

expeditions. Indeed, even in 1993 Fiennes and Stroud needed to be picked up from an ice shelf before reaching its edge, having totally exhausted their energy reserves man-hauling across the Antarctic continent. Thus, even today, while technological advancements have engineered out certain weaknesses of the human condition, others remain as limiting factors that must be stretched to breaking point if explorers on foot are to return home alive from the South Pole.

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References

1. Massey, P. (1959). Finger numbness and temperature in Antarctica. *J. Appl. Physiol.* 14, 616–620.
2. Zuntz, N. (1906). Höhenklima und Bergwanderungen in ihrer Wirkung auf den Menschen, (Berlin: Bong).
3. Stroud, M. (1998). The nutritional demands of very prolonged exercise in man. *Proc. Nutr. Soc.* 57, 55–61.
4. Westertep, K.R., Saris, W., van Es, M., and Ten Hoor, F. (1986). Use of the doubly labelled water technique in humans during heavy sustained exercise. *J. Appl. Physiol.* 61, 2162–2167.
5. Marshall, E. (1943). Off the beaten track. In *The Medical Press and Circular*, Volume 8. pp. 359–362.
6. Rogers, A. (1981). The influence of diet in Scott's last expedition. In *Starving Sailors. The Influence of Nutrition upon Naval and Maritime History*, J. Watt, E. Freeman and W. Bynum, eds. (London: National Maritime Museum), pp. 163–173.
7. Tsintzas, O., Williams, C., Singh, R., Wilson, W., and Burren, J. (1995). Influence of carbohydrate-electrolyte drinks on marathon running performance. *Eur. J. Appl. Physiol.* 70, 154–160.
8. Speth, J., and Spielmann, K. (1983). Energy source, protein metabolism, and hunter-gatherer subsistence strategies. *J. Anthropol. Archaeol.* 2, 1–31.
9. McArdle, W., Katch, F., and Katch, V. (2007). Exercise at medium and high altitude. In *Exercise Physiology Energy, Nutrition and Human Performance*, W. McArdle, F. Katch and V. Katch, eds. (Philadelphia: Lippincott Williams & Wilkins).
10. Grandjean, A., and Grandjean, N. (2007). Dehydration and Cognitive Performance. *J. Am. College Nutrition* 26, 5498–5548.
11. Wright, A. (1900). On the pathology and therapeutics of scurvy. *Lancet* 156, 565–567.

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Rocking synchronizes brain waves during a short nap

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Why do we cradle babies or irresistibly fall asleep in a hammock? Although such simple behaviors are common across cultures and generations, the nature of the link between rocking and sleep is poorly understood [1,2]. Here we aimed to demonstrate that swinging can modulate physiological parameters of human sleep. To this end, we chose to study sleep during an afternoon nap using polysomnography and EEG spectral analyses. We show that lying on a slowly rocking bed (0.25 Hz) facilitates the transition from waking to sleep, and increases the duration of stage N2 sleep. Rocking also induces a sustained boosting of slow oscillations and spindle activity. It is proposed that sensory stimulation associated with a swinging motion exerts a synchronizing action in the brain that reinforces endogenous sleep rhythms. These results thus provide scientific support to the traditional belief that rocking can soothe our sleep.

In the present study, we asked twelve healthy male volunteers (22–38 years old) to nap on a bed that could either remain stationary or rock gently (0.25 Hz; **Figure 1A**). All participants were good sleepers, non-habitual nappers with no excessive daytime sleepiness and had low anxiety levels. Sleep quality and quantity were assessed by questionnaires and actimetry recordings. The experimental procedure involved taking two 45-minute afternoon naps (2:30 to 3:15 PM): one with the bed stationary, and one with the bed put in motion (condition order randomized). The motion parameters were set to stimulate vestibular and proprioceptive sensory systems, without causing nausea or any entrainment of cardiac rhythm. In both conditions the naps

were spent in complete darkness in a controlled room temperature ($21 \pm 1^\circ\text{C}$) and the level of auditory stimulation was around 37 dB. During both sessions, polysomnography data were recorded continuously. Sleep stages and sleep spindles were visually identified by two experienced scorers, blind to the experimental conditions. We also performed spectral analysis (FFT routine) using the midline frontal (Fz) and parietal (Pz) derivations. The data from two participants were excluded from the final analyses (see the Supplemental Information).

