Spatial Spread of the Local Field Potential and its Laminar Variation in Visual Cortex

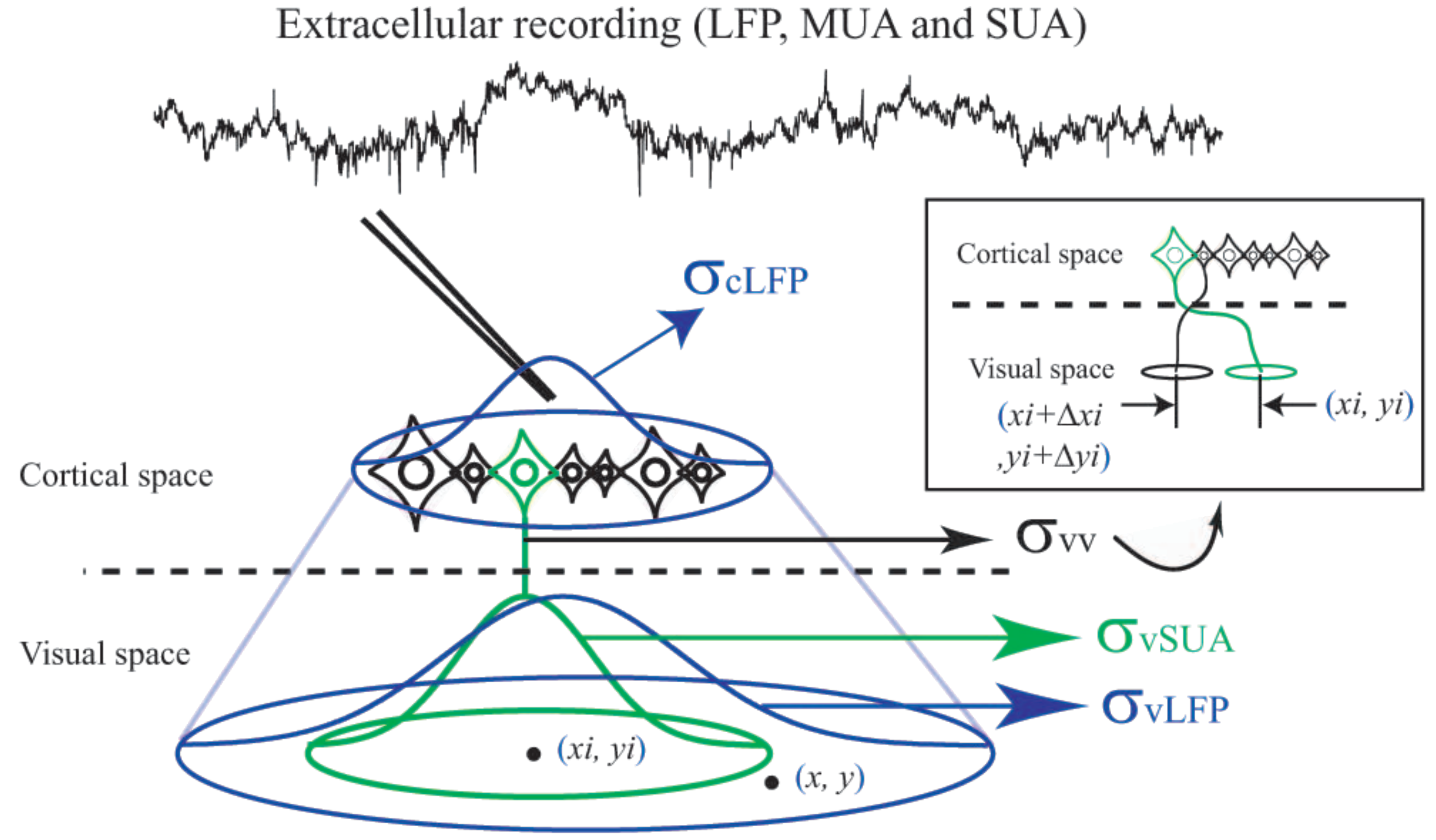
Dajun Xing, Chun-I Yeh, Robert Shapley

Center for Neural Science, New York University, New York, NY, USA.

