Challenge-Based Adaptation of Exoskeleton Assistance and Gamified Biofeedback Enables Automated Gait Rehabilitation

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Appropriate challenge is needed for effective rehabilitation

As children with gait impariments undergo gait training, their ability is expected to improve and an appropriate challenge level is beneficial to continue optimal progression.

- Previous studies have found 74% as a self-selected challenge level in gamified motor rehabilitation tasks[1], and that users who were enforced to a 70% success rate exhibited the most improvment in a video game task[2].
- In paradigms with multiple interventions, it is unclear how different parameter settings impact a specific individual, and how these settings are may change over time.
- An online optimization framework is needed to continuosly maintain a target success rate in order to maximize rehabilitative benefit.

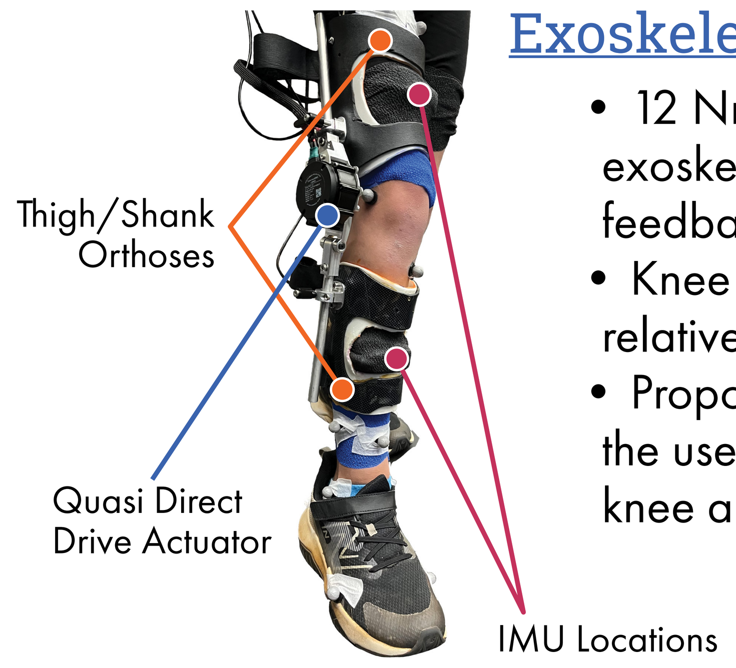
Approach

Covariance Matrix Adaptation - Evolutionary Strategy[3] (CMA-ES) was used to continuously tune parameters of a wearable exoskeleton and visual biofeedback system, to maintain a constant nominal success rate (70%) as the user adapts over time.

Three parameters (impedance stiffness, target angle, tolerance) were tuned independently during stance phase and swing phase walking.

Three healthy young adult participants and one child (13yo) with genu recurvatum (knee hyperextension) completed the protocol.

