The neuromuscular effects of exoskeleton assistance on balance depend on task difficulty

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Introduction

- Assistive exoskeletons that can restore or augment a user's physical abilities have a wide variety of applications e.g., rehabilitation, gait training, load carriage.
- Spring-loaded ankle exoskeletons that offload the ankle plantar flexors improve walking performance by reducing metabolic cost.[1,2]
- Maintaining balance requires constant monitoring of the ankle muscles and integration of proprioceptive information.
- Exoskeletons may disrupt neuromuscular function required for standing balance, but these ideas remain unexplored.[2,3]

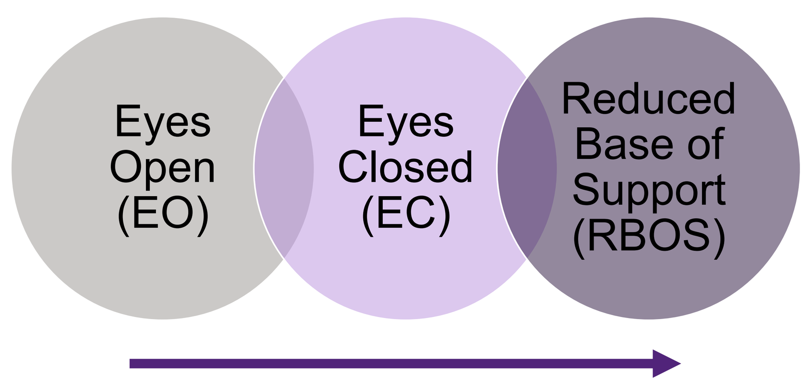
Aim

To determine the influence of passive ankle exoskeletons on neuromuscular behaviour during balance tasks of varied difficulty.

Methods

Protocol

- N = 15 healthy participants (10 males, 5 females; 24.7±4.9 years)
- Participants were fitted in bilateral, spring-loaded ankle exoskeletons that provided plantar flexion assistance (Fig. 1A).
- Three balance tasks performed under three exoskeleton stiffnesses: 0 (no assistance), 42 Nm rad^{-1} (low assistance), and 85 Nm rad^{-1} (high assistance):



Data Acquisition

- Centre of pressure (COP) was captured using a force plate (Fig. 1A,C).
- Muscle activation via surface electromyography (EMG) of medial gastrocnemius (MG), lateral gastrocnemius (LG), soleus (SOL), and tibialis anterior (TA) (Fig. 1A,C).
- B-mode ultrasound used to image the MG (Fig. 1A,B).

Statistical Analysis

- Linear mixed-effects models were used to examine the influence of balance task and exoskeleton assistance on COP parameters, muscle activation, and fascicle length. Significance was set at $p<0.05$.

