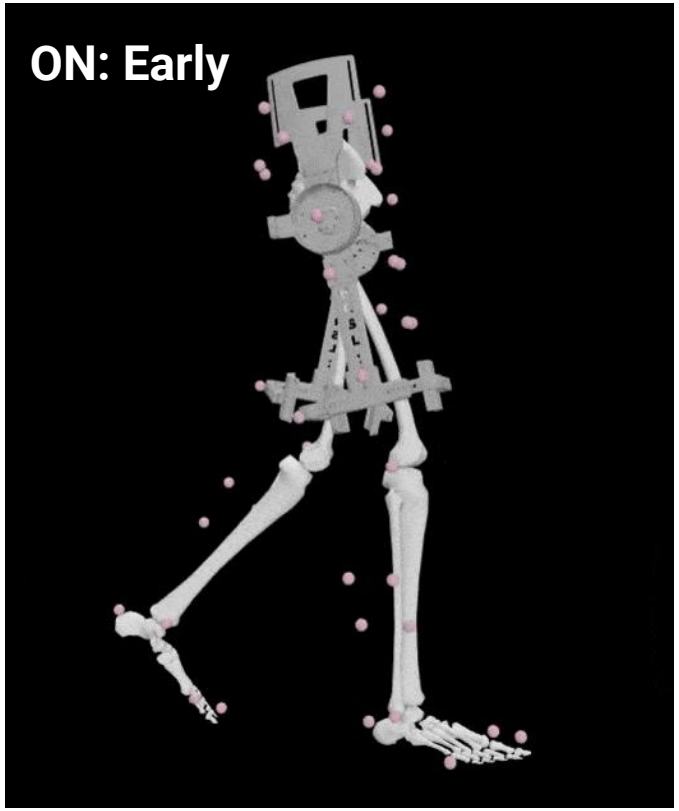
ASYMMETRIC STIFFNESS ADAPTATION



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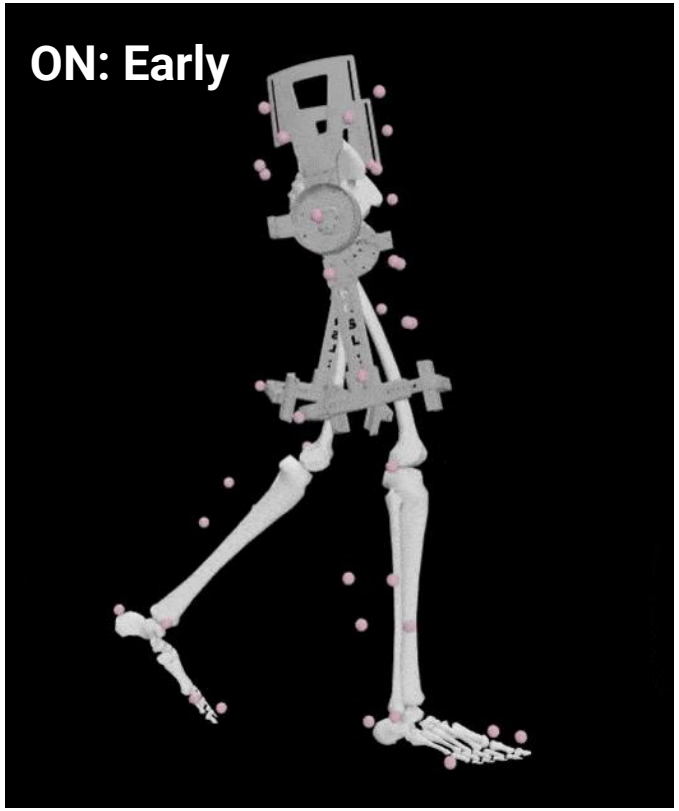

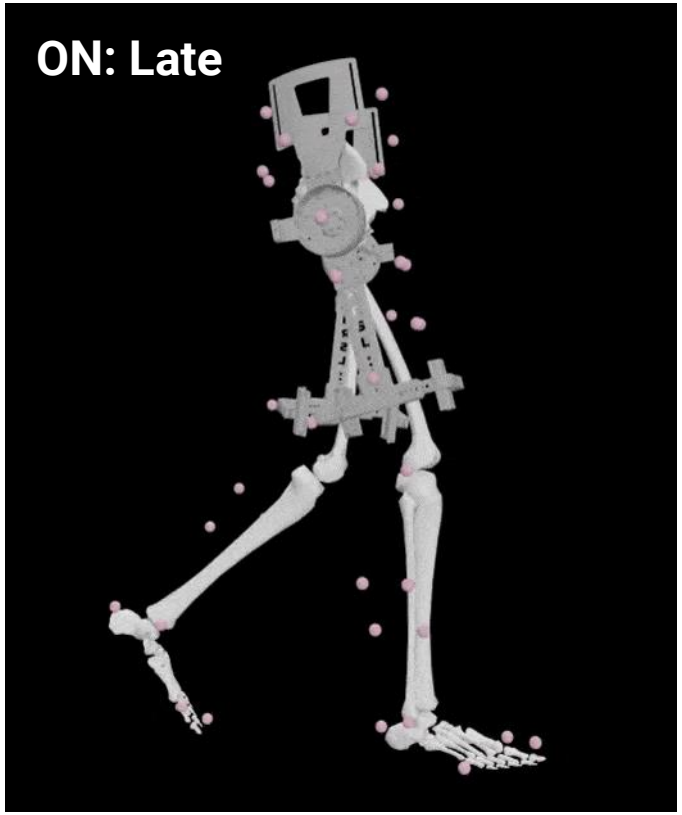

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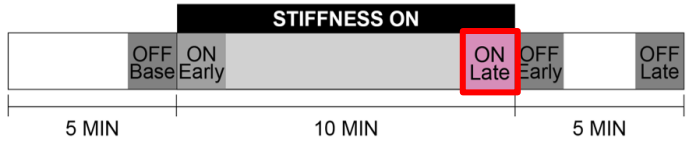

