A Passive Mechanical Add-on for Treadmill Exercise (P-MATE) in Stroke Rehabilitation

Irene L. Y. Beck[1,2], Belle C. Hopmans[1,3], Bram Haanen[1], Levi Kieft[1], Heike Vallery[2,3,4], Laura Marchal-Crespo[1,2], and Katherine L. Poggensee[1,2,3]

[1] Department of Cognitive Robotics, Delft University of Technology, Delft, Netherlands
[2] Department of Rehabilitation Medicine, Erasmus Medical Center, Rotterdam, Netherlands
[3] Department of Biomechanical Engineering, Delft University of Technology, Delft, Netherlands
[4] Institute of Automatic Control, RWTH Aachen University, Aachen, Germany

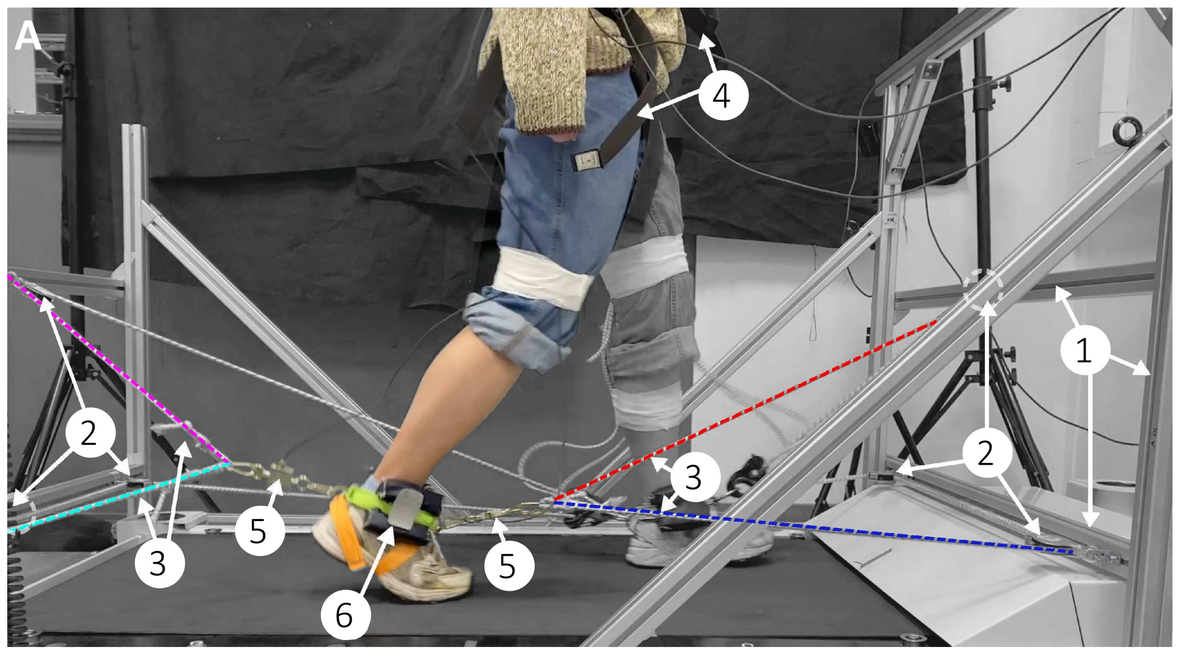


Motivation

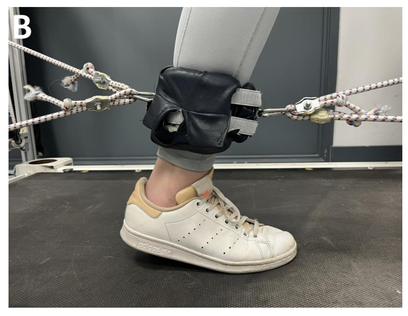
Robotic rehabilitation enables high-intensity therapy while reducing therapists' workload, however, cost and complexity limit adoption [1]. Using tendons in gait rehabilitation has shown promise in delivering effective assistance and resistance during treatment [1-3].
Particularly in stroke, one of the symptoms is hemiparesis, or gait asymmetry by impairing one side of the body [4]. We investigated how to leverage the strength and biomechanics of the non-paretic limb to assist the paretic limb's movement.