Dual Feedback for Walking Rehabilitation



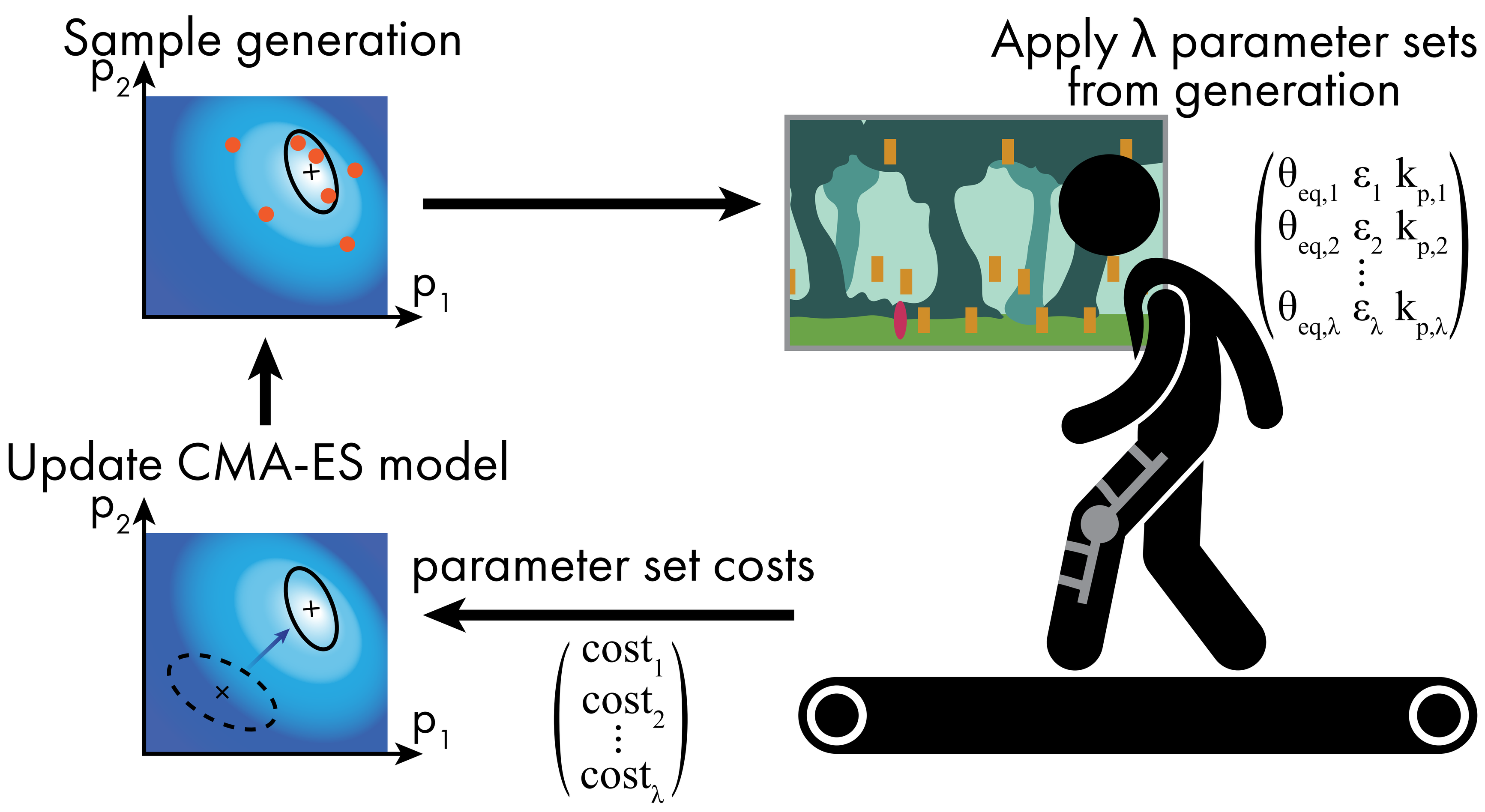
Exoskeleton - Haptic

- 12 Nm Quasi-direct drive knee exoskeleton provide assistance and haptic feedback[4]
- Knee angle is estimated in real-time by relative IMU position
- Proportional assistance is provided when the user deviates away from the specified knee angle profile and tolerance

Biofeedback- Visual

- Video game projects discretized knee kinematic profile
- User scores points when they hit the targets, controlling the avatar with their real-time knee kinematics

