Supporting Information

Chakravarthi and VanRullen 10.1073/pnas.1121622109

SI Text

The current study was aimed at determining whether conscious updating, a high-level process, is rhythmic or continuous. If it were rhythmic, conscious updating would be more efficient at some time points than at others, suggesting that the phase of neural activity would affect the outcome of conscious updating. To test this hypothesis, we computed circular-to-linear correlations between trial-by-trial phase of EEG activity and trial-by-trial flash-lag durations (FLD), a signature of conscious updating. We found strong correlations in occipital electrodes at around 7 Hz just before cue onset and in frontal electrodes at around 16 Hz just after cue onset. A recent study used a different approach, based on information theory, to determine the contribution of various aspects of oscillatory activity (phase, power, and conjunction of phase and power) to behavior [Eq. **S1**]. To further confirm our findings, we tested whether this alternate method also yielded the same results.

Using this method we determined the extent to which phase and the behavioral response, FLD, were mutually dependent. We computed a measure of this dependence, known as mutual information (MI), as follows:

$$MI(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log_2 (p(x,y)/p(x)p(y)), \qquad \textbf{[S1]}$$

where X and Y are the variables of interest, $p(x)$ and $p(y)$ are probabilities of x and y respectively, and $p(x,y)$ is the joint probability between x and y. We divided phase and FLD into four equipopulated bins and then computed the MI on the basis of the joint probabilities of the two. We also obtained a baseline distribution by a bootstrap procedure where we computed 1 million MI values, using the same procedure as above, between a variable with random values (again divided into four equipopulated bins) and FLD. We then compared the original MI values with those from the baseline distribution to obtain significance values (Fig. S1). These results support our earlier findings. Phase codes more information about FLD in the high-θ–low-α range just before cue onset and also in the low-β range just after cue onset. Focusing on the same set of occipital and frontal electrodes that showed a strong phase–FLD correlation, we found further support of earlier findings (Fig. S1).

However, there are noticeable differences in the results obtained by these two methods, which might reflect the difference in the two analyses. Circular-to-linear correlations reflect a systematic relationship between phase values and the corresponding behavioral outcomes wherein any change in phase leads to a corresponding change in FLD. On the other hand, MI determines whether two variables are codependent without taking into consideration the relationship between adjacent bins. That is, MI reflects the dependency of changes in FLD on changes in phase, even if they are not systematic or in corresponding directions. As such, MI strongly depends on the choice of the number of bins used to compute the respective distributions of probability for phase and FLD. Thus, the two analyses might not yield identical results. However, the fact that both methods show, overall, the same close relationship between phase and FLD around the same time-frequency points strongly supports our hypothesis that conscious updating is rhythmic.

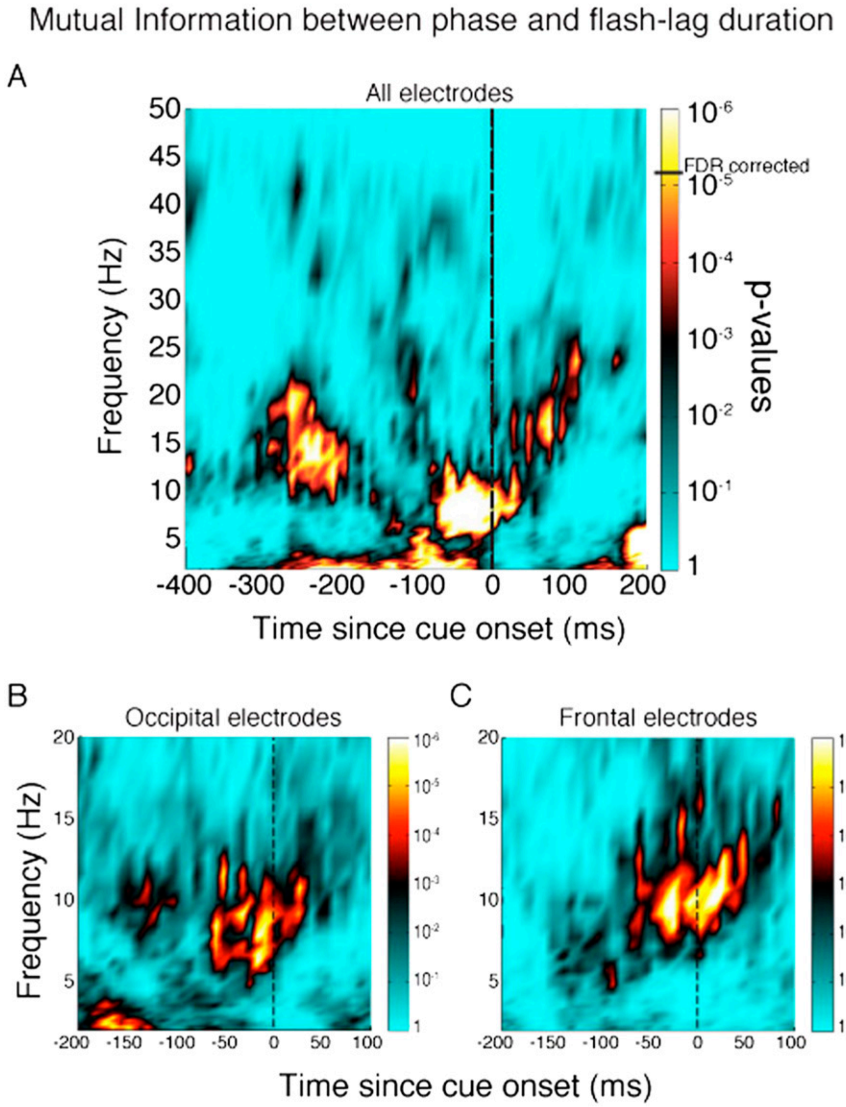

Fig. S1. Mutual Information (MI) between phase and FLD. We tested whether an alternative method would also yield the same results as with our earlier correlation analysis (main text). We computed the MI between phase and FLD according to Eq. **S1**. We compared these results with a distribution of bootstrapped baseline values (1 million repetitions) to obtain *P* values for the amount of information coded by phase. *P* values were corrected for multiple comparisons using the false discovery rate procedure at a conservative α value (10^{-4}), represented on the color bar by a black horizontal line (FDR corrected). We found results similar to what we found with the correlation analysis: more information is coded by phase just before cue onset in the high-θ–low-α range and also poststimulus in the low-β range (*A*) than expected by chance. Concentrating on the occipital and frontal electrodes (*B* and *C*), we see that occipital electrodes code information mostly before cue onset in the sub-α range and frontal electrodes mostly after cue onset and at a higher frequency range.