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DOI
10.1007/978-3-031-77588-8_37

Publication date
2025

Document Version
Final published version

Published in
Converging Clinical and Engineering Research on Neurorehabilitation V

Citation (APA)
van Asseldonk, E., Eveld, M., Keijsers, N., & van der Kooij, H. (2025). Rapid Adaptation to Exoskeleton Balance Support in Perturbed Gait. In J. L. Pons, J. Tornero, & M. Akay (Eds.), *Converging Clinical and Engineering Research on Neurorehabilitation V : Proceedings of the 6th International Conference on Neurorehabilitation (ICNR 2024), November 5–8, 2024, La Granja, Spain* (Vol. 1, pp. 190-194). (Biosystems and Biorobotics; Vol. 31). Springer. https://doi.org/10.1007/978-3-031-77588-8_37

Rapid Adaptation to Exoskeleton Balance Support in Perturbed Gait

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Abstract. Exoskeleton balance support can improve the ability to counteract perturbations. The process of human adaptation to this support, however, remains unclear. Here, we assessed how able-bodied individuals adapted to balance support provided by an ankle exoskeleton during walking, specifically when counteracting forward-directed pushes at the pelvis. Activation of the balance support led to immediate and clear reductions in both Center Of Mass (COM) displacement and soleus EMG activity. Further adaptations were observed across the first 35 perturbations for COM displacement and only across the first 5 perturbations for EMG activity before reaching a stable value. These findings demonstrate that adaptation to balance support is a rapid process. These results indicate that minimal training time is required for an individual to effectively utilize exoskeleton balance support.

1 Introduction

SINGLE joint lower limb exoskeletons and exosuits have a large potential to restore mobility in people with neuromuscular disorders. Not only by its ability to reduce the metabolic cost of walking, but also by the ability to support balance and thereby enhancing gait stability. Recently, we and others have shown that providing balance support with an ankle exoskeleton resulted in a reduction of the postural sway in perturbed stance [1] and a reduction of the activity in the human postural control muscles in perturbed gait [2, 3].

While adaptation to robotic ankle support aimed at reduction of metabolic cost has been widely studied, adaptation to support aimed at supporting balance is hardly addressed. Figures on time needed for adaptation of the metabolic cost and the underlying muscular activity vary widely, e.g. 19 min [4] or 109 min [5]. For adaptation to balance support these figures are lacking. Afschrift and colleagues [3] found no evidence

This work is part of the research program Wearable Robotics with proj. no. P16-05 which is partly funded by the Dutch Research Council (NWO).

J. L. Pons et al. (Eds.): ICNR 2024, BIOSYSROB 31, pp. 190–194, 2025.
https://doi.org/10.1007/978-3-031-77588-8_37

of adaptation as they found no significant difference in response to the first and last perturbation when receiving balance support. However, their study was not designed to study adaptation and only 22 pushes were being provided. The goal of the current study is increasing the understanding of human adaptation to exoskeleton balance support.

2 Methods

Eight young adults (2 female, mean height: 1.82+/−0.06m; mass: 71.3+/−9.8kg) participated. The experimental protocol was approved by the University Ethics Committee, and participants gave their written informed consent.

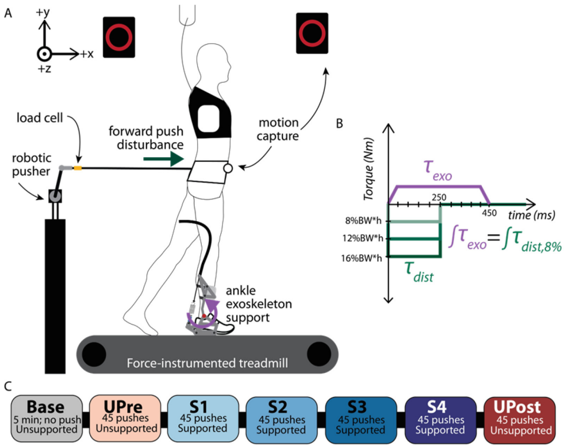

Fig. 1. A. Experimental setup: Participants walked on a treadmill while receiving forward pushes and wearing powered ankle exoskeletons. B. Forward pushes were applied at left heelstrike for 250 ms at three magnitudes (8, 12, and 16% bodyweight). Exoskeleton plantarflexion support was commanded at perturbation onset for 400 ms. C. Experimental protocol with the (un)supported perturbation trials.

Participants walked at 0.6 m/s on a dual-belt, force- instrumented treadmill (Bertec, Columbus, USA) while attached to a robotic pusher device via a modified hip brace and wearing two Bowden-cable driven exoskeletons and a safety harness (Fig. 1). Participants performed six walking trials that included 45 forward pushes each, block- randomized to include 15 at each magnitude (8%, 12%, and 16% bodyweight). Pushes were triggered randomly every 5 to 10 steps at left heel strike and lasted for 250ms. In the first and last trials, participants did not receive assistance from the exoskeletons. Only in the second through fifth trials, participants received assistance for every push (Fig. 1). The assistance was a 400-ms plantarflexion torque trapezoidal wave that was triggered at the same time as the push. The magnitude of this trapezoidal wave was calculated such that the impulse of the desired exoskeleton torque was equal and opposite to that of the estimated disturbance torque from the forward push at a magnitude of 8% (Fig. 1).