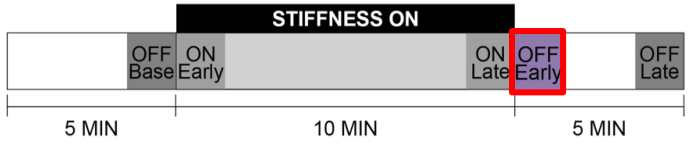

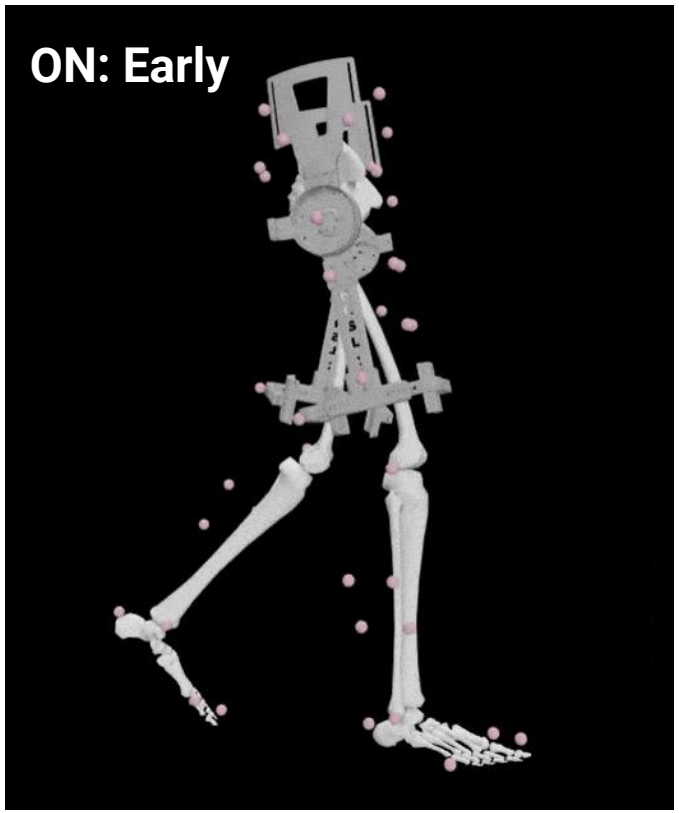

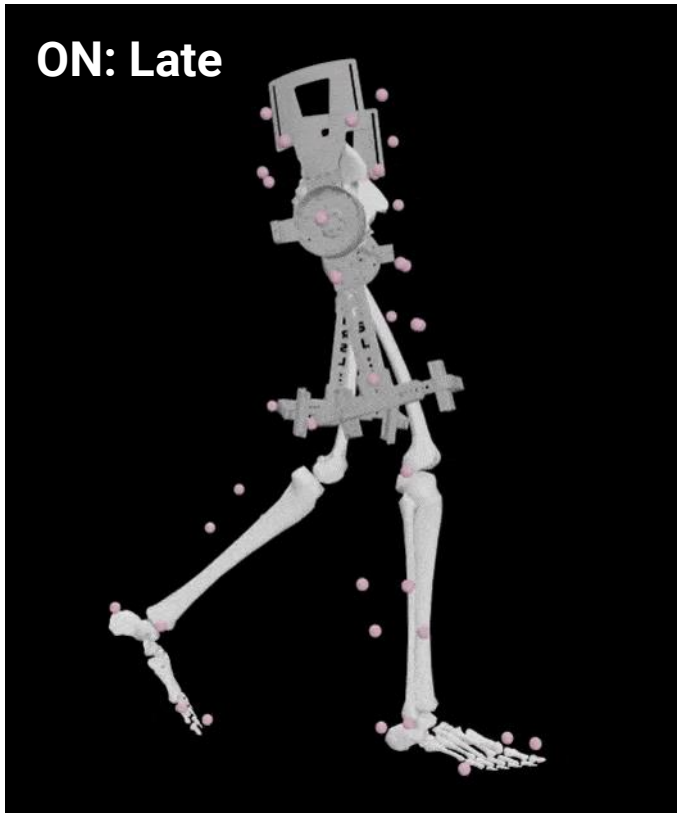

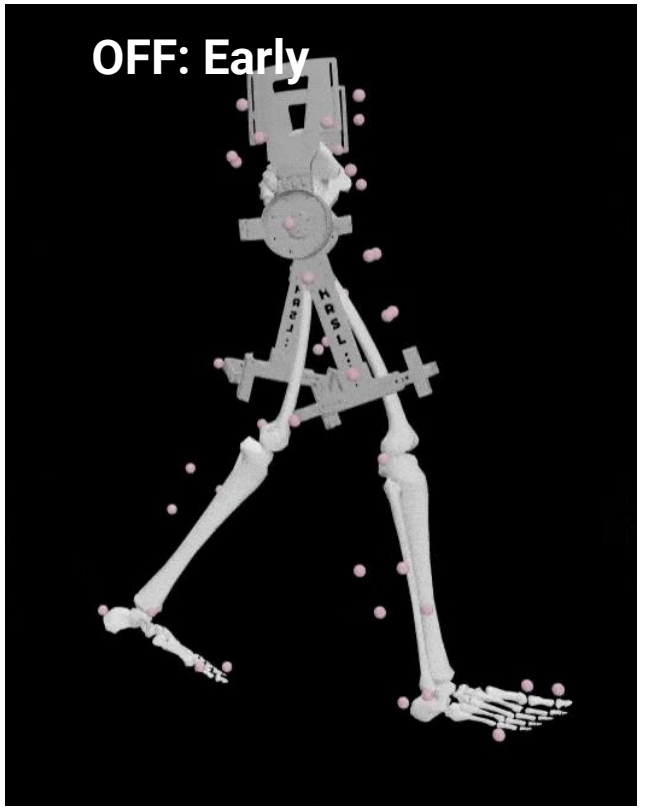

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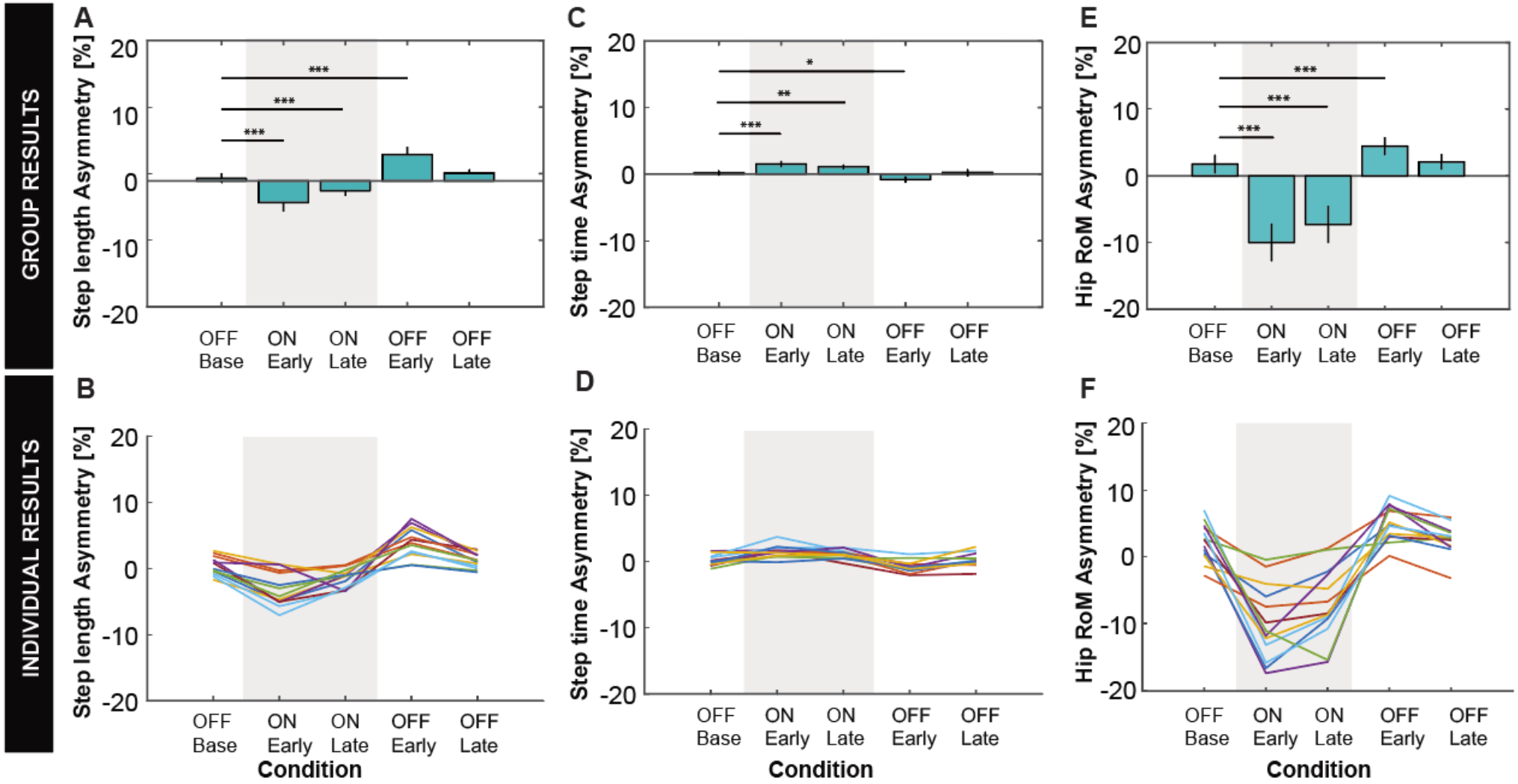
ASYMMETRIC STIFFNESS ADAPTATION



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ASYMMETRIC STIFFNESS ADAPTATION

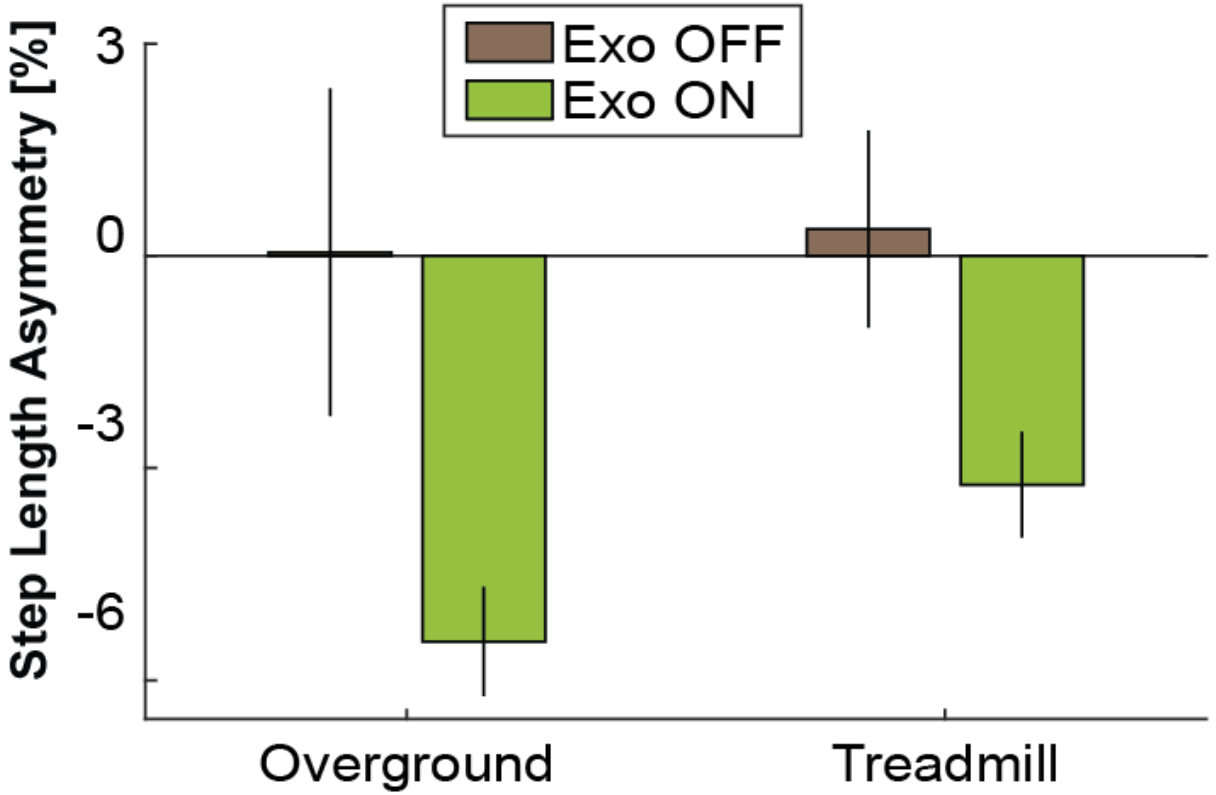
- Exaggerating or augmenting “errors” can elicit adaptation (when repeated, it can lead to learning)

- Design exoskeletons to be tools to make gait rehabilitation more practical and accessible
    - Allow for early intervention
    - Compliment in-clinic interventions

OPEN QUESTIONS?

- Should exoskeletons augment or compensate for “errors” during training?
- Exoskeletons can allow for training in real-world environments, is that important for transfer of learning?
- What drives adaptation to asymmetry intervention?

OPEN QUESTIONS?