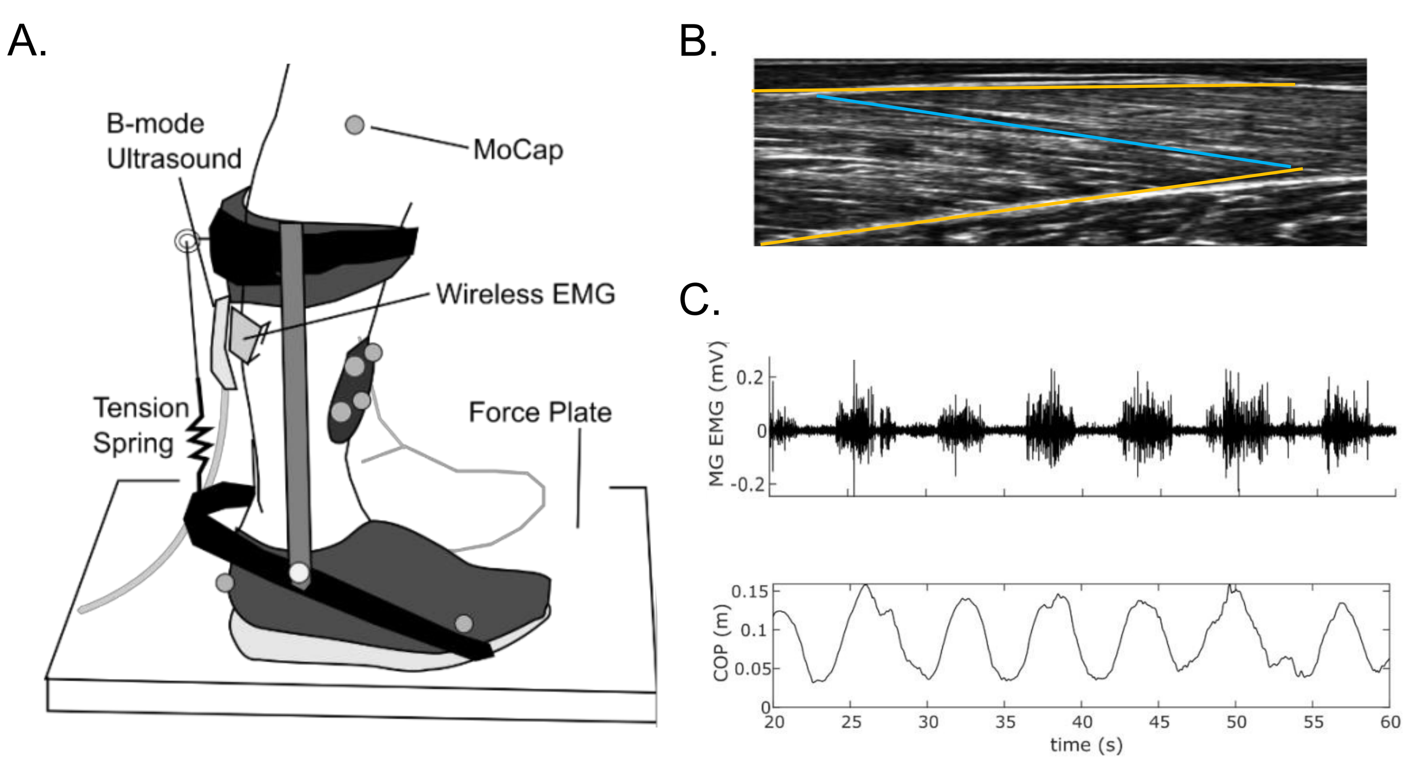


Fig. 1. (A) Experimental set-up with spring-loaded ankle exoskeleton, (B) B-mode ultrasound image of the MG, (C) sample time-varying EMG and COP data.

