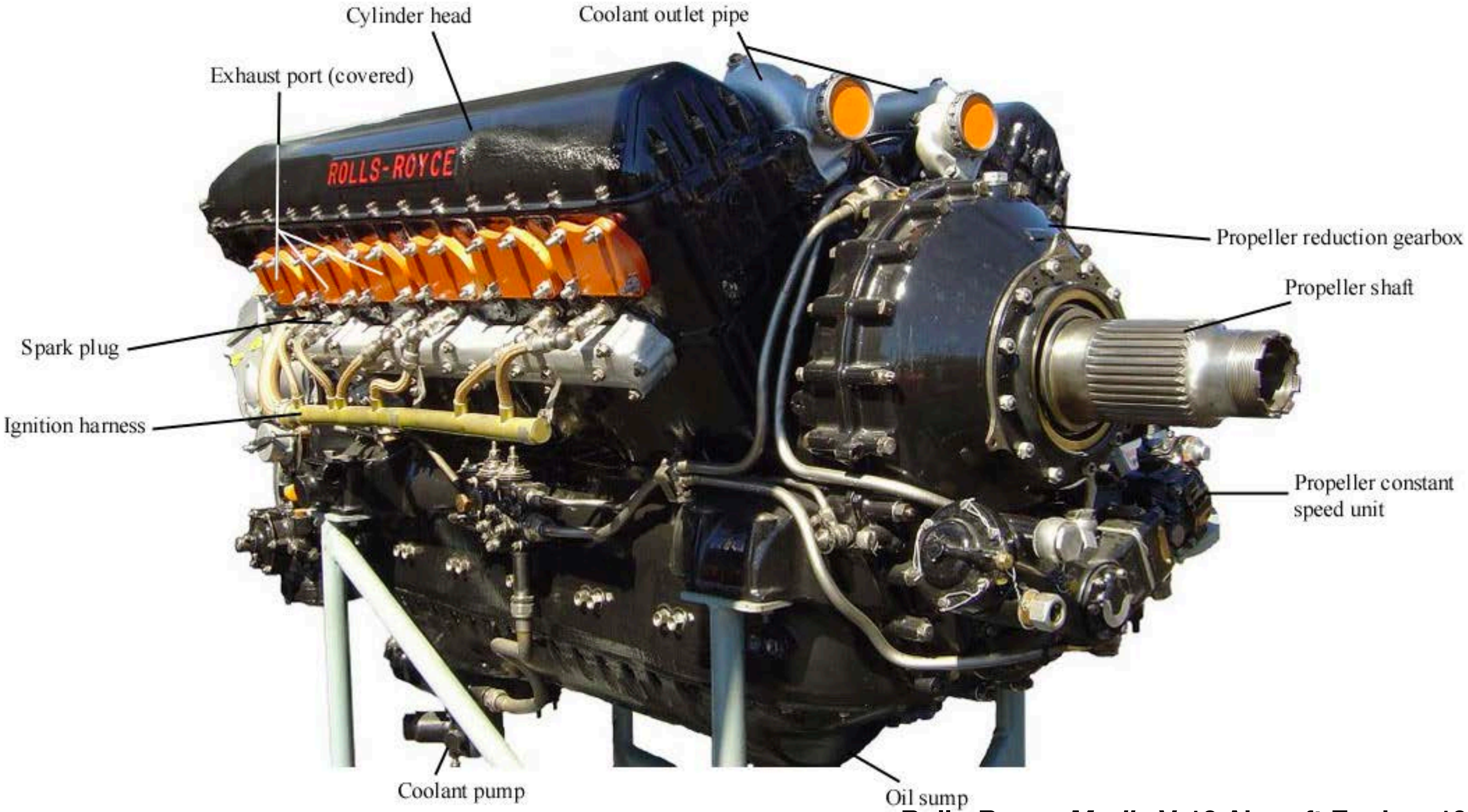
More than just a "Motor": Recent surprises from the frontal cortex

Christian L. Ebbesen, PhD



Rolls-Royce *Merlin* V-12 Aircraft Engine, 1933

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1:30 PM - 1:35 PM. **180.01 - Introduction**
C. L. Ebbesen; Chair. Skirball Inst. of Biomol. Med., New York University School of Medicine, New York, NY.

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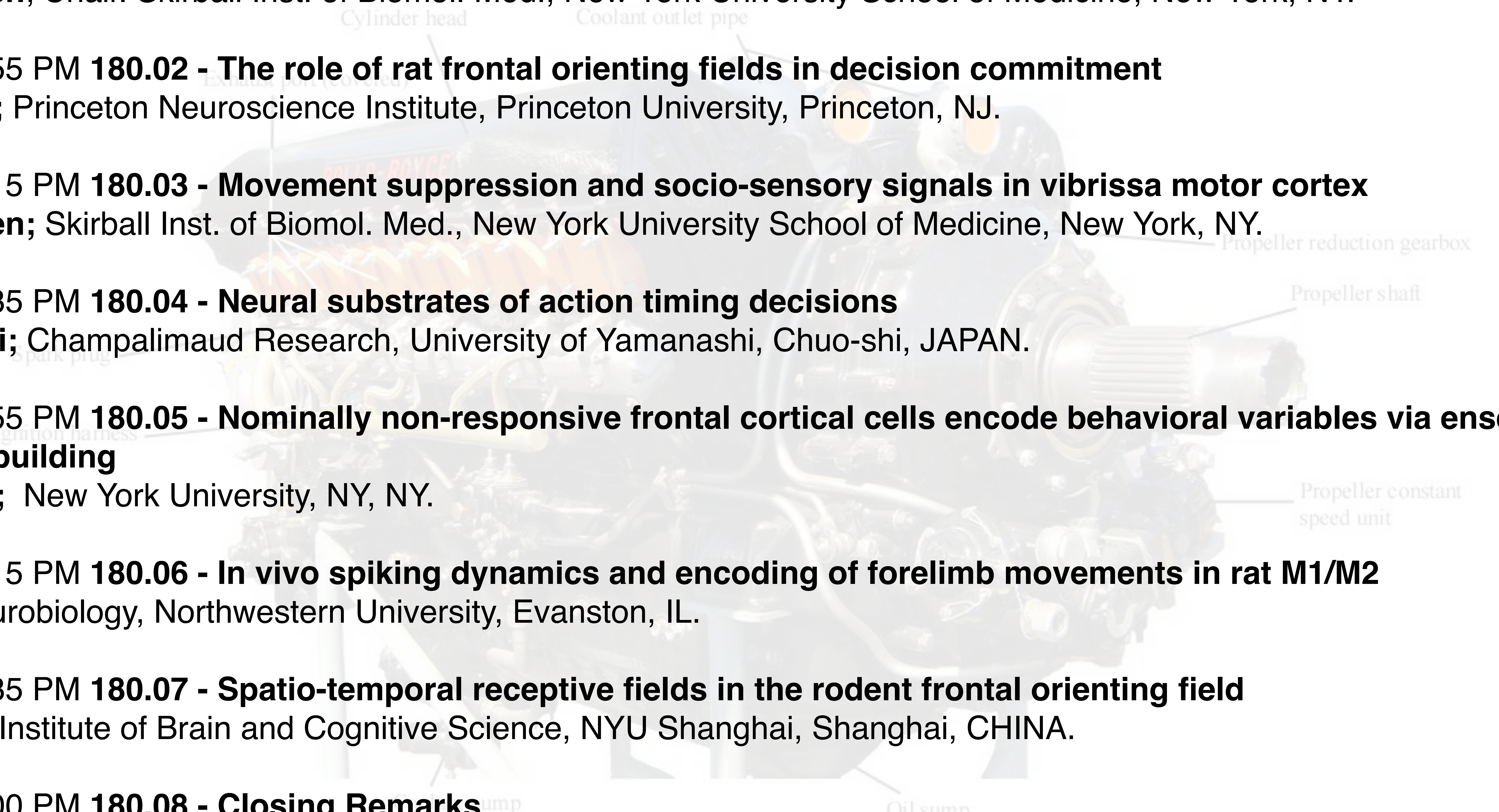
2:15 PM - 2:35 PM **180.04 - Neural substrates of action timing decisions**
M. Murakami; Champalimaud Research, University of Yamanashi, Chuo-shi, JAPAN.

2:35 PM - 2:55 PM **180.05 - Nominally non-responsive frontal cortical cells encode behavioral variables via ensemble consensus-building**
M. Insanally; New York University, NY, NY.

2:55 PM - 3:15 PM **180.06 - In vivo spiking dynamics and encoding of forelimb movements in rat M1/M2**
A. Saiki; Neurobiology, Northwestern University, Evanston, IL.

3:15 PM - 3:35 PM **180.07 - Spatio-temporal receptive fields in the rodent frontal orienting field**
J. C. Erlich; Institute of Brain and Cognitive Science, NYU Shanghai, Shanghai, CHINA.

3:35 PM - 4:00 PM **180.08 - Closing Remarks**



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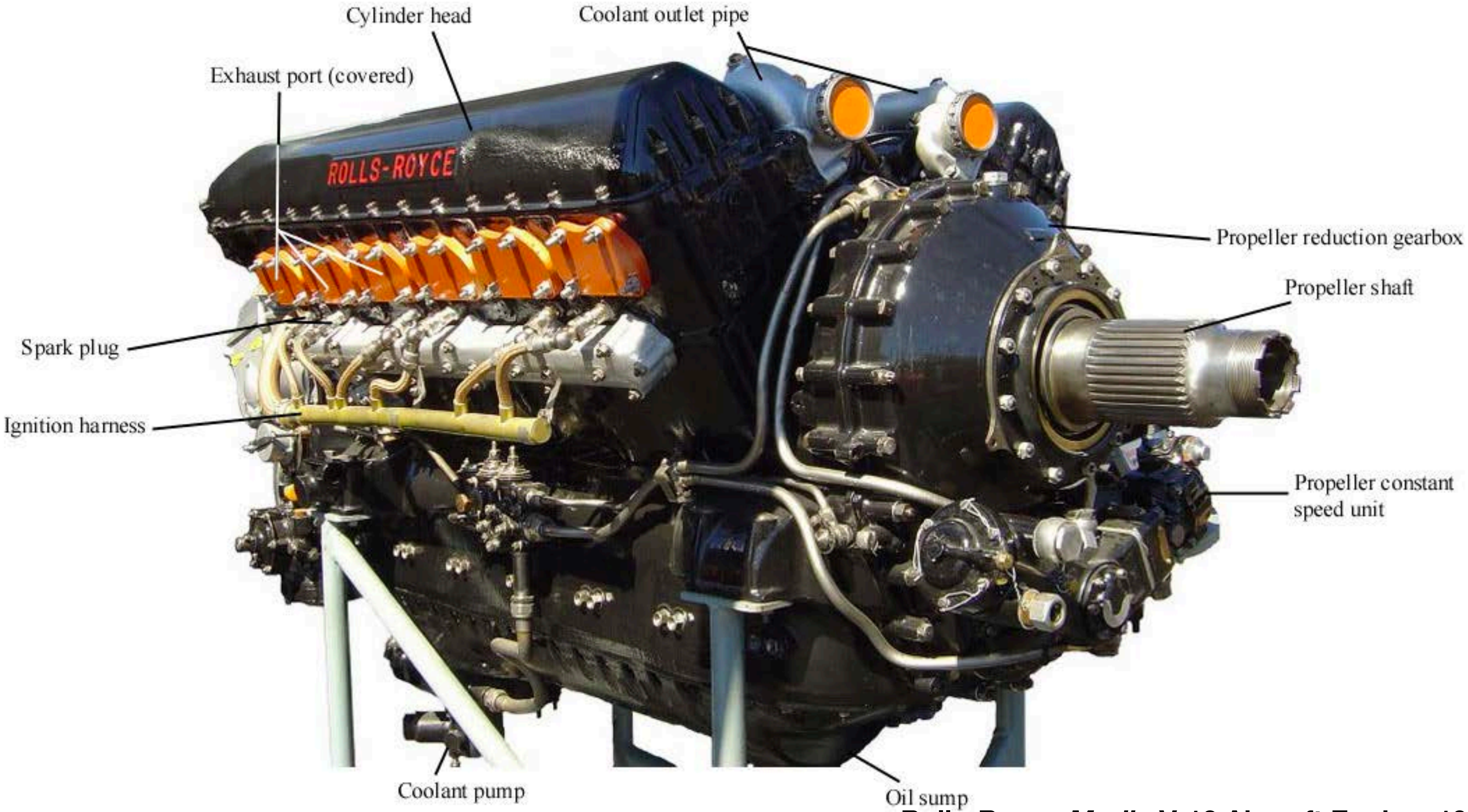


Rolls-Royce *Merlin* V-12 Aircraft Engine, 1933

Human M1

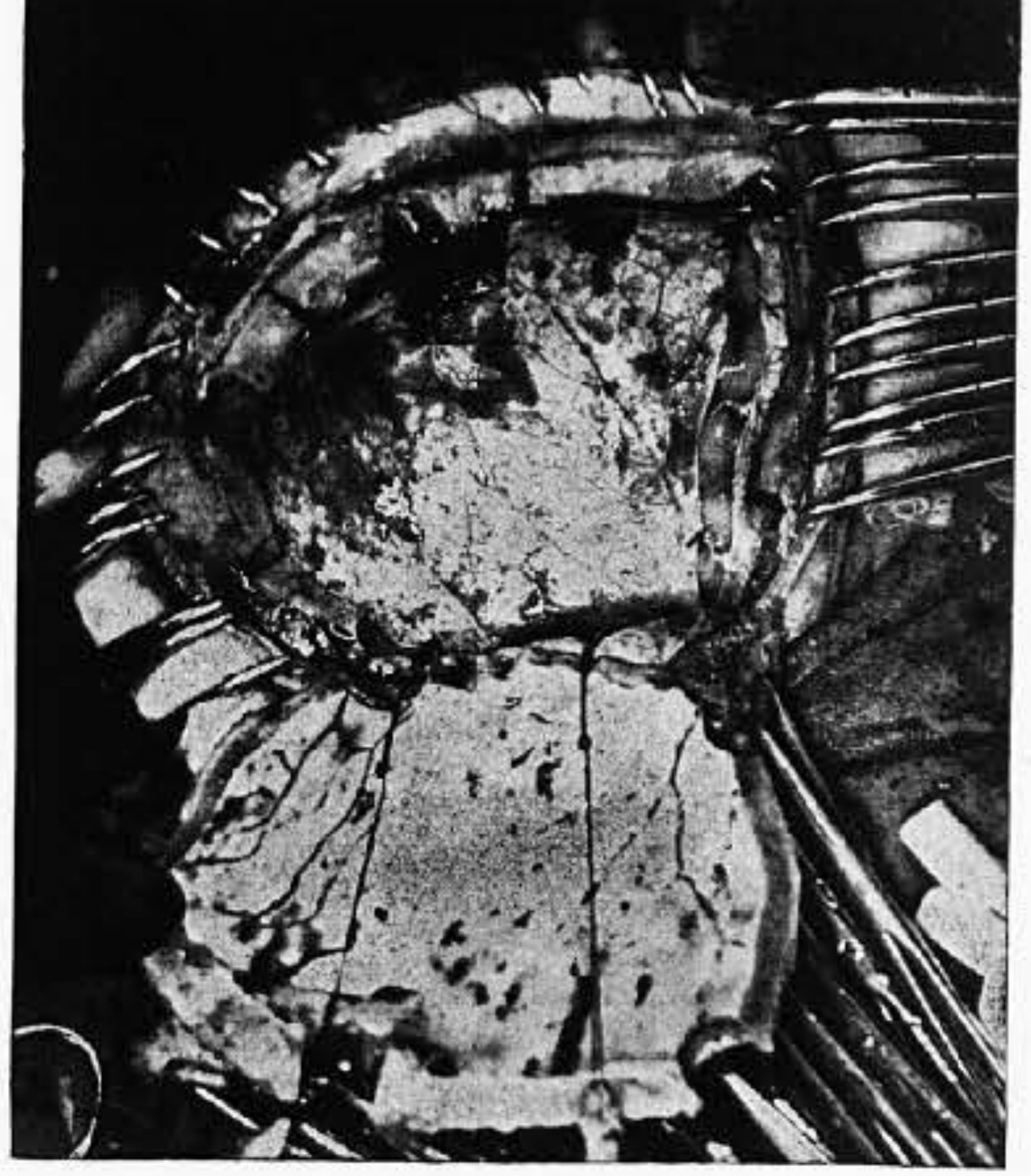


Fig. 2. CASE G.C. Osteoplastic bone flap turned down on its attachment of temporal muscle.

