Supporting Information

Weakly correlated activity of pallidal neurons in behaving monkeys

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List of Contents

Methodological consideration

To estimate the minimum detectable correlation and Type I error (false positive) of the two-step statistical analysis, a simulation study was performed. A pair of binary spike trains with arbitrary spike probabilities and correlation coefficient at a lag time of 0 ms was artificially generated using the dichotomized Gaussian distribution (Macke *et al*. 2009), in which random variables were drawn from a two-dimensional Gaussian distribution with adjusted means and covariance and converted to binary trains of 0 and 1 with a threshold. Spike trains are controlled by three parameters: firing rates of two neurons and the correlation coefficient. A data set consisting of 500 simulated neuronal pairs, each with 100 trials of spike trains (100-ms duration, 1-ms bin width), was generated. These data sets with various firing rates (50, 100, and 150 Hz, based on the physiological range of GPe/GPi firing rates) and correlation coefficients (ρ; $0 \leq \rho \leq 0.3$) were analyzed with the two-step statistical analysis. The minimum detectable correlation was defined as the correlation coefficient at which 50% of pairs showed significant spike correlations at a lag time of 0 ms, and the false positive rate was calculated from the data set of no correlation ($\rho = 0$).

When a pair of spike trains had a continuous correlation coefficient (ρ) during the 100-ms event period (active window = 100 ms), the minimum detectable correlation of the first step of the two-step statistical analysis was 0.0287-0.0308, and that of the two-step statistical analysis was 0.0342-0.0444 (Fig. S1a). When the correlated activity was assumed to occur in the first 50 ms of the 100-ms event period (active window = 50 ms), the minimum detectable correlation of the two-step statistical analysis decreased (Fig. S1b). Minimum detectable correlations were compared among different active windows (Fig. S1c). Although the two-step statistical analysis would fail to detect weakly correlated neuronal pairs (the minimum detectable correlation = 0.0444 ± 0.0025 at 100 ms), the sensitivity increases for phasic

correlated activity with short active windows, such as ≤50 ms (the minimum detectable correlation = 0.0342 ± 0.0015 at 30 ms).

False positive rates were calculated using simulated spike trains with $\rho = 0$ (Fig. S1d). False positive rates using the first step with lag times from –10 to +10 ms were 4.90 ± 0.37% (mean ± SD) and were decreased to 1.73 ± 0.33% with lag times from –3 to +3 ms, and were further decreased to 0.47 ± 0.37% using the two-step statistical analysis.

Reference

Macke, J.H., Berens P., Ecker A.S., Tolias A.S., & Bethge M (2009) Generating spike trains with specified correlation coefficients. Neural Comput., 21, 397-423.