Correspondence: xdj@cns.nyu.edu

Currently there is still a debate about what is the cortical spatial scale of the Local Field Potential (LFP). Different studies provided various estimates of the LFP's spatial spread, ranging from 100 to 3000 μm. Furthermore, it is not yet known how much laminar variation there is in the spatial scale of the LFP in cortex. In this study, we provide a general method to estimate the cortical spread of the Local Field Potential (LFP) in any cortical area that has a topographic map. We applied this new method to estimate the cortical spread of the LFP throughout all layers of Macaque primary visual cortex, V1.

Schematic Model



$$f_{vLFP}(x,y) = \sum_i f^{i}_{vSUA}(x-xi, y-yi) \bullet f_{cLFP}((xi-\Delta xi)\cdot MF, (yi-\Delta yi)\cdot MF)$$

$$p(\Delta x, \Delta y) = f_{vv}(\Delta x, \Delta y)$$

MF: *magnification factor.*
Δx, Δy: *visual variation*
f_{vLFP}: *visual spread for the LFP.*
f_{vSUA}: *visual spread for single neuron*
f_{cLFP}: *cortical spread for the LFP.*
f_{vv}: *probability density function of the visual variation*

Without visual variation, cortical spread for the LFP will be:

$$F(x,y) = f_{cLFP}(x\cdot MF, y\cdot MF) \otimes f_{vSUA}(x,y)$$

When we include the visual variation:

$$f_{vLFP}(x,y) = \int_{\Delta x,\Delta y} F(x-\Delta x, y-\Delta y) \bullet f_{VV}(\Delta x, \Delta y)$$

$$f_{vLFP}(x,y) = f_{cLFP}(x\cdot MF, y\cdot MF) \otimes f_{vSUA}(x,y) \otimes f_{vv}(x,y)$$

Now let's assume all functions are gaussian:

$$f(x,y) = e^{-\frac{(x^2+y^2)}{2\sigma^2}}, \text{ for } f_{vLFP}, f_{vSUA}, f_{cLFP}, f_{VV} \text{ etc.}$$

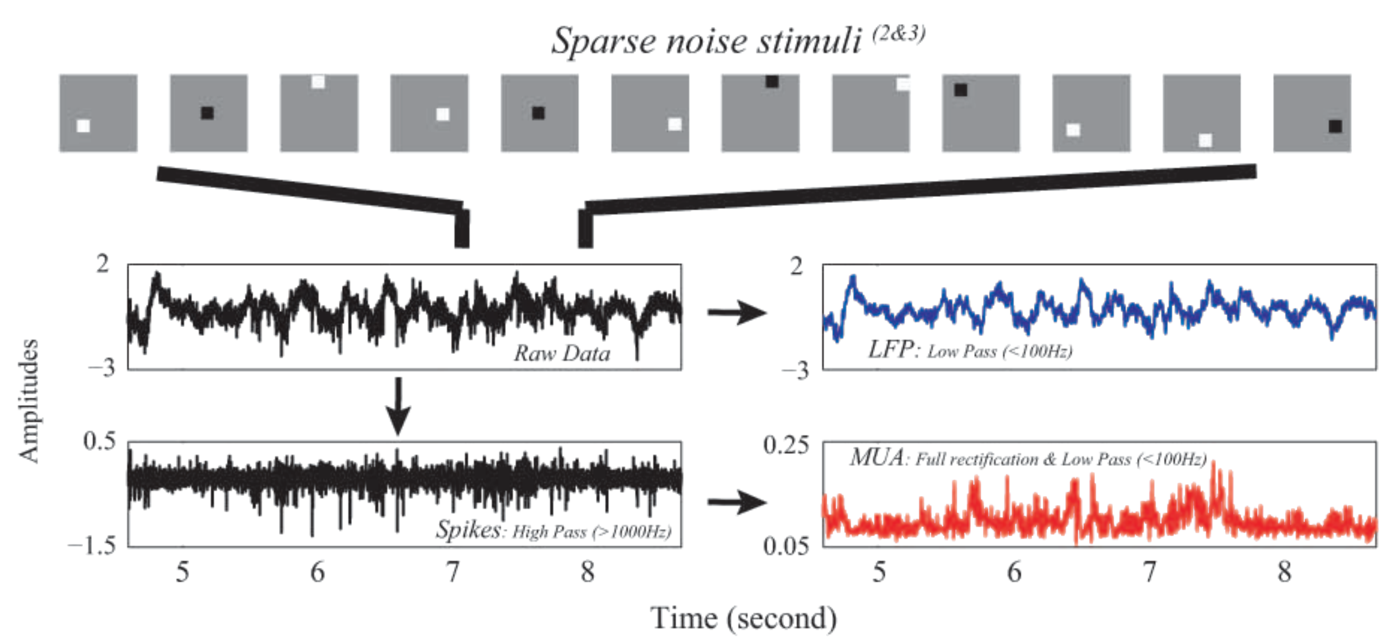
If single neurons' visual spreads for their spikes and membrane potential are similar [1]
Then we got the following for LFP and MUA:

$$\sigma^2_{vLFP} = \sigma^2_{cLFP}/MF^2 + \sigma^2_{vSUA} + \sigma^2_{vv}$$

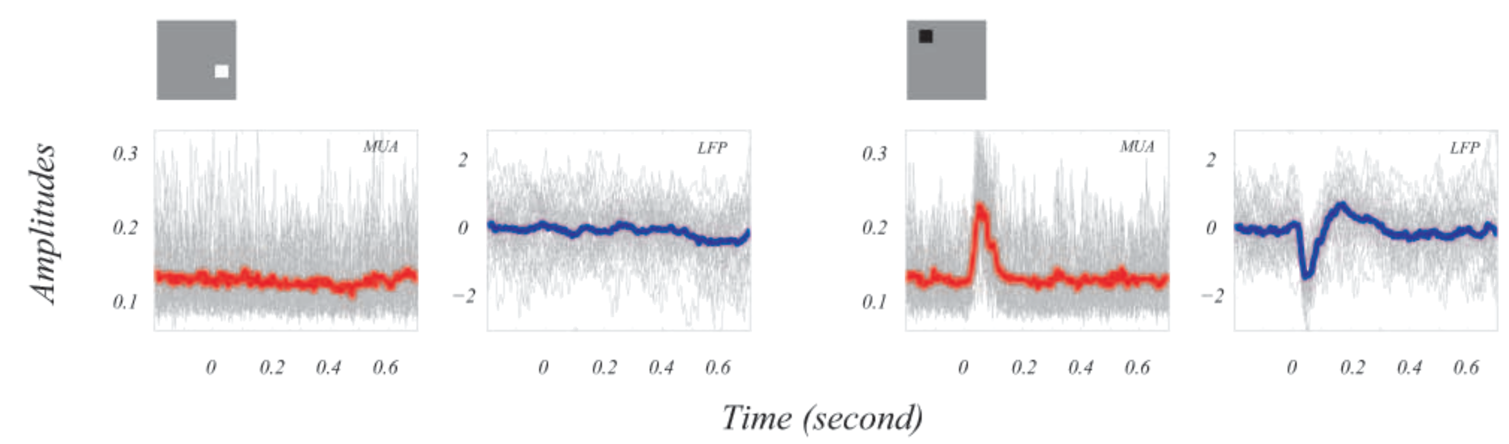
$$\sigma^2_{vMUA} = \sigma^2_{cMUA}/MF^2 + \sigma^2_{vSUA} + \sigma^2_{vv}$$

$$\sigma_{cLFP} = \sqrt{MF^2 \bullet (\sigma^2_{vLFP} - \sigma^2_{vMUA}) + \sigma^2_{cMUA}}$$