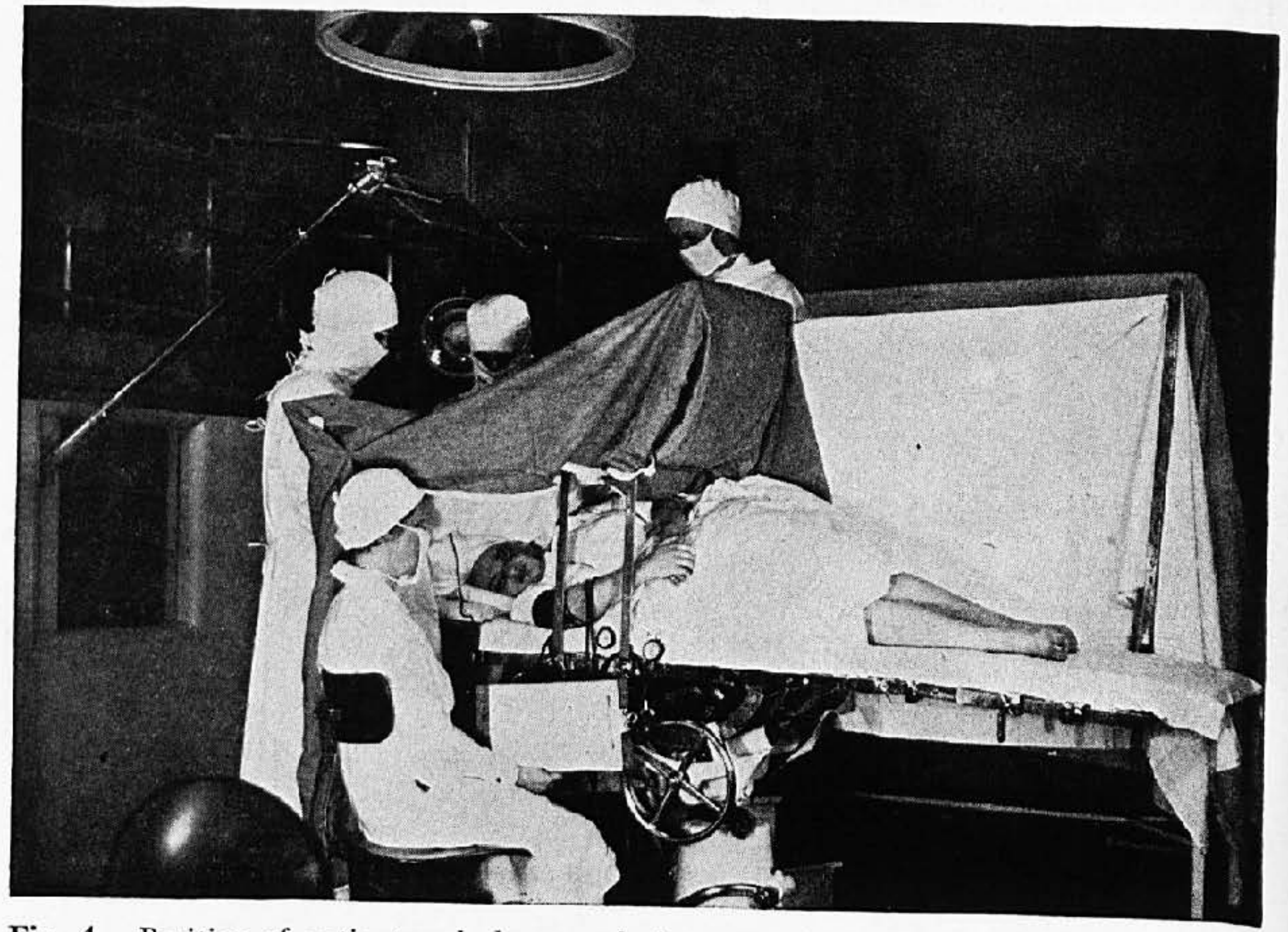
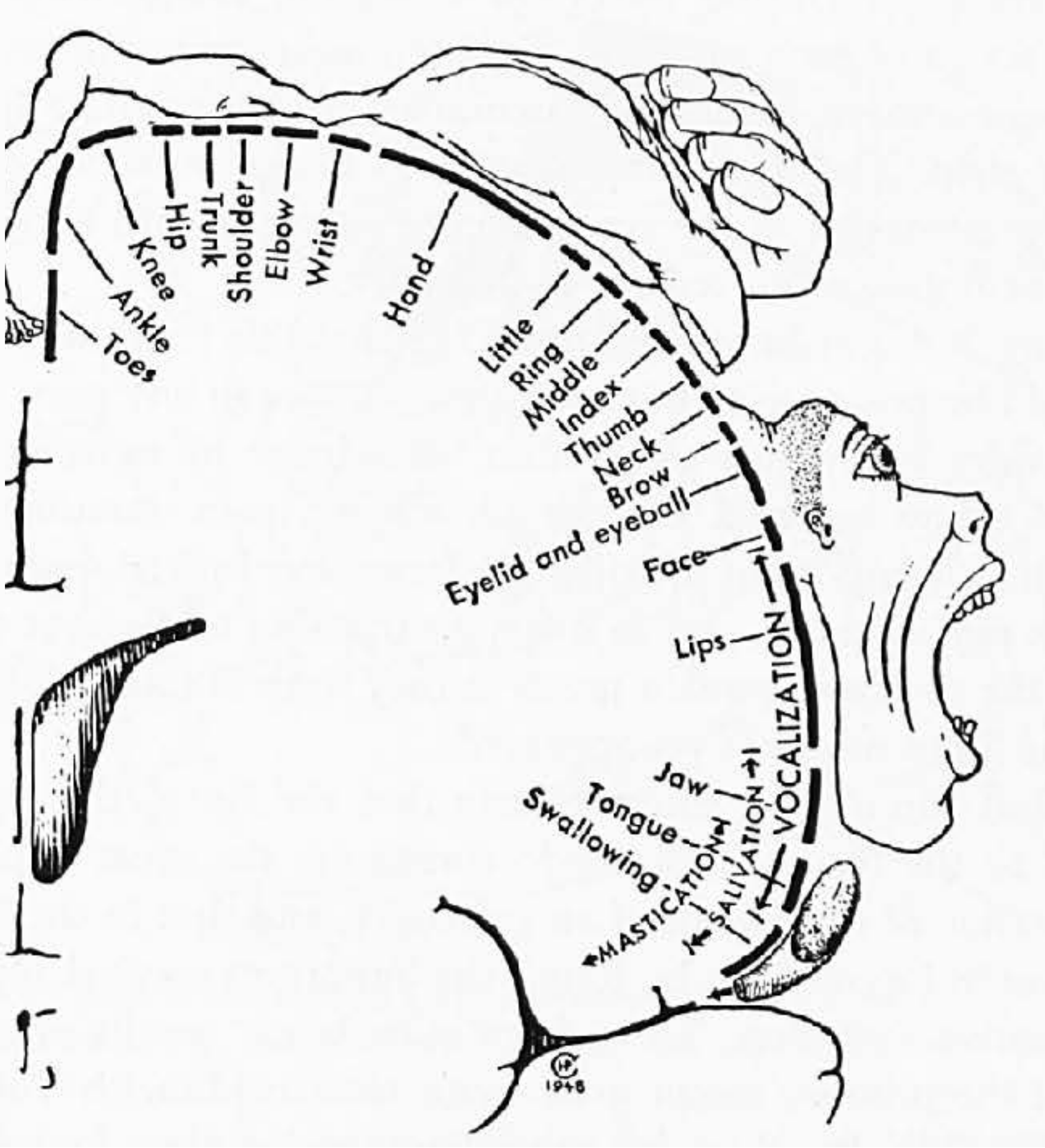
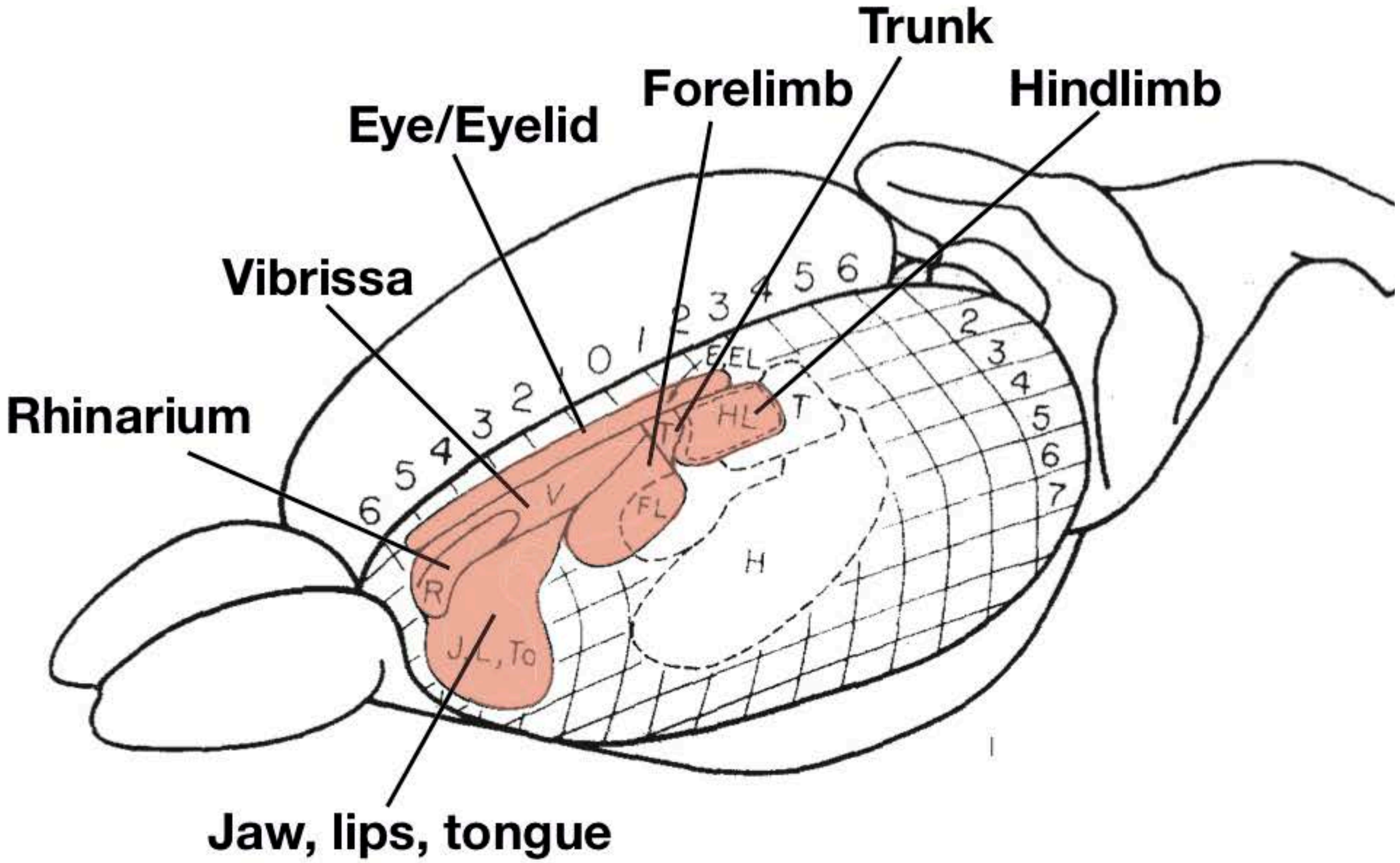


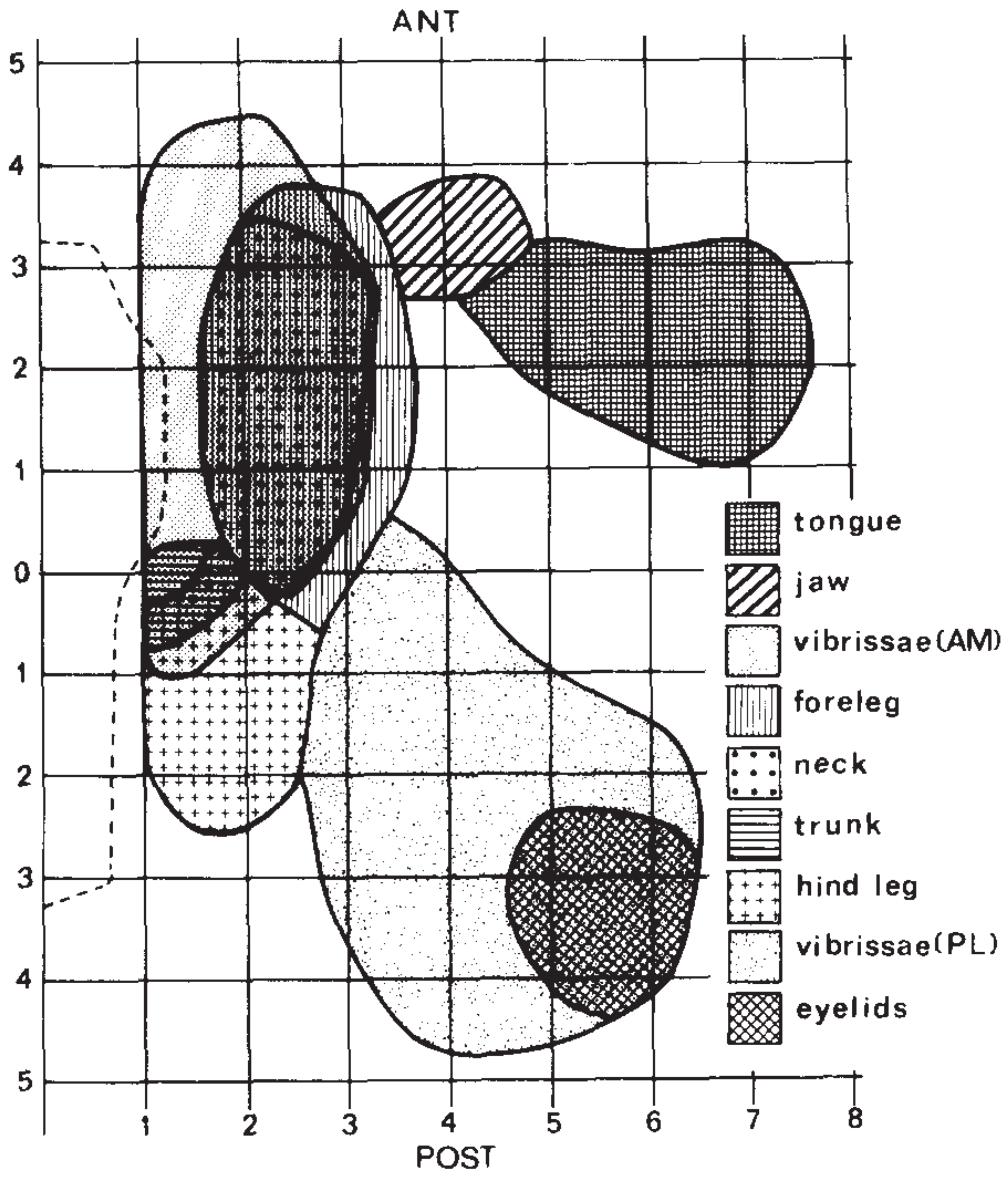
Fig. 4. Position of patient and observer during operation under local anesthesia. The photographer's camera is located outside window behind the surgeon and is focused on the brain through the mirror above.



