2025-2 | 50th congress of the Société de Biomécanique
27-29 October 2025, Marseille, France

Multidisciplinary Biomechanics Journal

Persistent Changes in Upper-Limb Coordination Following Repetitive Exoskeleton Use

Océane Dubois[a*], Giovanni Brunelli[a], Agnès Roby-Brami[a], Ross Parry[b], Nathanaël Jarrassé[a]

[a] Sorbonne Université, CNRS, Inserm, Institut des Systèmes Intelligents et de Robotique, ISIR, F-75005 Paris, France
[b] LINP2, UPL, UFR STAPS, Université Paris Nanterre, 200 Avenue de la République, 92001 Nanterre, France
* Corresponding author: dubois@isir.upmc.fr

Received date: 01/04/2025
Accepted date: 27/06/2025
Publication date: 27/10/2025

Keywords: exoskeleton, physical human-robot interactions, motor control

1. Introduction

Exoskeletons are increasingly used in industry to reduce musculoskeletal strain during tasks like lifting or overhead work. While they offer clear benefits, their long-term effects on user comfort and motor performance remain unclear (Theurel, 2019). Longitudinal studies yield mixed results, often based on subjective data with limited insight into biomechanical changes (Kim, 2021).

A key concern is the persistence of residual forces beyond the task for which the exoskeleton was designed, potentially disrupting motor coordination. These uncompensated force fields may lead to subtle but lasting changes in movement patterns. Although motor adaptation is well studied at the hand level, the effects of joint-level perturbations during exoskeleton use are less understood (Proietti, 2017). Prolonged use may alter daily movements, with unknown effects on natural biomechanics—that is, the body's typical movement patterns in the absence of assistive devices. Most prior work has focused on inter-joint coordination during or shortly after exoskeleton use (Dubois, 2024), with little attention to longer-term retention.

This study investigates whether repeated use of a typical upper-limb exoskeleton (which always apply uncompensated residual forces) induces persistent changes in motor coordination. It focuses on two force fields: gravitational support (reducing arm weight) and a viscous field (resisting movement speed). By tracking motor strategy changes persisting after device removal, the study aims to better understand long-term motor adaptations and their implications for safe exoskeleton integration in the workplace.

2. Methods

2.1 Material

This study utilized the ABLE exoskeleton, a 4-degree-of-freedom (DoF) robotic device designed to generate controlled forces at the joint level. It features three shoulder DoFs and one at the elbow, with high back-drivability enabled by a screw-cable transmission and gravity compensation. Two force fields were implemented: Gravitational Support (GS), which reduces perceived arm weight, and Viscous Field (VF), which adds velocity-dependent resistance. Motion tracking was conducted using an OptiTrack system with high-speed cameras and rigid body markers.

2.2 Set-up and protocol

The experiment examined motor adaptation over five days, with a 23-hour washout between sessions. 24 participants were divided into three groups: GS, VF, and a control group (NE). Participants were asked to perform a forward vertical reaching task, reflecting the types of upper-limb motions commonly observed in industrial settings, such as overhead assembly or workstation-based tool manipulation. Each session had three phases: a Spontaneous baseline task, an Exposure phase where the experimental groups used the exoskeleton while

To cite this article: Océane Dubois, Giovanni Brunelli, Agnès Roby-Brami, Ross Parry, Nathanaël Jarrassé, Persistent Changes in Upper-Limb Coordination Following Repetitive Exoskeleton Use, *Multidisciplinary Biomechanics Journal*, 2025, vol. 2, p. 279–281, DOI: 10.46298/mbj.16205.

the control group performed the same task without the exoskeleton, and a Washout phase where all participants performed the task without it.

Table 1. Summary of obtained results for the hand, joints and inter-joint coordination metrics.

	Metric	Statistical analysis	Interpretation
Hand	Overshoot	NS	No changes in the precision observed
	Task duration	p=0.004	NE group slows their movement over time, GS and VF have constant completion time
Joint amplitude	Shoulder ROM	NS	No changes in the maximum shoulder range of motion
	Elbow ROM	NS	No changes in the maximum elbow range of motion
Inter-joint coordination	Shoulder Contribution (JcvPCA Shou.)	p<0.001	GS force field resulted in decreased shoulder contribution compared to the NE group
	Elbow Contribution (JcvPCA Elb.)	p<0.001	GS force field resulted in increased elbow contribution compared to the NE and VF groups.
	Shou./Elb. Synch. (JsvCRP)	p<0.001	GS shows a progressive increase in desynchronization, while VF returns to baseline after an initial change in temporal coordination.

NS = non-significant.