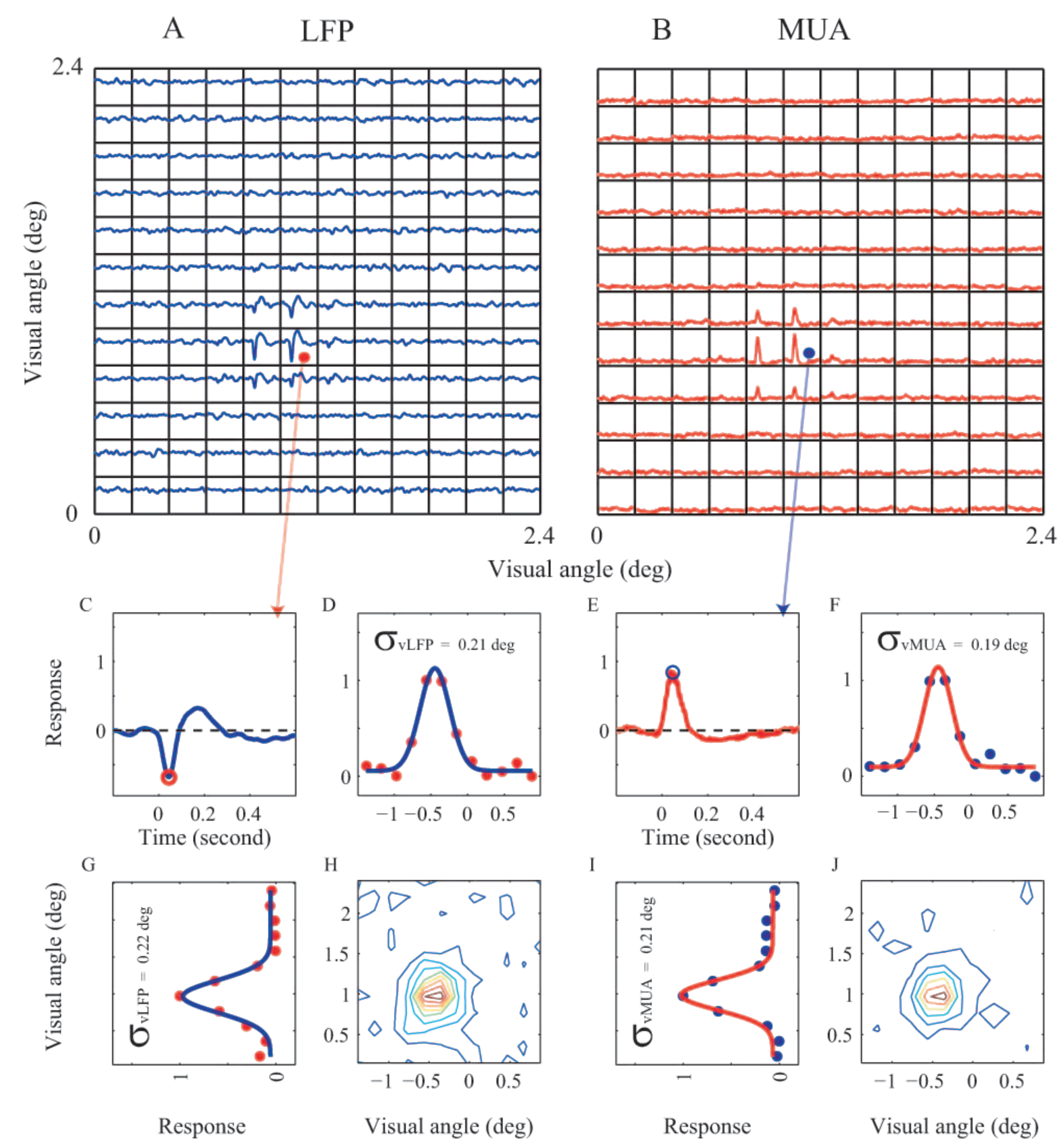
the LFP and MUA to Sparse noise stimuli



