People explore gait dimensions, and reduce this exploration as they learn to walk with exoskeleton assistance

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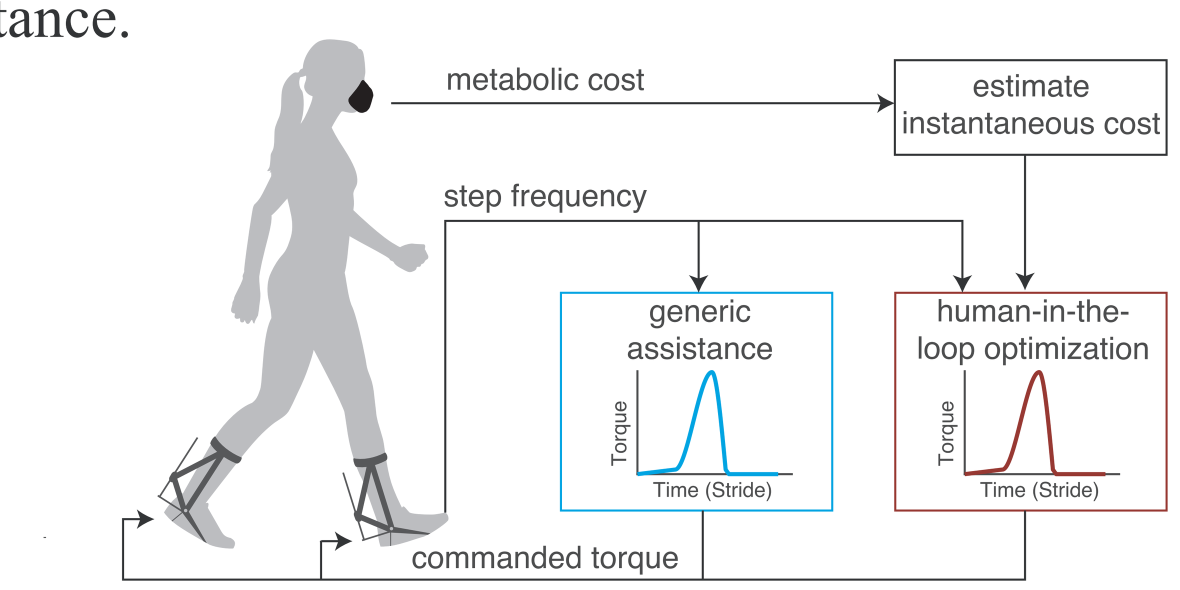
Introduction

The success of assistive devices relies on users learning to take advantage of the assistance [1]. In both everyday tasks and novel conditions, the nervous system is faced with the trade-off between exploiting, perhaps erroneously, previously learned strategies and exploring new, unknown strategies [2]. The goal of this study was to test how people balance this trade-off when learning to walk with ankle exoskeleton assistance. To accomplish this, we performed a post-hoc analysis of data from our previous study [3].

We hypothesized that 1) people explore many candidate gait dimensions as they identify which dimensions can take advantage of assistance, and 2) people reduce this exploration with experience as they learn to exploit new strategies that lower metabolic cost.