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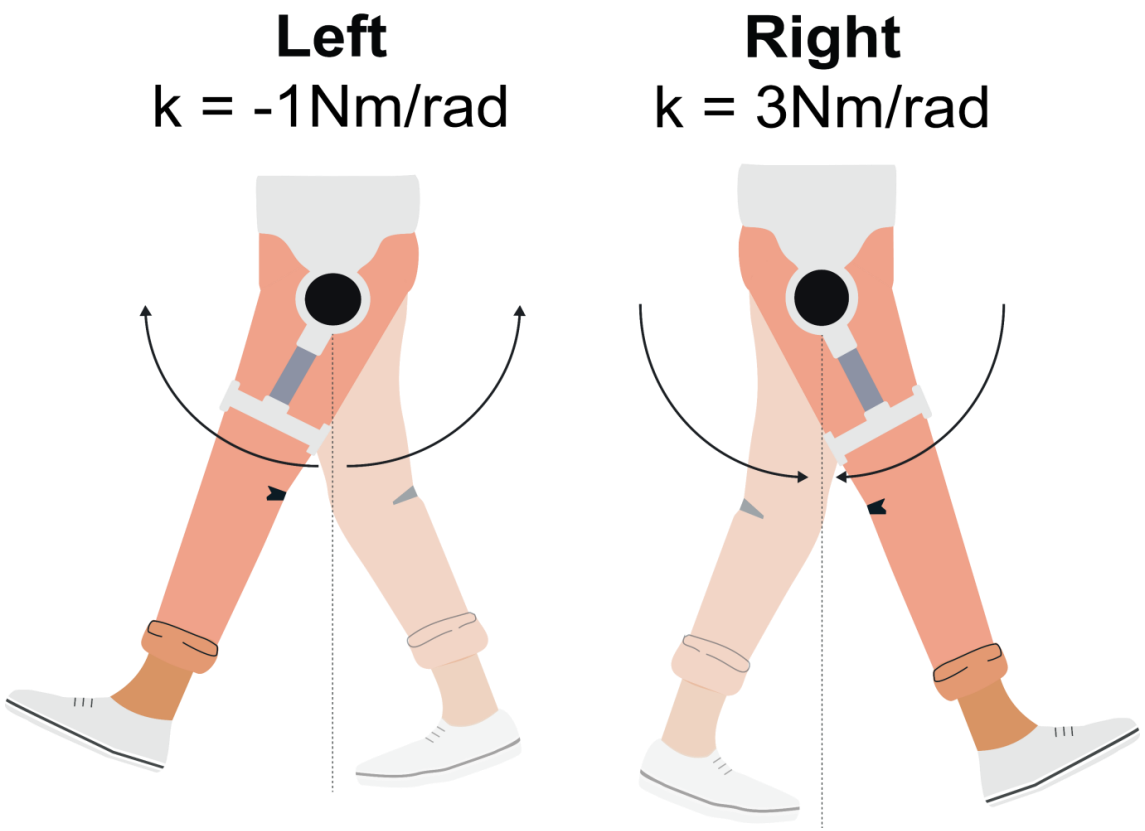
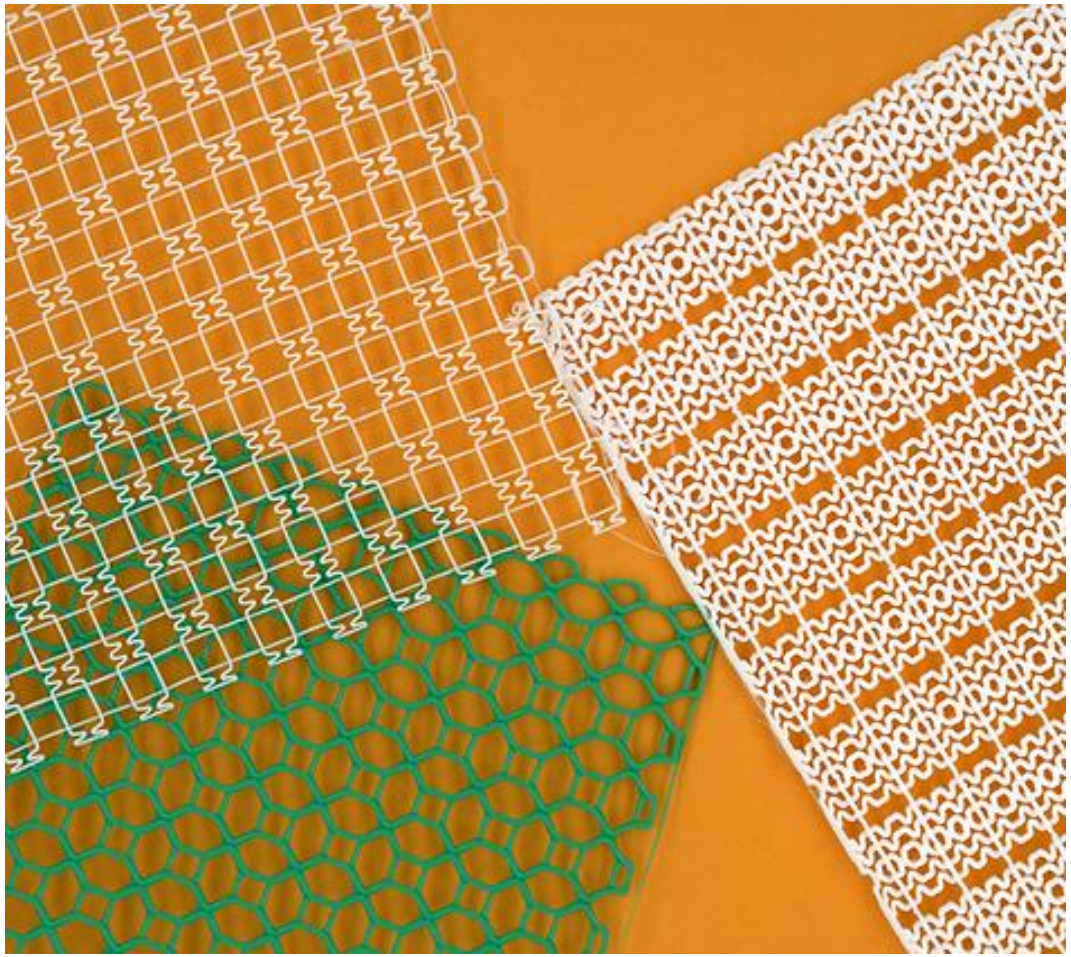
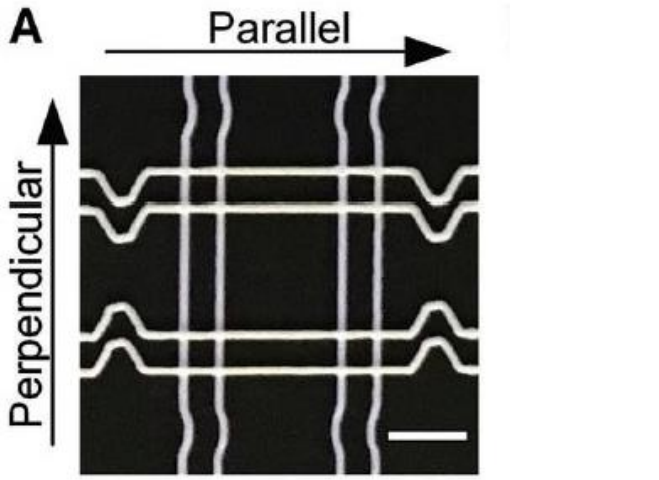
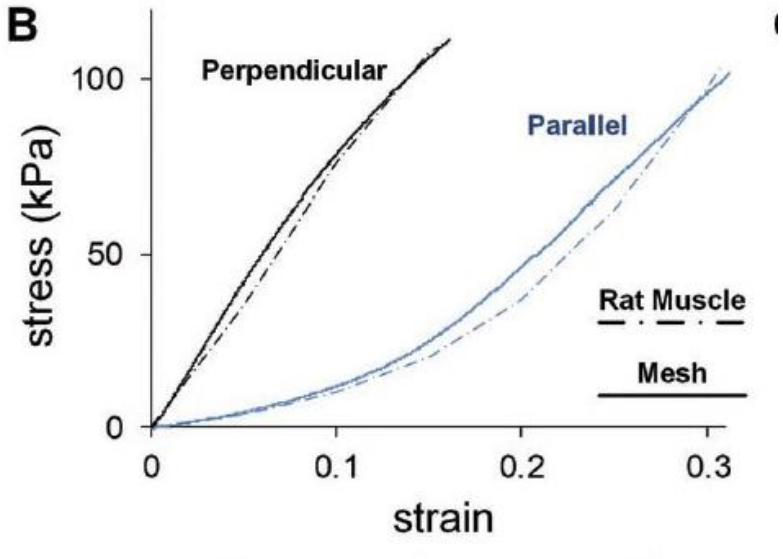
TOWARDS SOFT SOLUTIONS…

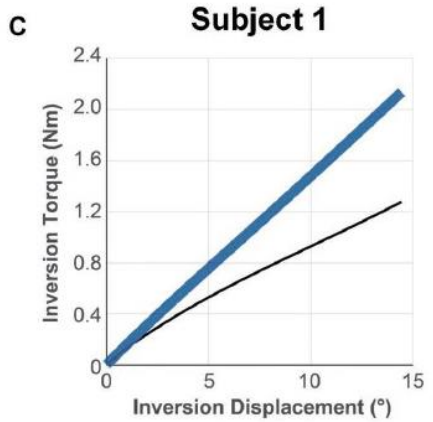


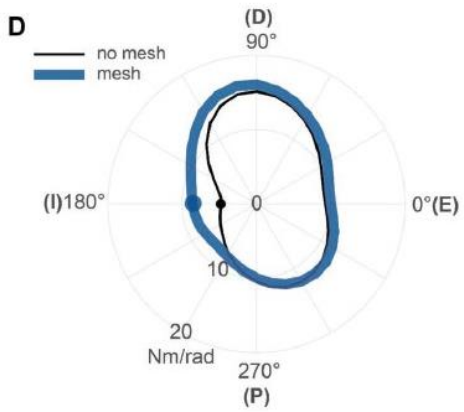


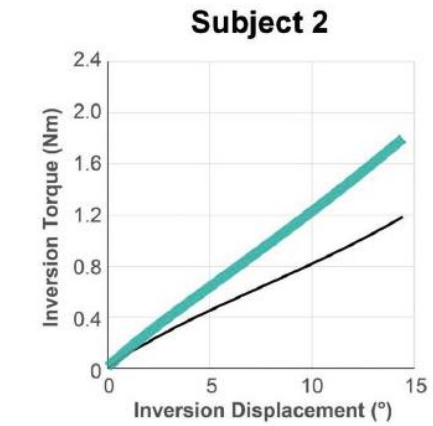
NONLINEAR STIFFNESS MATERIAL

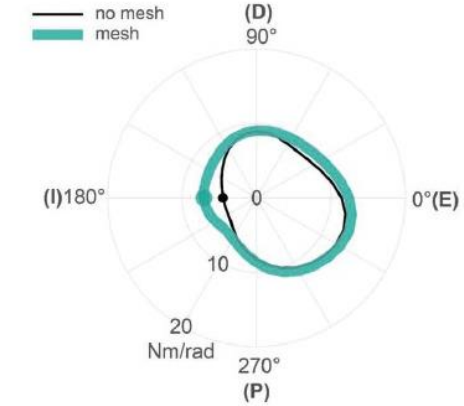




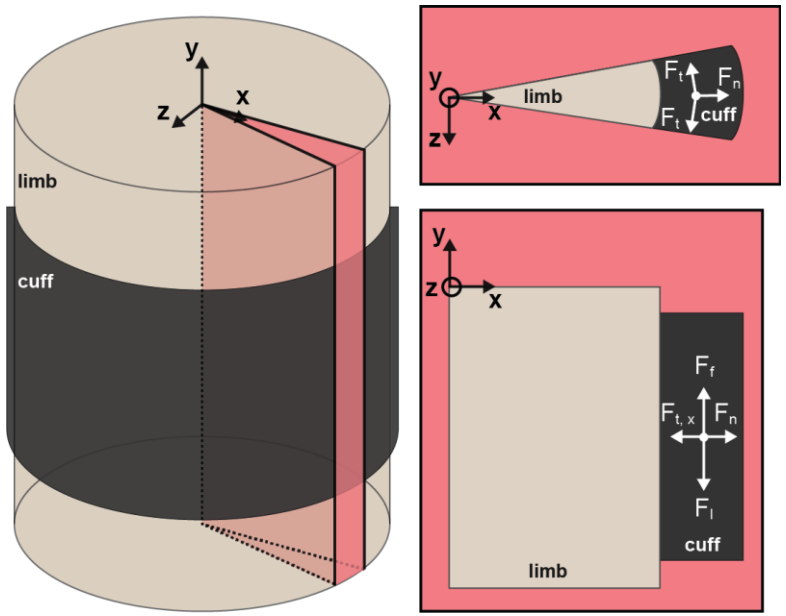








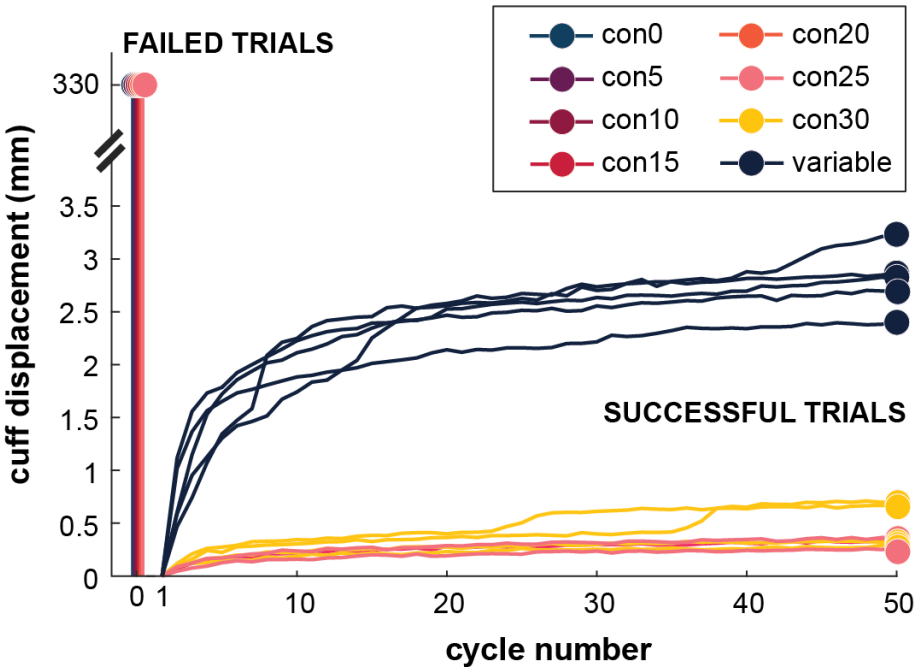
NOVEL ATTACHMENT MECHANISM



Huber M.E., Hermus, J., Enns, G.K., & Hogan, N. (2023)
Huber M.E., Hermus, J., Enns, G.K., & Hogan, N. (In Preparation)