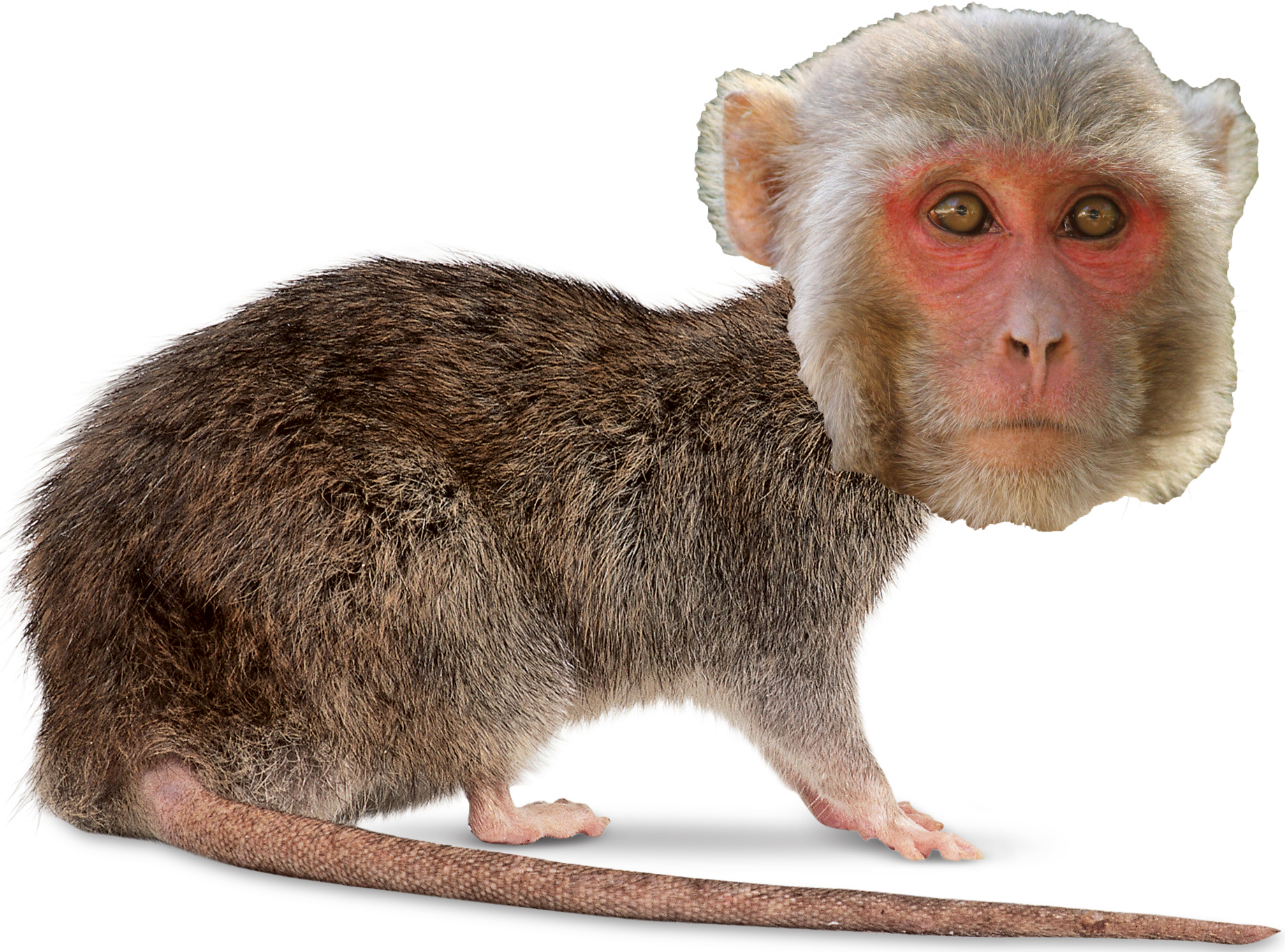
Penfield & Rasmussen, 1950

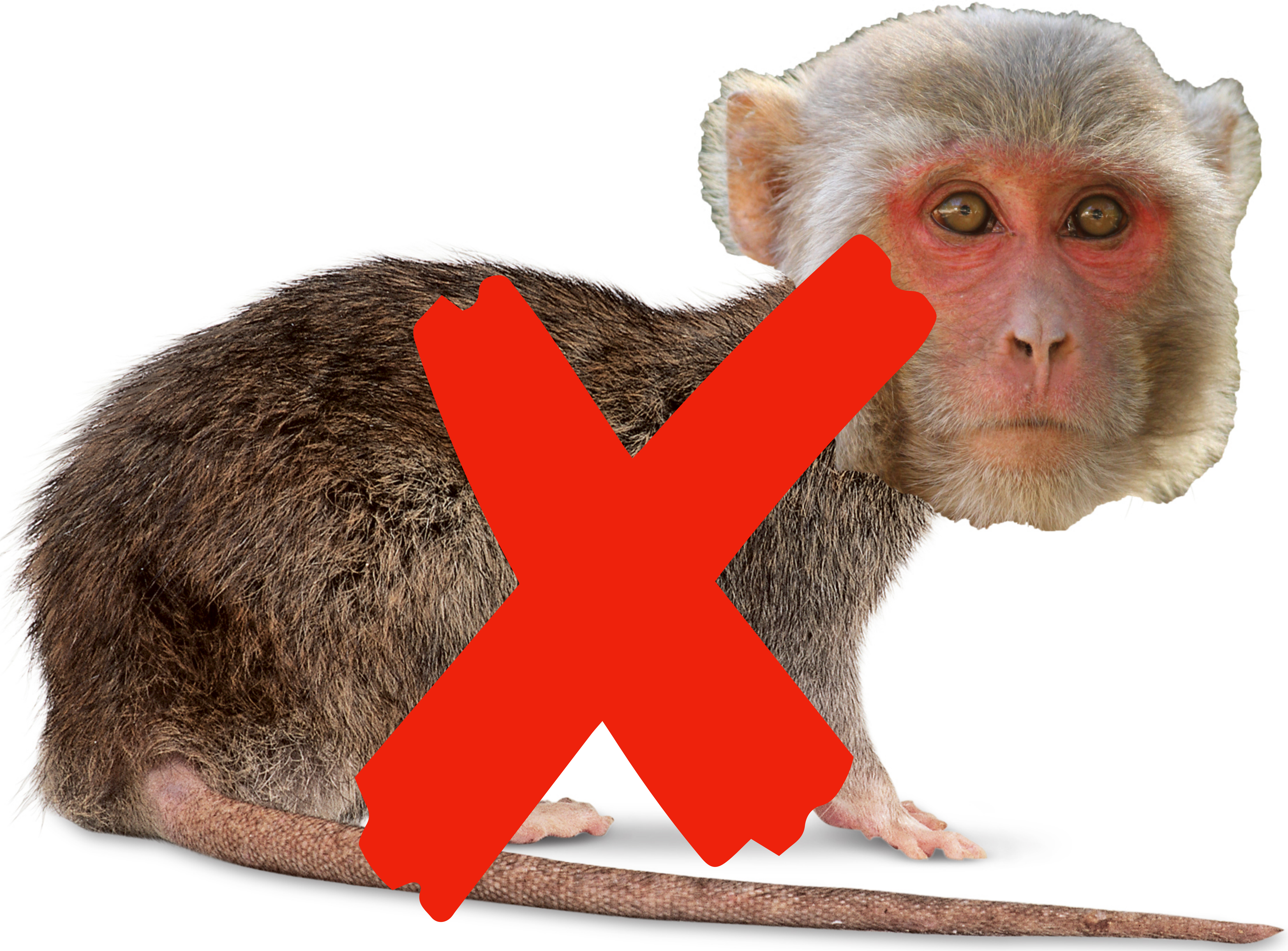


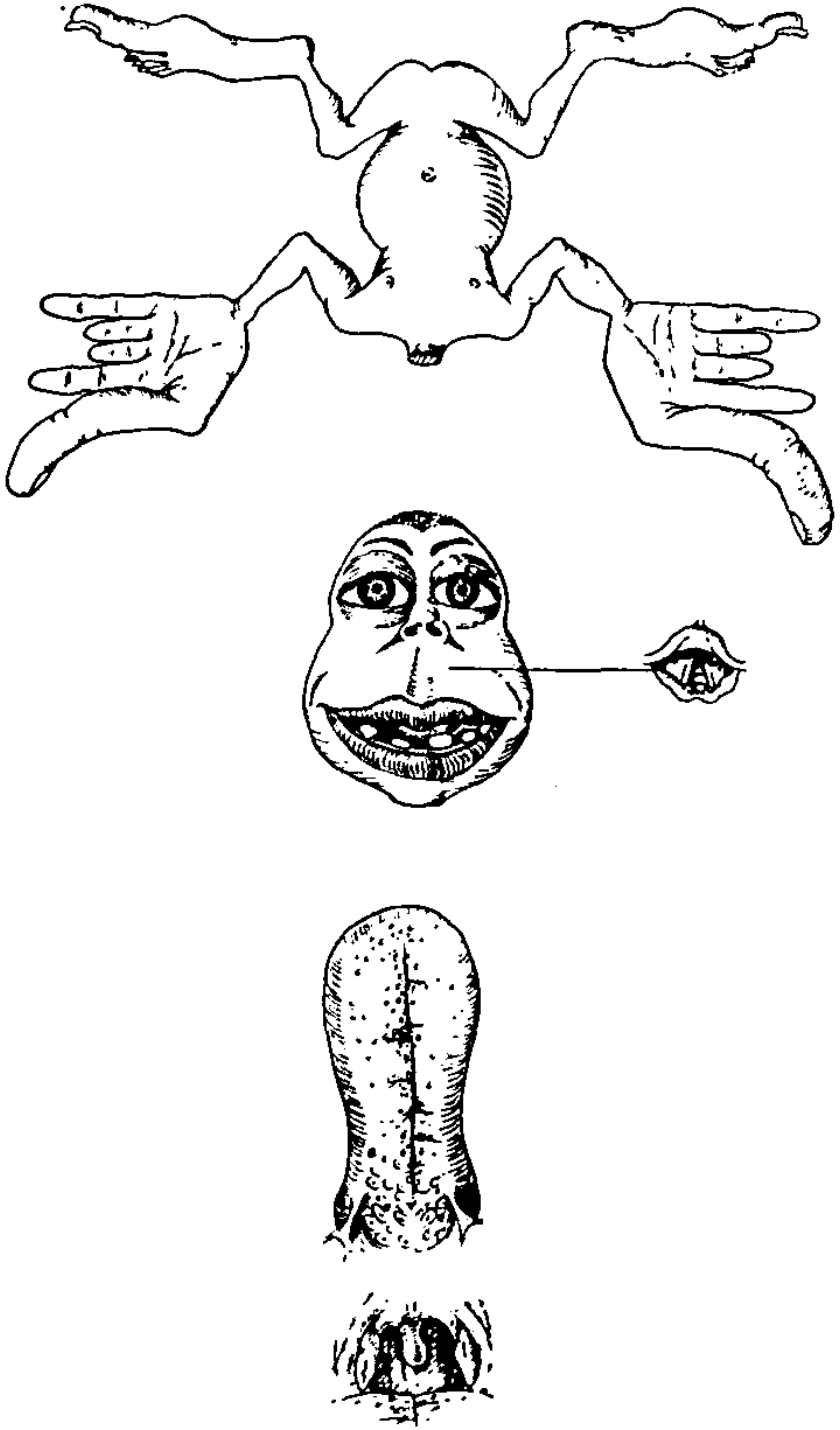
Hall & Lindholm, *Brain Res.* 1974



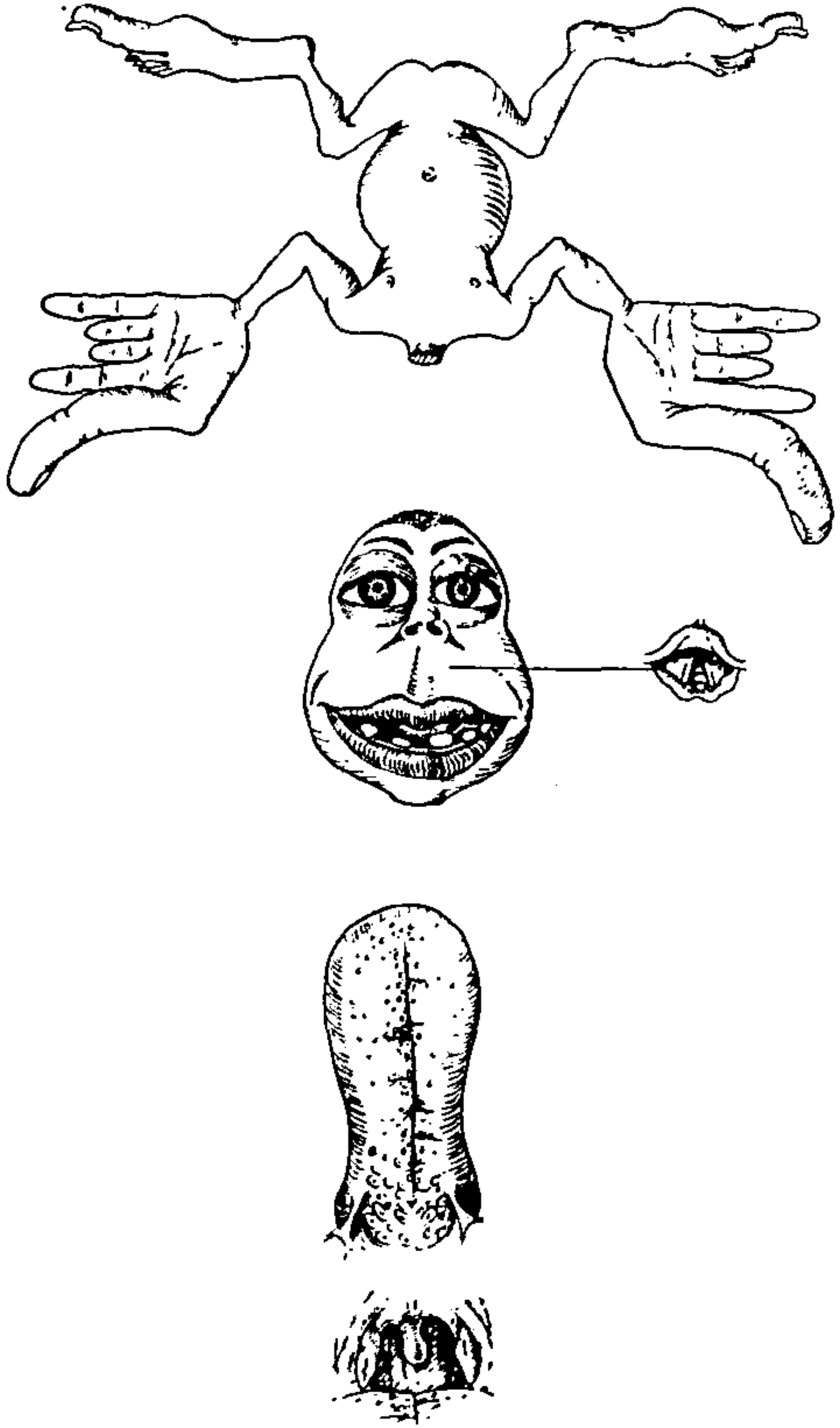
Gioanni & Lamarche, *Brain Res.* 1985







Penfield and Boldrey (1937). Brain *60*, 389–443.



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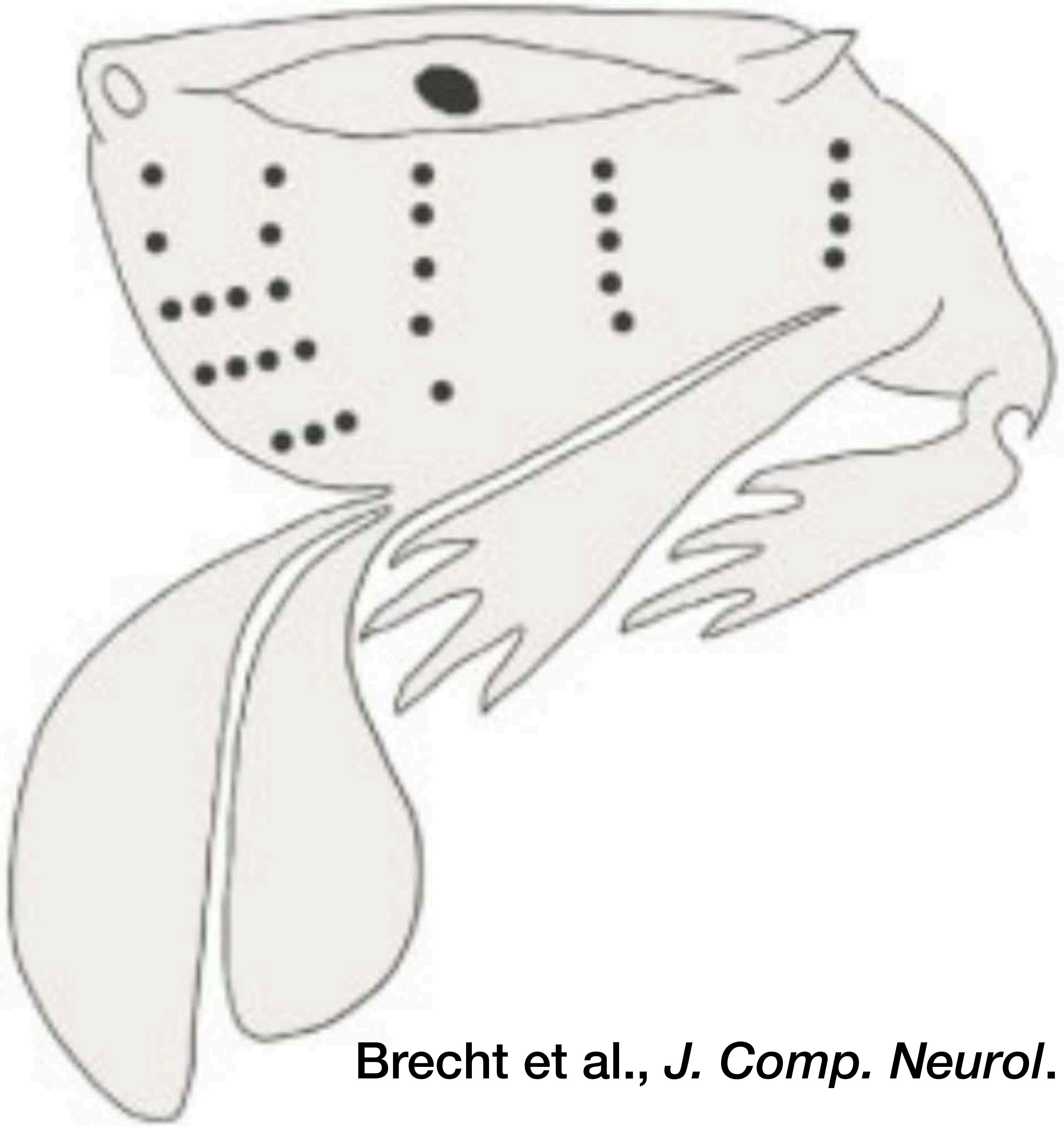
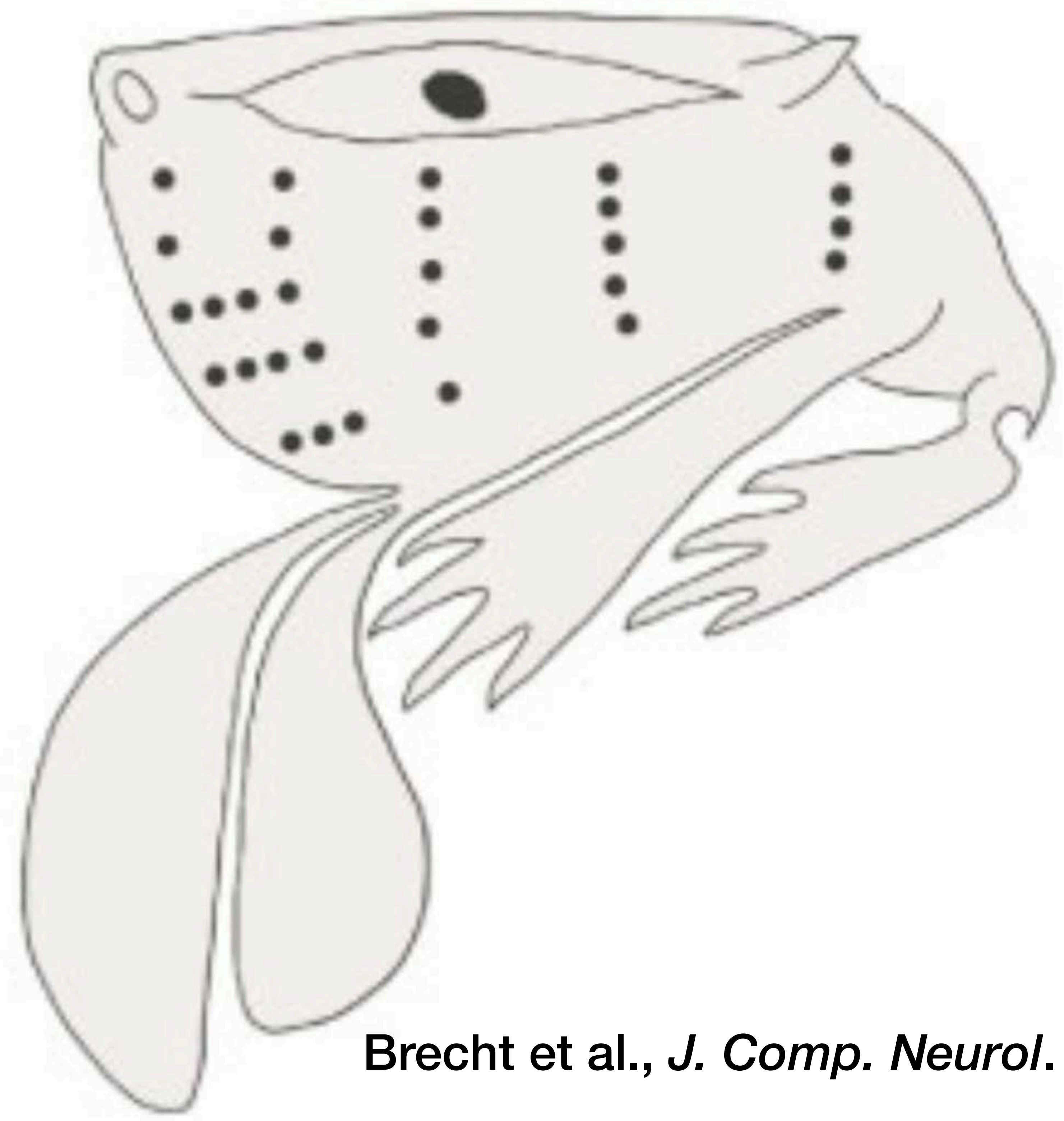


