Lesions of prefrontal cortex reduce attentional modulation of neuronal responses and synchrony in V4

Georgia G. Gregoriou,[1,2] Andrew F. Rossi,[3] Leslie G Ungerleider,[4] Robert Desimone[5]

[1]Department of Basic Sciences, Faculty of Medicine, University of Crete, [2]Institute of Applied and Computational Mathematics, Foundation for Research and Technology, Hellas, Heraklion, Crete, 70013 Greece

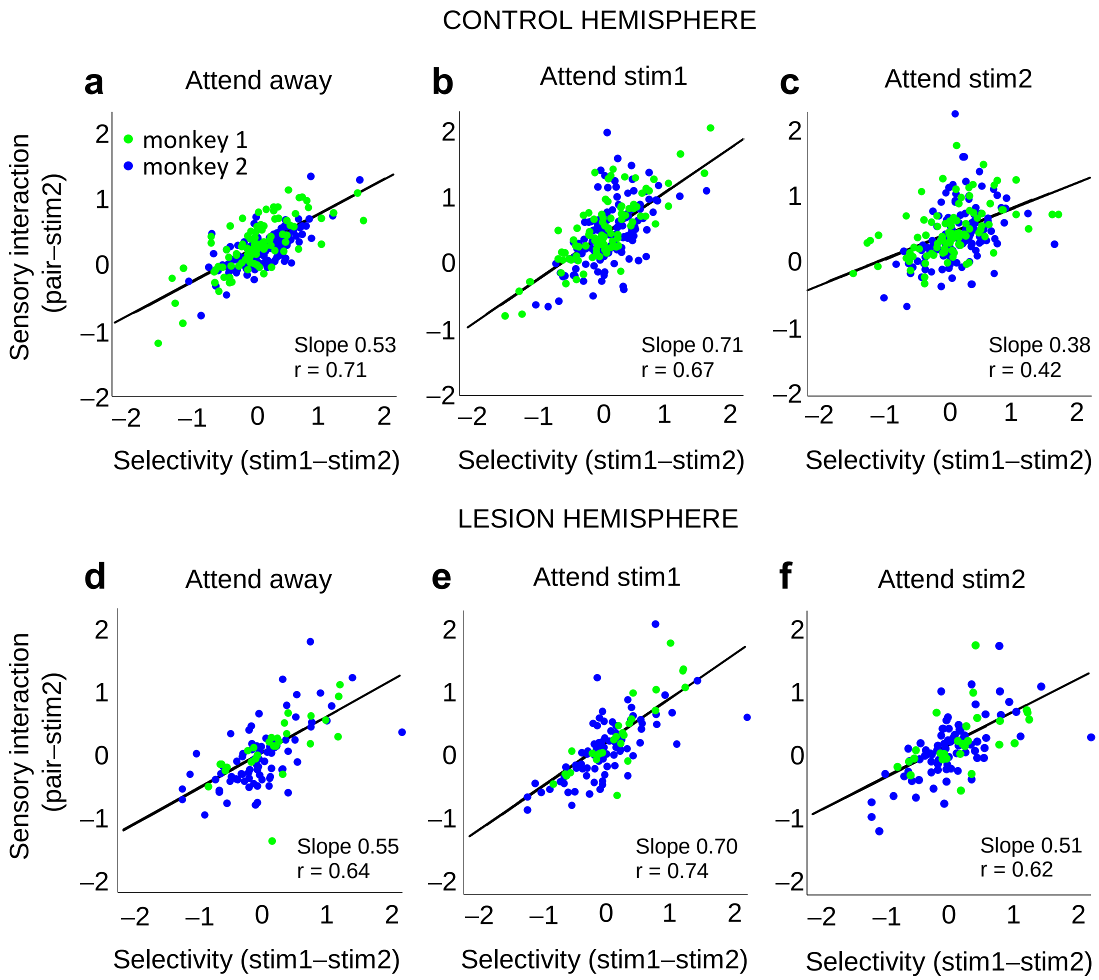
[3]Division of Neuroscience and Basic Behavioral Science, NIMH, NIH, Bethesda, MD 20892, USA.

