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Neuromuscular fatigue and motor learning: kinematic compensations

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1. Introduction

Neuromuscular fatigue can be defined as a decrease in motor performance following sustained effort—due for instance to a decreased force production capacity and to sensory impairments. Classic studies (e.g. Carron, 1969) have shown that while training with fatigue leads to an immediate drop in performance, it does not necessarily impair long-term motor learning. More recent research however suggests that fatigue can disrupt the consolidation of a motor skill and reduce its retention (e.g. Branscheidt et al., 2019). Moreover, fatigue is accompanied by motor compensations: the nervous system reorganizes the distribution of effort among different muscle groups to offset local fatigue-related impairments. For example, upper extremity fatigue during repetitive hammering leads to a reduction in shoulder involvement compensated by increased trunk motions, thus maintaining overall performance (Côté et al., 2008). Are such compensations learnt with a motor skill if we acquire it while being fatigued?

The present study aims to determine how localized shoulder fatigue affects joint kinematics when learning of a new motor task, both during the acquisition phase and during retention. We hypothesize that, during acquisition, participants exposed to fatigue will develop more pronounced compensatory adjustments reflected by a reduced humerothoracic movements compensated by increased trunk motions compared to the Control

group. Paradoxically, during retention the Fatigue group, having integrated these compensatory strategies during training, will exhibit attenuated kinematic reorganization compared to the Control group.

2. Methods

Twenty-three healthy adults were assigned to two groups (Fatigue vs. Control) to perform a motor task consisting of reproducing a visual target through arm abduction. During the first session (Day 1), all participants completed seven blocks of trials: one baseline block followed by six training blocks. Between each block, the Fatigue group underwent a fatigue induction protocol (4 sets of 15-20 dynamic shoulder abduction repetitions at 50 % of their maximal force), while the Control group performed the task without fatigue induction. Corrective feedback was provided on each trial. A retention phase was conducted one week later, comprising two blocks without fatigue and two blocks under fatigue, without corrective feedback.

Upper-body movements were recorded using a VICON system equipped with 10 cameras. Humerothoracic elevation and trunk lateral-flexion angles were determined (Wu et al., 2005) and normalized relative to the total humeral elevation angle to calculate each segment's relative contribution. The effects of fatigue on these contributions, both during acquisition and retention, were analyzed using two-way repeated-measures ANOVA (Group x Block).

3. Results and Discussion

During the acquisition phase (Day 1), ANOVA analyses revealed that the motor contributions of the shoulder (HT) and trunk did not vary significantly across learning blocks or between the Fatigue and Control groups ($p > 0.05$; see Table 1). These results indicate that initial acquisition of the motor task remains robust, regardless of fatigue induction.

Table 1. Preliminary ANOVA results on the effects of fatigue on motor learning: kinematic compensation.

	ANOVA Acquisition	ANOVA Retention
Humerothoracic Contribution (HT)	Block: $p = 0,450$ Group: $p = 0,402$ Block \times Group: $p = 0,530$	Block: $p = 0,023^*$ Group: $p = 0,901$ Block \times Group: $p = 0,623$
Trunk Contribution	Block: $p = 0,295$ Group: $p = 0,668$ Block \times Group: $p = 0,177$	Block: $p < 0,001^*$ Group: $p = 0,792$ Block \times Group: $p = 0,185$

In contrast, during the retention phase (Day 2), a significant effect of Block was observed for both shoulder contribution ($p = 0.023$) and trunk contribution ($p < 0.001$). As illustrated in Figure 1, this evolution manifests as a decrease in humerothoracic contribution, compensated by an increase in trunk activity. The absence of a significant Group effect and of a Block \times Group interaction ($p > 0.05$) suggests that these compensatory adjustments occur similarly in all participants during retention.

These observations align with the findings of Côté et al. (2008), who showed that fatigue induces modifications in intermuscular coordination during repetitive tasks to compensate for local loss of force. Furthermore, McDonald et al. (2018) demonstrated that, in repetitive upper-limb tasks, kinematic adaptations evolve over time, allowing the motor system to adjust its synergies to maintain overall performance despite fatigue. Thus, even in the presence of stable overall performance, the motor system integrates fatigue effects by reorganizing segmental contributions, shifting effort from the shoulder to the trunk during retention.

4. Conclusion

In conclusion, although initial acquisition remains intact, fatigue induces compensatory readjustments during consolidation. Humerothoracic contribution decreases, compensated by increased trunk activity, illustrating

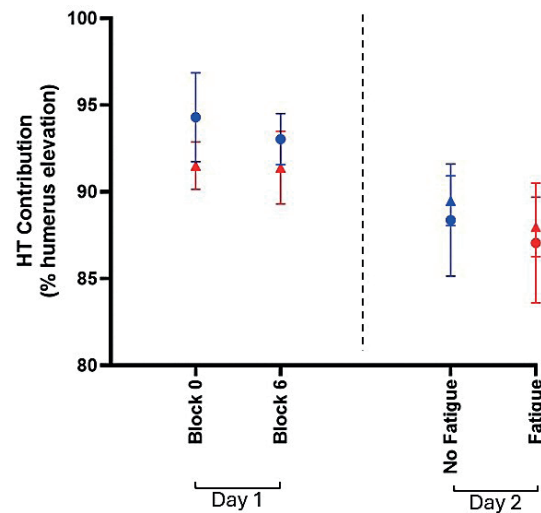


Figure 1. Effect of fatigue on motor learning: Kinematic compensation. Evolution of humerothoracic (HT) contribution (% of humeral elevation) during acquisition (Day 1) and retention (Day 2).

Circles represent the Control group, and triangles represent the Fatigue group; Blue indicates the No Fatigue condition, and red indicates the Fatigue condition. Data are presented as mean \pm SD.

motor system adaptation. These results underscore the importance of integrating such mechanisms into training and rehabilitation strategies to maintain performance under fatigue.

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Conflict of interest

None.

Roles of contributors

Conceptualization: AH, JB, MS; Methodology: AH, JB, MS; Data Collection: AH, SL, JB; Writing: AH; Review: SL, MS, JB.

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References

- Branscheidt, M., Oosterlaan, J., & Steenbergen, B. (2019). Fatigue-induced alterations in motor learning and consolidation. *Journal of Motor Behavior*, *51*(2), 123–133. <https://doi.org/10.7554/eLife.40578>
- Carron, A. V. (1969). Physical fatigue and motor learning. *Research Quarterly*, *40*(4), 682–686. <https://doi.org/10.1080/10671188.1969.10614902>
- Côté, J. N., Feldman, A. G., Mathieu, P. A., & Levin, M. F. (2008). Effects of fatigue on intermuscular coordination during repetitive hammering in motor control. *Motor Control*, *12*(2), 79–92. <https://doi.org/10.1123/mcj.12.2.79>
- McDonald, A. C., Mulla, D. M., & Keir, P. J. (2018). Muscular and kinematic adaptations to fatiguing repetitive upper extremity work. *Applied Ergonomics*. <https://doi.org/10.1016/j.apergo.2018.11.001>
- Wu, W., Siegler, S. C., Allard, P., Kamen, G., & van der Helm, F. C. T. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: Shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*(5), 981–992. <https://doi.org/10.1016/j.jbiomech.2004.05.042>