Personalized locomotor adaptation model reveals fall risk-aware locomotor performance

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Summary

Human locomotion in everyday settings achieves near-optimal performance along many motor objectives such as energy-minimization, stability, and symmetry. However, when exposed to a novel environment, locomotor performance unfolds over slow timescales and often falls short of the theorized optimum. Here, by personalizing a model of locomotor adaptation, we show that suboptimal performance in a novel environment is explained by prioritizing environment-dependent fall risk mitigation.

Introduction

In highly practiced and learned settings, human locomotion is optimized for multiple motor objectives including energy-minimization, stability, and symmetry [1]. Across, rehabilitation and wearable robotics, researchers design novel environments, with the hope that humans will also discover the new theorized optimum. However, contrary to predictions made by traditional optimization-based models, human locomotion in novel settings is often dominated by adaptation [2] – performance converges slowly if at all, and frequently falls short of theorized levels. Here, we put forth a personalized model of locomotor adaptation that quantitatively captures suboptimal locomotor performance and provides insight into why it occurs. Using this model, we find that in high-assistance environmental settings, slow convergence towards energy-minimal walking is explained by prioritizing mitigation of fall risk.

Methods

We conducted experiments and simulations to analyze adaptation in gait symmetry and energetics as a function of split-belt assistance (Fig. 1). The experiments included 24 participants walking for 45 mins at three split-belt assistance levels [0.4, 0.7, and 1 m/s] with a fixed average speed of 1 m/s (8 subjects for each condition). Model-based adaptation simulations [3] were matched to individuals to identify their best-fit learning rate and asymmetry weight (Fig. 2A).

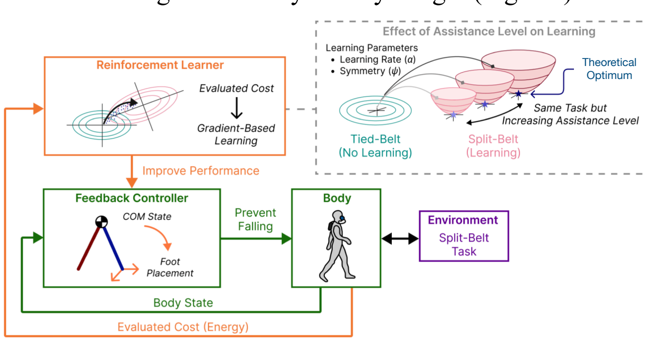

Figure 1: Computational model of locomotor adaptation for different split-belt assistance levels

Results and Discussion

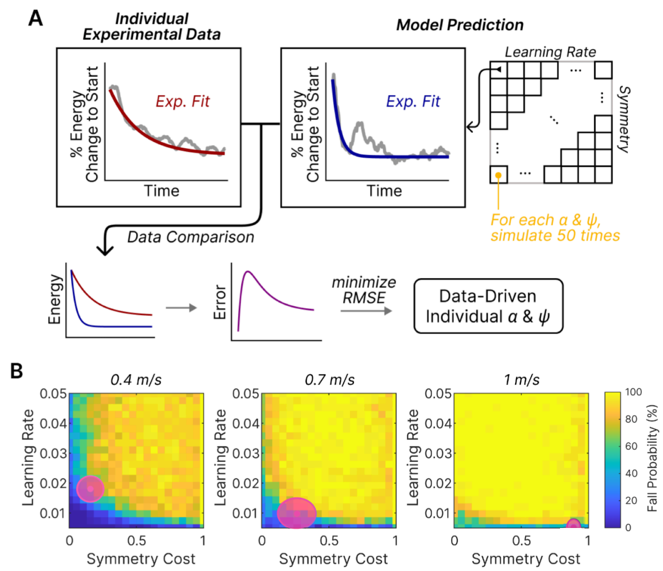

Figure 2: (A) The locomotor adaptation model in Figure 1 was personalized to each individual's adaptation, identifying their best-fit learning rate and asymmetry weight. (B) Individual's learning rate and asymmetry weight choices are modulated to mitigate fall risk.

We simulated the locomotor adaptation model for a range of learning rates and asymmetry weights, computing the energy and asymmetry transients as well as the fall probability for 50 simulations per condition. The best-fit learning rate and asymmetry weight for each individual were identified as shown in Fig. 2A. When analyzed together with the model-predicted fall probability, we find that individuals modulate their learning parameters across environments in a manner that mitigates fall risk (Fig. 2B). We find that deterministic time-to-fall [4] is a less robust measure of environmental risk than fall probability. To the best of our knowledge, this is the first simulation-guided quantification of probabilistic fall risk in human locomotor adaptation.

Conclusions

We show that slow energy minimization in novel environments can be the result of prioritizing fall risk mitigation, providing a way to quantify the effect of fall risk on locomotor performance. Our data-driven simulation-guided inference of perceived fall risk can advance rehabilitation engineering and wearable robot control.

References

[1] Holt et al. (1995). *J. Motor Behavior,* **27(2)** : 164-178
[2] Poggensee et al. (2021). *Sci. Robotics*, **6(58)**: eabf1078
[3] Seethapathi et al. (2024) *Nature Comms.*, **15(1)**: 9498
[4] Hausdorff et al. (2001) *Archives PMR*, **82(8)**: 1050-1056