Experimental setup

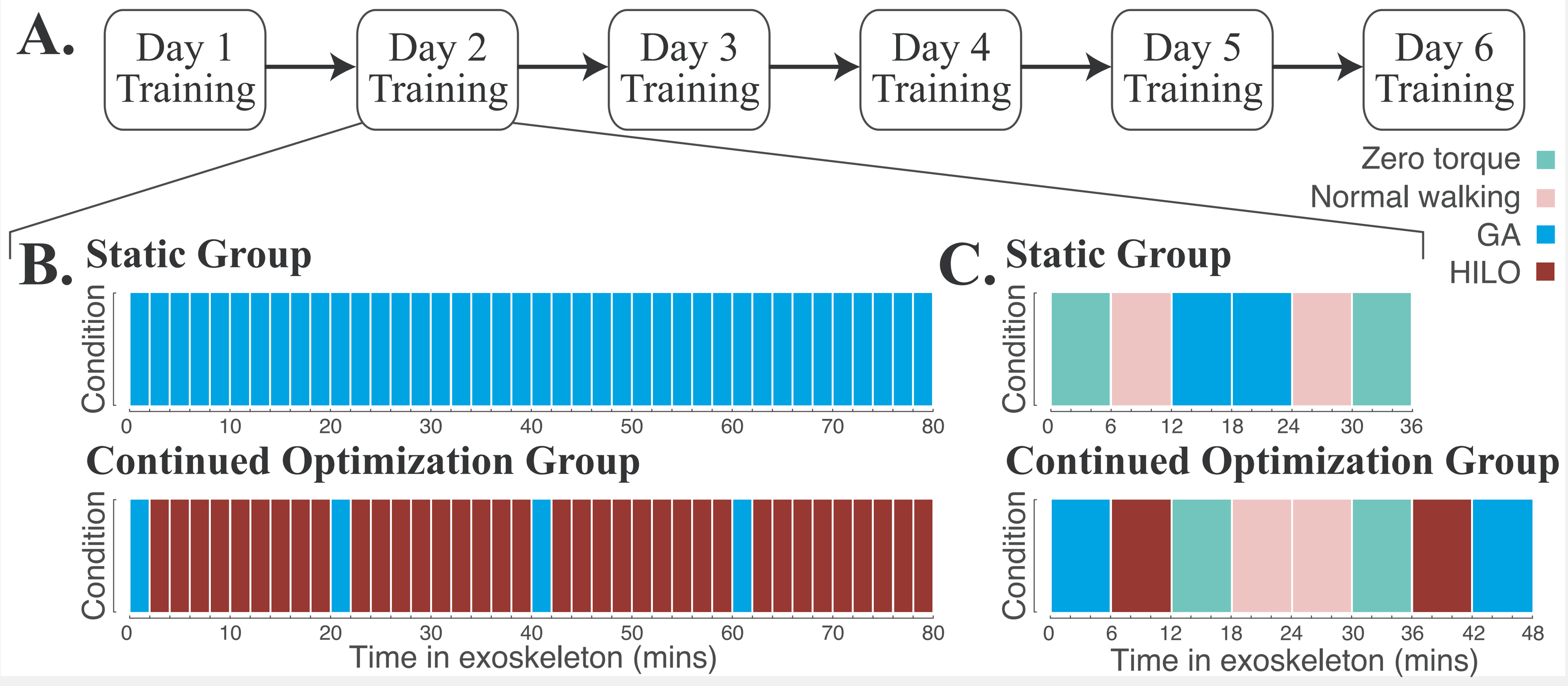
Figure 1. We randomly assigned 5 participants to a Static Group, and 5 to a Continued Optimization Group. Both experienced a predefined Generic Assistance (GA; blue) torque profile. Static repeatedly experienced it whereas Continued Optimization also experienced human-in-the-loop optimization (HILO; red). By design, both groups can influence the torque timing by varying their step frequency as well as the power and work applied to the ankle by varying their ankle kinematics. We are interested in how the nervous system learns to take advantage of this assistance.