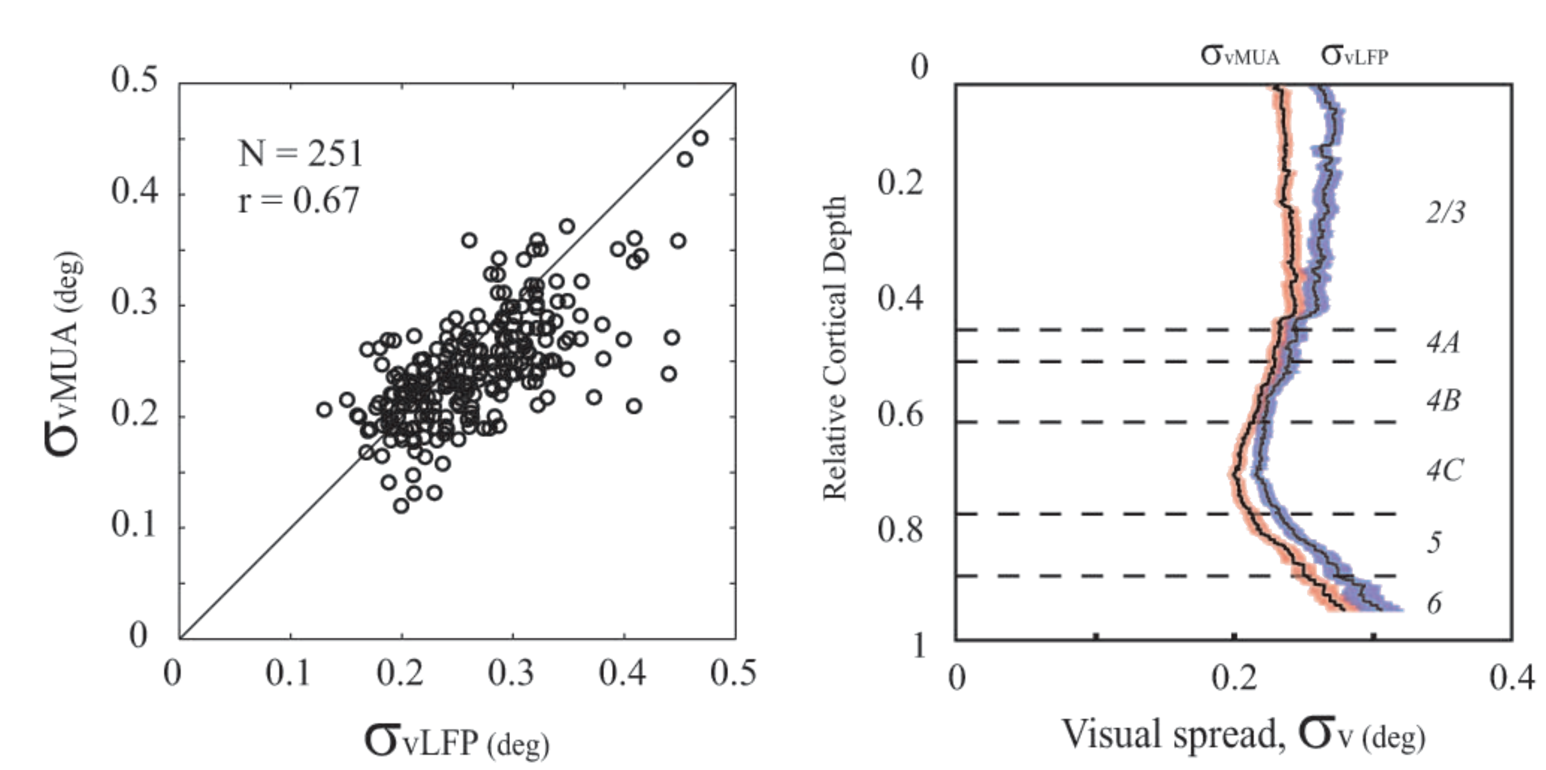
Cross-correlation between stimulus and the LFP/MUA