Brecht et al., *J. Comp. Neurol*. 2004

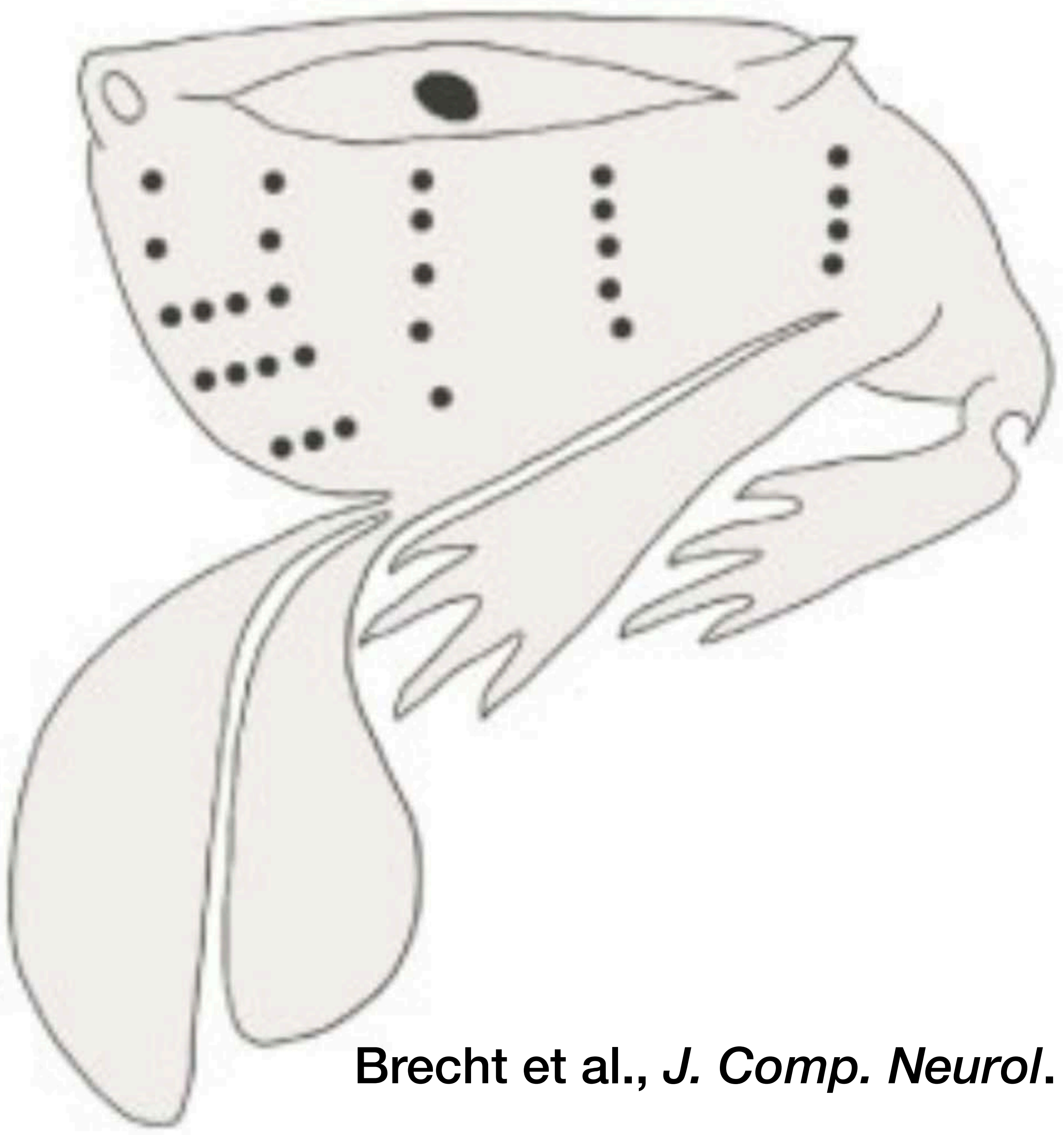
Different specializations



Brecht et al., *J. Comp. Neurol*. 2004

Different specializations

Vision

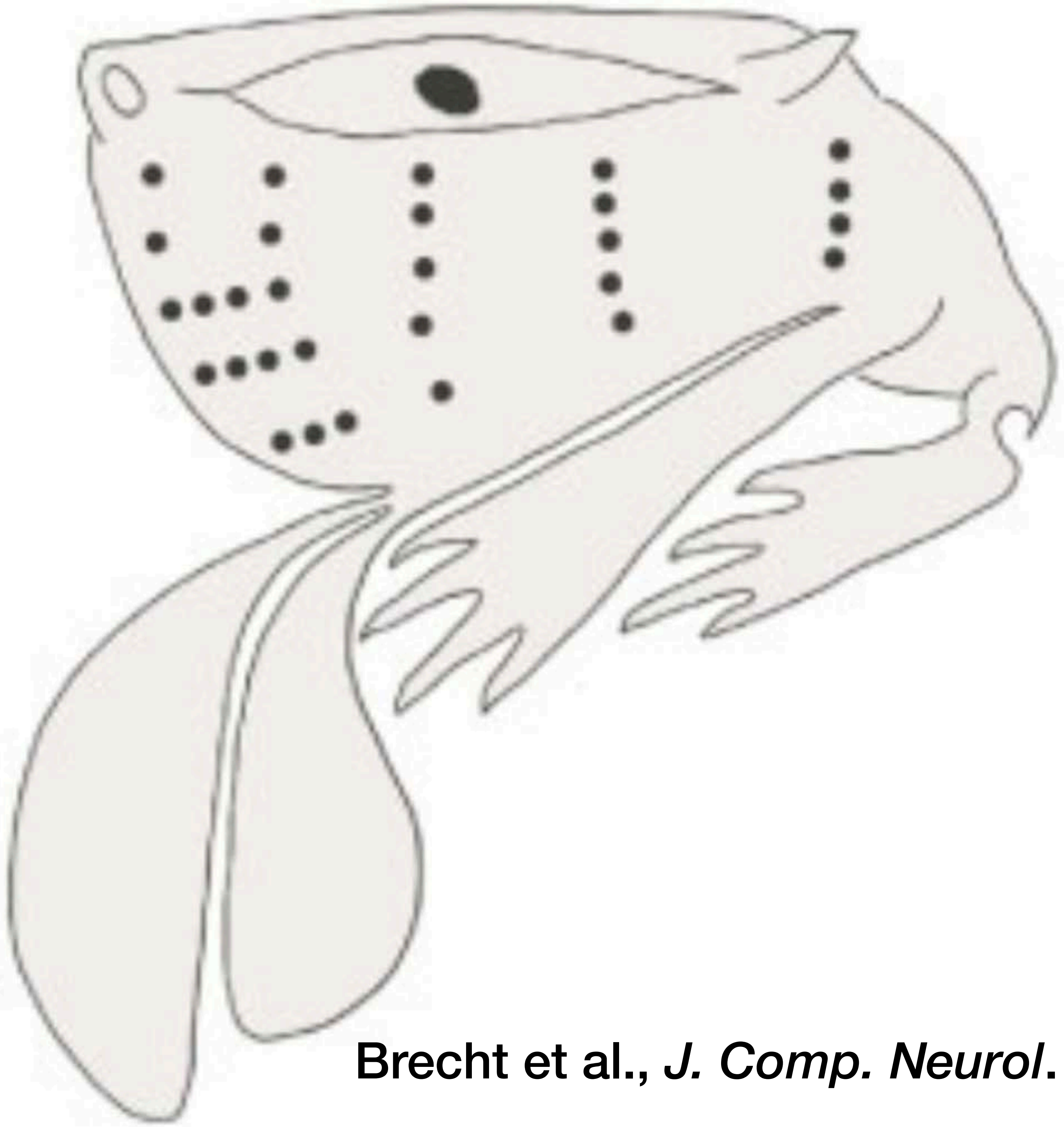


Brecht et al., *J. Comp. Neurol*. 2004

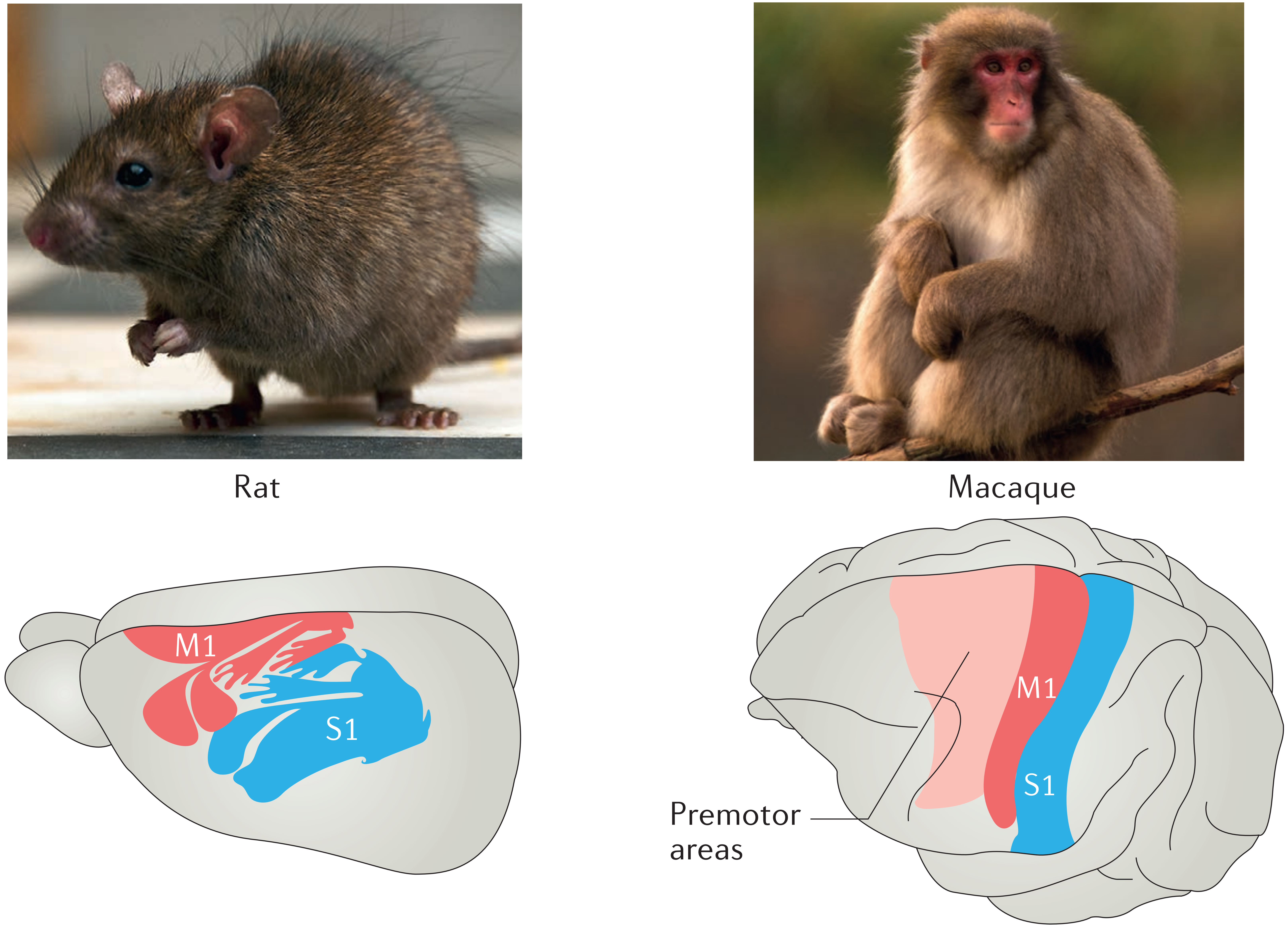
Different specializations

Vision

Whisker touch



Brecht et al., *J. Comp. Neurol*. 2004



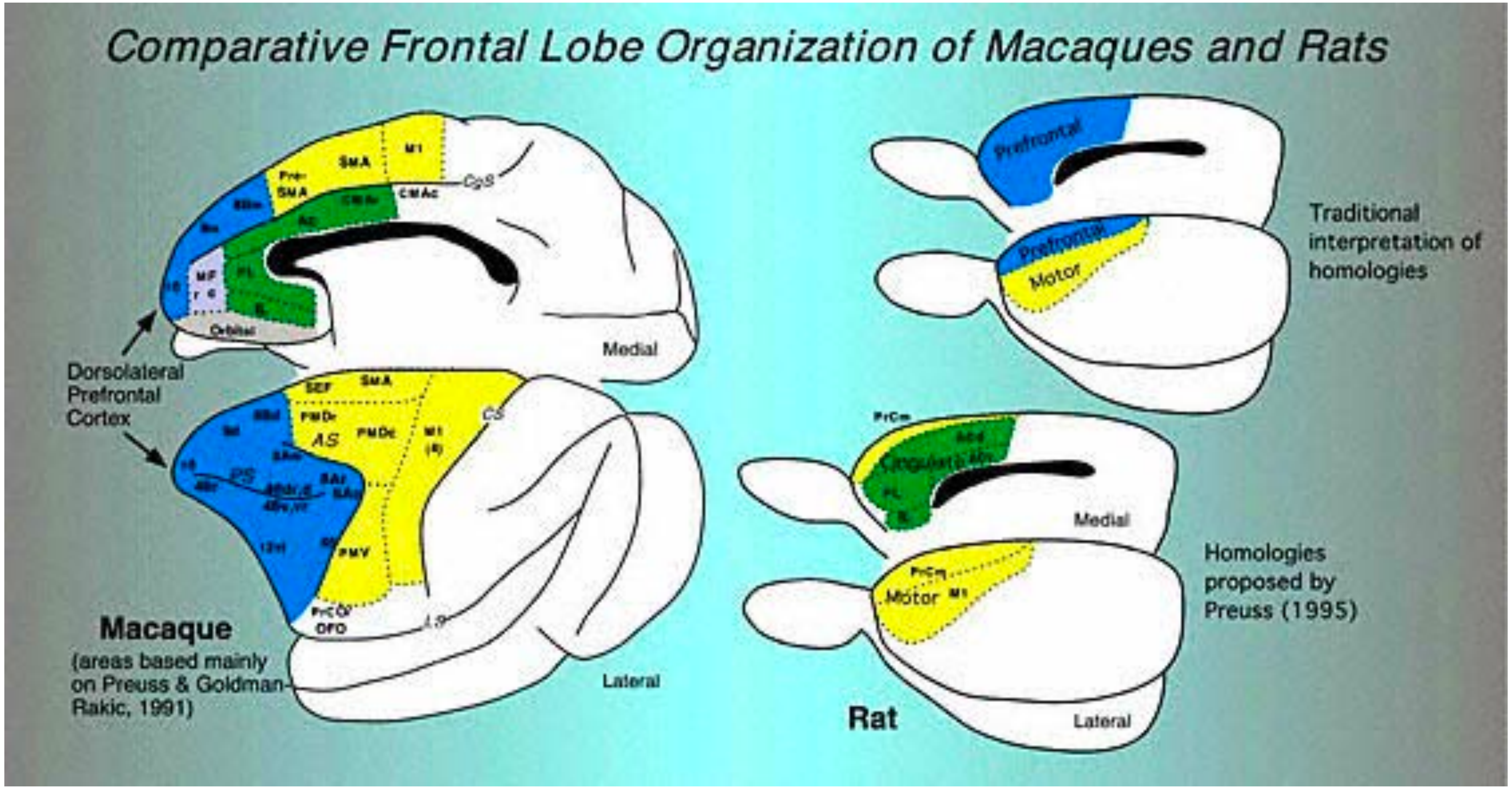
Rodents
Large motor cortex taking up most of the frontal cortex

Primates
Small motor cortex, but large frontal and premotor areas

Ebbesen & Brecht, *Nature Reviews Neurosci.* 2017

Do Rats Have Prefrontal Cortex? The Rose–Woolsey–Akert Program Reconsidered

Todd M. Preuss
Vanderbilt University



Preuss, T.M. (1995) J. Cogn. Neurosci. *7*, 1–24.

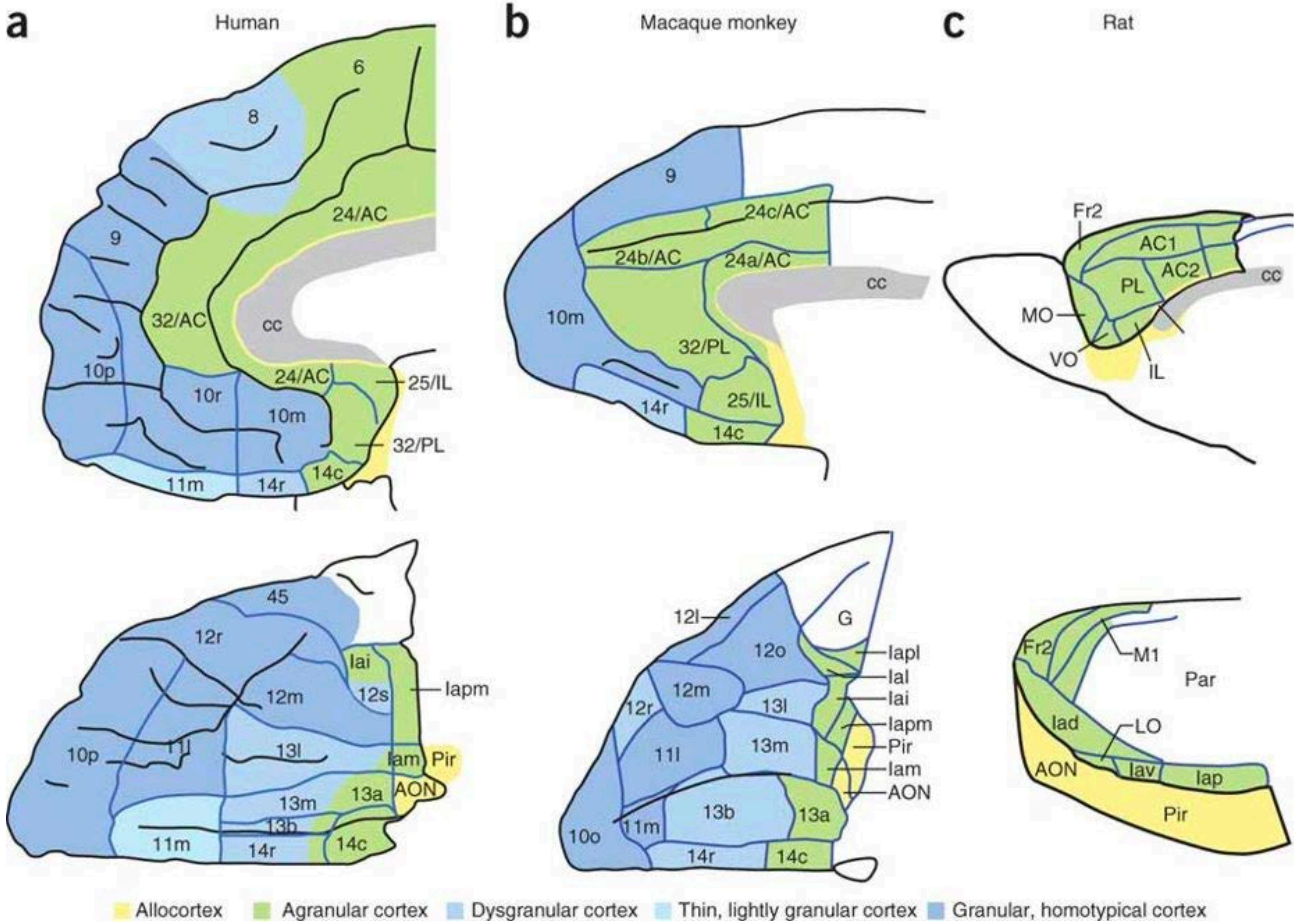
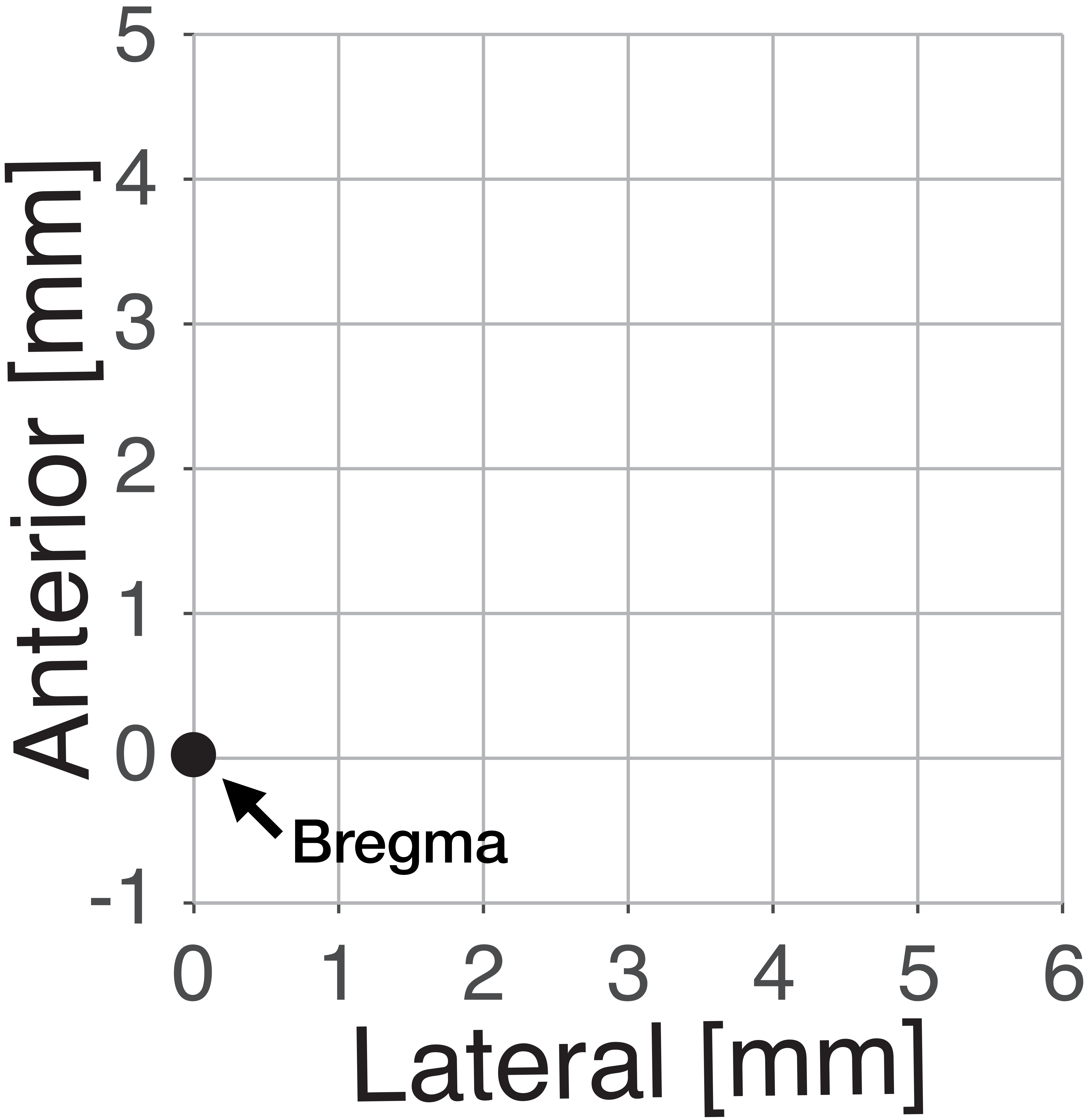
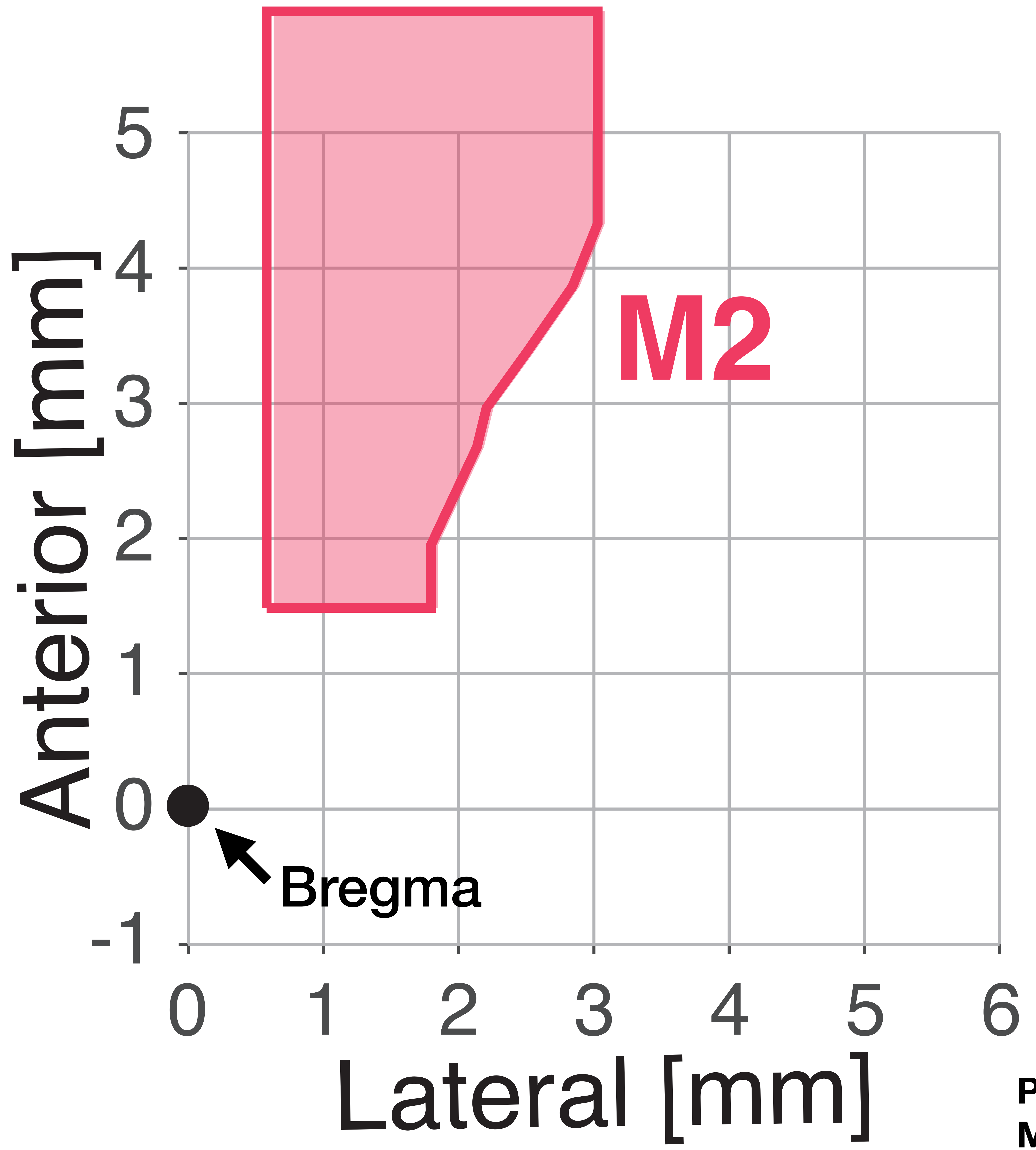