NOVEL ATTACHMENT MECHANISM

VARIABLE

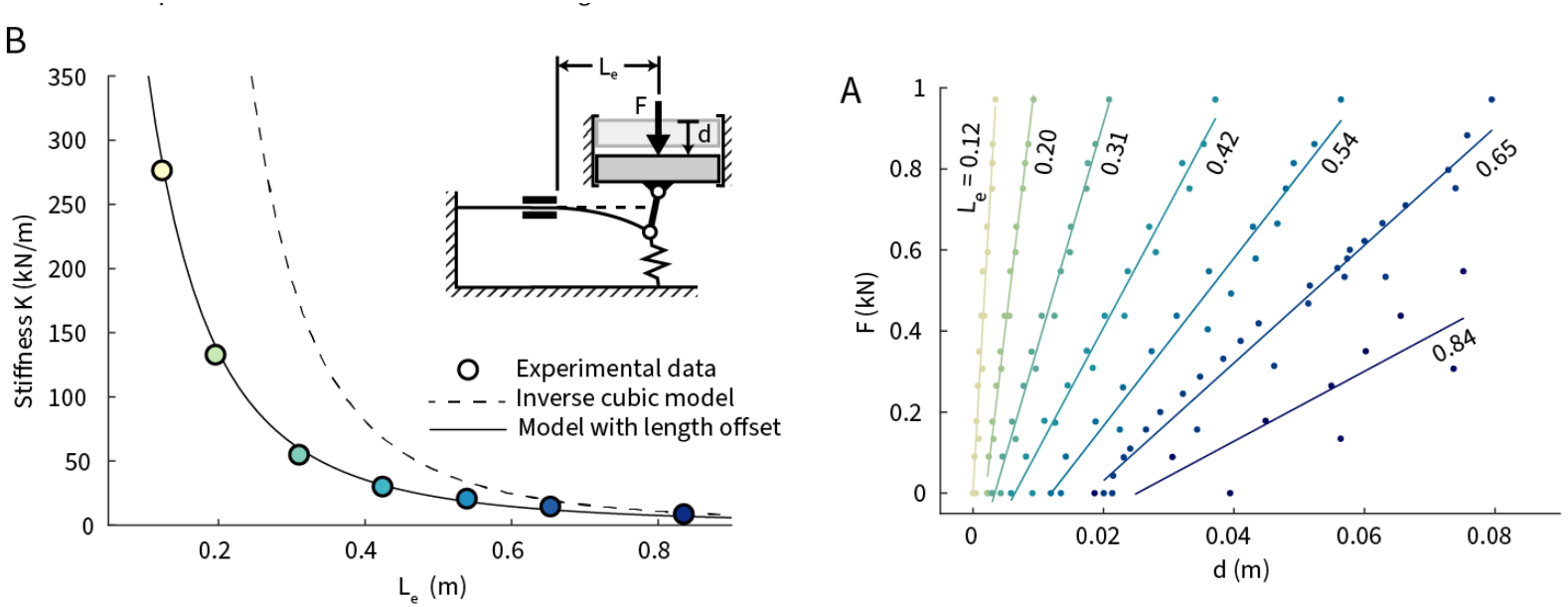


CONO

Huber M.E., Hermus, J., Enns, G.K., & Hogan, N. (2023)
Huber M.E., Hermus, J., Enns, G.K., & Hogan, N. (In Preparation)

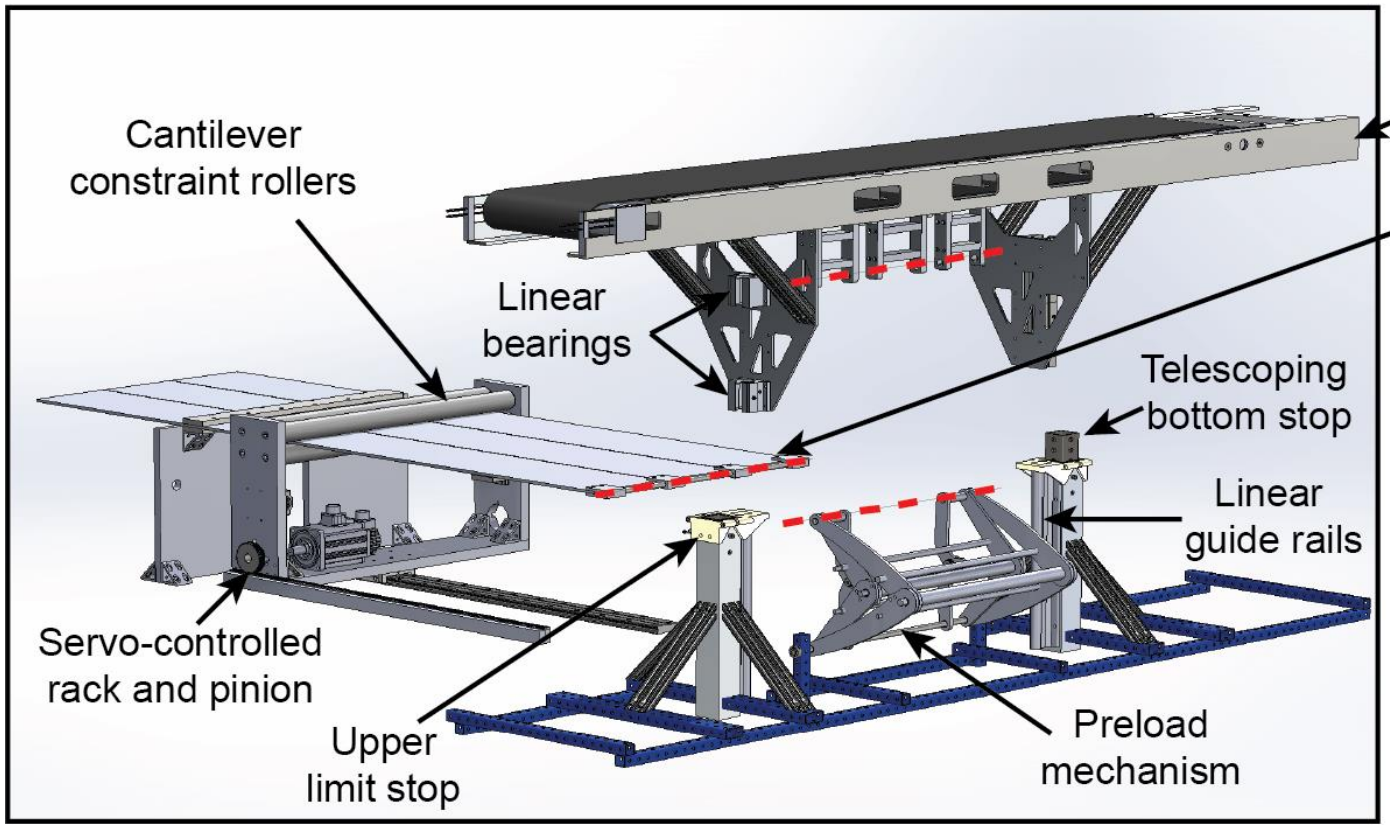
ADJUSST

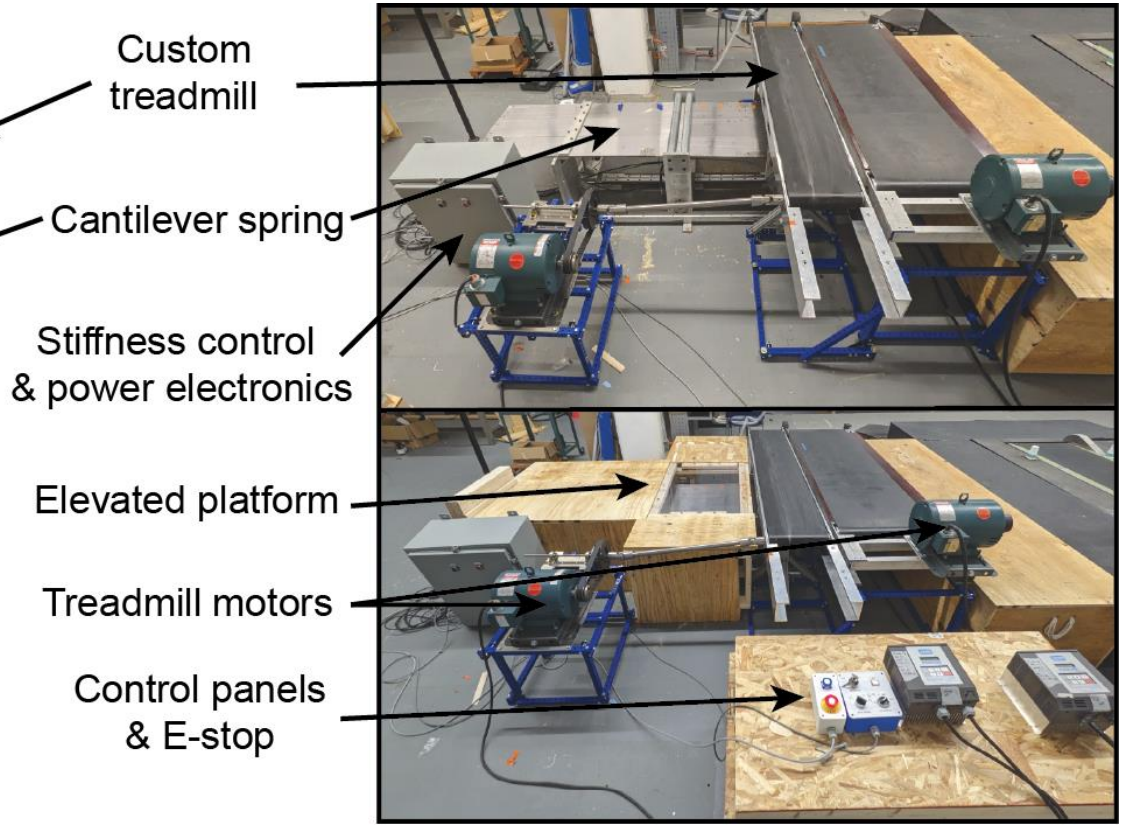
Adjustable surface stiffness treadmill to study (and possibly augment) how humans manage interaction with the ground during locomotion