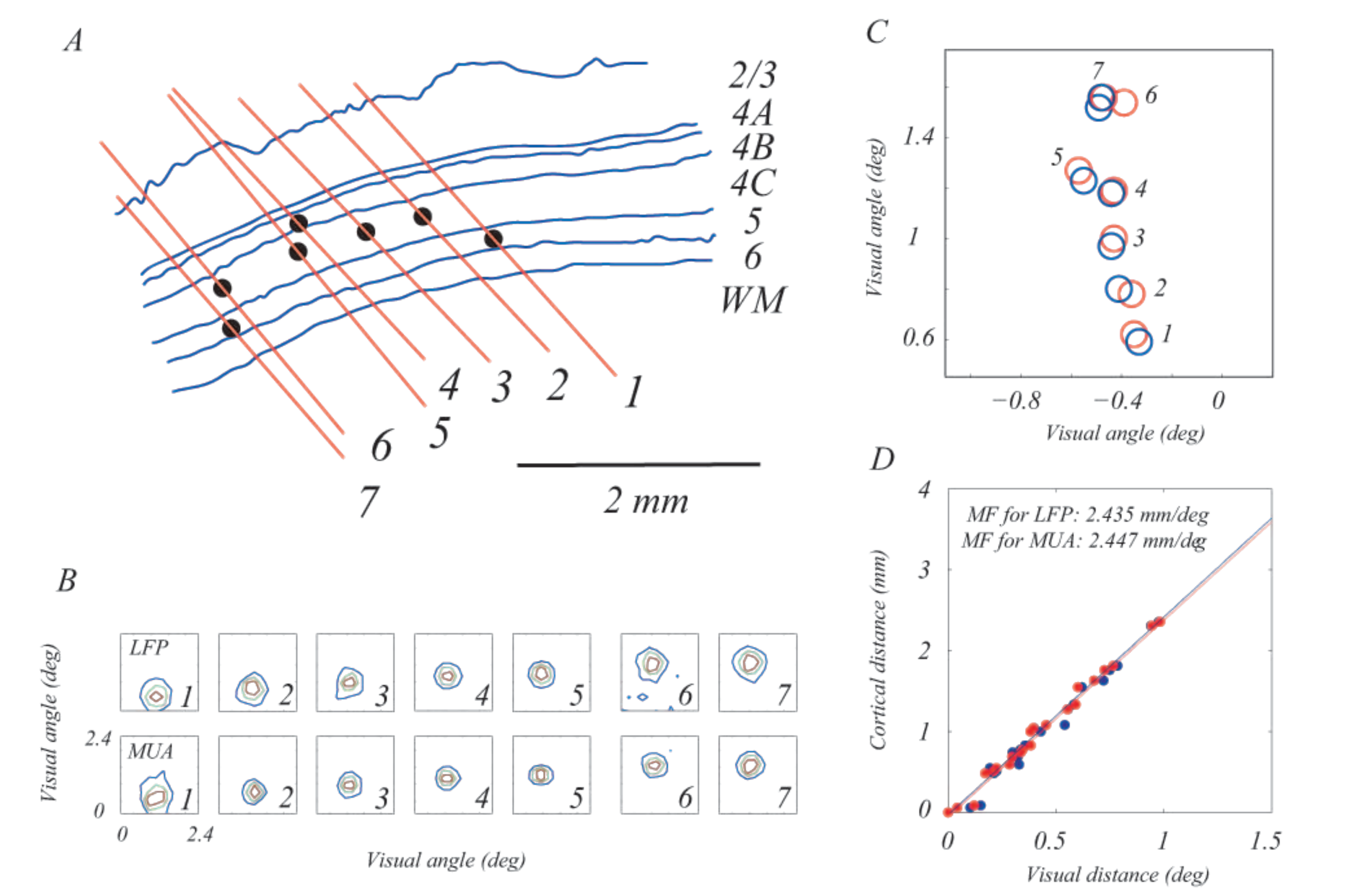
Visual spreads of the LFP (σ_{vLFP}) and MUA (σ_{vMUA}) (example)