Figure 1 Comparative anatomy of the human, monkey and rat frontal cortex.

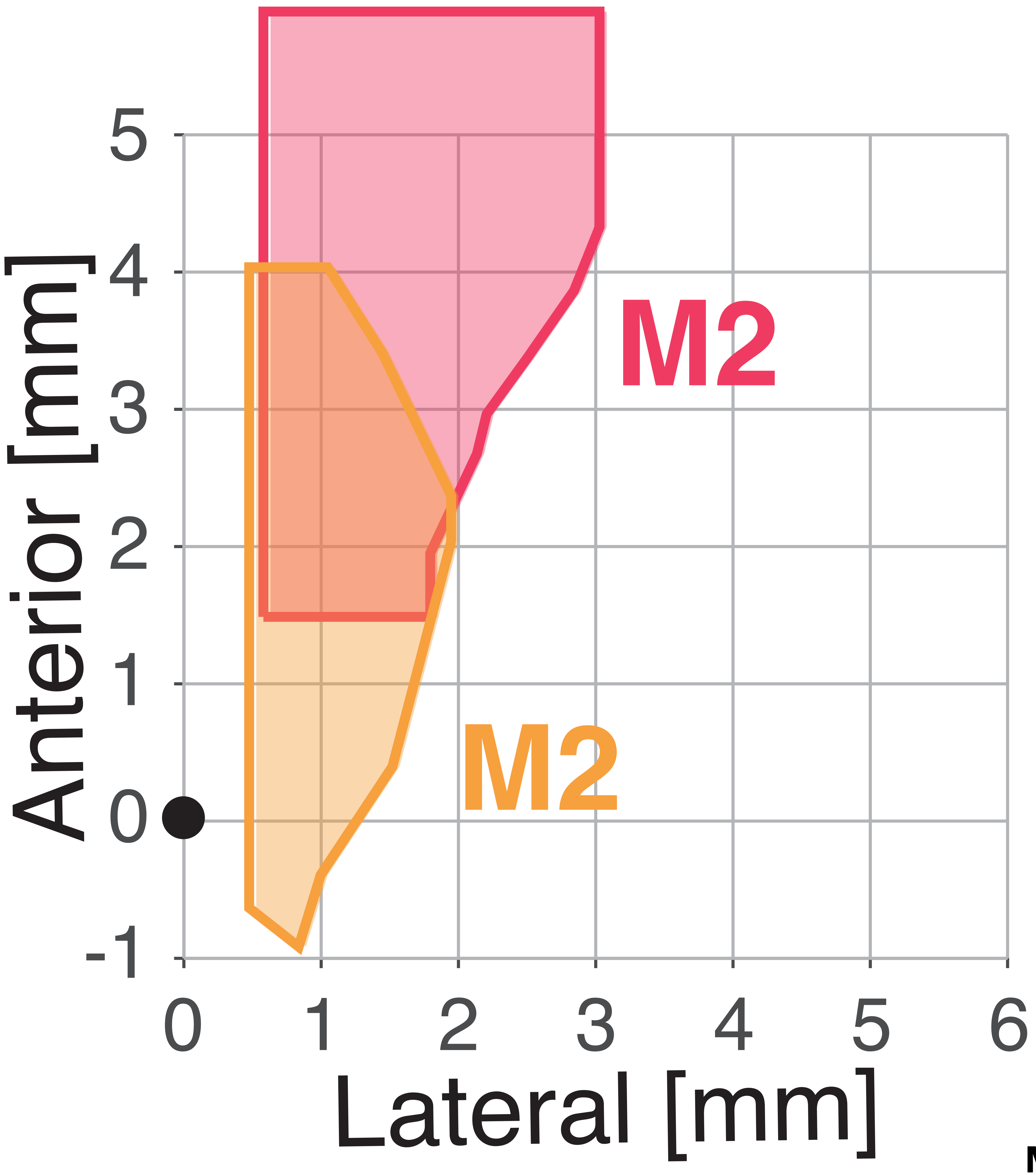
Wallis, J.D. (2011) Nat. Neurosci. *15*, 13–19.

Maps of rat frontal cortex

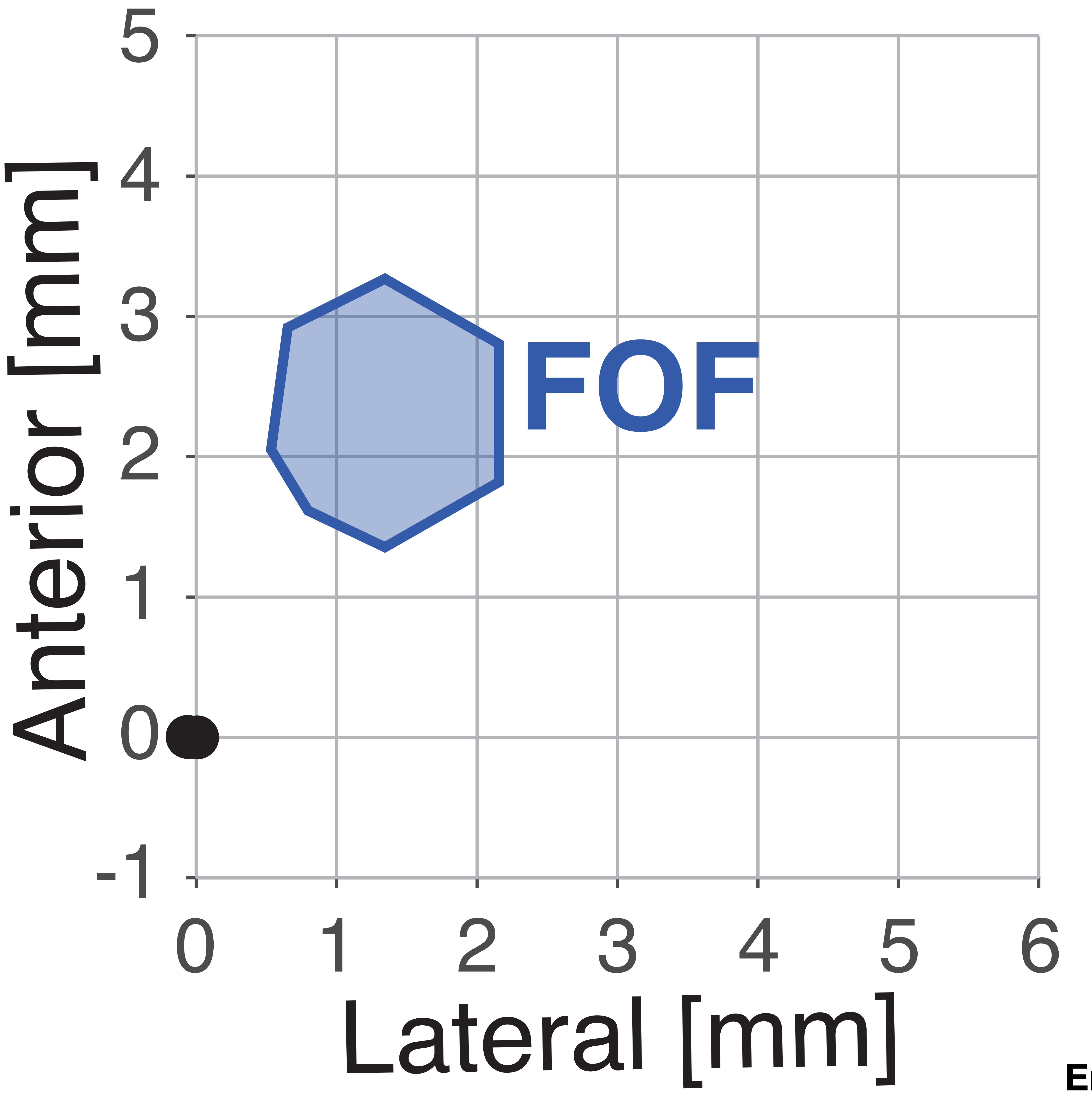




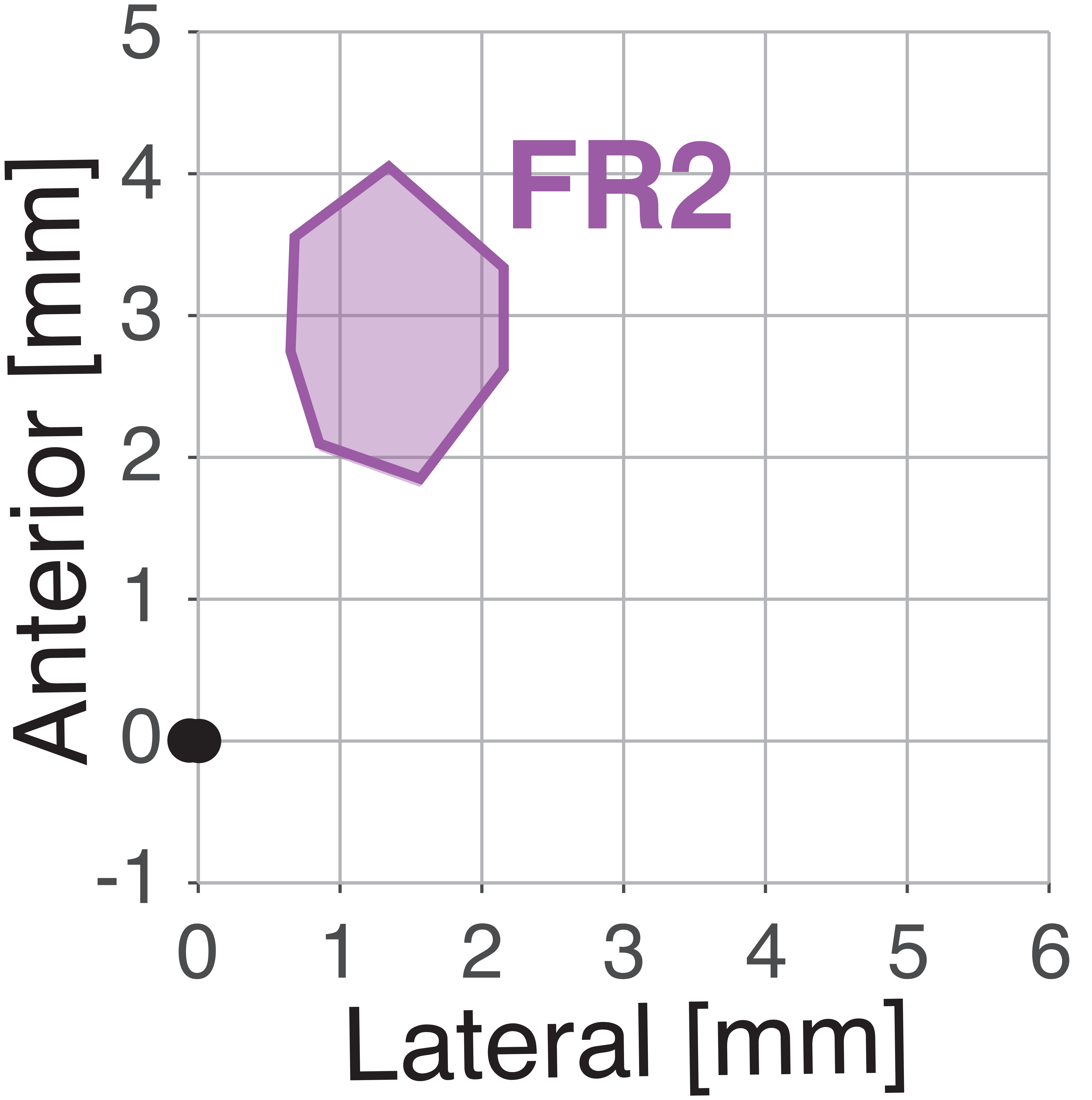
Paxinos & Watson 1982
Murakami et al. Nat.Neurosci. 2014



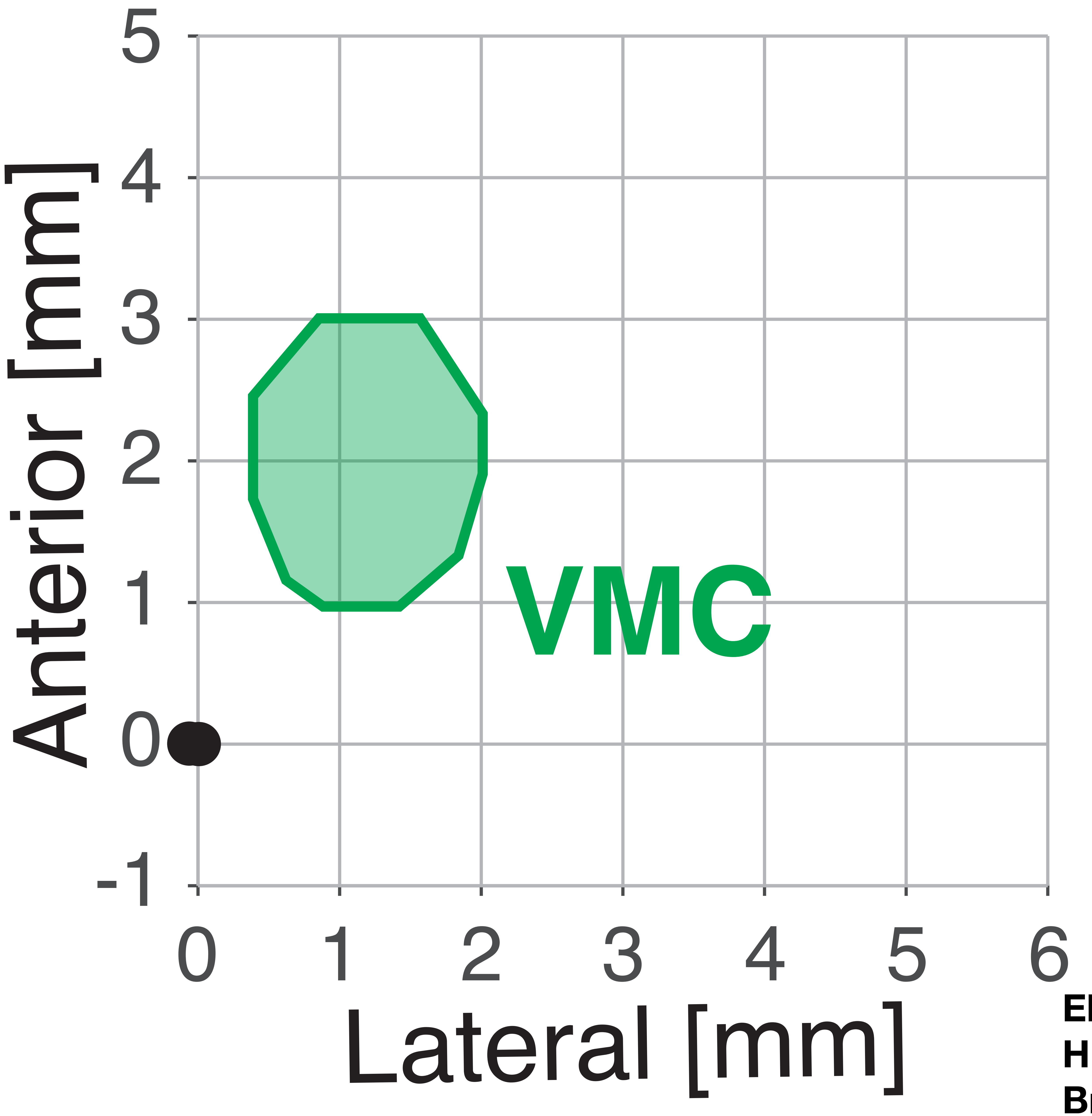
Mimica et al. Science 2018



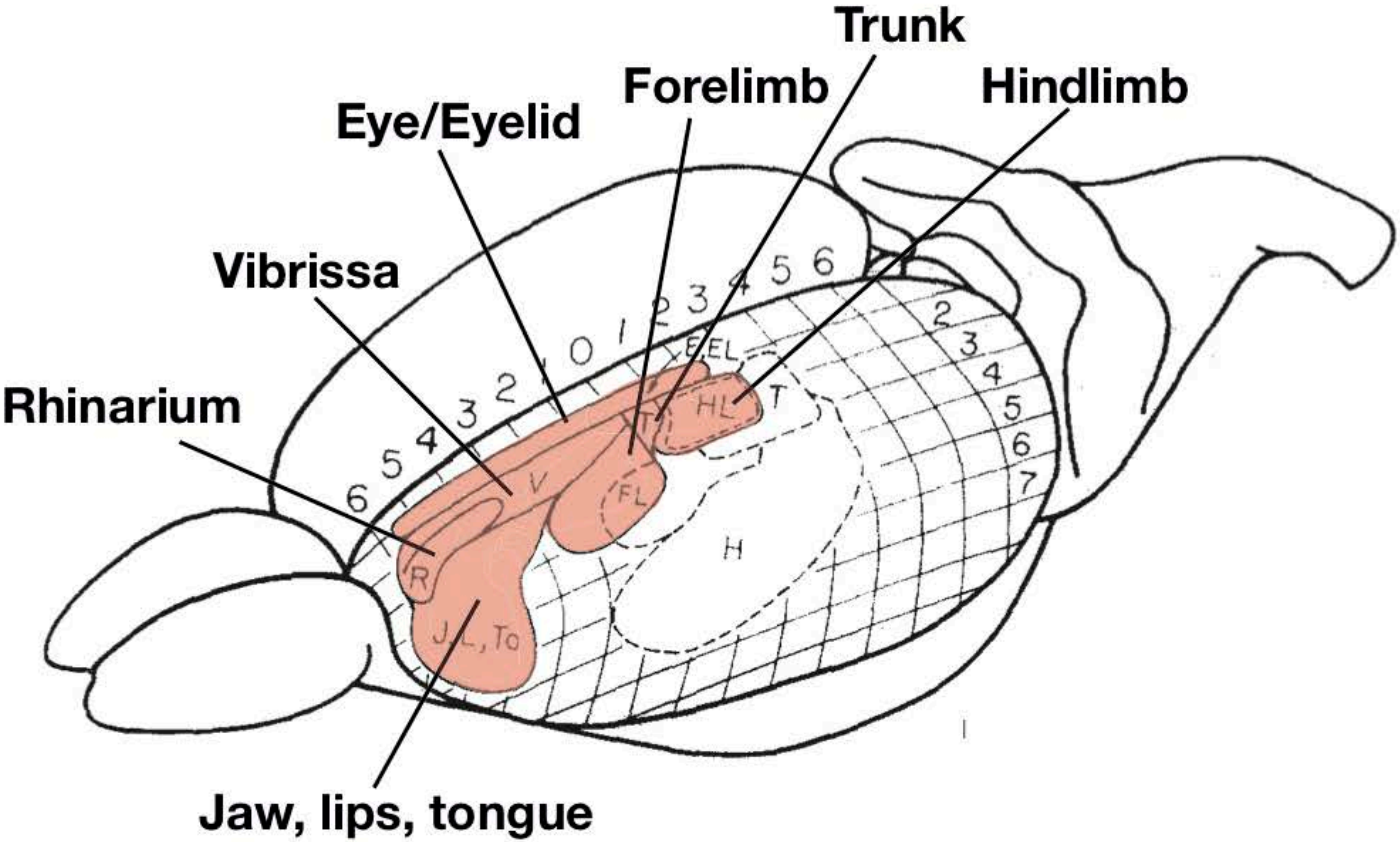
Erlich et al. Neuron 2011
Hanks*, Kopec* et al. Nature 2015