[4]Laboratory of Brain and Cognition, NIMH, NIH, Bethesda, MD 20892, USA

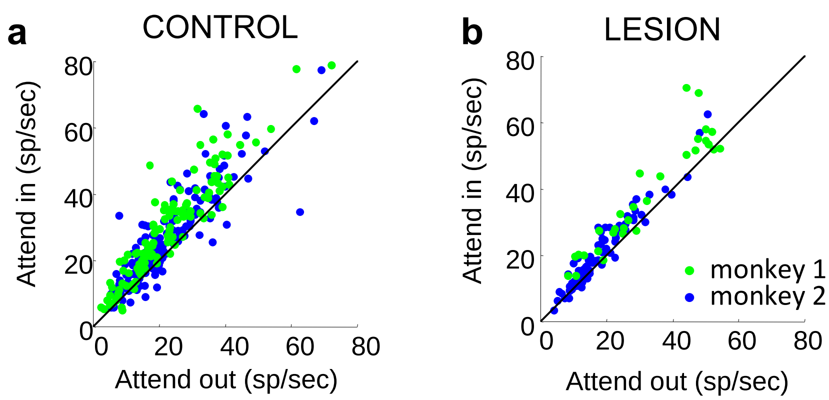
[5]McGovern Institute for Brain Research, Massachusetts Institute of Technology (MIT), Cambridge, MA 02139, USA.