Results: Longer MG fascicles with exoskeleton assistance for some balance tasks

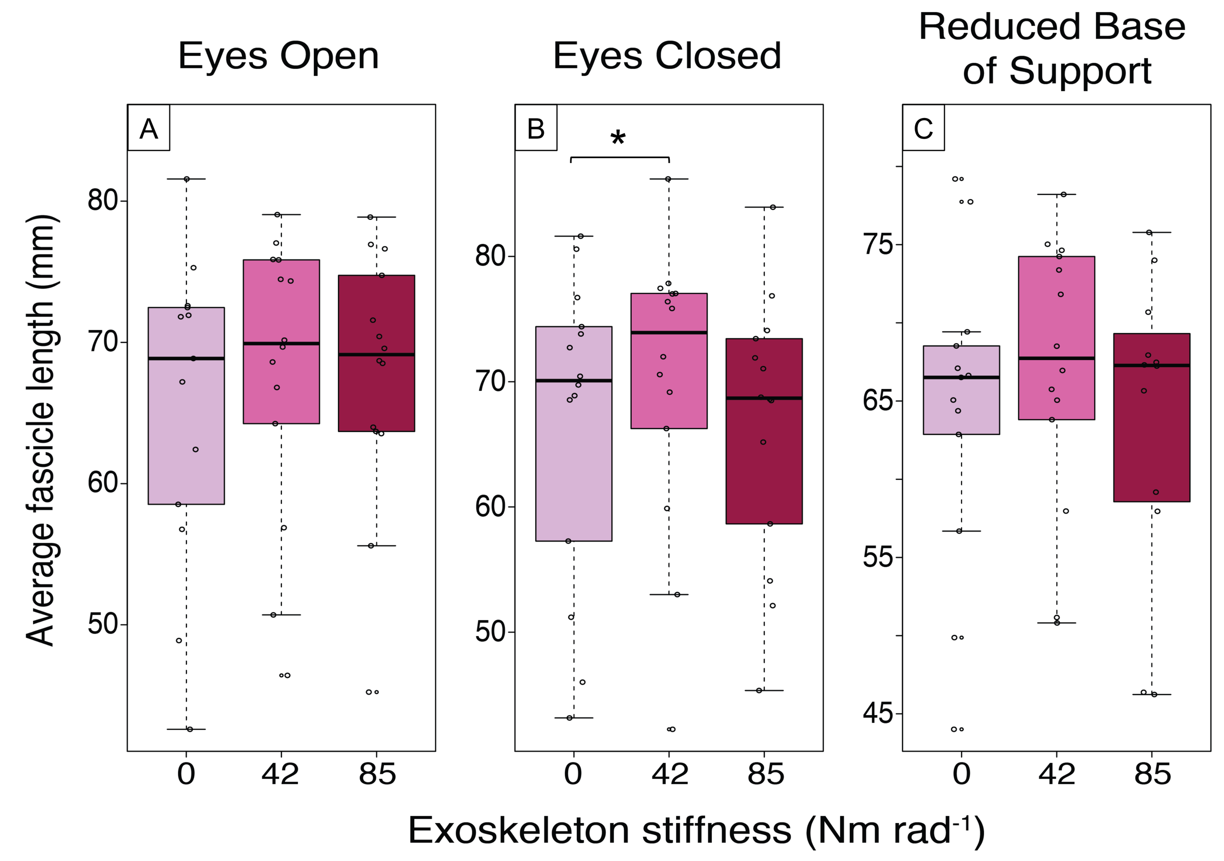


Fig. 2. Average MG fascicle lengths during three balance tasks: (A) Eyes Open, (B) Eyes Closed, and (C) Reduced Base of Support, performed at three exoskeleton spring stiffnesses: 0 (light pink), 42 (pink), and 85 (red) Nm rad^{-1}.

4.9% longer MG fascicles during **Eyes Closed** balance with low assistance (42 Nm rad^{-1}) (p=0.031).

No Δ in fascicle length for EO or RBOS with assistance.

