of their features with chimpanzees and humans. There is still much to learn about and from spider monkeys. For example, new research paradigms are exploring the extent to which spider monkeys have traditions shared among members of the same community and early evidence suggests they do. Furthermore, a new line of research integrates behavioral, ecological and molecular data using a comparative approach across populations of the same and different species. And, given their slow life histories and similarity with ourselves, monitoring their responses to hurricane activity and to climate-change related events has the potential not only to inform us about how other species might fare, but could shed light on our own prospects. Finally, spider monkeys are an umbrella species, which means that by protecting their habitats, we preserve countless other smaller and shorter-lived species living in the same ecosystem. Therefore, we must protect them, so we can learn more about them and in turn ourselves.

Where can I find out more?

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Spontaneous brain rhythms predict sleep stability in the face of noise

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Quality sleep is an essential part of health and well-being. Yet fractured sleep is disturbingly prevalent in our society, partly due to insults from a variety of noises [1]. Common experience suggests that this fragility of sleep is highly variable between people, but it is unclear what mechanisms drive these differences. Here we show that it is possible to predict an individual's ability to maintain sleep in the face of sound using spontaneous brain rhythms from electroencephalography (EEG). The sleep spindle is a thalamocortical rhythm manifested on the EEG as a brief 11–15 Hz oscillation and is thought to be capable of modulating the influence of external stimuli [2]. Its rate of occurrence, while variable across people, is stable across nights [3]. We found that individuals who generated more sleep spindles during a quiet night of sleep went on to exhibit higher tolerance for noise during a subsequent, noisy night of sleep. This result shows that the sleeping brain's spontaneous activity heralds individual resilience to disruptive stimuli. Our finding sets the stage for future studies that attempt to augment spindle production to enhance sleep continuity when confronted with noise.

The brain's response to sensory input is modulated by ongoing, spontaneous neuronal activity [4]. Indeed, during sleep, the thalamus spontaneously engages with the cortex. This interaction can produce transient fluctuations of the brain's electric field visible on the EEG as rhythmic spindles (Figure 1A). As the thalamus relays sensory information to perceptual cortices, it has been proposed that brain processes involved in spindle production gate sensory input during sleep [2]. If spindles hinder the transmission of external stimuli from the thalamus to the cortex, a higher rate of spindle production throughout the night would be expected to preserve sleep stability in the face of noise. We hypothesized that individuals who generate more spindles would require sounds of higher intensity to disrupt their naturally occurring sleep.

Twelve healthy human volunteers (age 26.3 ± 7.5, mean ± SD) were studied in the sleep laboratory for three consecutive nights. The first night was quiet, while the second and third were noisy. Brain activity was monitored each night with EEG. We detected spindles on central channels (C3, C4) during the quiet night using an automatic algorithm (Figure 1A, and Figure S1A in the on-line Supplemental Information), defining each subject's spindle rate as the number of detected events per minute during stage N2 and N3 (stages 2 and 3 of non-REM sleep). On the noisy nights we presented frequently encountered sounds — for example, road and air traffic, a telephone ringing, or hospital-based mechanical sounds — during stages N2, N3 and R (REM sleep). These ten-second noises were initiated at 40 decibels (dB) and presented every thirty seconds in 5 dB increments until the EEG signal was perturbed according to standard guidelines (that is, an arousal was observed) [5] (Figure 1B). In the present analysis, sleep stability is defined as the maintenance of sleep without arousal.

We first considered the relationship between spindles and sleep stability during stage N2, when spindles predominate. Using Cox regression, we found that those with higher spindle rates on the quiet night exhibited greater sleep stability during the noisy nights: spindle rate carried a sleep disruption hazard ratio (HR) of 0.39 from C3 ($p = 0.001$) and 0.51 from C4 ($p = 0.002$) (Figure 1C).

As spindles are also present in stage N3, we performed the same analysis considering stages N2 and N3 together. We again found a significant relationship between spindle rate and sleep stability (HR = 0.55, $p = 0.003$ for C3; HR = 0.64, $p = 0.018$ for C4).