Supplementary Information

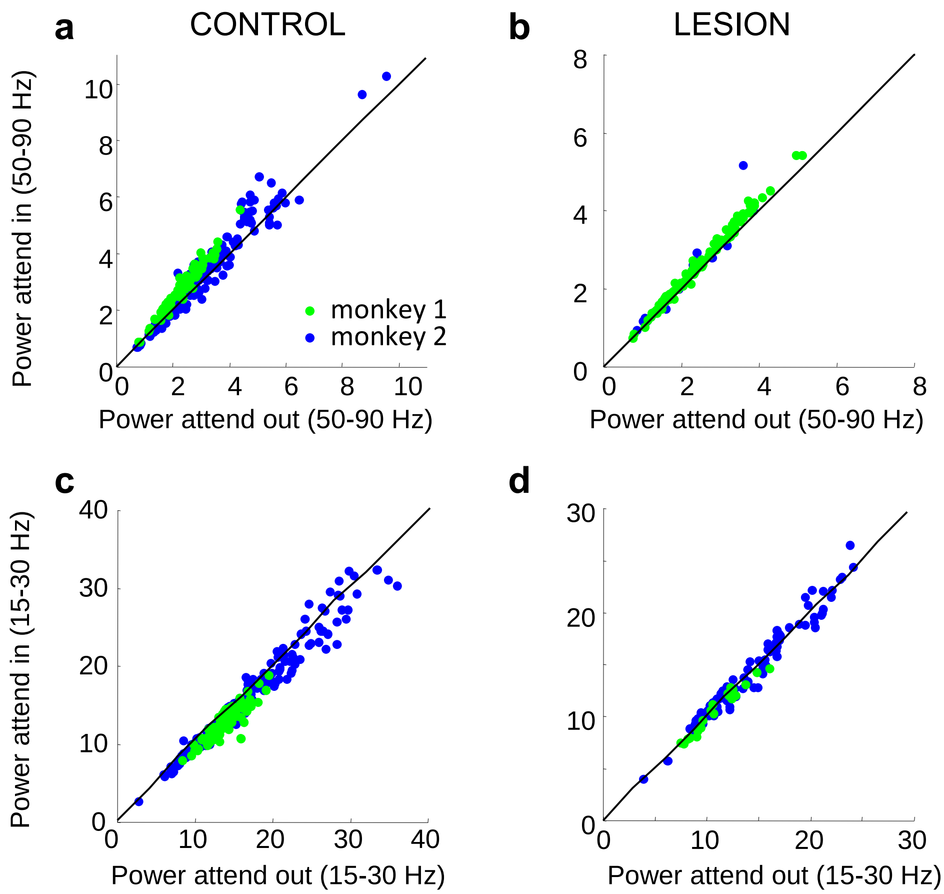
6 Figures



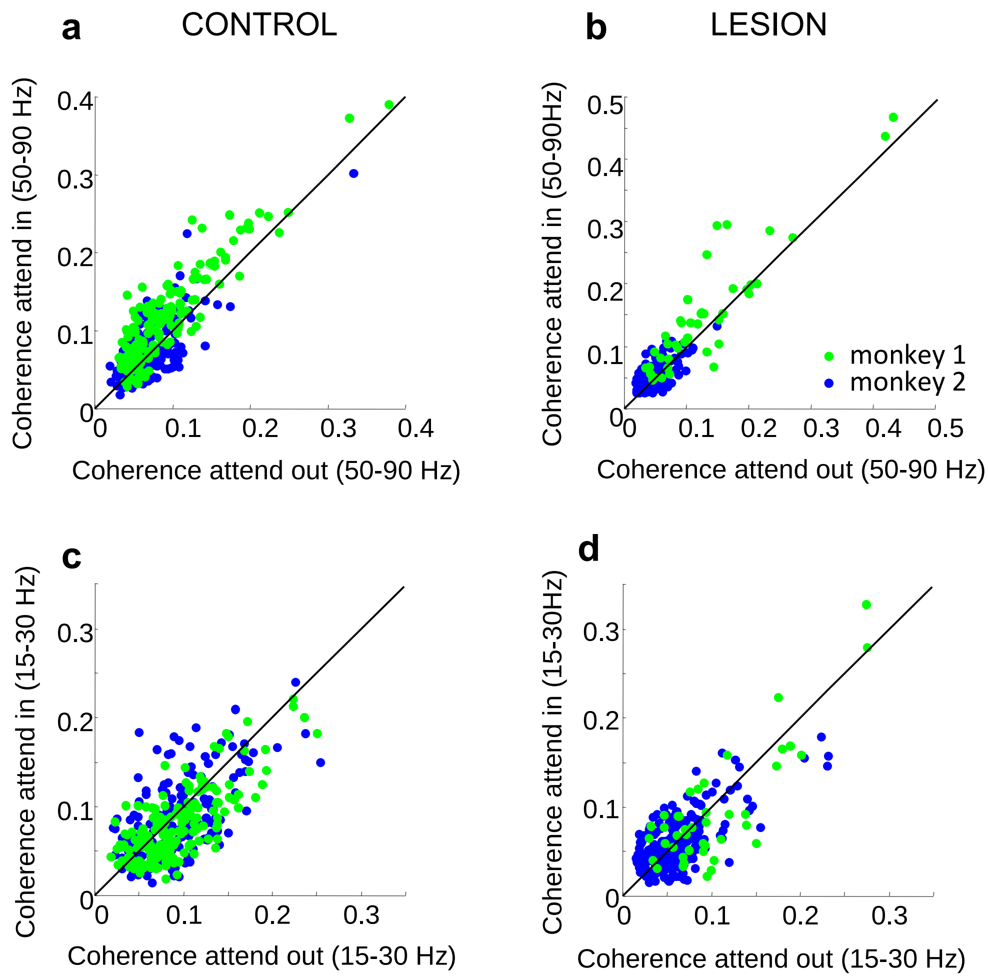
Supplementary Figure 1. Relationship between selectivity and sensory interactions and effect of attention on sensory interactions. (**a**) Relationship between sensory interaction indices (abscissa, SI) and selectivity indices (ordinate, SE) with attention away from the receptive field, in the intact hemisphere. (**b**) Same neuronal population as in **a** but with attention directed to stimulus 1. Responses to the pair show a greater influence of stimulus 1, as reflected by the increase in the slope of the regression line that describes the SE, SI relationship (Attend away, slope: 0.53 Attend stim 1, slope: 0.71). (**c**) Same neuronal population as in **a** and **b** but with attention directed to stimulus 2. In this case responses to the pair show a greater influence of stimulus 2, as reflected by the decrease in the slope of the regression line that describes the SE, SI relationship (Attend away, slope: 0.53 Attend stim 2, slope: 0.38). (**d**) Relationship between sensory interaction indices and selectivity indices with attention away from the receptive field, in the lesion-affected hemisphere. (**e**) Same neuronal population as in **d** but with attention directed to stimulus 1. Responses to the pair show a greater influence of stimulus 1, as reflected by the increase in the slope of the regression line that describes the SE, SI relationship (Attend away, slope: 0.55 Attend stim 1, slope: 0.70). (**f**) Same neuronal population as in **e** and **f** but with attention directed to stimulus 2. In this case responses to the pair show a greater influence of stimulus 2, as reflected by the decrease in the slope of the regression line that describes the SE, SI relationship (Attend away, slope: 0.55 Attend stim 2, slope: 0.51). All visually responsive neurons are included, each contributing one data point. Green circles correspond to data from monkey 1 and blue circles to data from monkey 2. Slopes and correlation coefficients (r) are reported for each graph. Responses were computed within a window from 150 to 300 ms following stimulus onset.