2.3 Data Analysis

Kinematic data from the motion capture were filtered and then used to compute metrics such as: movement duration, overshoot, and joint maximum amplitude (Range Of Motion). Additionally, inter-joint coordination changes over time were also monitored by two metrics quantifying respectively joint contribution using Principal Component Analysis (JcvPCA) and synchronisation using Continuous Relative Phase (JsvCRP)

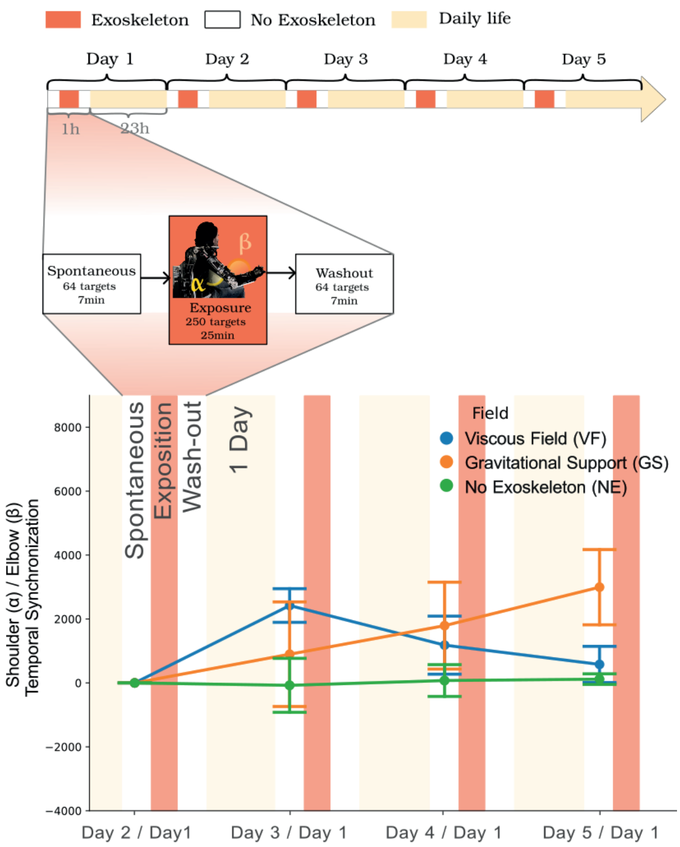

Figure 1. Experimental protocol schema and evolution of shoulder (α) and elbow (β) joint temporal synchronization results across 5 days of exposure to an exoskeleton.

(Dubois 2025). Data from the Spontaneous datasets of each day are compared to evaluate potential lasting effects due to repetitive use of exoskeletons.

3. Results and discussion

The results obtained indicate that, although task duration and range of joint movement were not significantly affected by wearing the exoskeleton, significant changes in shoulder-elbow coordination were observed. Results are summarized in Table 1.

In the GS condition, gravitational support led to persistent changes in shoulder and elbow contribution. Specifically, there was a reduced contribution from the shoulder and an increased contribution from the elbow. These changes were stable across the 5 days. Temporal synchronization between shoulder and elbow, however, continued to diverge with exposure to the exoskeleton. The VF condition showed an initial disruption of the joint temporal synchronization, which reversed by the fourth and fifth days. No specific changes in joint contribution was observed. However, movement variability in joint contribution was reduced, indicating a temporary inhibition of motor flexibility.

The study suggests that repetitive exposure to assistive forces providing imperfect gravitational support, such as the ones met in industrial settings with overhead or manipulation tasks, can induce lasting changes in coordination, potentially leading to musculoskeletal disorders over time. These results may have implications for the control of occupational exoskeletons. In contrast, the VF condition, mostly used in rehabilitation, did not induce long-term changes but reduced movement variability, which should be avoided both in rehabilitation and in assistance cases.

4. Conclusions

In conclusion, the study provides insights into how joint-level perturbations affect motor coordination, emphasizing the need for careful design of exoskeletons and the consideration of individual needs. Future research should focus on longer exposure times, diverse participant populations, and tasks similar to working conditions to better understand the impact of exoskeletons on motor adaptation and retention.

Conflict of Interest Statement

None.

Contributor Roles

O.D, R.P, A.R and N.J designed the protocol. O.D and G.B recorded the data. O.D performed the data analysis and statistics. O.D drafted the manuscript and all authors reviewed and approved the final version of the manuscript.

Funding

This study has been funded by the French National Research Agency with the Exoman Project (19-CE33-0009).

References

Theurel, J. & Desbrosses, K. (2019). Occupational exoskeletons: Overview of their benefits and limitations in preventing work-related musculoskeletal disorders. *IISE Transactions on Occupational Ergonomics and Human Factors*, *7*, 1–21. https://doi.org/10.1080/24725838.2019.1638331

Kim, S., Nussbaum, M. A., Smets, M., & Ranganathan, S. (2021). Effects of an arm-support exoskeleton on perceived work intensity and musculoskeletal discomfort: An 18-month field study in automotive assembly. *American journal of industrial medicine*, *64*(11), 905–914. https://doi.org/10.1002/ajim.23282

Proietti, T., Guigon, E., Roby-Brami, A., & Jarrassé, N. (2017). Modifying upper-limb inter-joint coordination in healthy subjects by training with a robotic exoskeleton. *Journal of neuroengineering and rehabilitation*, *14*(1), 55. https://doi.org/10.1186/s12984-017-0254-x

Dubois, O., Roby-Brami, A., Parry, R., & Jarrassé, N. (2024). Short term after-effects of small force fields applied by an upper-limb exoskeleton on inter-joint coordination. In *2024 IEEE International Conference on Robotics and Automation (ICRA)* pp. 959-965, Yokohama, Japan. https://doi.org/10.1109/ICRA57147.2024.10610645

Dubois, O., Roby-Brami, A., Parry, R., & Jarrassé, N. (2025). JcvPCA and JsvCRP: a set of metrics to evaluate changes in joint coordination strategies. *arXiv [Cs.RO]*. Retrieved from http://arxiv.org/abs/2505.09020