This result shows that it is possible to predict an individual's ability to maintain sleep in the face of external sound: those with more abundant spindles are more resistant to sounds during sleep. It remains to be seen whether this relationship emerges from the cumulative effects of spindle

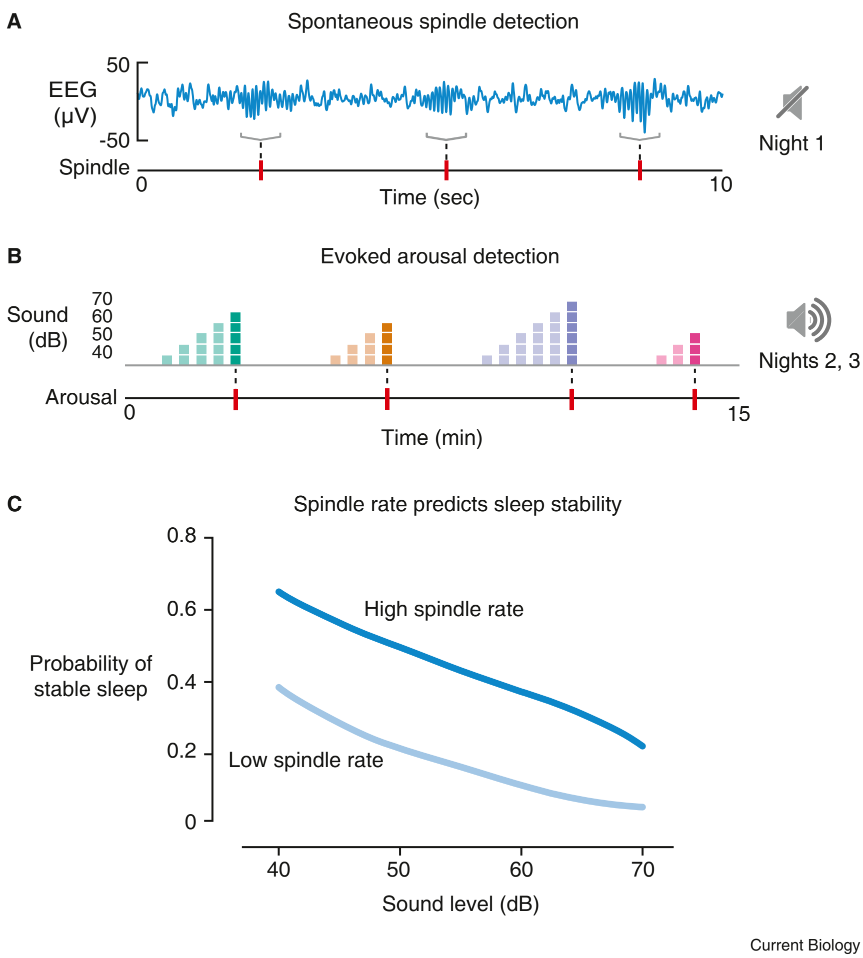

Figure 1. Spindle rate predicts sleep stability.

(A) Sleep spindles were automatically detected on central EEG channels during a quiet night of sleep. The number of detected events (vertical bars on the bottom line) per minute defined each subject's spindle rate. (B) On two subsequent nights we introduced ten-second noises, initiated at 40 decibels (dB) and presented every thirty seconds in 5 dB increments until the EEG signal was perturbed (arousal, vertical bars on the bottom line). Each colour represents a different sound type; a sample of four is shown here. (C) Observations were pooled among subjects in the lower and upper halves of the spindle rate distribution (ranges 4.57–5.44 and 5.48–6.14 spindles/min, respectively) based on EEG lead C3 during stage N2. Corresponding sleep survival curves were derived from each pool in stage N2 using the Kaplan-Meier (product-limit) method.

and sound collision, as we suspect, or whether it is due to a yet undetermined biological process.

In line with previous reports [3], we observed consistent spindle rates from night to night (Figure S1B). We thus regard spindle rate as a stable trait, suitable for predicting sleep continuity under noisy conditions.

The extent to which the relationship between spindle rate and noise tolerance bears on different populations awaits exploration. Noise tolerance during sleep [6], like spindle rate [7], diminishes with age. On the other hand, despite reporting poor sleep, people with insomnia possess arousal thresholds similar to those of normal sleepers [8]. They likewise produce spindles at normal rates [9]. It is tempting to link these pairs of observations based on our result.

Our finding also suggests a tantalizing explanation for associations uncovered between spindle rate and learning potential (see for instance [10]): in addition to perhaps actively contributing to memory consolidation, spindles may shield sleep from disruption, allowing consolidating processes to operate unhindered.

Our data raise important questions about whether augmenting spindle rate through behaviour, drug or device might protect sleep by harnessing the spindle's ability to deflect incoming stimuli. While we await intervention-based exploration, this study provides evidence that sleep spindle rate — readily quantified from EEG — serves as a biomarker for vulnerability to sound during sleep.

Supplemental Information

Supplemental Information is available at doi:10.1016/j.cub.2010.06.032

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