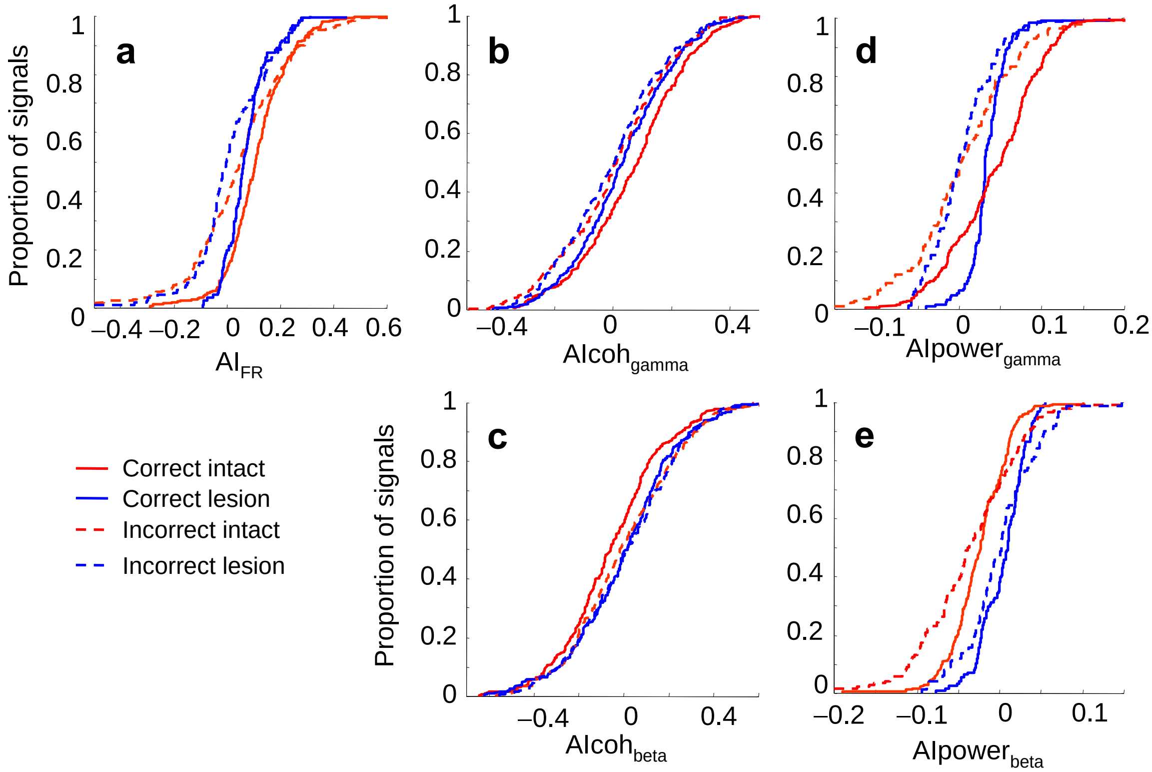
Supplementary Figure 2. Distribution of attentional effects on firing rate in V4. Distribution of mean normalized firing rate averaged in a window 150-300 ms following the array onset with attention outside (y-axis) and attention inside (x-axis) the RF of the recorded neurons in the control (**a**) and lesion (**b**) hemisphere. Points above the diagonal indicate a positive attentional effect (higher response with attention) whereas points below the diagonal indicate a negative attentional effect (lower responses with attention). Each point represents one neuron. Green circles correspond to data from monkey 1 and blue circles to data from monkey 2.