Design of the P-MATE

The P-MATE was designed to provide support during treadmill walking, particularly for individuals with hemiparesis. The add-on combines four elastic tendons attached to both legs and guided by pulleys.
The pulleys are optimally located around a treadmill to have minimal ''parasitic'' forces acting on the legs during gait. The paretic leg is assisted during the swing phase while the non-paretic leg is moved backward by the treadmill during stance. The system does not require any actuators or control and allows for the individual's active participation.



(A) System overview of P-MATE
(1) Off-the-shelf aluminum profiles (40x40, item, Germany)
(2) Six pulleys located symmetrically about the coronal and sagittal planes
(3) Elastic tendons connecting the legs at the front and back
(4) Safety harness
(5) Load cells to measure interaction forces (KD40S 1000N, ME-Meßsysteme, Germany)
(6) The human-device interface connecting the system to the user



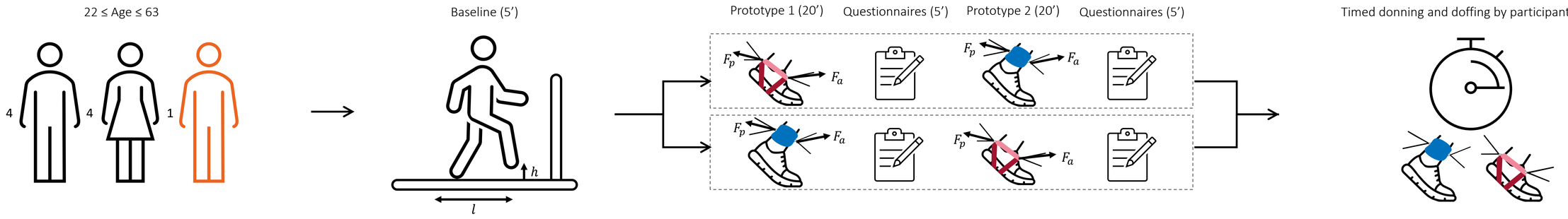
(B) Human-device interface 1
Cuff prototype



(C) Human-device interface 2
Bandage prototype

Methods

Participants – eight healthy adults and one physical therapist



Outcome metrics

Biomechanical data – step length (l), step height (h), and anterior and posterior forces in elastic tendons of the right leg (F_a and F_p)

Setup time – donning and doffing of both human-device interfaces by experimenter and participants

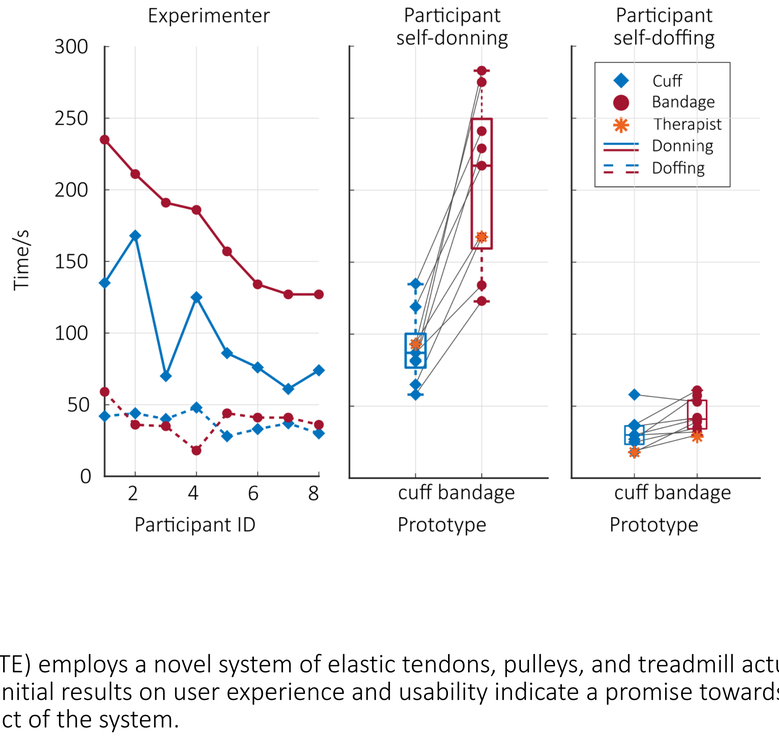
Questionnaires – System Usability Scale (SUS), User Experience Questionnaire (UEQ), acceptance and satisfaction of Van der Laan Acceptance Questionnaire (AQ_U and AQ_S)