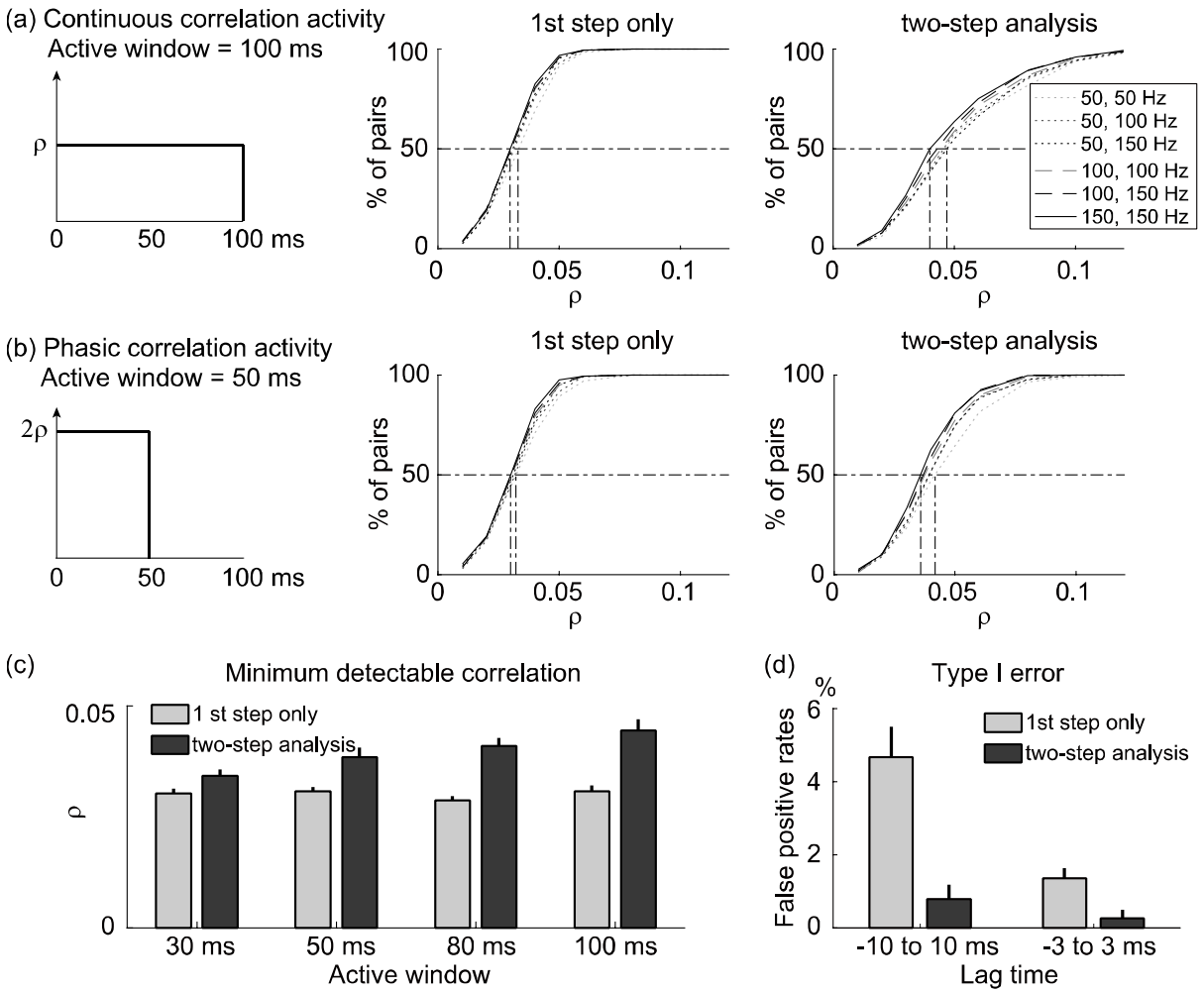

Figure S1. Simulation study of two-step statistical analysis with artificially generated spike trains. (a) A pair of spike trains with a constant correlation coefficient (ρ) during the 100-ms event period (Active window = 100 ms) is generated (left). Ratios of neuronal pairs showing significant correlation with the first step of the two-step statistical analysis are shown as a function of ρ (middle). Ratios of different frequencies (50, 100, and 150 Hz) are indicated by different lines. The result of the two-step statistical analysis is shown in the same format (right). Vertical dashed lines in the middle and right panels indicate the minimum detectable correlation at which 50% of pairs showed significant correlation. (b) Same format as (a) but the correlated activity is assumed to occur for the first 50 ms of the 100-ms event period (Active window = 50 ms). (c) Minimum detectable correlations of the first step and the two-step statistical analysis are shown for different active windows. (d) False positive rates of the first

step and the two-step statistical analysis with two lag times (from –3 to +3 ms, and from –10 to +10 ms) are calculated using artificially generated spike trains.