Speaker Area

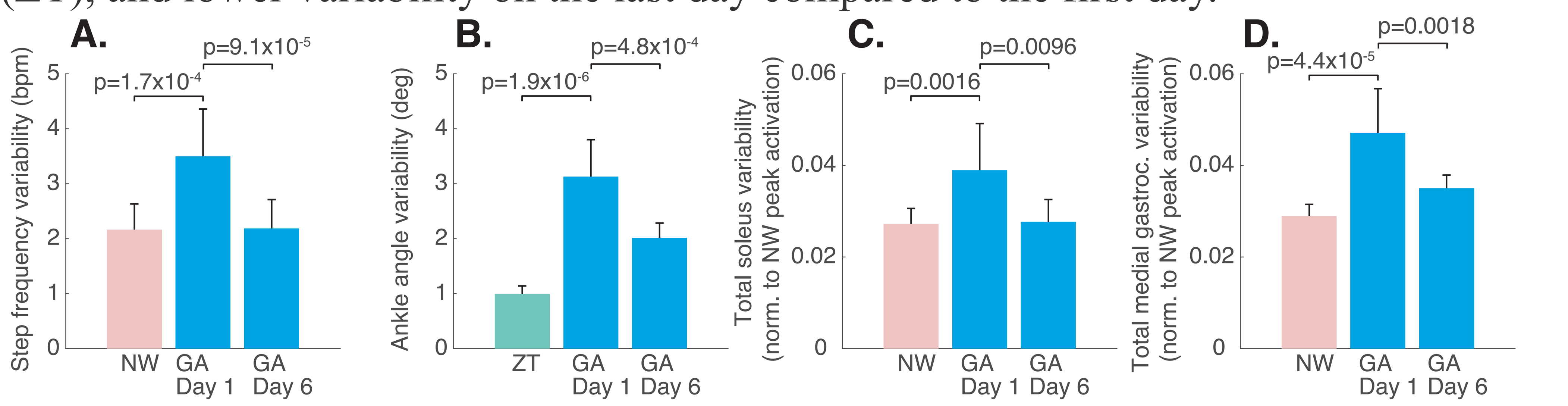
Experimental protocol

Figure 2. We analysed how all participants (n=10) learned to walk with repeated exposure to GA across multiple days. **(A)** All participants completed a training session on each day for a total of 6 days. **(B)** From day 2 onwards, participants first completed an adaptation trial where they either experienced GA repeatedly (Static Group) or periodically (Continued Optimization Group). **(C)** All training days ended with a validation trial that included two, 6-minute GA conditions.



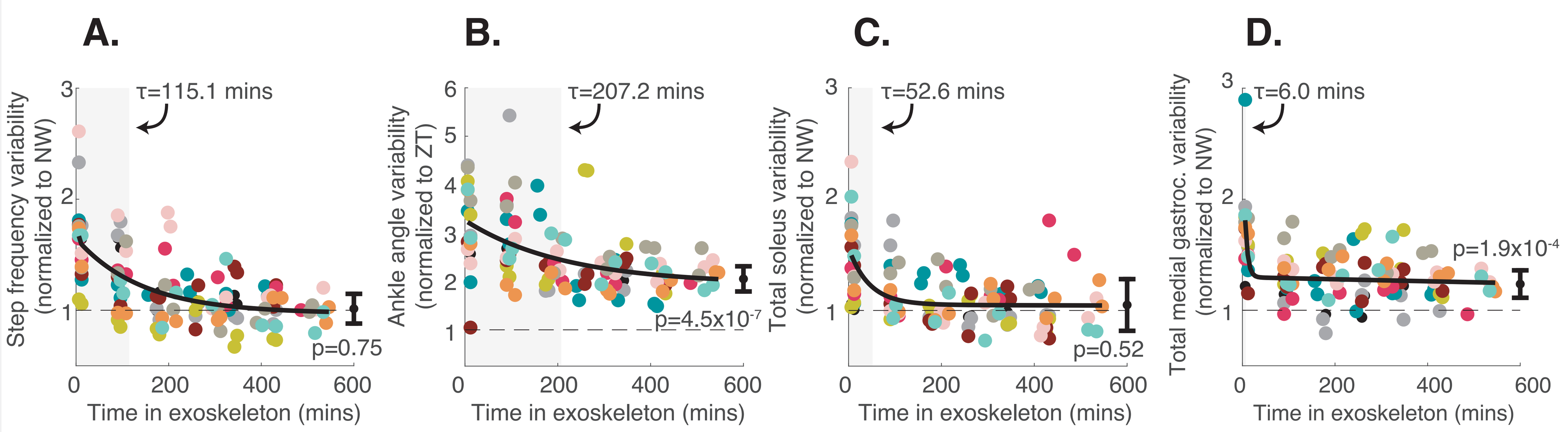
1. Exploration first increases along many gait dimensions, and then decreases with increased experience.

Figure 3. We observed higher variability along **(A)** step frequency, **(B)** ankle angle, **(C)** total soleus activity, and **(D)** total medial gastrocnemius activity at the beginning of the multi-day protocol compared to baseline levels in normal walking (NW) or zero torque (ZT), and lower variability on the last day compared to the first day.