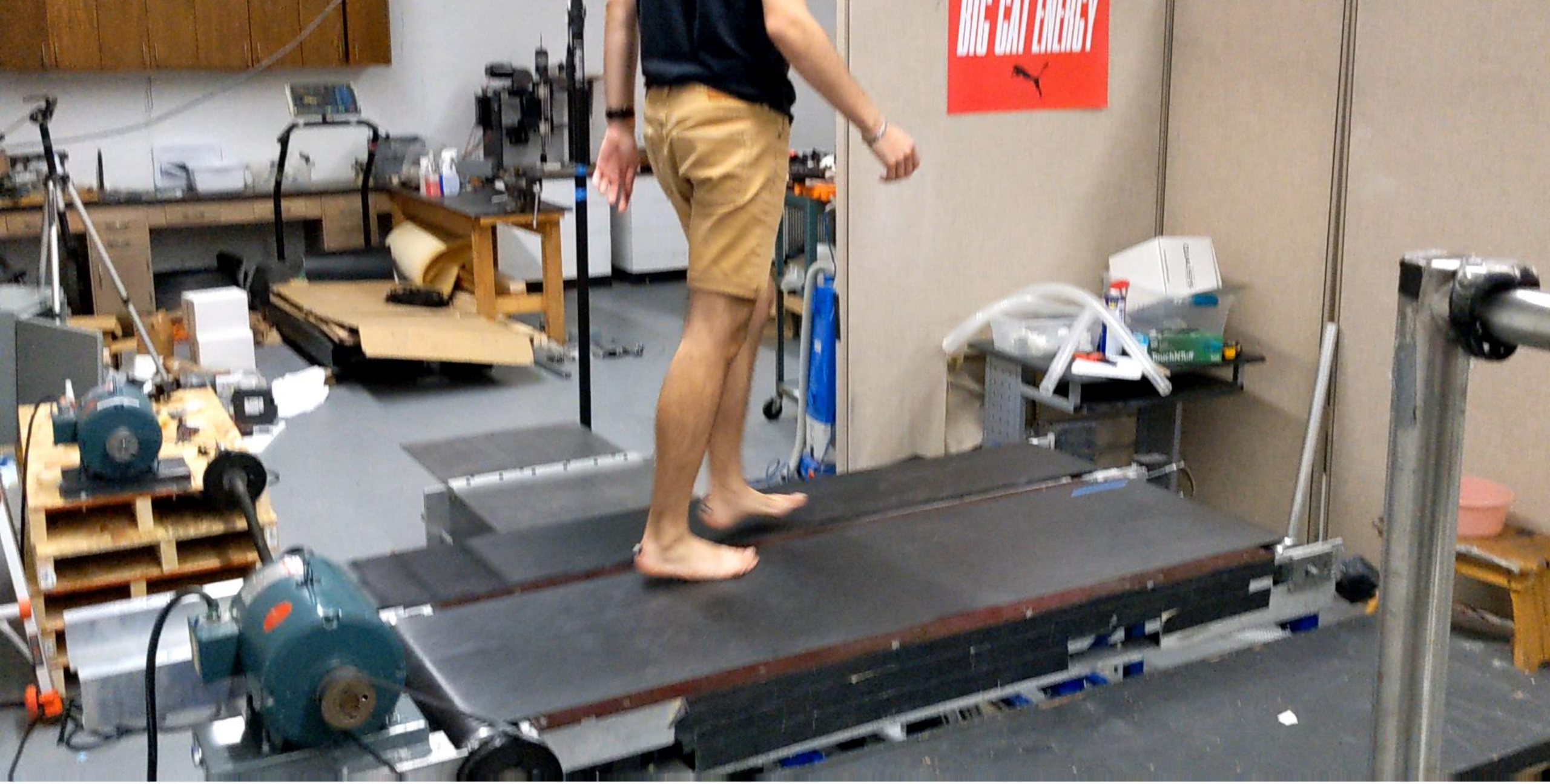
Price, M., Locurto, D., Abdikadirova, B., Huber, M.E., & Hoogkamer, W. (Under Review) *TMECH*

ADJUSST





Price, M., Locurto, D., Abdikadirova, B., Huber, M.E., & Hoogkamer, W. (Under Review) *TMECH*



HRSL UMILL UMASS INTEGRATIVE LOCOMOTION LAB

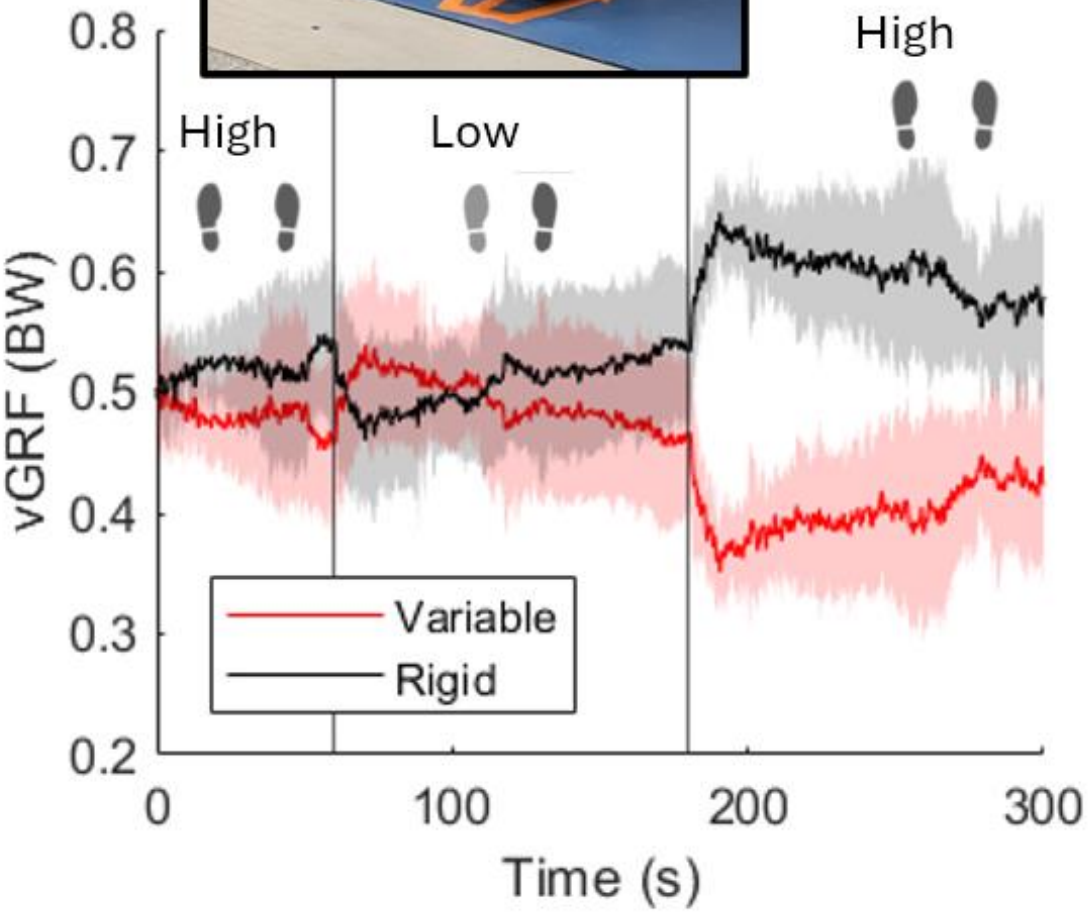
Price, M., Locurto, D., Abdikadirova, B., Huber, M.E., & Hoogkamer, W. (Under Review) *TMECH*

UMassAmherst

ADJUSST

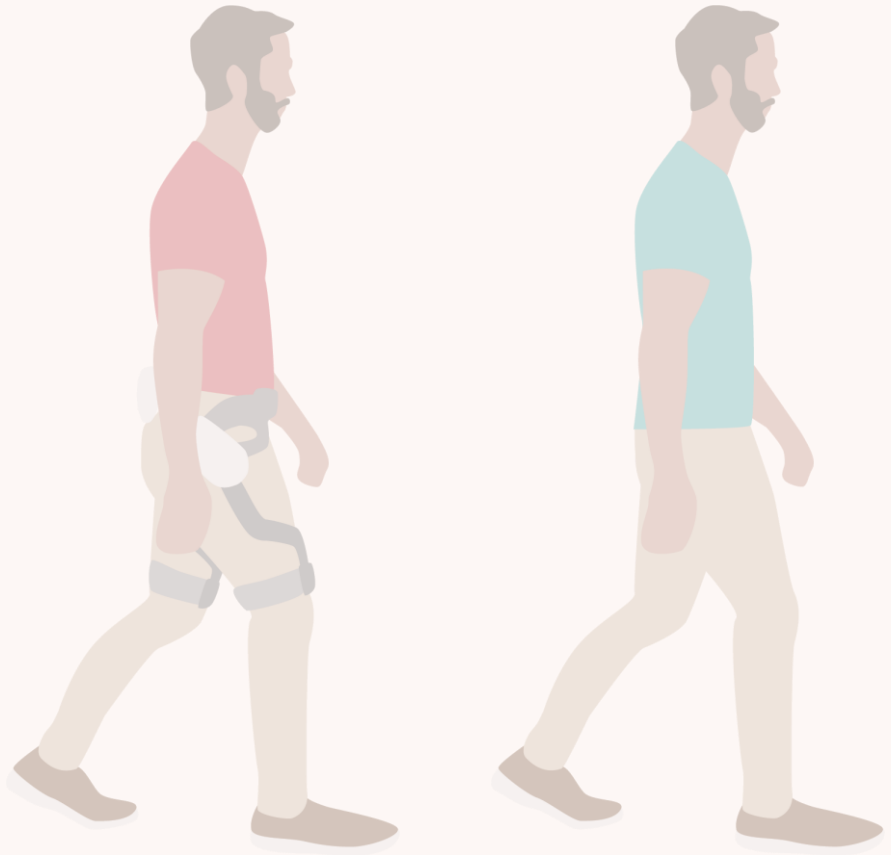
Price, M., Locurto, D., Abdikadirova, B., Huber, M.E., & Hoogkamer, W. (Under Review) *TMECH*