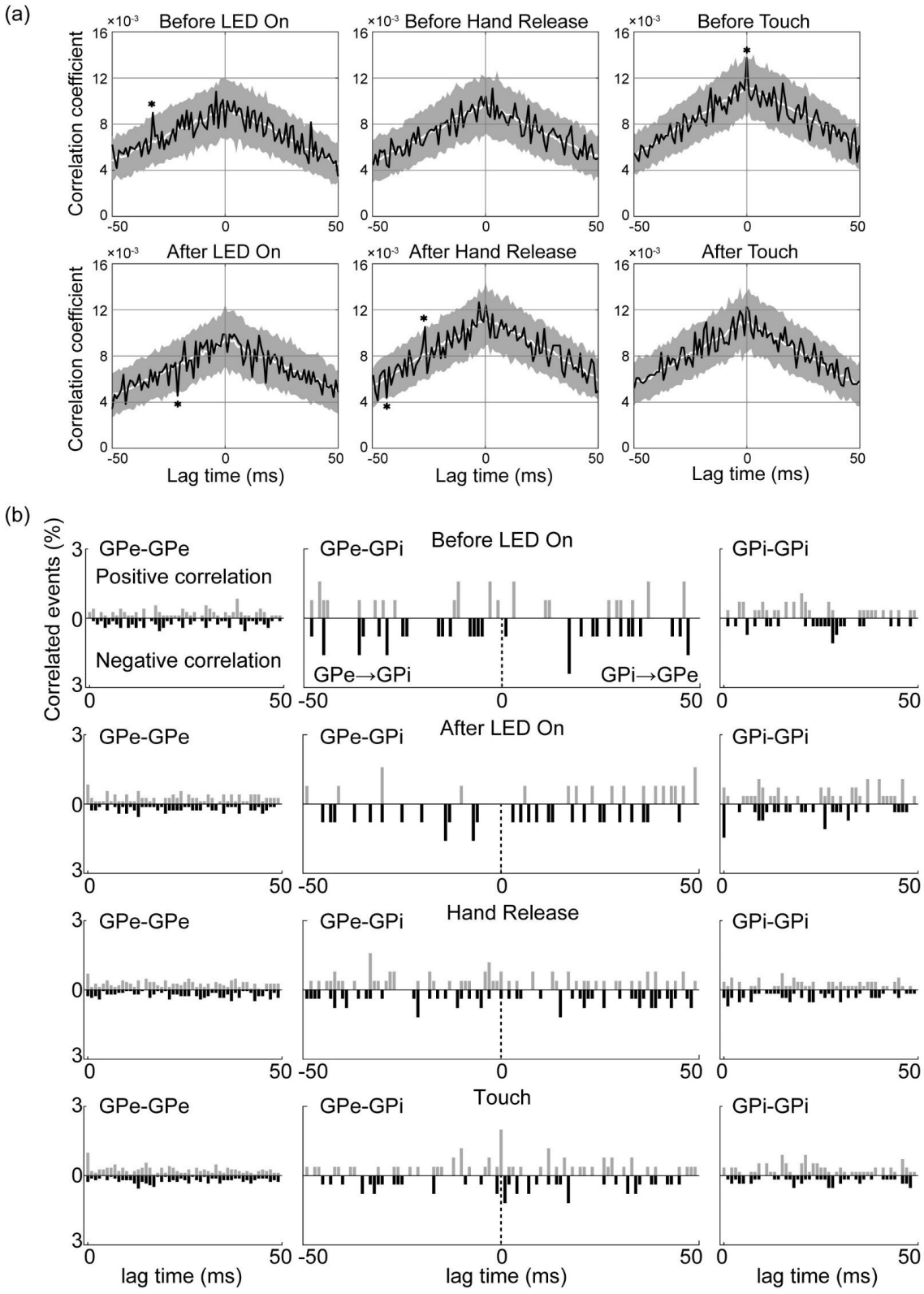

Figure S2. Cross-correlation analyses with a longer lag time. (a) Example of cross-correlation analyses (only the first step) of a GPe-GPe pair (GPe1 and GPe2) with lag times from –50 to +50 ms. Cross-correlograms of the GPe-GPe pair were constructed during the Before LED On,

After LED On, Before Hand Release, After Hand Release, Before Touch, and After Touch periods. The black line, white line, and shaded area in each graph represent the cross-correlogram, median, and 99.5% confidence interval of permuted cross-correlograms, respectively. Small and short correlated activity (∗) was observed. (b) Distribution of lag times based on the first step analysis. Lag times were evenly distributed except for the peak at a lag time of 0 ms during the Touch period in GPe-GPi pairs. Ratios of correlated pairs were not different among task events ($p > 0.05$, one-way ANOVA).