Training Personalization Loop

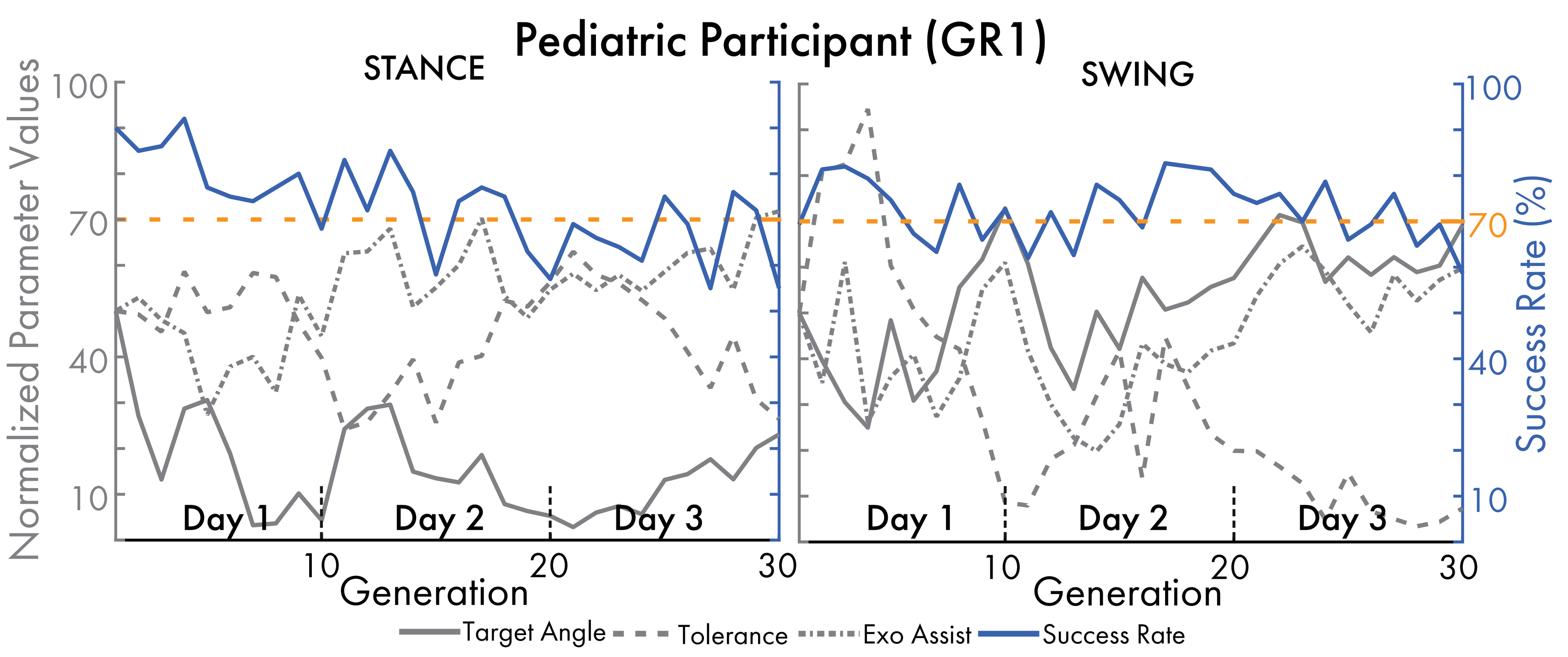


Optimizer Implementation

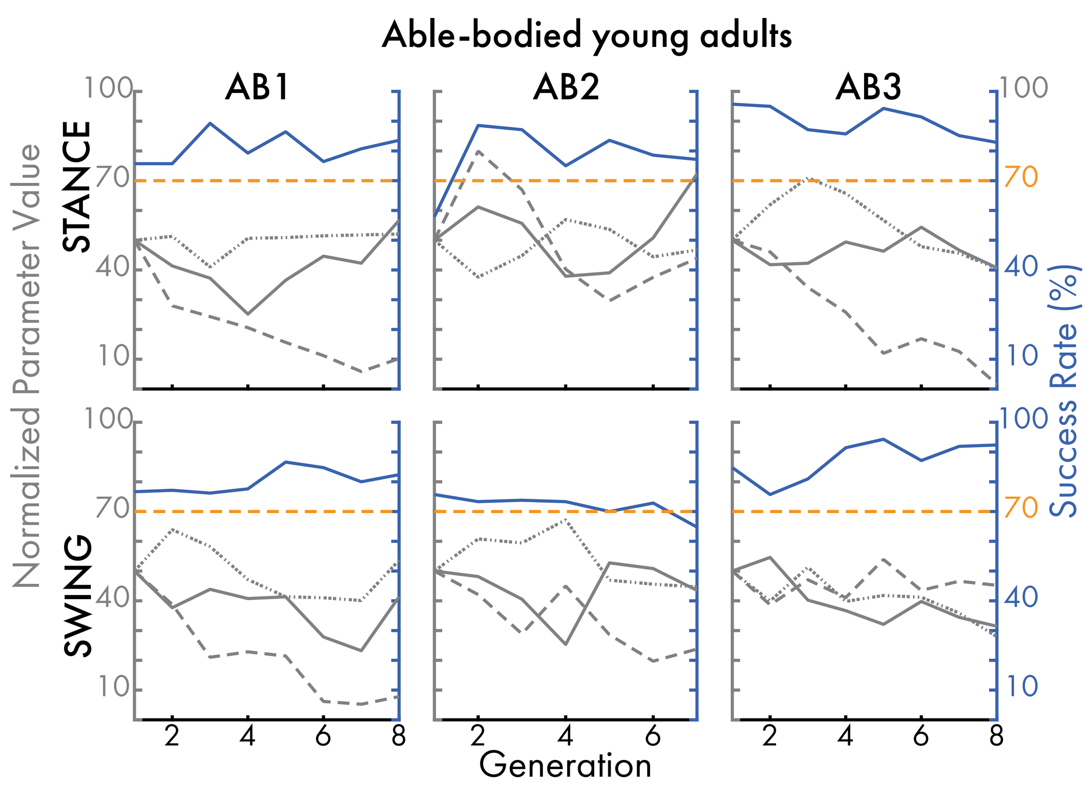
CMA-ES, was selected for the online optimizer, due to its ability to handle an inherently dynamic environment. CMA-ES samples generations of new parameter sets based on the best performing ones from the previous generation.