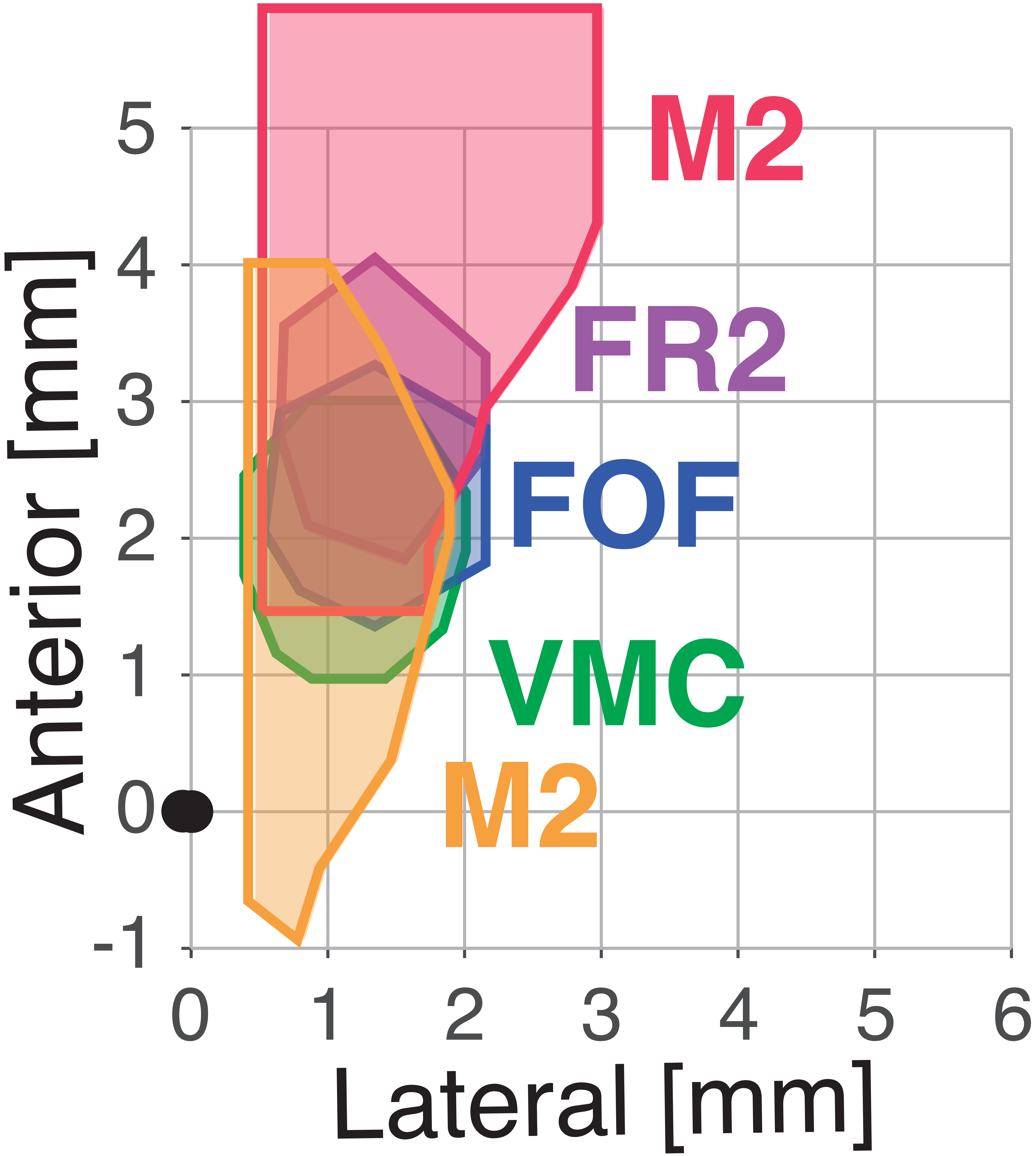
Insanally et al. BioRXiv 2018



Ebbesen et al. Nat.Neurosci. 2017
Hill et al. Neuron 2011
Brecht et al. Nature 2004
Berg & Kleinfeld J.Neurophys. 2003

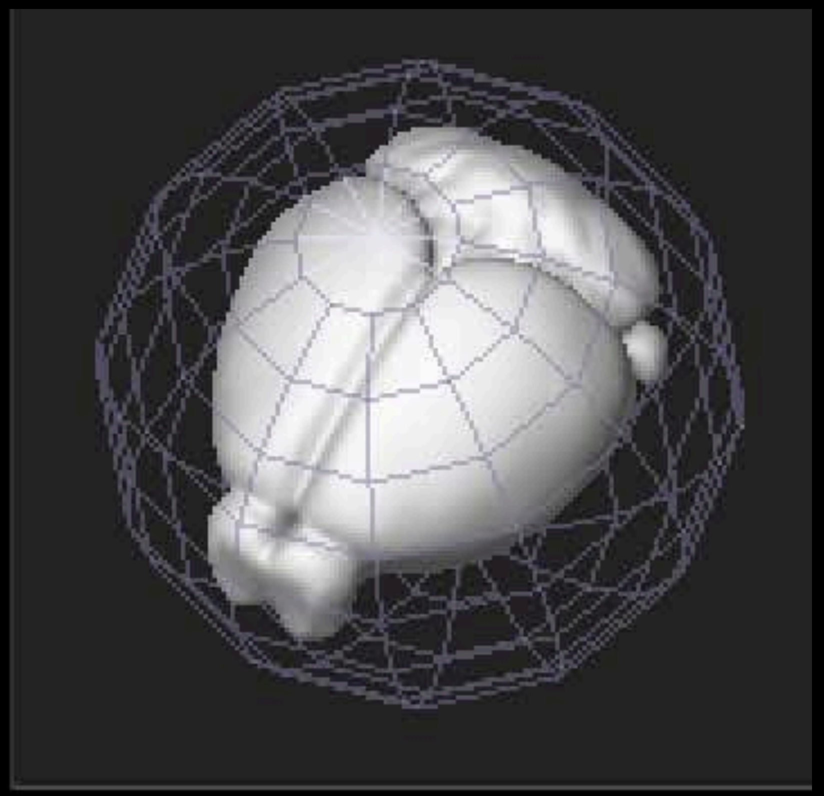


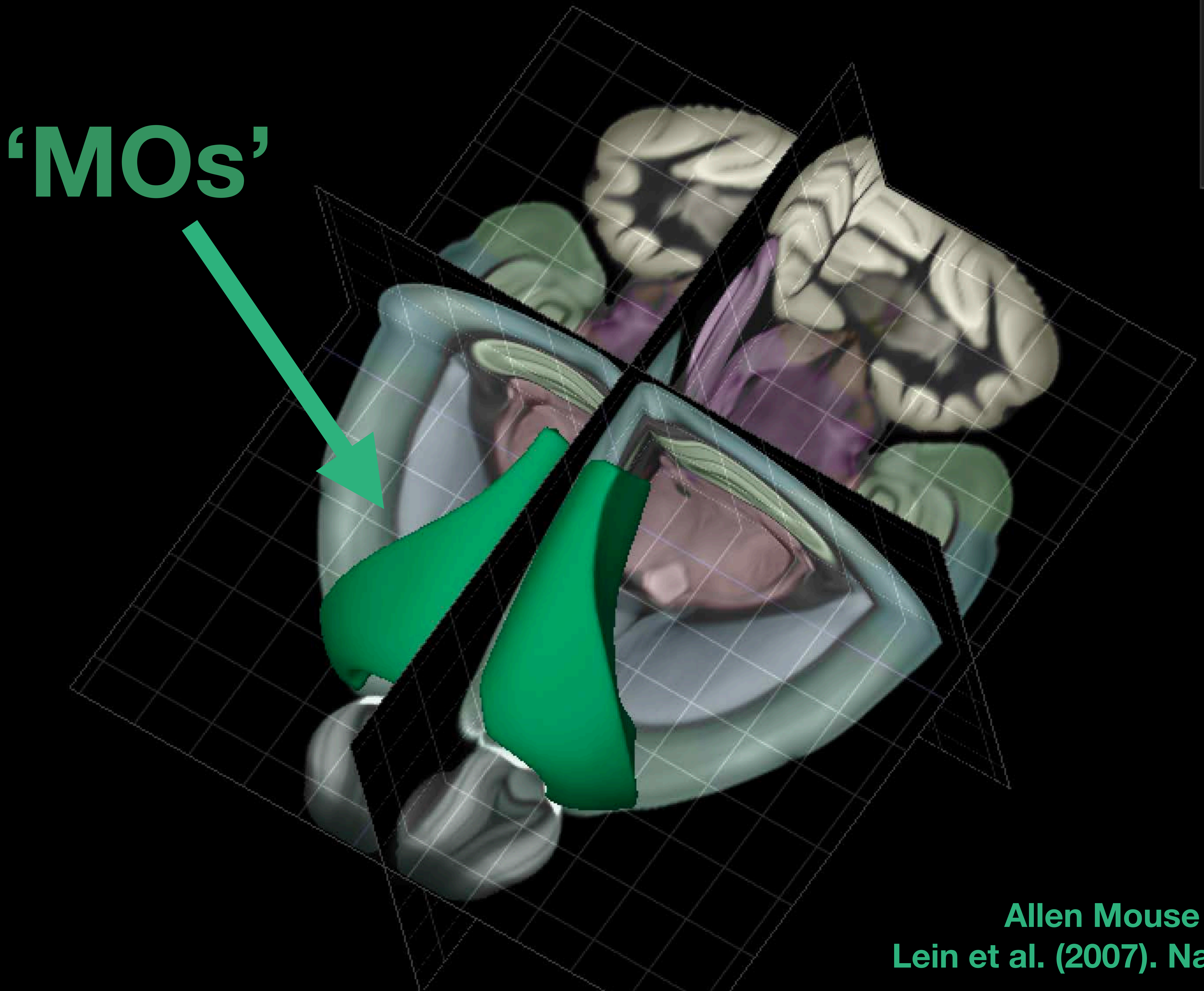
Hall & Lindholm, *Brain Res.* 1974



Ebbesen, Insanally, Kopec, Murakami, Saiki & Erlich, *J.Neurosci.* 2018

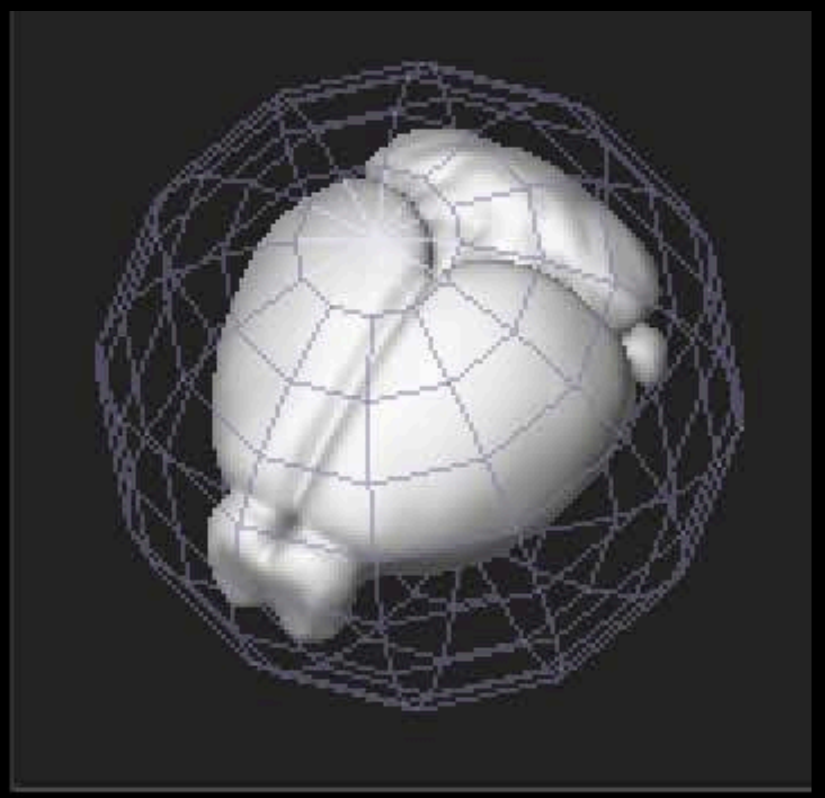
Secondary motor area



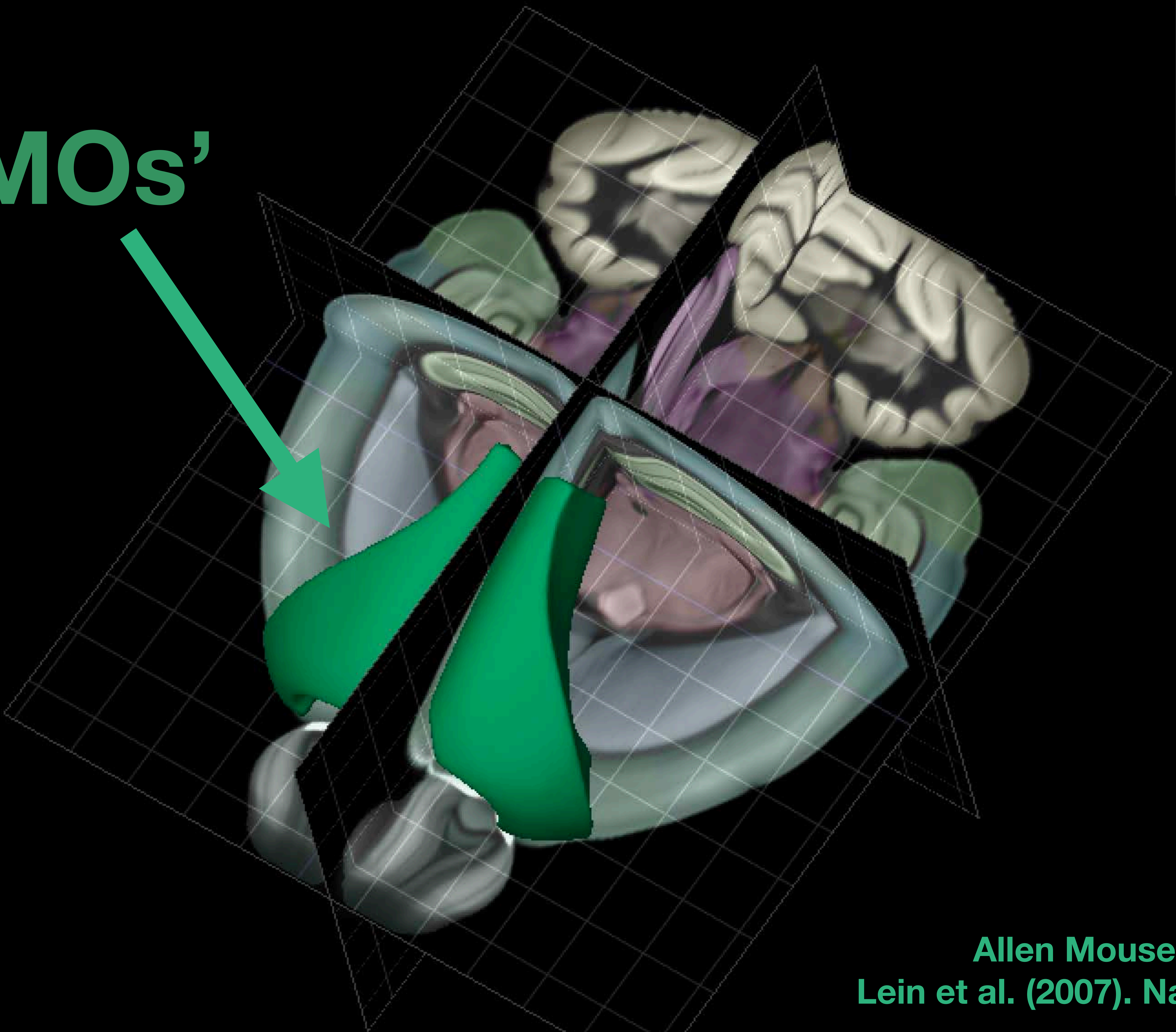


Allen Mouse Brain Atlas
Lein et al. (2007). Nature *445*, 168–176.