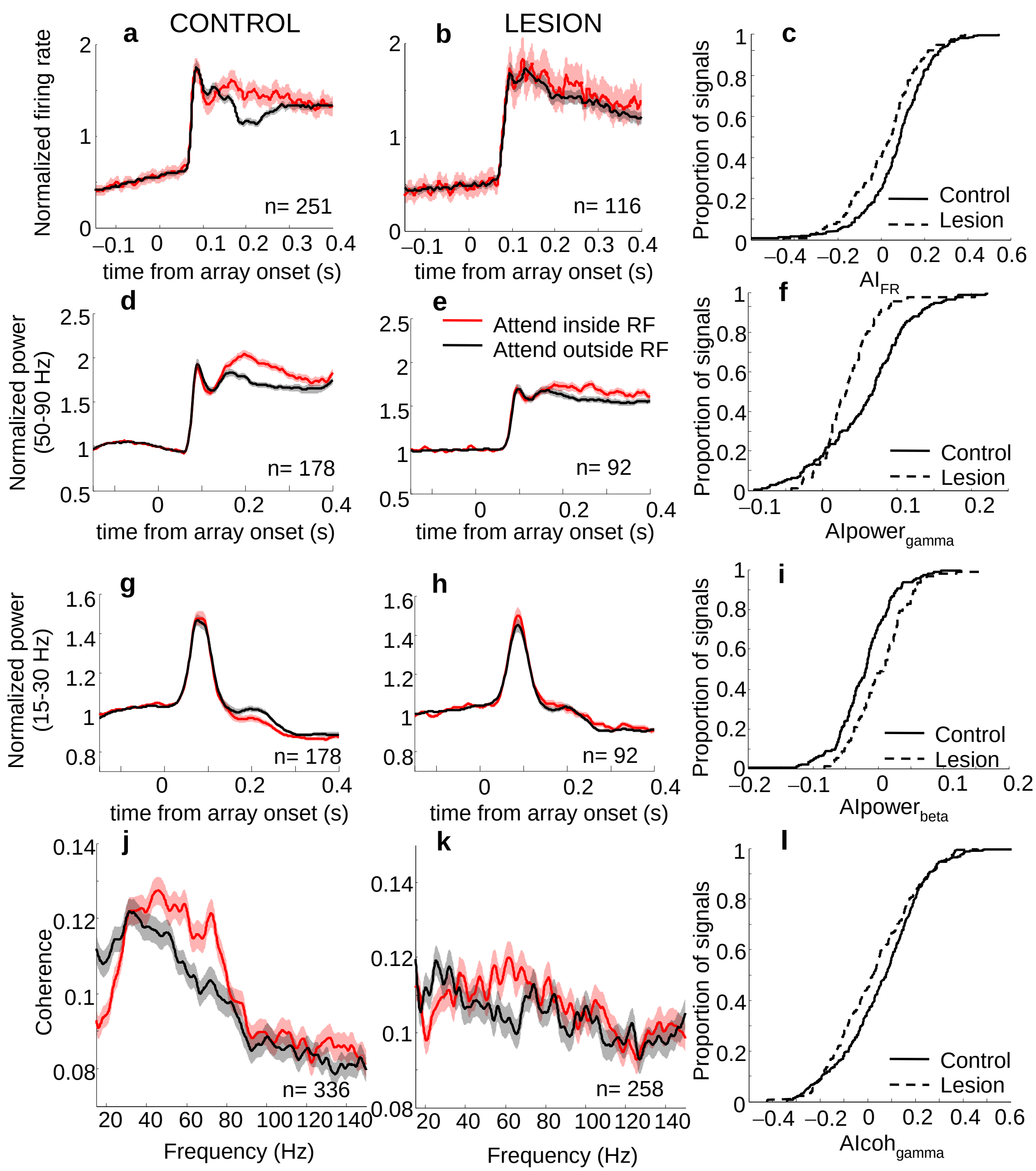
Supplementary Figure 3. Distribution of attentional effects on LFP power in V4. (**a,b**) Distribution of mean LFP gamma power (averaged between 50-90 Hz) calculated within a window 200-300 ms following the array onset with attention outside (y-axis) and attention inside (x-axis) the RF in the control (**a**) and lesion (**b**) hemisphere. (**c,d**) Distribution of mean LFP beta power (averaged between 15-30 Hz) calculated within a window 200-300 ms following the array onset with attention inside (y-axis) and attention outside (x-axis) the RF in the control (**c**) and lesion (**d**) hemisphere. Points above the diagonal indicate a positive attentional effect (higher power with attention) whereas points below the diagonal indicate a negative attentional effect (lower power with attention). Other conventions as in Supplementary Figure 2.