Participants wore reflective markers on their trunk and lower-limbs, which were tracked with an 8-camera infrared motion capture system (Oqus 600+, Qualisys, Gotenborg, Sweden) at 100 Hz. Muscle activity for the soleus, gastrocnemeus medialis, gastrocnemius lateralis, and tibialis anterior muscles (Bagnoli, Delsys, Natick, MA, USA) as well as ground reaction forces were collected at 2000 Hz.

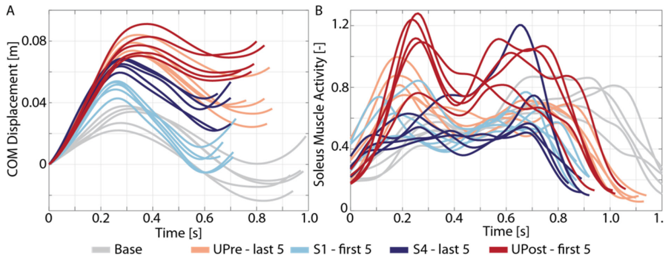

Fig. 2. Time-series trajectories of A. COM displacement and B. soleus muscle activity (right) for one participant for different intervals during the adaptations. COM displacement is plotted from perturbation onset (left heel-strike) to the contralateral (right) heel-strike. Soleus activity is plotted from perturbation onset (left heel-strike) to the ipsilateral (left) toe-off.

We analyzed adaptation by calculating Center Of Mass (COM) displacement and soleus muscle effort. COM position was estimated from pelvis marker positions, and its displacement quantified as the anterior-posterior shift from perturbation onset to 500ms after. Soleus muscle effort was the integral of muscle activity from perturbation onset to 1s after. These metrics were computed for each push for all trials for each participant, and then grouped into bins of 5.

3 Results

The provided robotic support resulted in a clear and immediate reduction of the COM displacement in response to the perturbations (Fig. 2A). This decrease was accompanied by a reduction in the soleus EMG activity needed to counteract the perturbation (Fig. 2B). With repeated perturbations, participants adapted and the reductions of the COM displacement were getting smaller before reaching a stable value (Fig. 3A). Wilcoxon sign rank test showed that after 7 bins the COM displacment for the first time was equal to the final mean (as calculated from the 4 last bins in S4). For the Soleus EMG activity adaptation appeared to occur faster on the group level. Following the reduction in the first bin, the EMG activity already stabilized in the second bin as it was not signficantly different from the final value (Fig. 3B). Yet, there was considerable variation among participants with two participants showing gradual further reductions up to the 20th bin.

An after-effect was observed in COM displacements, with a significant increase in the first bin post-deactivation of robotic support compared to pre-activation. For EMG activity similar increases were also observed in some participants (see Fig. 2B), on a group level no evidence of a significant after effect was found.

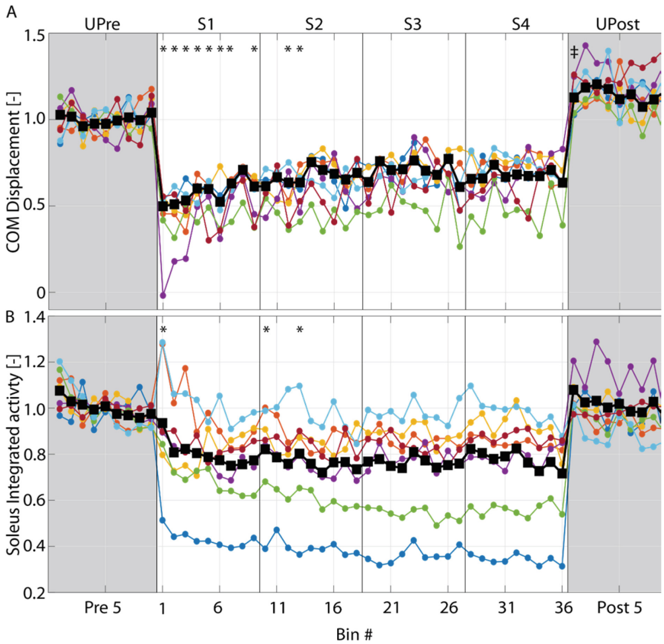

Fig. 3. Mean bins of five pushes for COM displacement 500 ms after perturbation onset (top) and soleus muscle integrated activity (bottom) for each participant (colored circles, in which each color indicates a separate participant), along with the group average (black squares). Values are normalized using the average of the UPre trial. * indicates a significant difference of the bin with the final supported mean reached in S4, ‡ indicates a significant difference of the bin with the last 4 bins of Upre.

4 Discussion and Conclusion

The goal of this study was to increase the understanding of how humans adapt to receiving robotic balance support. We showed clear signs of adaptation in the form of gradual changes during early exposure to the robotic support and the presence of an after-effect. Remarkable, the adaptation occurred very fast: for COM displacment within 7 bin, i.e. 35 steps with perturbations and for the EMG activity even within 1 bin, i.e. 5 steps. these timescales are particularly fast compared to reported adaptation of metabolic cost where effects seem to plateau after about 2000 steps [4].

Our findings give an initial insight into the adaptation process for balance support. Following the immedicate effect, our participants further relied on the robotic support and lowered their muscle activity at the expense of a decrease in the reduction of the CoM displacement. The results suggest that humans only need a minimal amount of training time to utilize the exoskeleton balance support. However these results are preliminary and might not have caputered all aspects. Allthough, the number of perturbations given in this study largely exceeds those in other studies [2, 3], possibly more perturbations are needed to capture the slower processes in adapting. Especially the responses in muscle activity are quite variable and after the first fast adaptation might have a slower adaptation process going on.

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