Secondary motor area



‘MOs’



Also know as:
‘AGm’,
‘vFMCx’,
‘fMR’, ‘MOs’,
‘vM1/wM1’

Allen Mouse Brain Atlas
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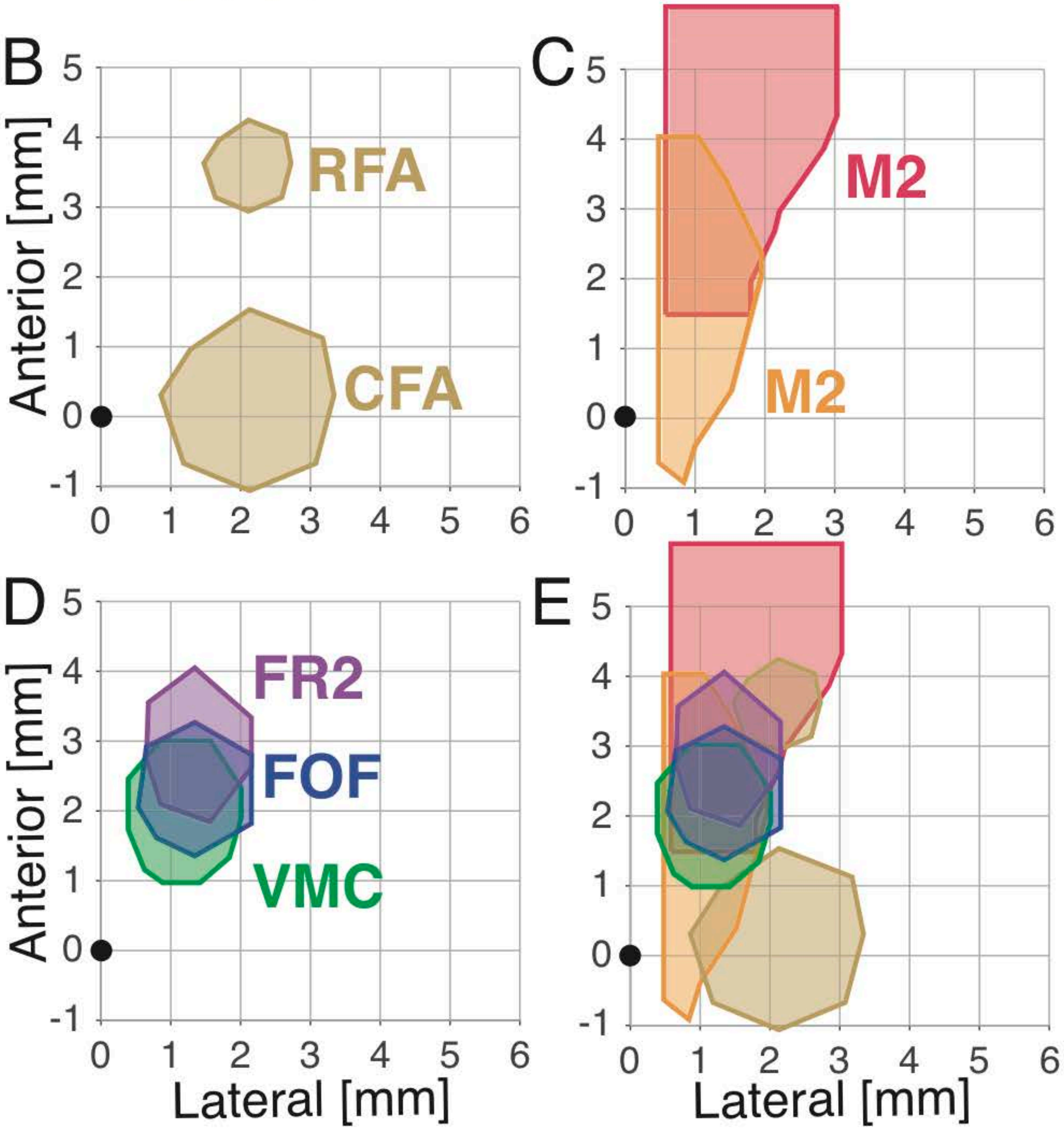

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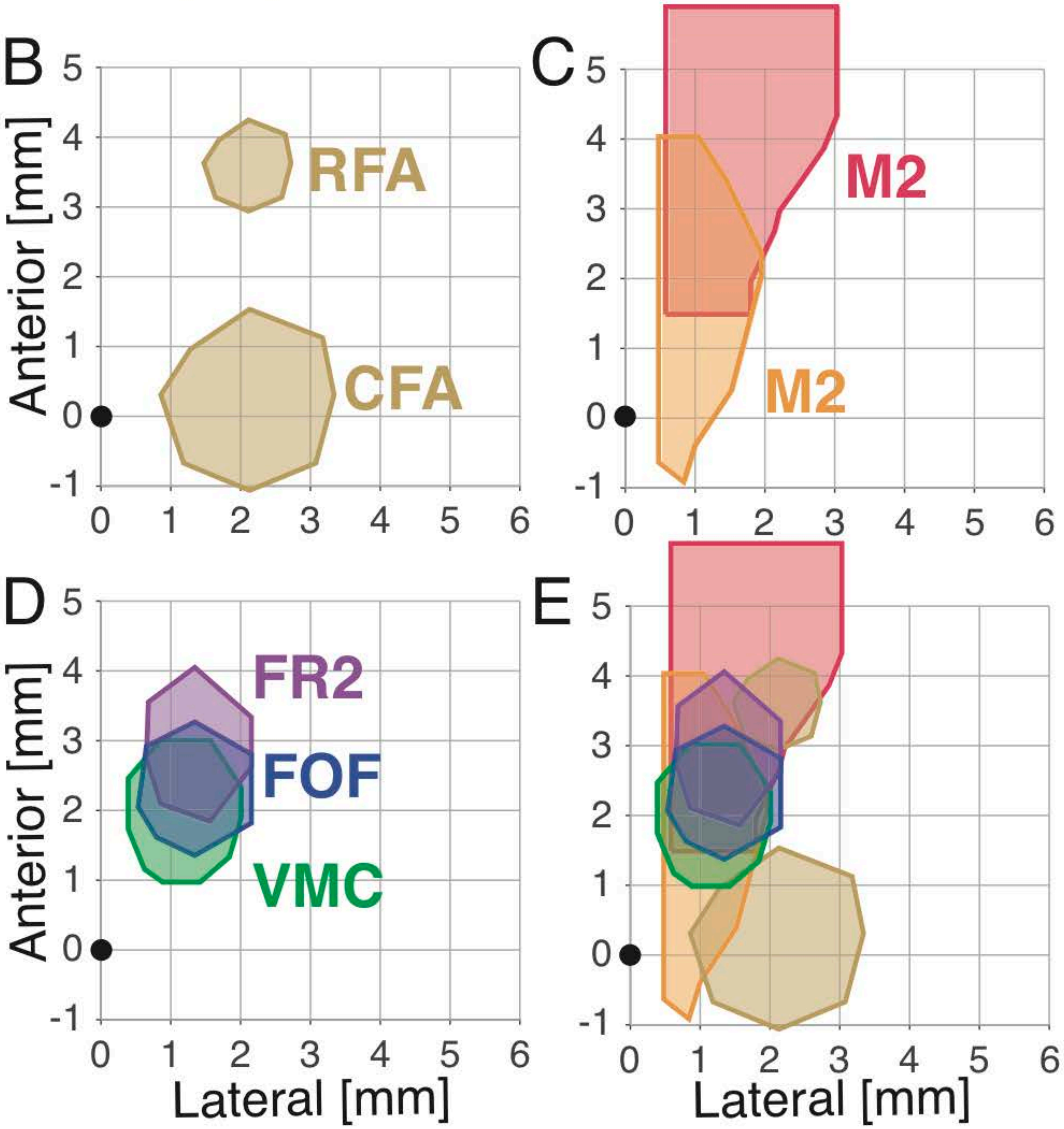

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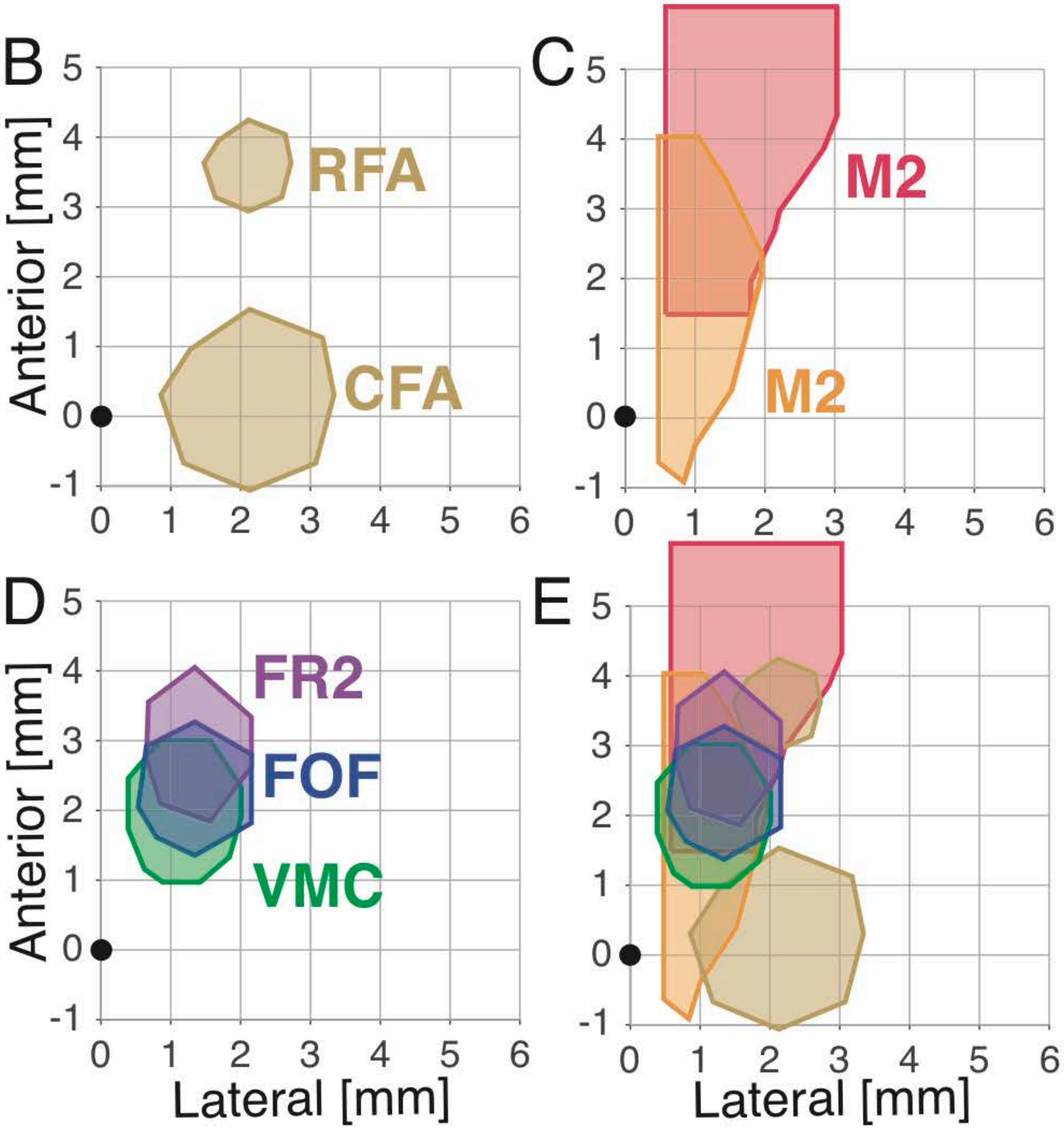

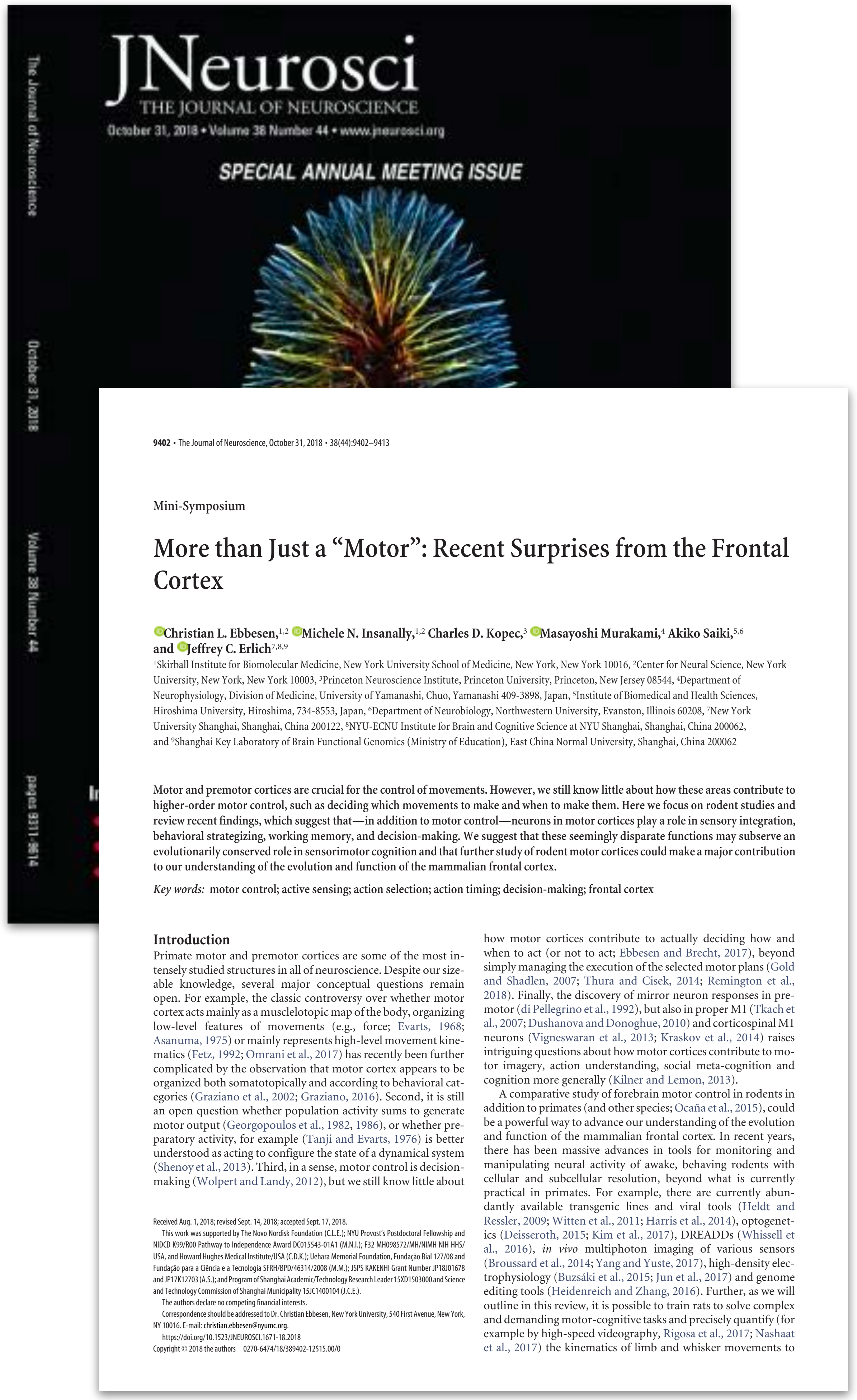

9402 • The Journal of Neuroscience, October 31, 2018 • 38(44):9402–9413

Mini-Symposium

More than Just a "Motor": Recent Surprises from the Frontal Cortex

Christian L. Ebbesen,[1,2] Michele N. Insanally,[1,2] Charles D. Kopec,[3] Masayoshi Murakami,[4] Akiko Saiki,[5,6] and Jeffrey C. Erlich[7,8,9]

[1]Skirball Institute for Biomolecular Medicine, New York University School of Medicine, New York, New York 10016, [2]Center for Neural Science, New York University, New York, New York 10003, [3]Princeton Neuroscience Institute, Princeton University, Princeton, New Jersey 08544, [4]Department of Neurophysiology, Division of Medicine, University of Yamanashi, Chuo, Yamanashi 409-3898, Japan, [5]Institute of Biomedical and Health Sciences, Hiroshima University, Hiroshima, 734-8553, Japan, [6]Department of Neurobiology, Northwestern University, Evanston, Illinois 60208, [7]New York University Shanghai, Shanghai, China 200122, [8]NYU-ECNU Institute for Brain and Cognitive Science at NYU Shanghai, Shanghai, China 200062, and [9]Shanghai Key Laboratory of Brain Functional Genomics (Ministry of Education), East China Normal University, Shanghai, China 200062

Motor and premotor cortices are crucial for the control of movements. However, we still know little about how these areas contribute to higher-order motor control, such as deciding which movements to make and when to make them. Here we focus on rodent studies and review recent findings, which suggest that—in addition to motor control—neurons in motor cortices play a role in sensory integration, behavioral strategizing, working memory, and decision-making. We suggest that these seemingly disparate functions may subserve an evolutionarily conserved role in sensorimotor cognition and that further study of rodent motor cortices could make a major contribution to our understanding of the evolution and function of the mammalian frontal cortex.

Key words: motor control; active sensing; action selection; action timing; decision-making; frontal cortex

Introduction

Primate motor and premotor cortices are some of the most intensely studied structures in all of neuroscience. Despite our sizeable knowledge, several major conceptual questions remain open. For example, the classic controversy over whether motor cortex acts mainly as a musclelotopic map of the body, organizing low-level features of movements (e.g., force; Evarts, 1968; Asanuma, 1975) or mainly represents high-level movement kinematics (Fetz, 1992; Omrani et al., 2017) has recently been further complicated by the observation that motor cortex appears to be organized both somatotopically and according to behavioral categories (Graziano et al., 2002; Graziano, 2016). Second, it is still an open question whether population activity sums to generate motor output (Georgopoulos et al., 1982, 1986), or whether preparatory activity, for example (Tanji and Evarts, 1976) is better understood as acting to configure the state of a dynamical system (Shenoy et al., 2013). Third, in a sense, motor control is decision-making (Wolpert and Landy, 2012), but we still know little about how motor cortices contribute to actually deciding how and when to act (or not to act; Ebbesen and Brecht, 2017), beyond simply managing the execution of the selected motor plans (Gold and Shadlen, 2007; Thura and Cisek, 2014; Remington et al., 2018). Finally, the discovery of mirror neuron responses in premotor (di Pellegrino et al., 1992), but also in proper M1 (Tkach et al., 2007; Dushanova and Donoghue, 2010) and corticospinal M1 neurons (Vigneswaran et al., 2013; Kraskov et al., 2014) raises intriguing questions about how motor cortices contribute to motor imagery, action understanding, social meta-cognition and cognition more generally (Kilner and Lemon, 2013).

A comparative study of forebrain motor control in rodents in addition to primates (and other species; Ocaña et al., 2015), could be a powerful way to advance our understanding of the evolution and function of the mammalian frontal cortex. In recent years, there has been massive advances in tools for monitoring and manipulating neural activity of awake, behaving rodents with cellular and subcellular resolution, beyond what is currently practical in primates. For example, there are currently abundantly available transgenic lines and viral tools (Heldt and Ressler, 2009; Witten et al., 2011; Harris et al., 2014), optogenetics (Deisseroth, 2015; Kim et al., 2017), DREADDs (Whissell et al., 2016), *in vivo* multiphoton imaging of various sensors (Broussard et al., 2014; Yang and Yuste, 2017), high-density electrophysiology (Buzsáki et al., 2015; Jun et al., 2017) and genome editing tools (Heidenreich and Zhang, 2016). Further, as we will outline in this review, it is possible to train rats to solve complex and demanding motor-cognitive tasks and precisely quantify (for example by high-speed videography, Rigosa et al., 2017; Nashaat et al., 2017) the kinematics of limb and whisker movements to

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The authors declare no competing financial interests.