Supplementary Figure 4. Distribution of attentional effects on spike-LFP coherence in V4. (**a,b**) Distribution of mean gamma spike-LFP coherence (averaged between 50-90 Hz) calculated within a window 200-400 ms following the array onset with attention inside (y-axis) and attention outside (x-axis) the RF in the control (**a**) and lesion (**b**) hemisphere. (**c,d**) Distribution of mean beta coherence (averaged between 15-30 Hz) calculated within a window 200-400 ms following the array onset with attention inside (y-axis) and attention outside (x-axis) the RF in the control (**c**) and lesion (**d**) hemisphere. Points above the diagonal indicate a positive attentional effect (higher coherence with attention) whereas points below the diagonal indicate a negative attentional effect (lower coherence with attention). Other conventions as in Supplementary Figure 2.



Supplementary Figure 5. Distribution of attentional effects on firing rates, LFP power and spike-LFP coherence in V4 in correct and error trials. (**a**) Cumulative distributions of attentional indices computed for firing rates in the control and lesion-affected hemisphere for correct and error trials. (**b,c**) Cumulative distributions of attentional indices for gamma SFC averaged over 50-90 Hz (**b**) and beta SFC averaged over 15-30 Hz (**c**) for the control and lesion-affected hemisphere in correct and incorrect trials. (**d**) Cumulative distributions of attentional indices computed for gamma power in the control and lesion-affected hemisphere in correct and incorrect trials. (**e**) Cumulative distributions of attentional indices computed for beta power in the control and lesion-affected hemisphere in correct and incorrect trials. In all plots red lines illustrate data from the control hemisphere, blue lines data from the lesion-affected hemisphere, solid lines data from correct trials and dashed lines data from incorrect trials.



