Supporting Text 1 – “Burstiness” as a confounding factor

A possible cause for the observed difference of theta-gamma and theta-fast gamma coupling between active wakefulness (aWk) and REM-sleep (REM) could be a difference in “burst-like” oscillations (“burstiness”), i.e. in the time-dependent variation of the amplitude of each oscillation. To investigate this possibility we adopted three approaches. First, we computed the coefficient of variation of the amplitude envelope of gamma and fast gamma oscillations during aWk and REM. A “burst-like” oscillation should result in a larger coefficient of variation of its amplitude envelope. According to this metric, we found that fast gamma oscillations have a greater variation of their amplitude envelope than gamma oscillations. However, the coefficient of variation of fast gamma oscillations during REM sleep was not larger than in aWk, as shown in the Figure S2. Therefore, coefficient of variation cannot explain the increase in theta-fast gamma CFC during REM.

Second, we analyzed the distribution of the amplitude envelope in units of standard deviations (SD) from the mean amplitude (that is, we studied the distribution of the z-scored amplitude). We reasoned that a greater level of burst activity would be characterized by a greater number of amplitude values above a certain threshold (say, 5 SD). Again, we found that fast gamma oscillations have a greater “burstiness” than gamma oscillations, as shown in the insets of the Figure S3A. However, using this analysis, we again did not find more “burstiness” in REM compared to aWk (Figure S3B). Third, we investigated the number of times at which the amplitude envelope crossed a given threshold (from below) per unit of time. We chose a threshold of 5 SD above the mean amplitude (other threshold values provide similar results). As before, we found no increased “burstiness” in REM compared to aWK (Figure S3C). We therefore conclude that an increase in the “burst-like” activity of fast gamma oscillations is unlikely to explain our CFC results.

Supporting Text 2 – Sharp edges as a confounding factor

As detailed in Kramer and colleagues [1] there are a couple of ways to test whether sharp edge effects cause spurious high frequency oscillations. A first simple but important procedure is visual inspection of raw traces. Is the oscillation visible in the unfiltered signal? Does it originate from sharp deflections of the theta wave? In our case, we observed that fast gamma and gamma are genuine oscillations that co-occur with theta waves in the unfiltered local field potentials (LFP, Figure S1A). The direct observation in the LFP (which did not undergo band pass filtering) excludes that the fast oscillations are filtering artefacts. Secondly, both types of fast oscillations can be observed in plots of power spectral density (PSD) as shown in Figure 3A. This does indicate that oscillations in the gamma range and in the range of ~ 120-150 Hz (fast gamma) exist as genuine network activity. High-frequency harmonics can, in principle, result from deviations of the theta waves from a pure sinusoidal wave form. However, these oscillations would express decreasing peaks at multiples of the theta wave frequency (i.e., 8, 16, 24, 32, 40 Hz etc). Lastly, as pointed out in Kramer et al. 2008 [1], spurious coupling can be distinguished from genuine oscillations by averaging the unfiltered field potential triggered by the peaks of the high frequency activity. If oscillating field potentials result from sharp edge artefacts, this procedure does not lead to visible oscillations in the averaged trace. Genuine theta-nested oscillations, on the other hand, should yield oscillations in the averaged trace (this effect is illustrated in the upper left and right panels of Fig. 4 in [1]). Applying this technique to our data, we found the averaged traces shown in Fig. S1B (upper trace: gamma peak-triggered average; bottom trace: fast gamma-peak-triggered average). These findings strongly speak against sharp-edge artefacts. It should also be noted that theta oscillations are much sharper and much larger in amplitude in CA1 below the pyramidal cell layer as compared to the neocortex (see reference [2] and raw traces in Fig. S4A). Nevertheless, we find no prominent coupling between theta and fast gamma oscillations in this region (see Fig. S4B and [3]).

References

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