Results

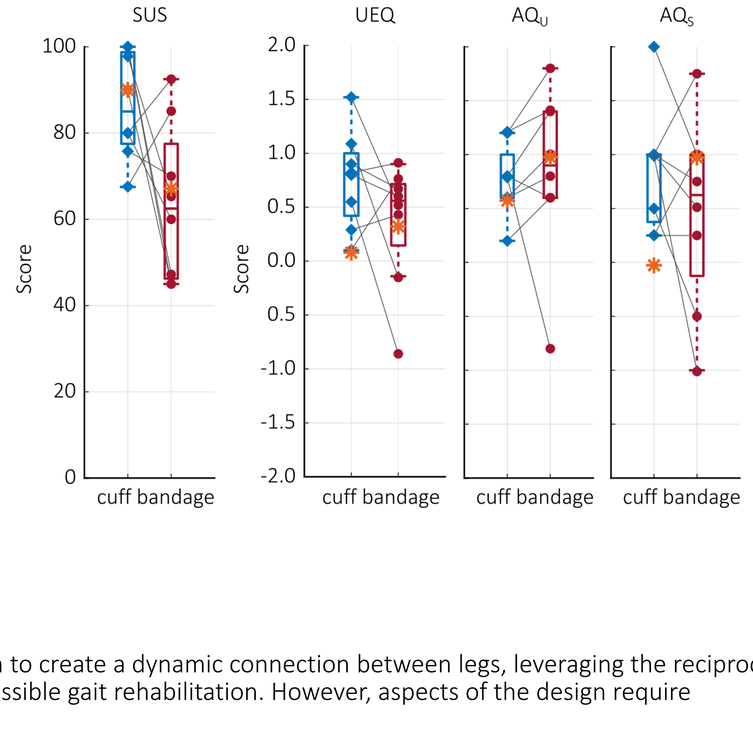
Biomechanical data
Reduced step length and step height in both prototypes, bandage has higher anterior forces

	Median of average step length	Median of average step height	Average peak forces anterior/posterior
	0.58 m	0.16 m	-
	0.53 m	0.15 m	118 / 110 N
	0.53 m	0.10 m	141 / 114 N

Setup time
Fast to setup up, faster to take off, and improves with experience



Questionnaires
Cuff highly usable, variations in user experience and acceptance on usability and satisfaction per human-device prototype



Conclusion

The Passive Mechanical Add-on for Treadmill Exercise (P-MATE) employs a novel system of elastic tendons, pulleys, and treadmill actuation to create a dynamic connection between legs, leveraging the reciprocal movement of the unimpaired leg to assist the impaired leg. Initial results on user experience and usability indicate a promise towards accessible gait rehabilitation. However, aspects of the design require refinement to further improve the usability and clinical impact of the system.

References
[1] S. A. Foley and E. P. Washabaugh, *Gait and Posture,* 2012. [2] R. Hidayah et al., *IEEE TNSRE*, 2020. [3] X. Jin et al., *IEEE TNSRE*, 2018. [4] D. V. Skvortsov et al., *Diagnostics*, 2025

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