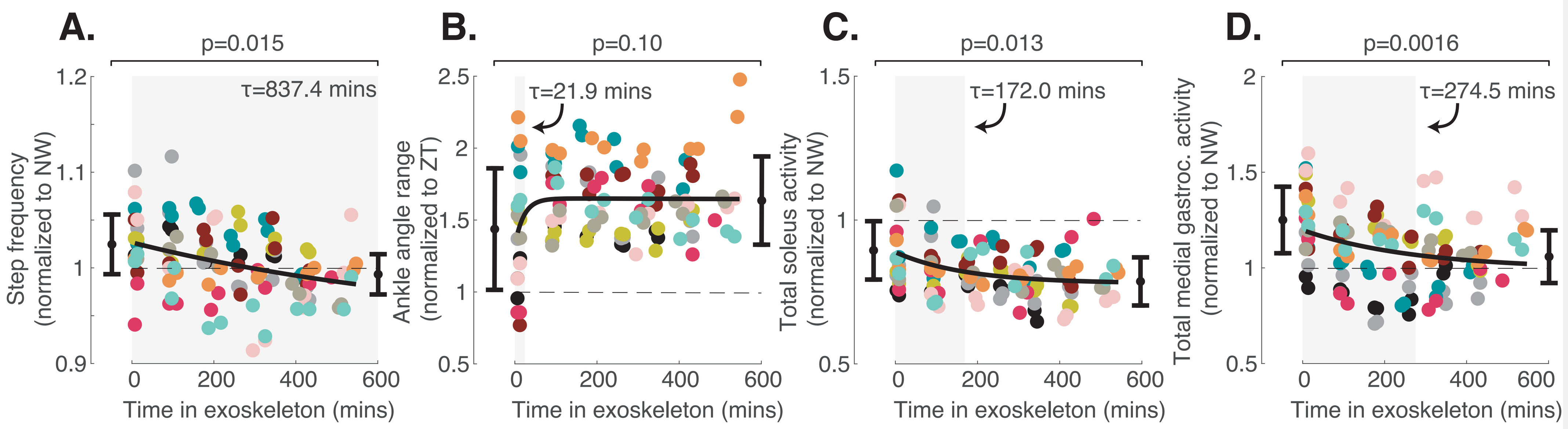
2. Exploration converges on baseline levels of exploration for some gait dimensions with increased experience.

Figure 4. Variability decreased along all gait dimensions and converged on baseline levels for **(A)** step frequency and **(C)** total soleus activity, whereas it remained elevated for **(B)** ankle angle and **(D)** total medial gastrocnemius activity.



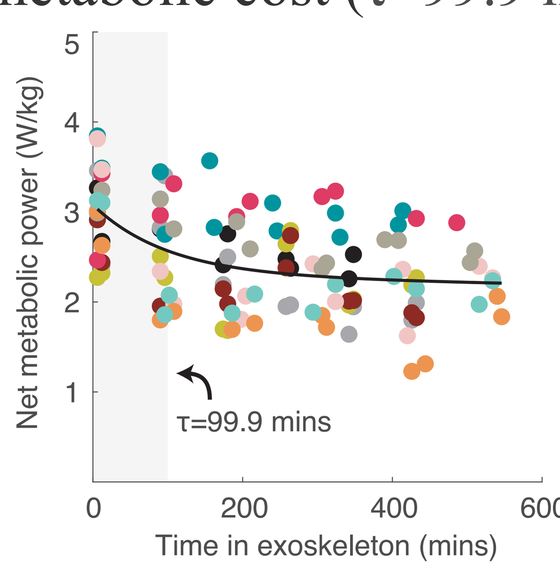
3. Exploration results in adaptation along some gait dimensions.

Figure 5. Participants learned to adapt their **(A)** step frequency, **(C)** total soleus activity and **(D)** total medial gastrocnemius activity with experience. We did not observe adaptation in **(B)** ankle angle range during stance when comparing the last day to the first day.



4. New strategies result in lower metabolic cost.

Figure 6. The average time constant of exploration (τ=95.2±87.0 mins) is similar to that by which the nervous system reduces metabolic cost (τ=99.9 mins).



Conclusions

Here we find that the nervous system learns to reduce metabolic cost by first exploring along many gait dimensions, and then reducing this exploration with experience. However, this only results in adaptation along some dimensions, suggesting that the nervous system did not know a priori which dimensions to adapt.

References

[1] N. Sanchez, et al. (2019) J Physiol.
[2] R.C. Wilson, et al. (2014) J Exp Psychol Gen.
[3] K.L. Poggensee, et al. In Prep.

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