Over the three consecutive nights preceding each experimental day, all participants had a good quality and quantity (mean \pm s.e.m.; 7.32 ± 0.78 h) of sleep as assessed by self-rated sleep questionnaires, with no difference for these measurements between stationary and swinging conditions. Similarly, wrist actimetry recorded during these same nights did not show any difference in sleep efficiency between conditions (mean \pm s.e.m.; swinging: $86.63 \pm 1.95\%$; stationary: $86.71 \pm 1.23\%$). For both conditions, participants were more alert (on visual analogue scale) after napping than before ($F(1,9) = 8.4$, $P = 0.018$). Eight participants rated the swinging condition as 'more pleasant' than the stationary condition; for one participant both sessions were equally pleasant and for one participant the stationary condition was more pleasant.

We found that rocking accelerated sleep onset, as evidenced by a shorter duration of stage N1 sleep and a reduction of stage N2 latency, compared to the stationary condition (Supplemental Table S1). Rocking also affected deeper sleep stages by increasing the duration of stage N2 sleep and the mean spindle density per 30-s epoch (Supplemental Table S1, **Figure 1B**). Spindle density increased significantly from the second half of the nap (**Figure 1C**) and persisted throughout the entire duration of stage N2 (Supplemental **Figure S1A**). All these modifications were observed in each and every participant (all $P < 0.009$; Supplemental Table S1). In the only previous study investigating the effect of rocking on sleep, Woodward *et al.* [1] found no consistent modulation for the percentage of stage 1 sleep and an overall reduction of the percentage of stage 2 sleep during the motion condition. In contrast to our present

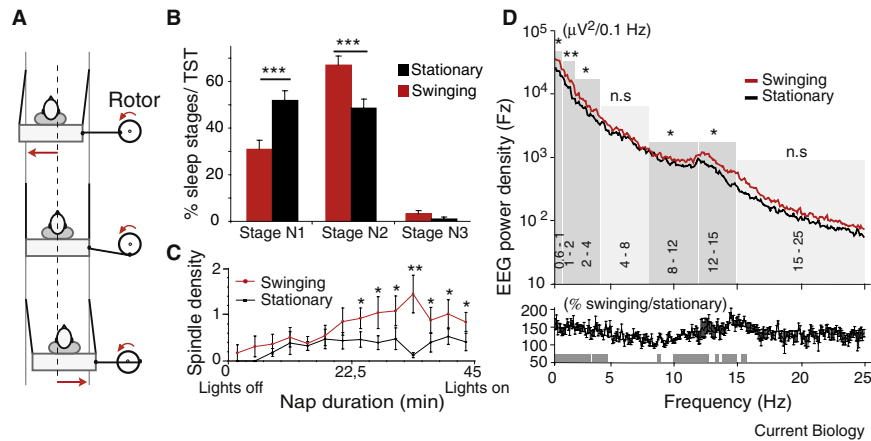


Figure 1. Experimental set-up and results. (A) Schema of bed rocking. (B) Decreased stage N1 and increased stage N2 during rocking compared to stationary condition. *** $P < 0.001$. (C) Spindle density (mean number of spindles per 30-s epoch) against time from lights off until lights on. The total nap period is divided in 14 equal parts for each individual recording. Paired t-tests are performed at each time point. ** $P < 0.005$, * $P < 0.05$. (D) Fast Fourier analysis during N2 at Fz derivation. Top: average power spectrum for the swinging and stationary condition: ** $P < 0.005$, * $P < 0.05$. Bottom: relative power density (swinging/stationary $\times 100$) for successive frequency bins of 0.1 Hz from 0.6 to 25 Hz. Horizontal gray bars indicate the significant bins, $P < 0.05$.

study, however, these data were computed over whole nights of sleep recordings, and did not address the question of whether vestibular/somatosensory inputs influence the transition from wakefulness to sleep (stage 1 and 2 sleep early in the night after sleep onset).

Rocking also increased EEG power of slow wave activity (SWA: 0.6–5 Hz; Figure 1D), predominantly during the last third of stage N2 (Supplemental Figure S1B; $P < 0.005$). A significant increase of EEG power within spindle frequency bands was also observed for the frontal derivation ($P < 0.05$; Figure 1D and Supplemental Figure S1C), but not for the parietal derivation ($P > 0.07$; Supplemental Results [3]). Together these results show that rocking induces a speeded transition to an unambiguous sleep state, and may enhance sleep by boosting slow oscillations and spindle activity.