- Parameters were normalized between 0 and 10
- Initial search space (σ) = 2
- Parameter sets per generation (λ) = 7 for AB and 5 for pediatric
- For AB, 8 generations on one visit (56 parameter sets)
- For pediatric, 10 generations per visit, for 3 visits (150 parameter sets)

Success rate is maintained for pediatric participant

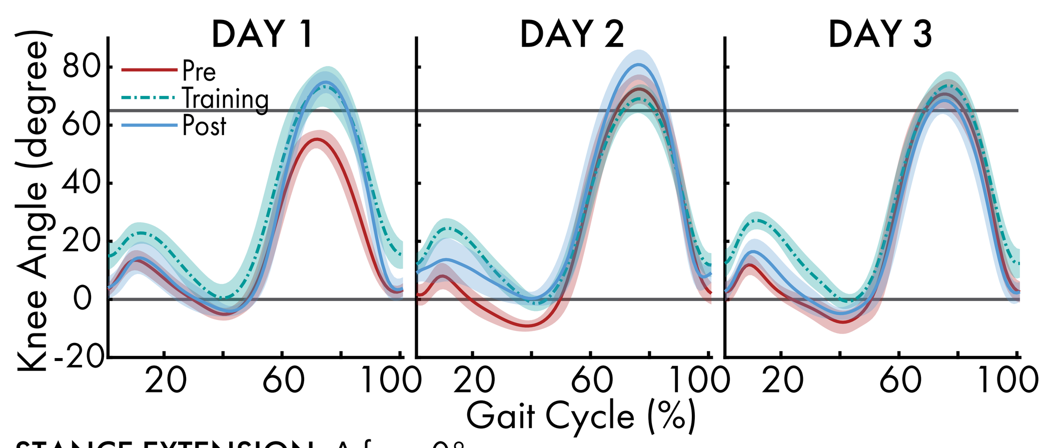


- Both stance and swing phase hit 70% success rate by the end of day 1
- Success rate was stable throughout subsequent visits
- Parameters significantly changed throughout the training implying continuous training and adaptation
- The tolerance (target size) was the most important factors in controling score rate in both stance and swing phase

