

**Supplemental Information:**

**Rocking synchronizes brain waves during a short nap**

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***Supplemental Experimental Procedures***

**Participants**

Twelve healthy male volunteers gave informed consent to participate in this study according to the ethical regulations of the Geneva University Hospitals. Female participants were not included because of the effects of menstrual cycle on EEG and sleep [1]. All participants included in the study were good sleepers, with normal and regular sleep-wake habits, and were non-habitual nappers (taking a short nap less than once per week in the last two years). None of them suffered from excessive daytime sleepiness as assessed by Epworth sleepiness scale [2]. They had no psychiatric or neurological history, had never suffered from any vestibular disorder, and did not take any medication during the whole experimental period. The data from two participants had to be excluded before performing the analyses: one because of elevated anxiety before one experimental session preventing him from falling asleep (in the stationary condition), and the other one because of technical problems with the EEG recording. The remaining 10 participants had a mean age of 30.1 (range of 22-38 years) and had low anxiety levels, as assessed by State Trait Anxiety Inventory [3] (mean score  $\pm$  s.d.;  $32.56 \pm 3.68$ ). Sleep quality and quantity were assessed by self-rated sleep questionnaires over 3 consecutive nights before each experimental session. Wrist actimetry was also recorded during the last night preceding each experimental session.

**Protocol**

The experimental procedure consisted of a 45-minute afternoon nap spent in a custom-made bed that could either remain stationary or rock gently (Figure 1A in main text). This bed was suspended by four metal rods to a metallic frame and connected to an electrical motor that produced sinusoidally-modulated horizontal accelerations. The electrical engine and the experimental bed were built to be silent (adding only 2.5 dB to background noise). During pilot testing, we selected a set of motion parameters that generated stimulation while minimizing physical discomfort. The optimal parameters were obtained for total lateral excursion of 10.5 cm amplitude at the level of the bed and a swinging frequency of 0.25 Hz. Data recorded with an accelerometer (sampling frequency: 500 Hz; 3D motion tracker; Xsens MTx, Netherlands) on the bed and on the participants' head measured a peak horizontal acceleration of  $0.1 \text{ m/s}^2$  (g load = 0.01) and confirmed a negligible (non-detectable) vertical acceleration.

The nap protocol consisted of two sessions: one with the bed stationary, one with the bed put in motion. The order of the experimental conditions was randomized across participants and the two sessions were at least one week apart. Time in bed from lights off (2:30 PM) to lights on (3:15 PM) was controlled by the experimenters. The naps were spent in complete darkness and the temperature of the sleep room was controlled ( $21^\circ \pm 1^\circ \text{ C}$ ). During the stationary condition, the motor was turned on, but disconnected from the bed, so that both conditions included the same level of auditory stimulation (37 dB in each condition). In these conditions, auditory input can be excluded. Visual input can be discounted since in both controls and experimental conditions subjects closed their eyes closed and the lights were off. During both

sessions, polysomnography data were recorded continuously with a sampling rate of 1024 Hz, a high-pass filter at 0.5 Hz, and low-pass at 70 Hz (Vitaport3, TEMEC, Netherlands). The montage included 10 scalp electrodes placed according to International 10-20 system (Fz, Cz, C3, C4, Pz, Oz, O1, O2, A1, A2), plus electrooculogram and electromyogram contacts. To keep vestibular inputs due to the swinging motion constant across participants, each participant had his head placed on a soft and comfortable pillow that adopted the shape of the head and slept in a supine position. This setting also minimized movement artifacts. Before the experiment, the participants were told that they should bring comfortable clothes for the nap. Bedcovering consisted of a bed sheet and a blanket. Prior pilot experiments were performed to ensure that the experimental conditions were comfortable. During the main experiment, a careful debriefing of each subject at the end of the experiment confirmed that the sleeping conditions, including the imposed sleeping position and swinging parameters, were judged as comfortable and pleasant by all the subjects. One subject who experienced anxiety during one of the session was not included in the analysis (see above). None of the subjects reported difficulties falling asleep, as also supported by short sleep latencies in both conditions.

### **EEG data analyses**

Sleep polysomnography was scored over 30s epochs, according to standard criteria [4], by two experienced scorers blind to the experimental conditions. Several sleep parameters during the naps were determined: latencies to stage N1 (from lights-off) and N2 (from first N1 period), time and percentage of each sleep stage, total sleep time (TST; sum of the time spent in different sleep stages), total sleep period (TSP; total time from sleep onset to final awakening, including intra-sleep wake intervals),

sleep efficiency and number of intra-sleep awakenings (Table S1). Sleep efficiency was defined as TST/TSP x 100. Sleep spindles were visually quantified at Cz contact referenced against mastoid channels, based on their typical fusiform morphology, frequency of 11-16 Hz, minimum duration of 0.5 s, and minimal amplitude of 10  $\mu$ V [4] (Table S1). Scoring agreement for both sleep stages and spindles was greater than 95%, and points of disagreement were resolved by mutual agreement between scorers.

EEG spectral analysis was applied at the midline frontal and midline parietal sites (Fz and Pz) on stage N2. Fast Fourier transform was performed on average, 25% overlapping, 10 s windows, with a Hanning window, free of artefacts resulting in a frequency resolution of 0.1 Hz. Values below 0.6 Hz and above 25 Hz were omitted. Analyzes were performed using the Cartool software by Denis Brunet (<http://brainmapping.unige.ch/Cartool.htm>). Mean power in the following bands was calculated: slow oscillations (0.6-1 Hz), delta 1 (1-2 Hz), delta 2 (2-4 Hz), theta (4-8 Hz), slow spindles (8-12 Hz), fast spindles (12-15 Hz), and beta (15-25 Hz). Comparisons between rocking and stationary conditions were performed using paired 2-tailed t-tests.