ADJUSS-SHOES

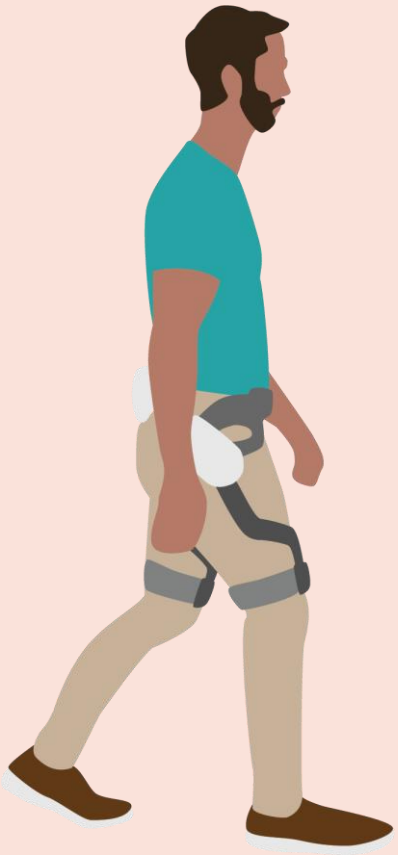


Price, M., Robbins, C., Abdikadirova, B., Hoogkamer, W., & Huber, M.E. (In Preparation)

DIFFERENT EXOSKELETON GOALS



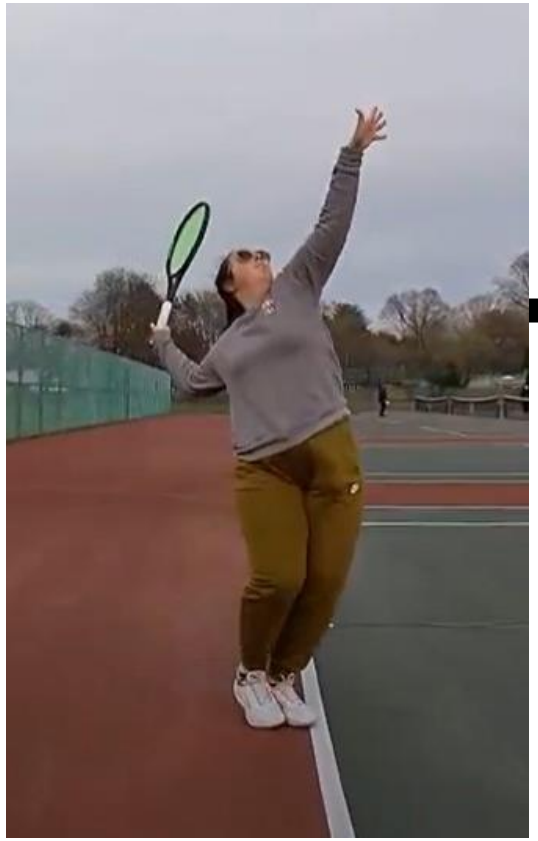
(RE)TRAIN/REHAB



ASSISTANCE

NOVICE

EXPERT



?

PRACTICE

COACH

MATCH PLAY

RIGHT RACKET

PRACTICE

GUIDANCE

REAL WORLD LOCOMOTION

RIGHT CONTROLLER

RIGHT MECHANICAL DESIGN

TRULY NOVEL SKILL LEARNING!!

PRACTICE

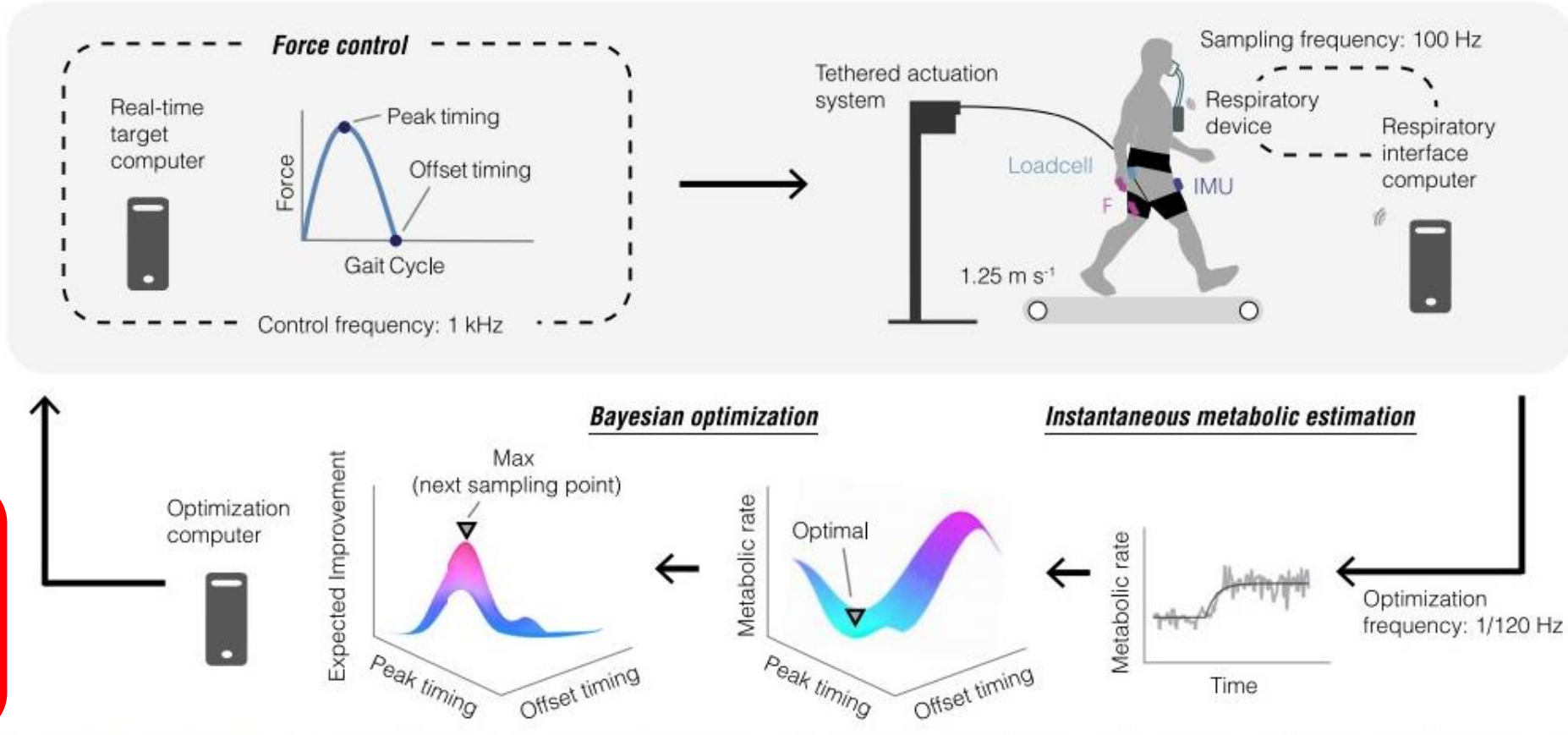
GUIDANCE

REAL WORLD LOCOMOTION

RIGHT CONTROLLER

RIGHT MECHANICAL DESIGN

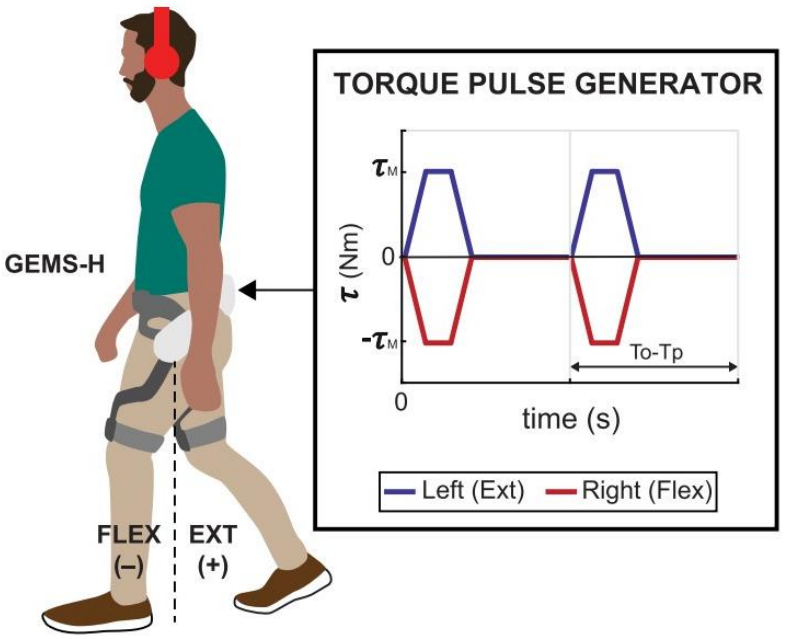
HUMAN-IN-THE-LOOP OPTIMIZATION

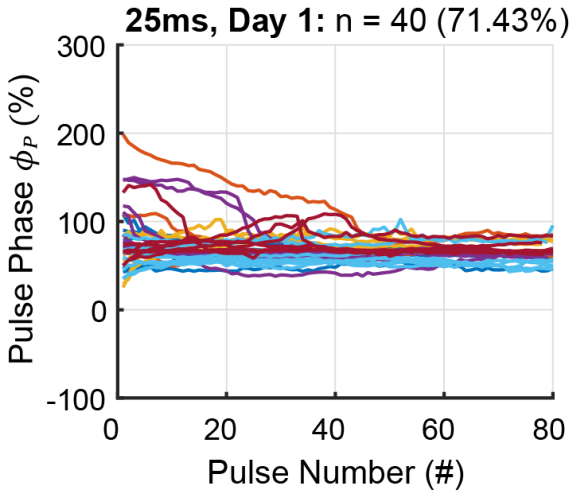


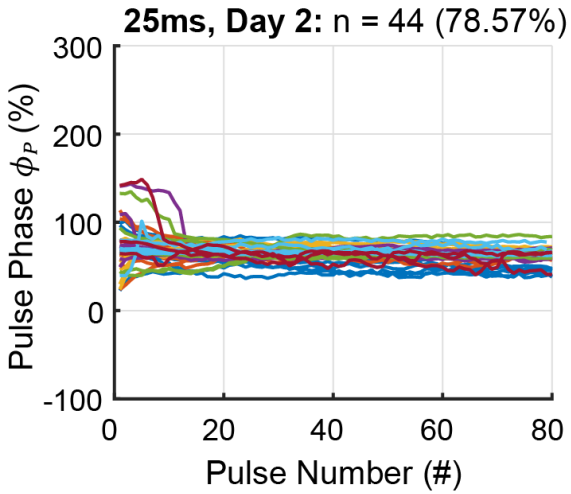
IN CASE OF EMERGENCY SLIDE!