Supplementary Figure 6. Effect of attention on firing rates, gamma and beta LFP power and coherence in the control and lesion-affected hemispheres limiting analysis to trials from conditions with similar performance in the two hemifields. (**a**) Normalized population average firing rates from the control hemisphere. At the population level, activity was enhanced with attention by 18.5%, 150-300 ms post-stimuli onset (16.9%, 200-300 ms post-stimuli onset; Wilcoxon sign-rank test, $p < 0.001$ in both cases). (**b**) Normalized population average firing rates from the lesion-affected hemisphere. At the population level, activity was enhanced with attention by 9.7%, 150-300 ms, post-stimuli onset (10.4%, 200-300 ms post-stimuli, Wilcoxon sign-rank test, $p < 0.01$ in both cases) (**c**) Cumulative distributions of attentional indices computed from firing rates for the control (solid line) and lesion-affected (dashed line) hemisphere. Attentional modulation of firing rates was significantly lower in the lesion affected side (150-300 ms post-stimuli: control hemisphere: median AI_{FR} = 0.09, lesion-affected hemisphere: median AI_{FR} = 0.05, Wilcoxon rank-sum test $p < 0.001$; 200-300 ms post-stimuli: control hemisphere: median AI_{FR} = 0.09, lesion-affected hemisphere: median AI_{FR} = 0.04, Wilcoxon rank-sum test $p < 0.001$). (**d,e**) Normalized LFP gamma power averaged between 50-90 Hz in the control (**d**) and lesion-affected (**e**) hemisphere. At the population level, we found a significant attentional enhancement of LFP power in gamma frequencies between 50 and 90 Hz in both hemispheres (average power 200-300 ms, 225-325 ms post-stimuli onset, paired t-test, $p < 0.001$ in all four cases). Gamma power was enhanced by 14.5% in the intact hemisphere and by 7% in the lesion-affected hemisphere (12.6% and 7%, respectively, 225-325 ms post-stimuli onset). (**f**) Cumulative distributions of attentional indices in gamma power for the control (solid line) and lesion-affected (dashed line) hemisphere. Attentional indices ($AIpower_{gamma}$) were significantly lower in the lesion-affected hemisphere (200-300 ms post-stimuli: median $AIpower_{gamma}$ control: 0.07, lesion: 0.03; 225-325 ms post-stimuli: median $AIpower_{gamma}$ control: 0.06, lesion: 0.03; Wilcoxon rank-sum test $p < 0.01$ in both cases). (**g,h**) Normalized LFP beta power averaged between 15-30 Hz in the control (**g**) and lesion-affected (**h**) hemisphere. Beta power was significantly reduced with attention in the control hemisphere (average power 200-300 ms and 225-325 ms post stimuli onset, paired t-test, $p < 0.001$ in both cases; 200-300 ms post stimuli onset: 3.9% decrease, 225-325 ms post stimuli onset: 3% decrease with attention at the population level) and was not significantly modulated by attention in the lesion-affected hemisphere (paired t-test, 200-300 ms post stimuli onset: $p=0.17$, 1.4% increase with attention at the population level; 225-325 ms post stimuli onset: $p=0.08$, 2% increase with attention). (**i**) Cumulative distributions of attentional indices in beta power for the control (solid line) and lesion-affected (dashed line) hemisphere. Attentional indices ($AIpower_{beta}$) were significantly lower in the control hemisphere (200-300 ms post stimuli onset: median $AIpower_{beta}$ control: -0.02, lesion: 0.01; 225-325 ms post stimuli onset: median $AIpower_{beta}$ control: -0.013, lesion: 0.006; Wilcoxon rank-sum test $p < 0.001$). (**j,k**) Spike-LFP coherence (SFC) in the control (**j**) and lesion-affected (**k**) hemisphere. SFC was significantly enhanced with attention in the gamma frequency range (50-90 Hz) in both hemipsheres (control hemisphere: 11.6% increase with attention, paired t-test, $p < 0.001$; lesion-affected hemisphere: 6% increase with attention, paired t-test, $p < 0.01$). Moreover, beta SFC was significantly reduced with attention in the control hemisphere and the effect was only marginal in the lesion-affected hemisphere (control: 10% decrease with attention, paired t-test $p < 0.001$; lesion-affected hemisphere: 5.8% decrease with attention, paired t-test $p = 0.065$). (**l**) Cumulative distribution of attentional indices for gamma coherence (averaged between 50 and 90 Hz) in the control (solid line) and lesion (dashed line) hemisphere. The attentional modulation of coherence between 50 and 90 Hz was significantly lower in the lesion-affected hemisphere compared to the intact hemisphere (Wilcoxon rank-sum test, $p < 0.05$, median $AIcoh_{gamma}$, control: 0.08, lesion: 0.02). Responses in **a,b,d,e,g,h,j,k** are aligned on the presentation of the stimuli array. Red lines correspond to responses when the target stimulus appeared inside the RF of the recorded neurons and the black line corresponds to responses when the target stimulus appeared outside the RF. Shaded areas represent mean ± s.e.m.