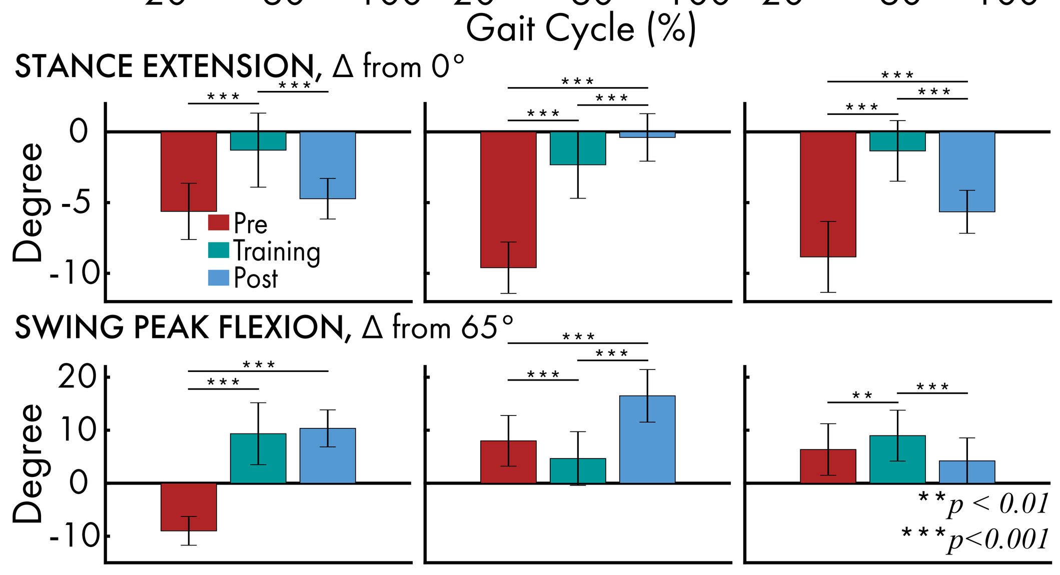


AB participants did not show the same consistent score rate, likely due to the difficulty hitting the set bounds and the AB participants still being able to perform the task effectively

Knee kinematics improve during & after training

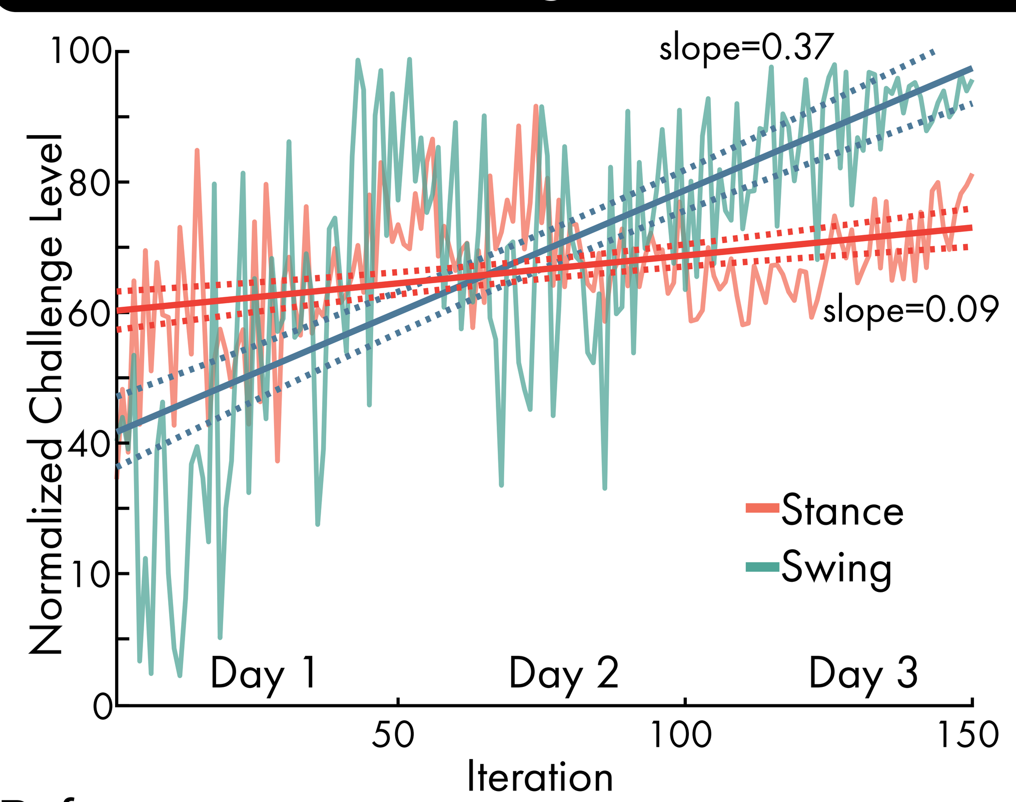


For all three visits, hyperextension reduced during training, with carryover reductions on visits 2 & 3



Peak knee flexion also increased, though some excessive knee flexion was seen on visit 1 & 2

Effective challenge level increases throughout training



Parameters significant to changes in success rate were used to determine an overall "challenge"

Challenge level showed a strong upward trend in swing and a weak upward trend in stance, indicating improvement in skill throughout the training

References

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Acknowlegements

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