Results: Exoskeletons alter ankle muscle activity in a task-dependent manner

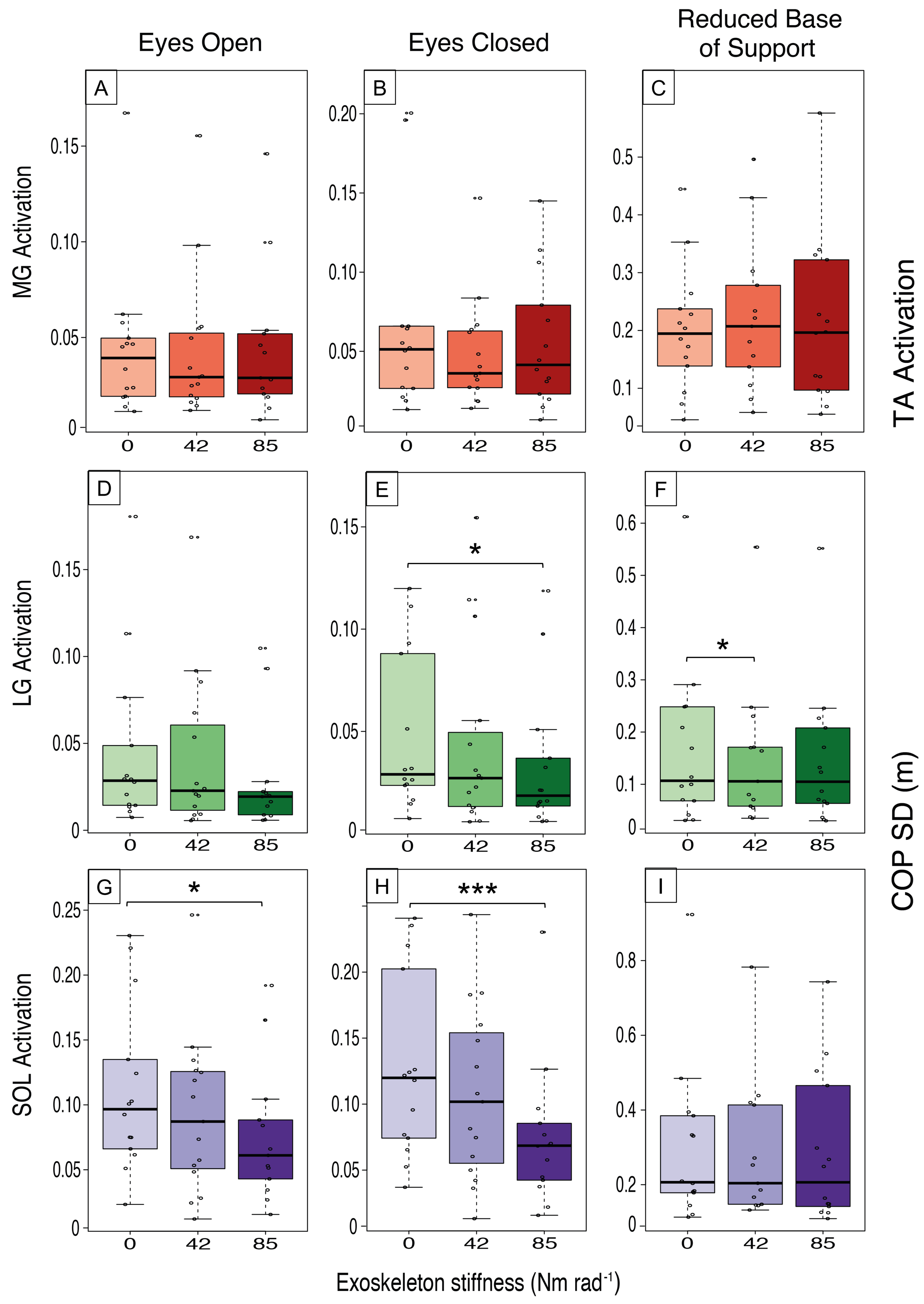


Fig. 3. Muscle activation of MG (reds), LG (greens), SOL (purples) during three balance tasks: (A,D,G) Eyes Open, (B,E,H) Eyes Closed, and (C,F,I) Reduced Base of Support, performed at three exoskeleton spring stiffnesses: 0, 42, and 85 Nm rad^{-1}.

↓ **LG** (p=0.02) and **SOL** (p<0.001) **muscle activation** during **Eyes Closed** balance with assistance.

No Δ in MG activity with assistance for any tasks.