### ***Supplemental Results***

#### **Spindle power and spindle characteristics**

Marshall et al. (2006) found that slow oscillation stimulation simultaneously enhanced slow oscillation, spindle counts, as well as EEG power within the slow spindle frequency range (8–12 Hz) at the frontal location (Fz), but within the fast spindle frequency range (12-15Hz) at the parietal location [5]. We investigated this issue in two ways. We applied the same FFT approach than Marshall et al. (2006). We found

that while Fz showed significant effect of swinging on the slow spindle band (8-12 Hz,  $P < 0.05$ ), no such effect was observed on Pz neither in slow (8-12 Hz) nor fast (12-15 Hz) spindle frequency ranges (all  $P > 0.07$ ). These results are therefore consistent with those found by Marshall *et al.* (2006) when applying slow oscillation transcranial stimulation.

We also tested for any change in the peak frequency of the spindles themselves by extracting the frequency for each spindle in each condition for Fz and for Pz. We performed an ANOVA with condition (swinging, stationary) and electrode (Fz, Pz) as repeated measures and found an effect of electrode ( $p = 0.011$ ), reflecting slower spindles at Fz, but no effect of condition and no interaction. From these results we conclude that swinging affected the frequency power (at frontal electrodes) but did not lead to a shift of the peak spindle frequency.

### ***Supplemental References***

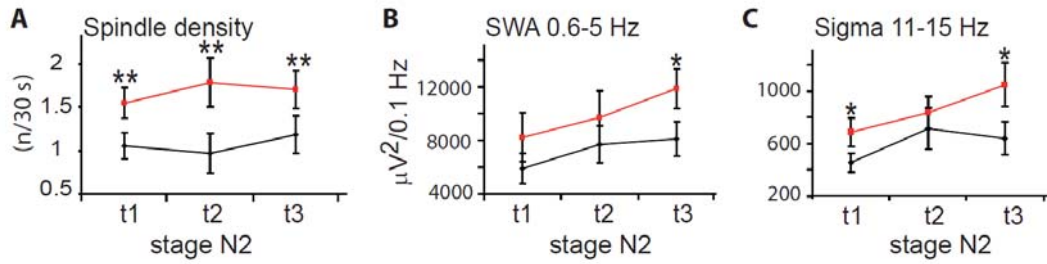
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## Supplemental Figure

Fig. S1



## Supplemental Figure Legend

**Fig. S1.** Time-course of (A) spindle density (mean of spindle per 30 s epoch) during N2, as well as (B) SWA (0.6-5 Hz) and (C) sigma activity (spindle range, 11-15 Hz) at the midline frontal electrode (Fz) during N2. Data from each subject were split into 3 successive equi-duration periods (T1-T3) of time spent in N2 and t-tests comparing the swinging and stationary conditions were performed at each time point (N=10 for each time-point). \*  $P < 0.05$  \*\*  $P < 0.005$

**Table S1.** Sleep parameters in each experimental condition (n=10, mean  $\pm$  s.e.m )

	Bed stationary	Bed swinging
Latency to stage N1 (min) <sup>a</sup>	8.75 $\pm$ 2.45	7.75 $\pm$ 1.48
Latency to stage N2 (min) <sup>b</sup> *	8.85 $\pm$ 2.05	5.35 $\pm$ 1.56
Stage N1 (min) *	12.4 $\pm$ 1.61	7.9 $\pm$ 1.17
Stage N2 (min) *	12.2 $\pm$ 1.94	16.9 $\pm$ 1.04
Stage N3 (min)	0.3 $\pm$ 0.3	0.87 $\pm$ 0.52
Total sleep time (min)	24.9 $\pm$ 3.07	25.67 $\pm$ 1.31
Total sleep period (min)	34.05 $\pm$ 2.61	34.85 $\pm$ 1.74
Awakenings nb	5.45 $\pm$ 1.08	4.85 $\pm$ 0.9
Sleep efficiency	73.1 $\pm$ 5.74	73.65 $\pm$ 2.78
Spindles :		
- Total number*	29.15 $\pm$ 6.27	57.5 $\pm$ 9.27
- Density (per 30s)*	1.20 $\pm$ 0.57	1.64 $\pm$ 0.70
- Frequency (Hz)	12.41 $\pm$ 0.49	12.96 $\pm$ 0.69
- Amplitude ( $\mu$ V)	36.38 $\pm$ 3.6	35.48 $\pm$ 3.48
- Duration (s)	1.06 $\pm$ 0.19	1.09 $\pm$ 0.42
- Proportion of spindles preceded by a K-complex	0.17 $\pm$ 0.03	0.24 $\pm$ 0.03
<p>All measurements are reported as mean <math>\pm</math> s.e.m.  * significant difference between bed stationary and swinging, t-student, d.f.=9, all P &lt; 0.001 except for latency to stage N2 P &lt; 0.01  <sup>a</sup> calculated from lights-off  <sup>b</sup> calculated from first N1 period  Note that mean alpha frequency of the population was within normal ranges: 9.68 +/- 0.77 Hz</p>		