How can we explain that rocking may accelerate wake-sleep transition and promote sleep consolidation? Three mechanisms could explain these effects of rocking on sleep. First, because vestibular/somatosensory pathways have anatomical links with structures implicated in emotions such as the amygdala [4] and because the amygdala affects the regulation of sleep-wake states [5], faster sleep onset could be due to a ‘relaxing’ feeling associated with the rocking condition, which most of

our participants (8 out of 10) found pleasant. Second, rhythmic vestibular/somatosensory inputs associated with rocking may modulate sleep-wake centres via direct or indirect connections between sensory systems and hypothalamic [6] or brainstem areas [7]. Third, sensory inputs could affect the synchrony of neural activity within thalamo-cortical networks because both somatosensory and vestibular inputs send direct projections to thalamic nuclei [8]. Consistent with this view, slow rhythmic cortical stimulation was recently found to increase EEG slow oscillations and spindles [3,9], which are both hallmarks of deep sleep. The latter hypothesis of an influence on neural synchrony fits best the present observation that rocking does not only facilitate sleep onset but has a persistent effect on brain oscillations and spindles. Recent evidence that increased spindle activity protects sleep against disruptive stimuli is in agreement with this interpretation [10]. Follow-up experiments could assess whether sleep changes triggered by rocking have beneficial functional consequences on post-sleep performance or on memory consolidation processes [3].

We suggest that rhythmic rocking may enhance synchronous activity within thalamo-cortical networks, which in turn could promote the onset of sleep and its maintenance. The use of rocking to soothe sleep thus belongs

to our repertoire of adaptive behaviours in which a natural mechanism of sleep (thalamo-cortical synchronization) has been harnessed in the simplest manner since immemorial times.

Supplemental Information

Supplemental Information includes one figure, one table, Supplemental Results and Supplemental Experimental Procedures, and can be found with this article online at doi:10.1016/j.cub.2011.05.012.

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References

- Woodward, S., Tauber, E.S., Spielmann, A.J., and Thorpy, M.J. (1990). Effects of otolithic vestibular stimulation on sleep. *Sleep* 13, 533–537.
- Krystal, A.D., Zammit, G.K., Wyatt, J.K., Quan, S.F., Edinger, J.D., White, D.P., Chiacchierini, R.P., and Malhotra, A. (2010). The effect of vestibular stimulation in a four-hour sleep phase advance model of transient insomnia. *J. Clin. Sleep Med.* 6, 315–321.
- Marshall, L., Helgadottir, H., Molle, M., and Born, J. (2006). Boosting slow oscillations during sleep potentiates memory. *Nature* 444, 610–613.
- Carmona, J.E., Holland, A.K., and Harrison, D.W. (2009). Extending the functional cerebral systems theory of emotion to the vestibular modality: a systematic and integrative approach. *Psychol. Bull.* 135, 286–302.
- Chou, T.C., Bjorkum, A.A., Gaus, S.E., Lu, J., Scammell, T.E., and Saper, C.B. (2002). Afferents to the ventrolateral preoptic nucleus. *J. Neurosci.* 22, 977–990.
- Horowitz, S.S., Blanchard, J., and Morin, L.P. (2005). Medial vestibular connections with the hypocretin (orexin) system. *J. Comp. Neurol.* 487, 127–146.
- Jones, B.E. (2003). Arousal systems. *Front. Biosci.* 8, s438–s451.
- Moruzzi, G. (1972). The sleep-waking cycle. In *Reviews of Physiology: Biochemistry and experimental pharmacology*, R.H. Adrian, E. Helmreich, H. Holzer, R. Young, K. Kramer, O. Kreayer, F. Lynen, P.A. Miescher, H. Rasmussen, A.E. Renold, et al., eds. (Berlin, Heidelberg, New York: Springer-Verlag), pp. 1–165.
- Massimini, M., Ferrarelli, F., Esser, S.K., Riedner, B.A., Huber, R., Murphy, M., Peterson, M.J., and Tononi, G. (2007). Triggering sleep slow waves by transcranial magnetic stimulation. *Proc. Natl. Acad. Sci. USA* 104, 8496–8501.
- Dang-Vu, T.T., McKinney, S.M., Buxton, O.M., Solet, J.M., and Ellenbogen, J.M. (2010). Spontaneous brain rhythms predict sleep stability in the face of noise. *Curr. Biol.* 20, R626–R627.

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