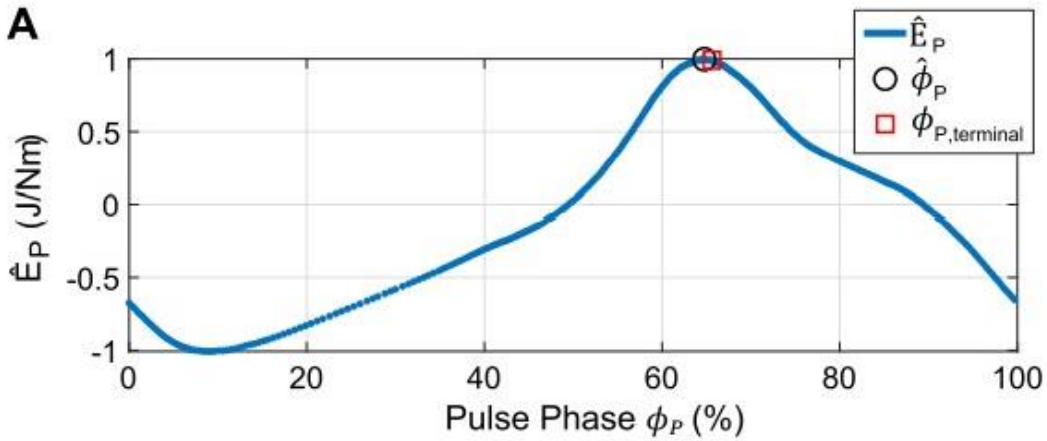
e.g., Zhang et al. 2017; Ding et al. 2018;

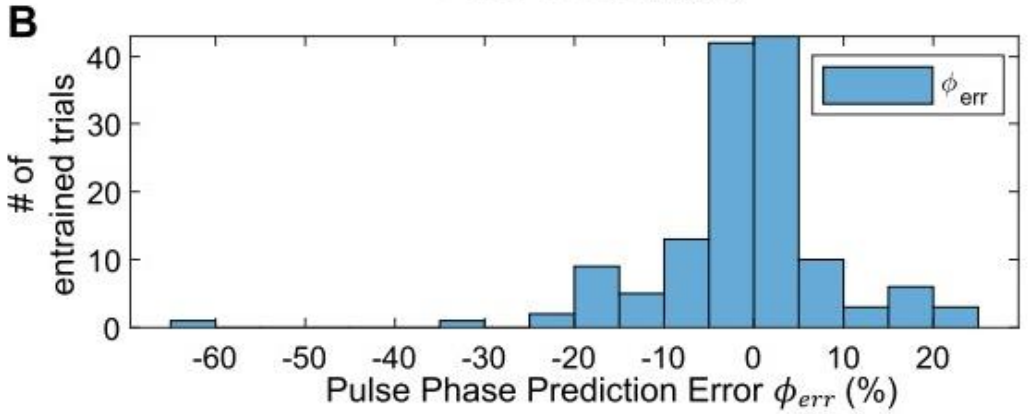
LEARNING TO BE ASSISTED





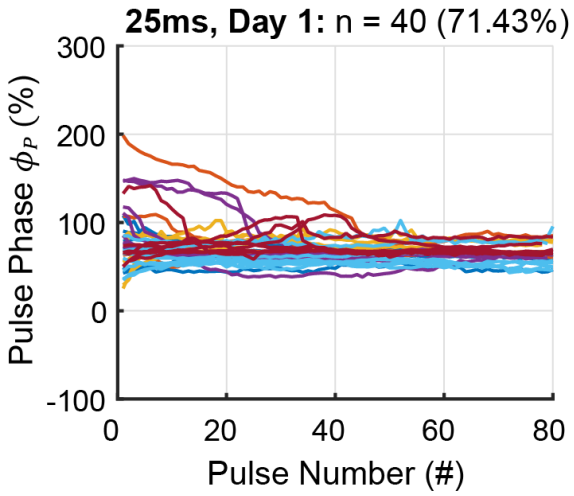


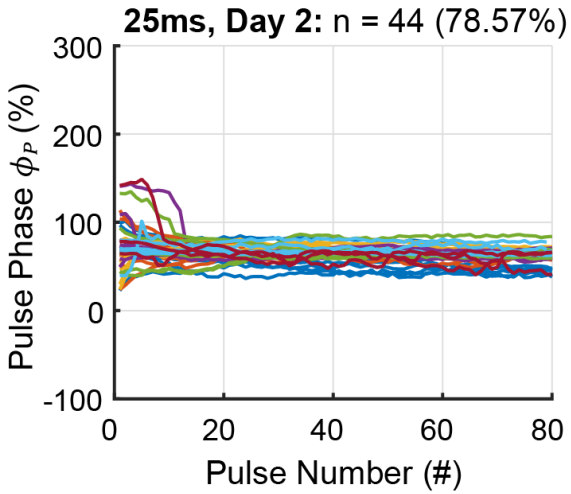


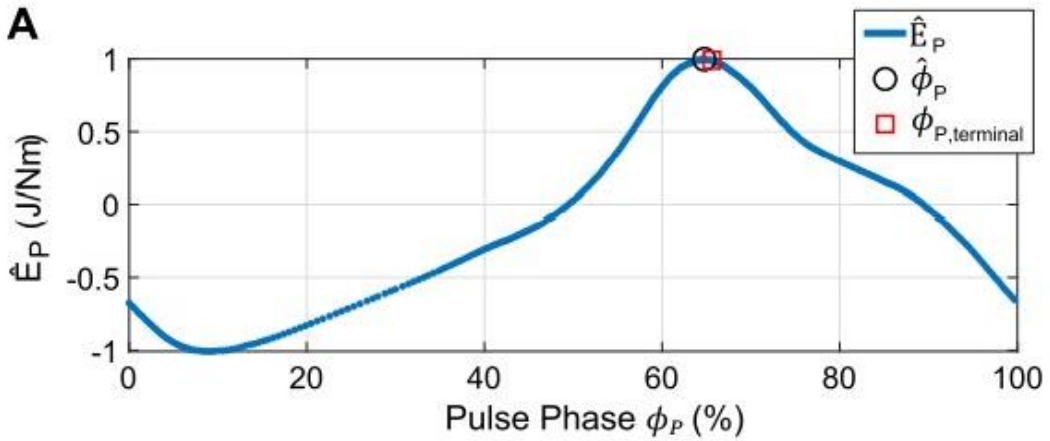


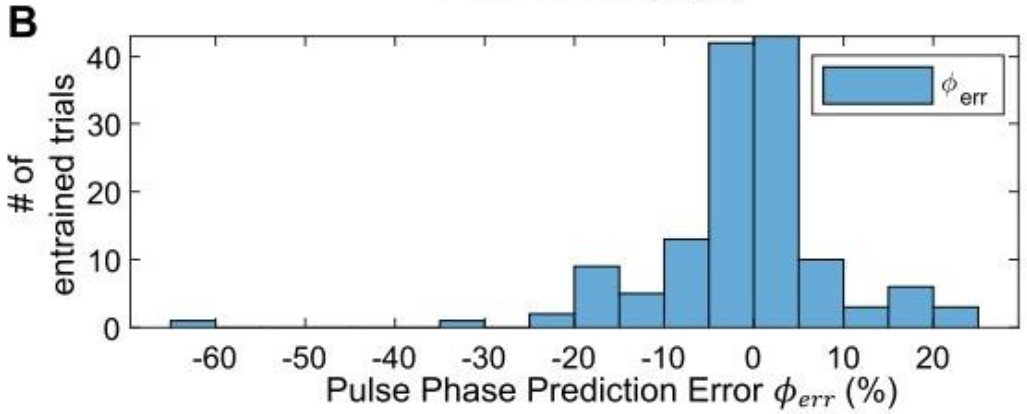
Lee, J., Huber, M.E., & Hogan, N. (2022) *TNSRE*
Lee, J., Goetz, D., Huber, M.E., & Hogan, N. (2019) *IROS*

LEARNING TO BE ASSISTED



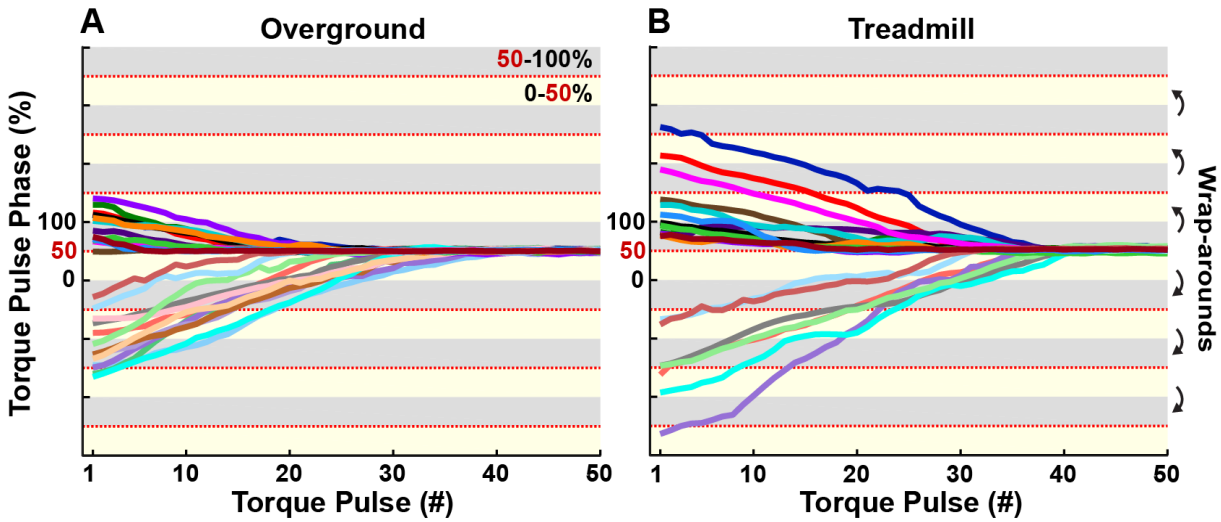






LEARNING TO BE ASSISTED

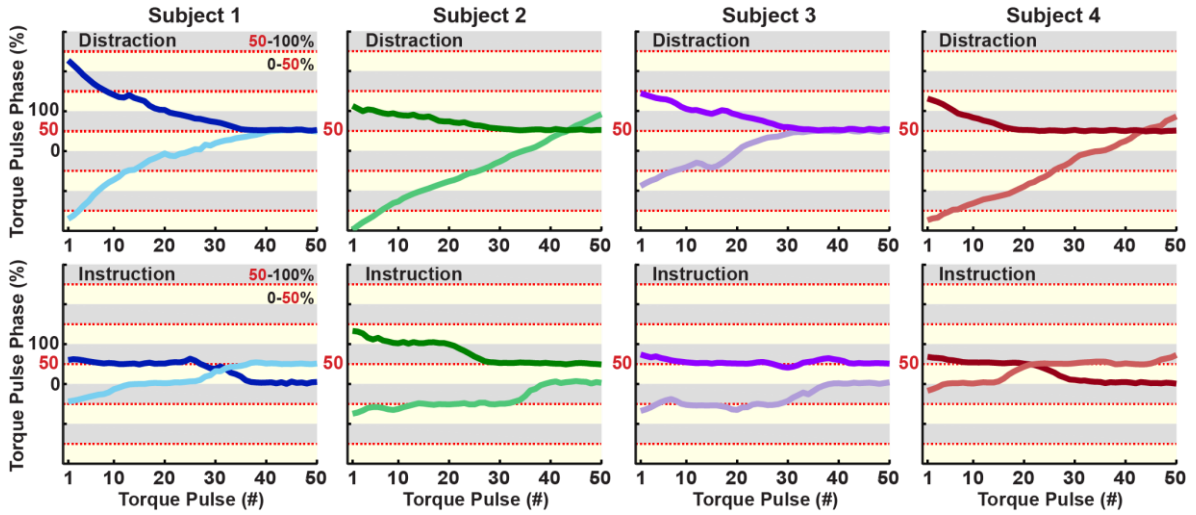
WALKING ENVIRONMENT



Entrainment to ankle torque pulses (Ochoa et al. 2017)