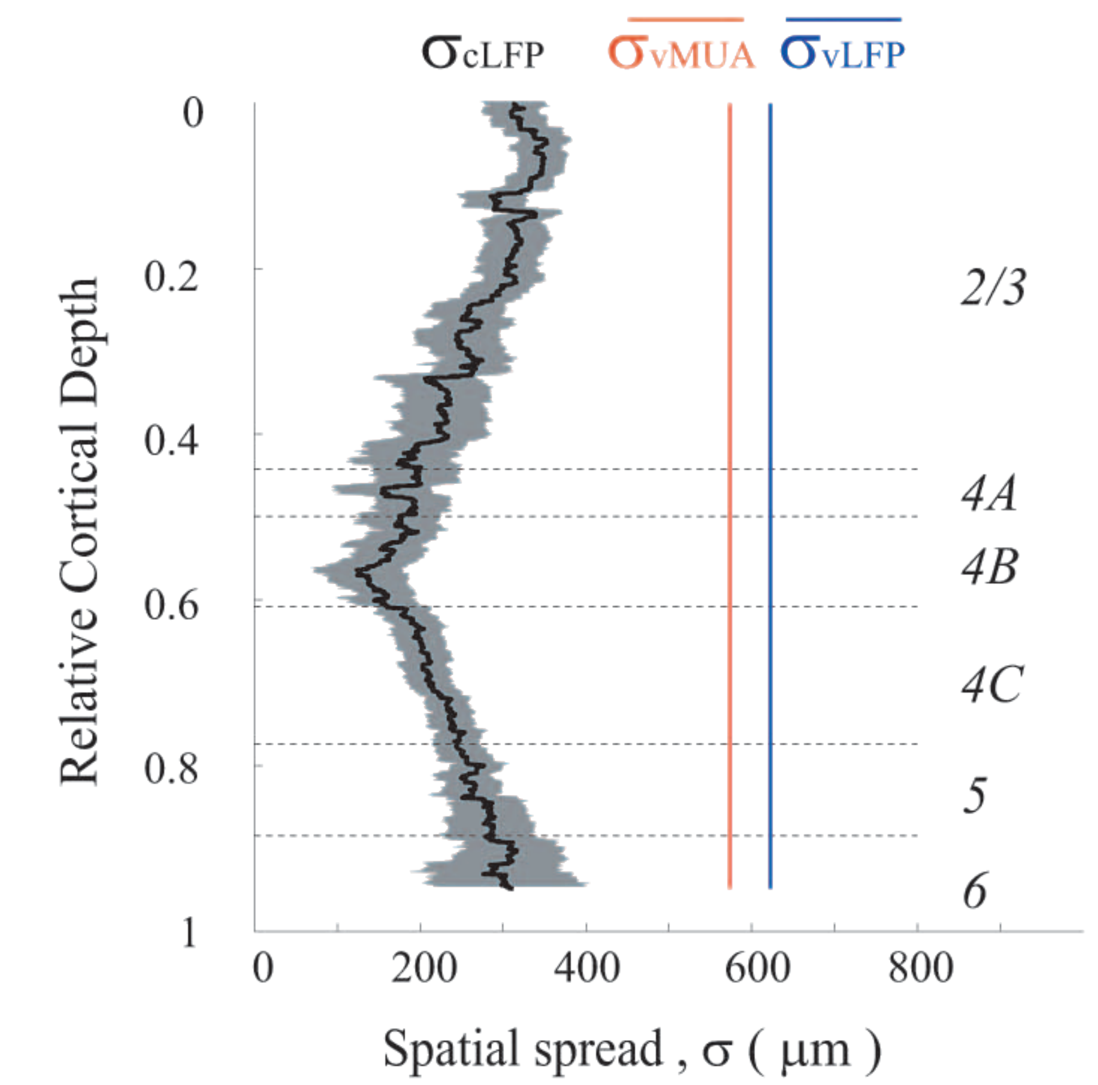
σvLFP and σvMUA are similar and laminar dependent



Precisely measure magnification factor with 7-electrode system



the LFP is local and laminar dependent



Summary:

1) the LFP and MUA recorded simultaneously had similar visual field maps across all cortical layers.
2) the LFP was the sum of signals from a very local region, the radius of which was on average 250 μm.
3) the LFP's cortical spread varied across cortical layers, reaching a minimum value of 120 μm in layer 4B.
4) the LFP is a good index of local circuit activity.

References:

1) Nicholas J. Priebe, and David Ferster. Direction Selectivity of Excitation and Inhibition in Simple Cells of the Cat Primary Visual Cortex. Neuron. 2005
2) Judson P. Jones and Larry A. Palmer. The two-dimensional spatial structure of simple receptive fields in cat striate cortex. J Neurophysiol 1987
3) Gail A, Brinksmeyer HJ, Eckhorn R. Contour decouples gamma activity across texture representation in monkey striate cortex. Cereb Cortex. 2000.

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