Effects of short-term sensorimotor restriction on functional neuroplasticity and motor memory consolidation during sleep

Arnaud Boutin*[1], Damien Léger[2,3], and Adrien Conessa[1]

[1]Complexité, Innovation, Activités Motrices et Sportives – Université Paris-Saclay – France
[2]Centre du Sommeil et de la Vigilance [Paris] – Hôpital Hôtel-Dieu [Paris] – France
[3]VIFASOM – Université Paris Cité – France

Résumé

Introduction. Sleep benefits the consolidation of motor skills, mainly through brief bursts of thalamo-cortical spindle activity (0.2-3 sec, 11-16 Hz) and associated reactivations of task-related neural patterns during non-rapid eye movement (NREM) sleep. Recent evidence shows that spindles cluster in "trains", following an infraslow rhythm (˜0.02 Hz) with spindle trains recurring every ˜50 seconds, while individual spindles within these trains iterate every 3 to 4 seconds (˜0.2-0.3 Hz mesoscale rhythm) (Boutin and Doyon, 2020). This temporal cluster-based organization of spindles is considered a critical sleep mechanism for the timed and repeated reactivation of memories, though the functional significance of this organization remains unclear. Additionally, cross-frequency coupling and the hierarchical nesting of NREM oscillations–particularly slow oscillations (SO; 0.5-1 Hz) and spindles–are thought to facilitate synaptic plasticity (Staresina, 2024). Current trends postulate that SOs confer a temporal window for spindles to occur in their excitable up-states and that a timely phase-locking facilitates the induction of persistent synaptic plastic changes (Helfrich et al., 2018). Using a short-term upper-limb immobilization procedure (Huber et al., 2006), combined with the recording of behavioral and electroencephalographic (EEG) night sleep measures, the aim of the present study was to determine the effects of daytime sensorimotor experience on sleep spindle expression (i.e., clustering and rhythmicity) and the integrity of the cross-frequency coupling between SOs and spindles. Specifically, we examined how spindle clustering and SO-spindle coupling contribute to motor memory consolidation by promoting local reduction in synaptic efficacy over sensorimotor cortical regions through upper-limb immobilization after motor sequence learning. We also evaluated memory generalization using a transfer test assessing the ability to generalize the newly acquired skill to another one (new sequence). **Method.** Thirty right-handed young healthy adults were equally divided into a left-limb immobilization group (IMMO) or a control group without immobilization (CTRL). The immobilization procedure (13 hours) was administered to promote local synaptic depression in contralateral sensorimotor cortical regions, immediately following the practice of an 8-element motor-sequence task with their left-hand fingers (14 training blocks). Sleep EEG recordings were collected the night before and after motor sequence learning. Sleep spindles were categorized as grouped (occurring in trains of ≤6 seconds apart on the same electrode) or isolated (spaced > 6 seconds apart) (Boutin & Doyon, 2020). Slow oscillation events were detected for each participant separately from sleep spindle events. Phase-amplitude coupling analyses were performed to measure the alignment

*Intervenant

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between high-frequency spindle bursts and the SO phase during SO-spindle co-occurrences.
Results and Discussion. Our results first replicate prior findings by revealing localized reductions in SO power during early sleep (first 20 min) in the IMMO group (IMMO-CTRL contrast), particularly over the sensorimotor cortex contralateral to the immobilized limb. Despite this immobilization-induced synaptic depression, we found no significant differences in spindle clustering or rhythmicity between the IMMO and CTRL groups. While the temporal cluster-based organization of spindles appears unaffected by prior daytime sensorimotor experience, distinct behavioral outcomes were elicited following sleep. Interestingly, immobilization induced a phase shift in the SO-spindle coupling for spindles grouped in trains, but not for isolated spindles outside trains. Moreover, the grouped-to-isolated spindle ratio showed a double dissociation by positively correlating with skill consolidation and negatively correlating with skill generalization following sensorimotor restriction. Our results thus suggest that spindle trains may promote skill-specific strengthening of motor memories, whereas isolated spindles may instead create memory-instability conditions facilitating skill generalization. This dissociation highlights distinct mechanistic roles for grouped and isolated spindles in memory processing.

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