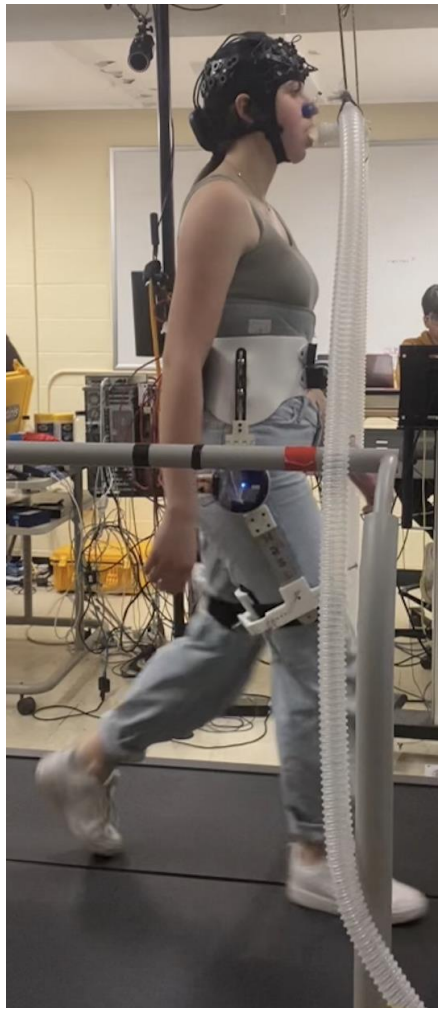
FASTER ENTRAINMENT DURING OVERGROUND

INSTRUCTION

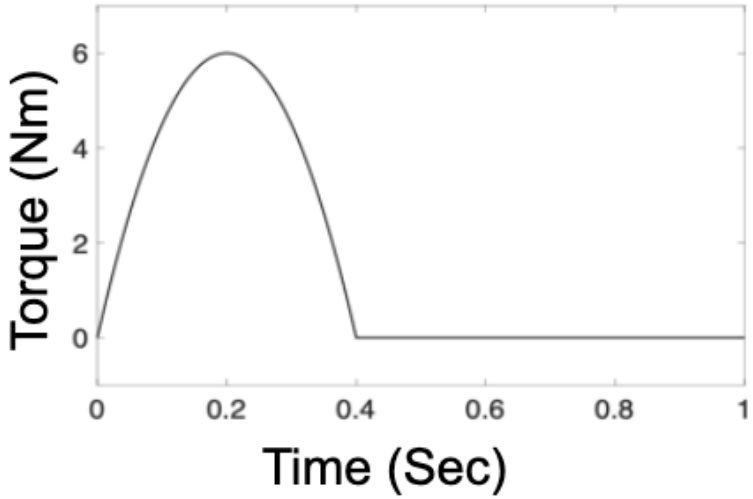


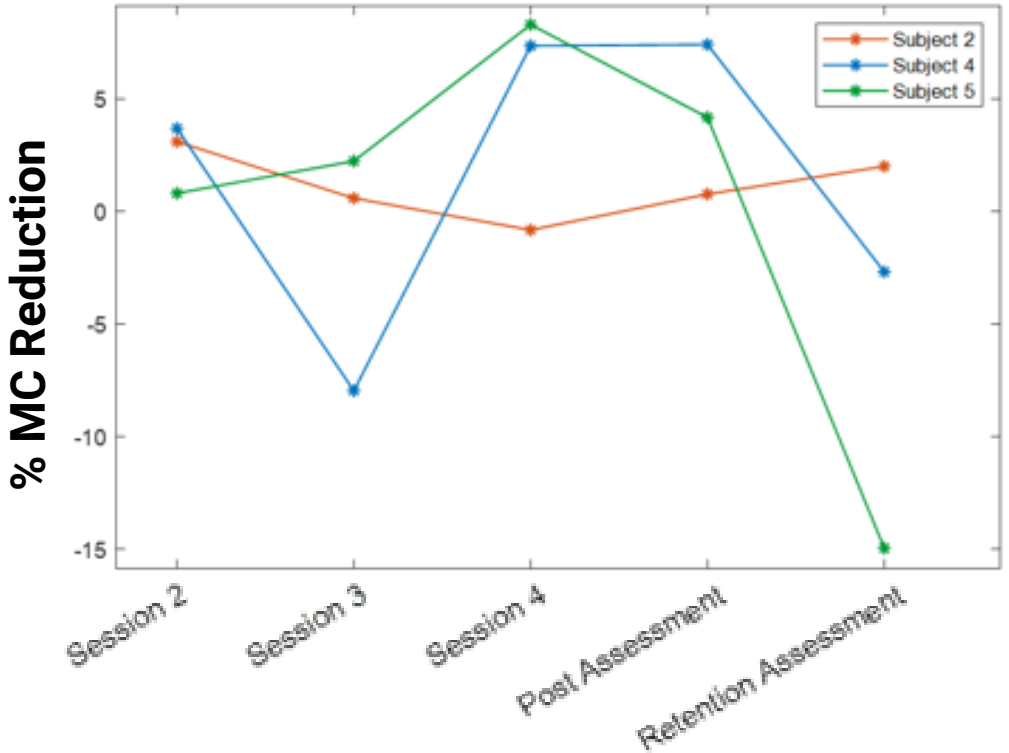
REDUCED ENTRAINMENT WHEN INSTRUCTED TO DO SO

LEARNING TO BE ASSISTED



METABOLIC COST
PFC AND MC ACTIVITY





TRAINING ENVIRONMENT?

INSTRUCTION?

MULTI-MODAL GUIDANCE?

CONTROLLER TYPE?

HRSL UMILL UMASS INTEGRATIVE LOCOMOTION LAB MNL

Abdikadirova, B., McDonnell, P., Fabrizio, M., Hoogkamer, W., Martini, D., & Huber, M.E. (ongoing) UMassAmherst

CONCLUDING REMARKS

- Exoskeletons can enhance opportunities for practice and when, combined with motor learning principles can enhance gait rehabilitation

- Learning to walk with an assistive exoskeleton is a an example of truly novel skill learning

- To guide and accelerate learning of exo-assisted walking, we need to first understand:
  - what is being learned?
  - how it is being learned?
  - what factors influence learning?

ASSISTING HIGHLY LEARNED SKILLS

PRACTICE

GUIDANCE

REAL WORLD LOCOMOTION

RIGHT CONTROLLER

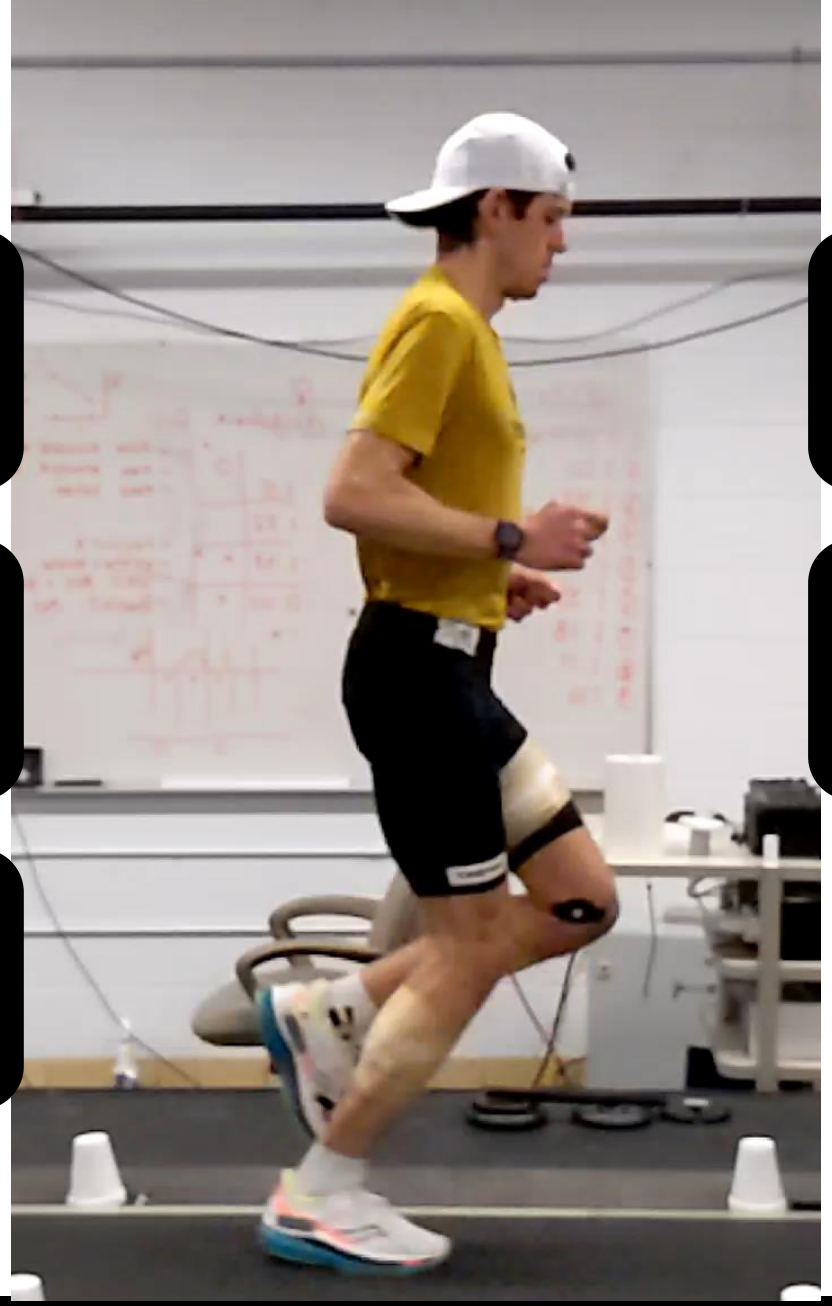
RIGHT MECHANICAL DESIGN

ASSISTING HIGHLY LEARNED SKILLS

PRACTICE

GUIDANCE

REAL WORLD LOCOMOTION



RIGHT CONTROLLER

RIGHT MECHANICAL DESIGN

ACKNOWLEDGEMENTS

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QUESTIONS????

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