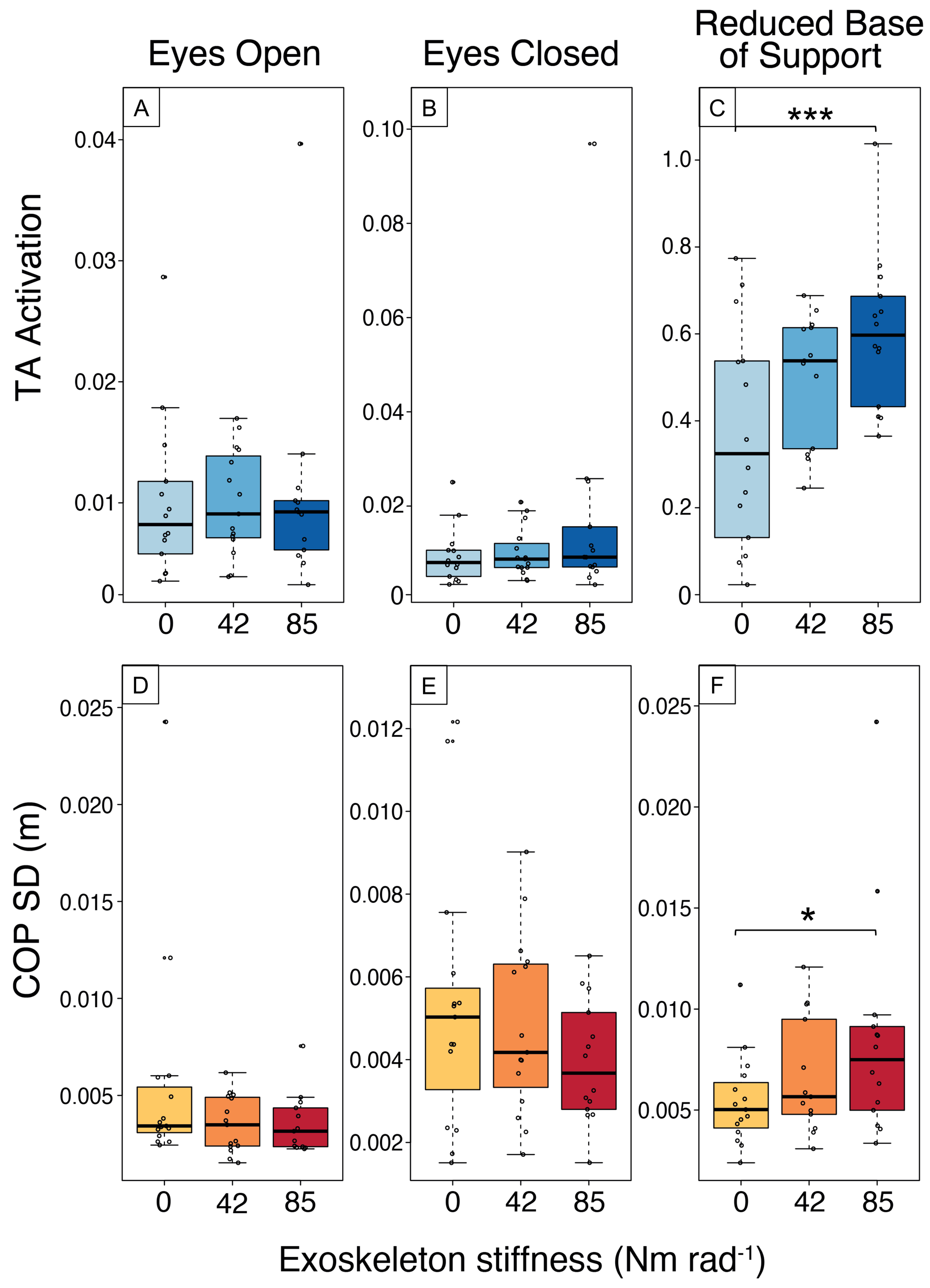


Fig. 4. TA muscle activation (blues) and COP variation (SD) (yellow/orange/red) during three balance tasks: (A,D) Eyes Open, (B,E) Eyes Closed, and (C,F) Reduced Base of Support, performed at three exoskeleton spring stiffnesses: 0, 42, and 85 Nm rad^{-1}.

↑ **TA activation** (p<0.001) and **COP variation** (p=0.01) with assistance in **Reduced Base of Support** balance only.

Discussion

- Longer fascicle operating lengths and reduced muscle activation demonstrate that passive ankle exoskeletons effectively offload the ankle plantar flexors for some balance tasks, with likely energetic benefits → potentially reducing fatigue.
- Decreases in muscle activation with assistance were not consistent across balance tasks because the three plantar flexors may have different functions in the control of standing balance.
- Exoskeletons led to an increase in TA muscle activity in the most difficult balance task, possibly disrupting fascicle behaviour and TA's proprioceptive function. This may impair balance and account for the concurrent increased COP variation which reflects greater whole-body instability.

Conclusion

There may be a threshold effect whereby spring-loaded exoskeletons improve balance during simple tasks by offloading the ankle plantar flexors but impair balance control during more difficult tasks. Future investigations into populations with balance deficits (e.g., ageing) will provide insights into the restorative potential of passive devices.

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References

1. Collins, SH et al. *Nature* 522: 212-215, 2015.
2. Nuckols, RW et al. *Sci Rep* 10: 3604, 2020.
3. Ringhof, S et al. *Front Sports Act Living* 1: 22, 2019.

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