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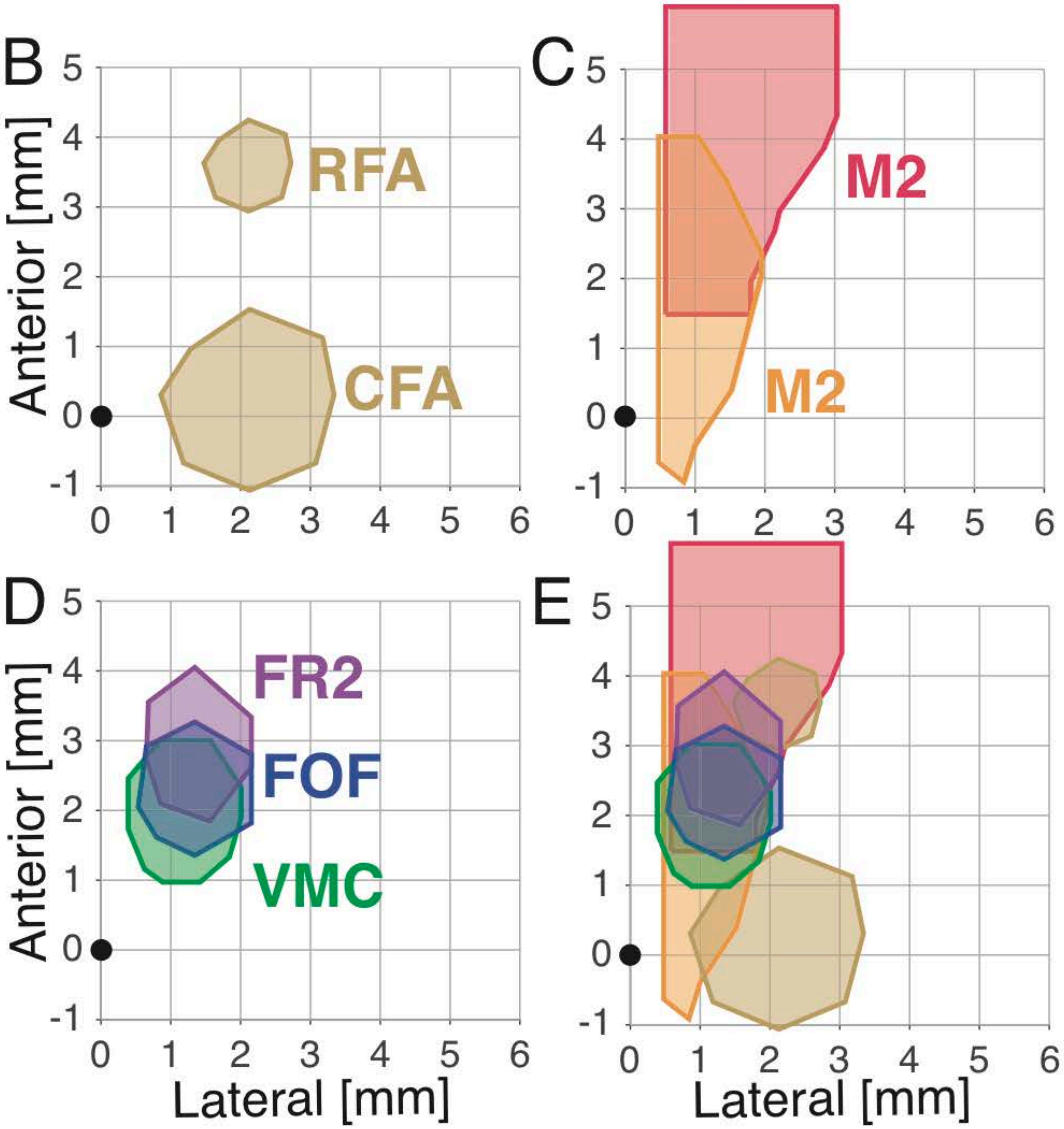

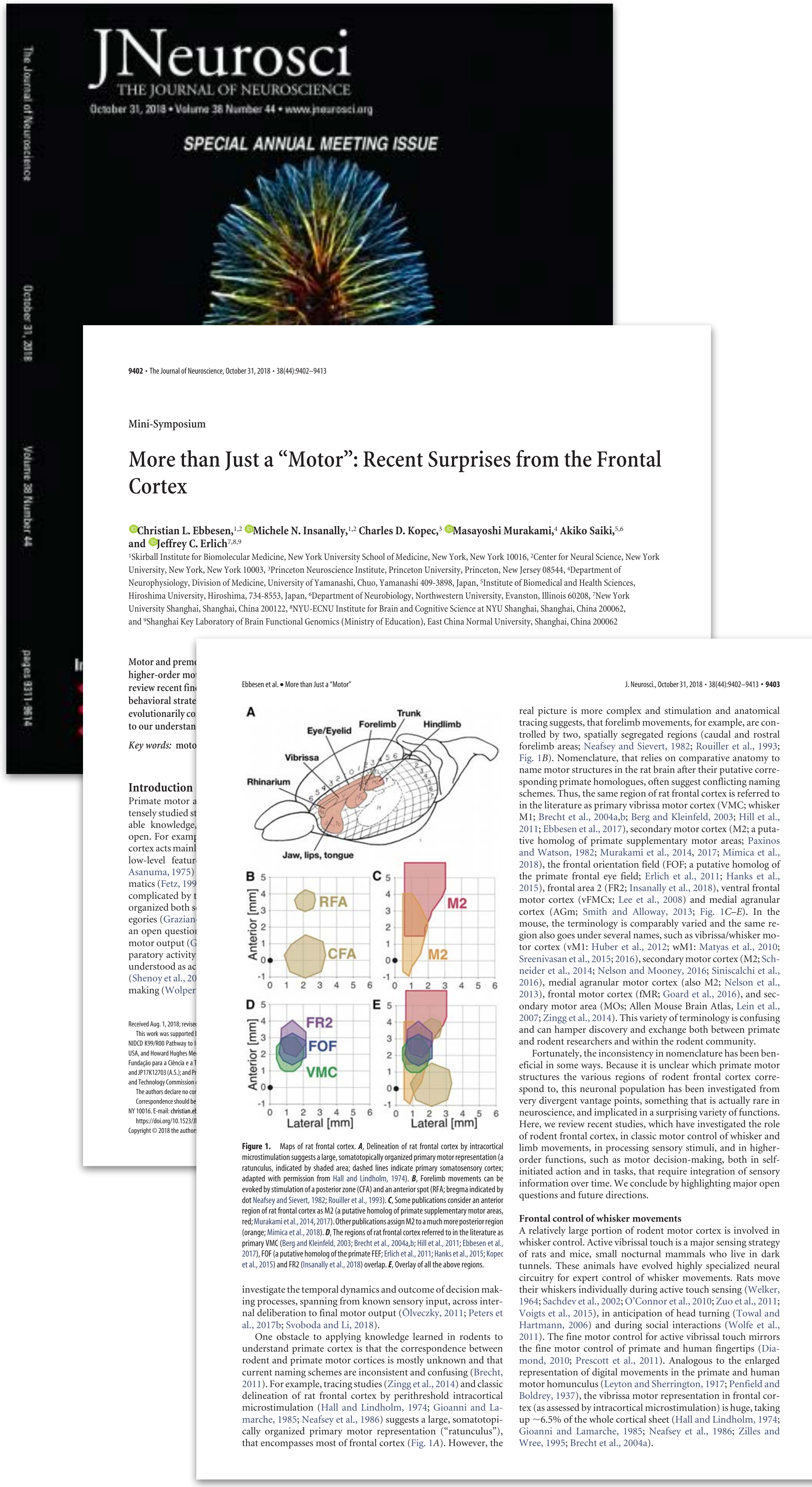

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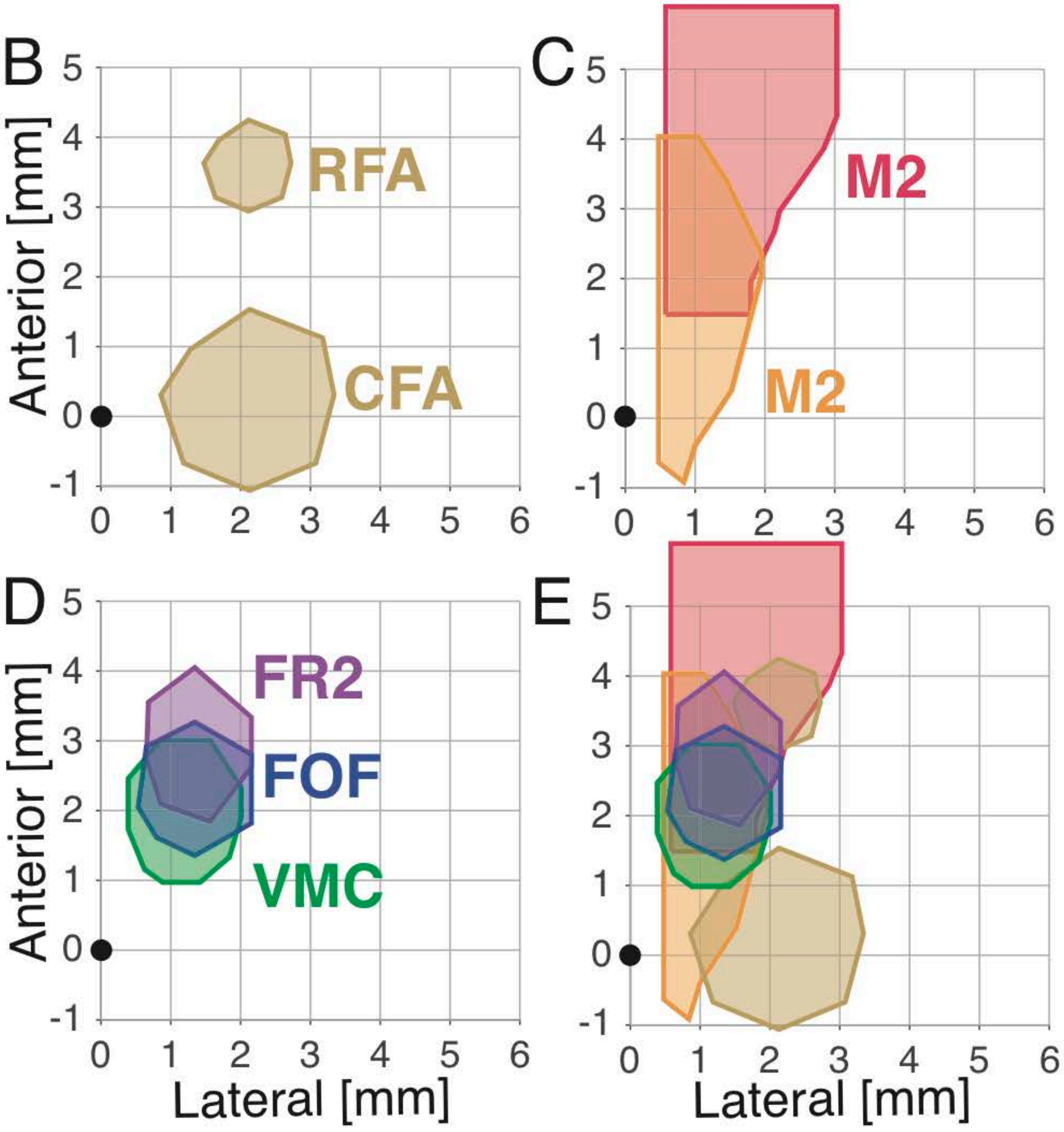

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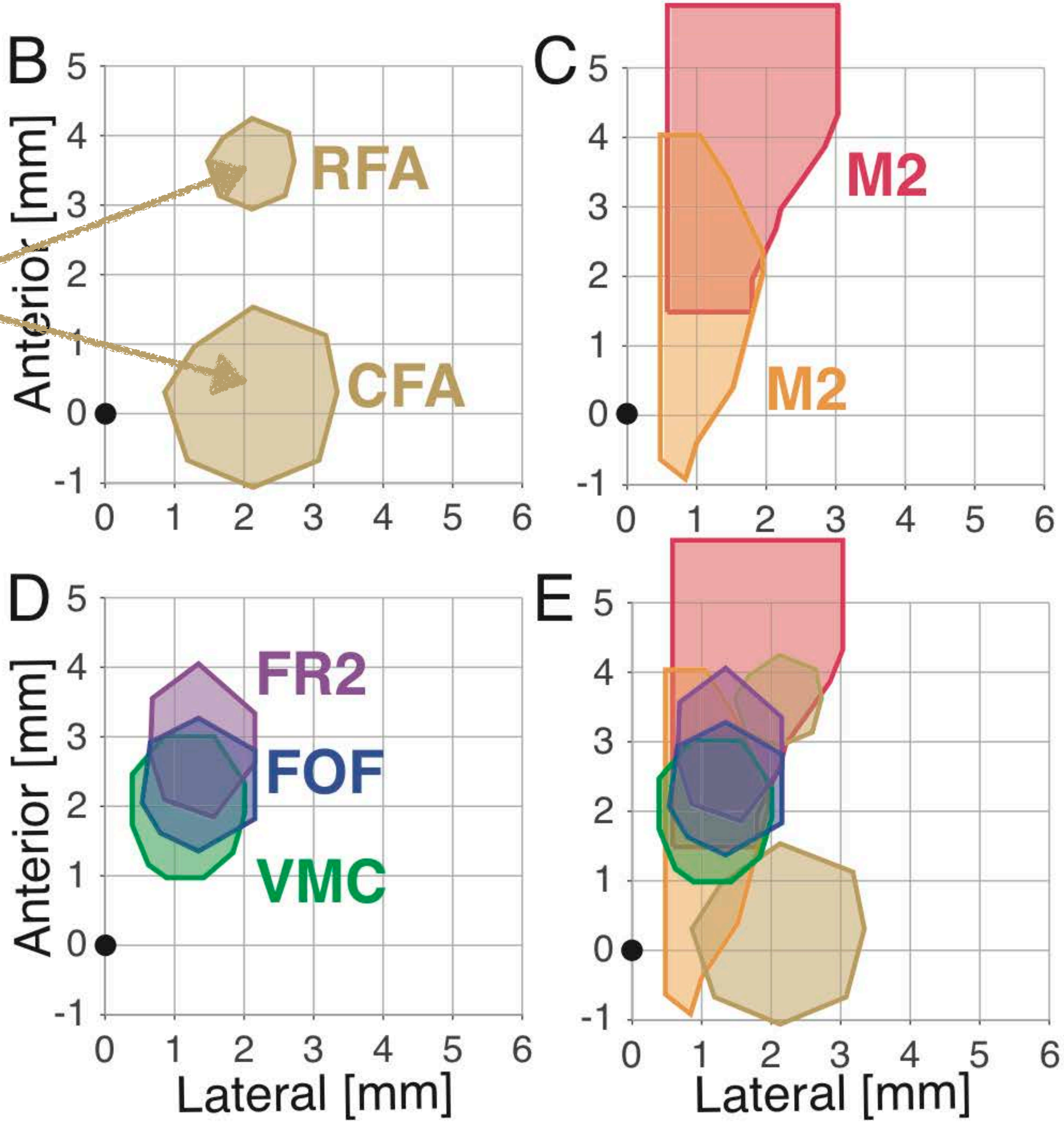
Akiko Saiki
Isomura Lab
Tamawaga



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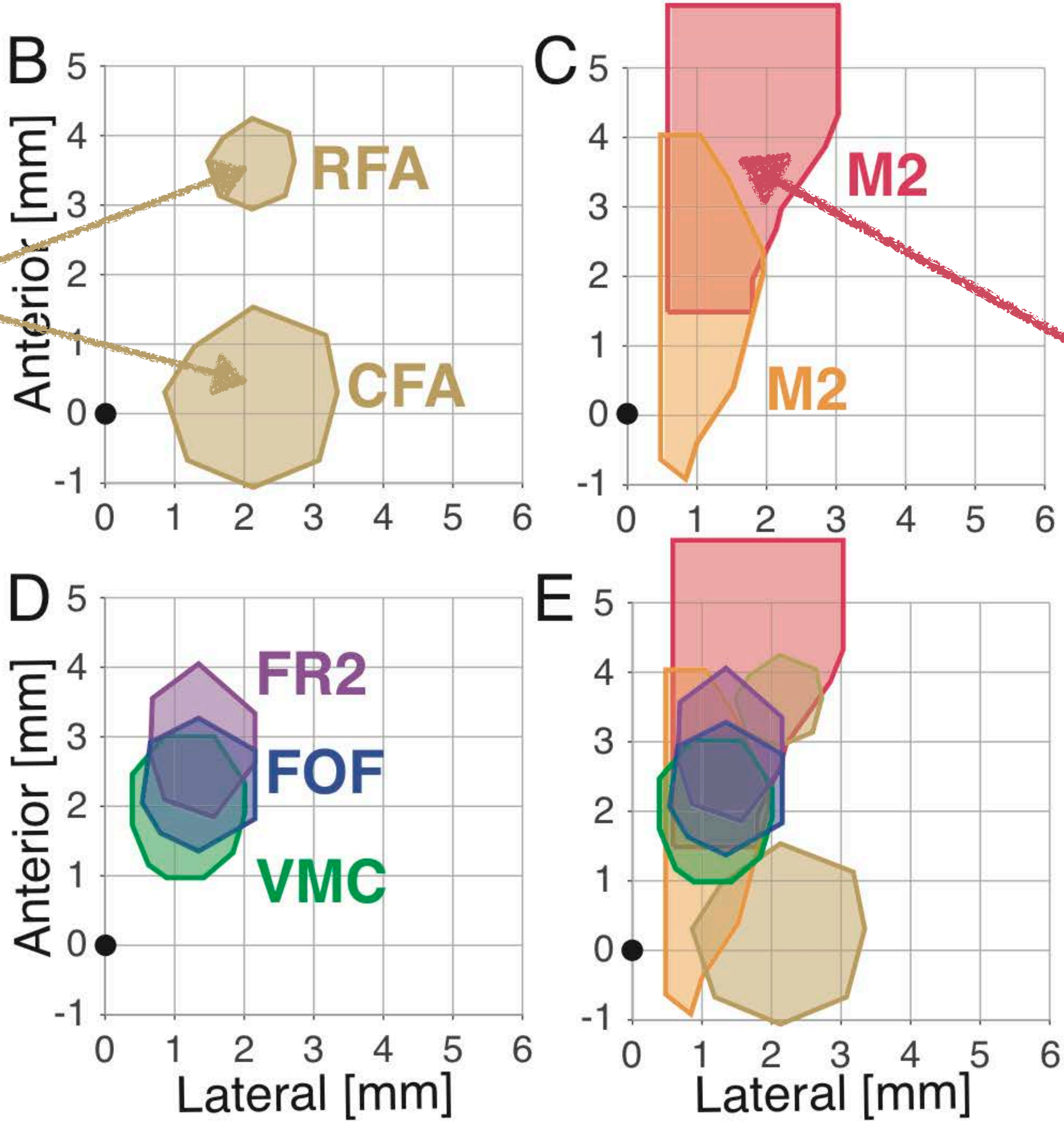

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Mainen Lab
Champalimaud

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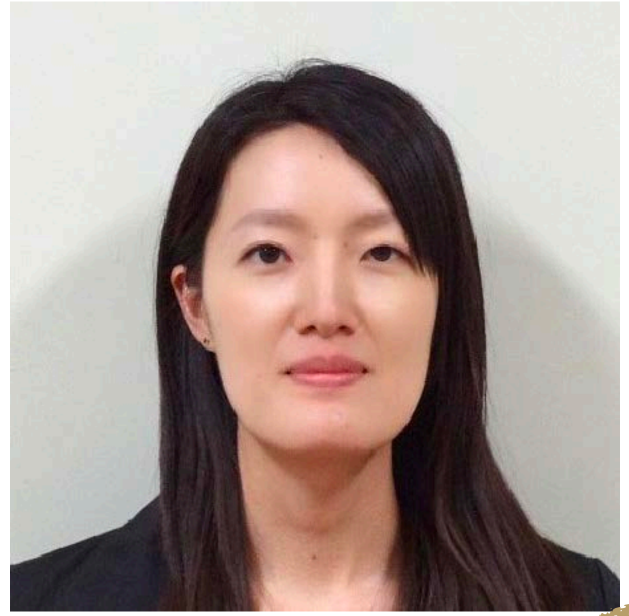

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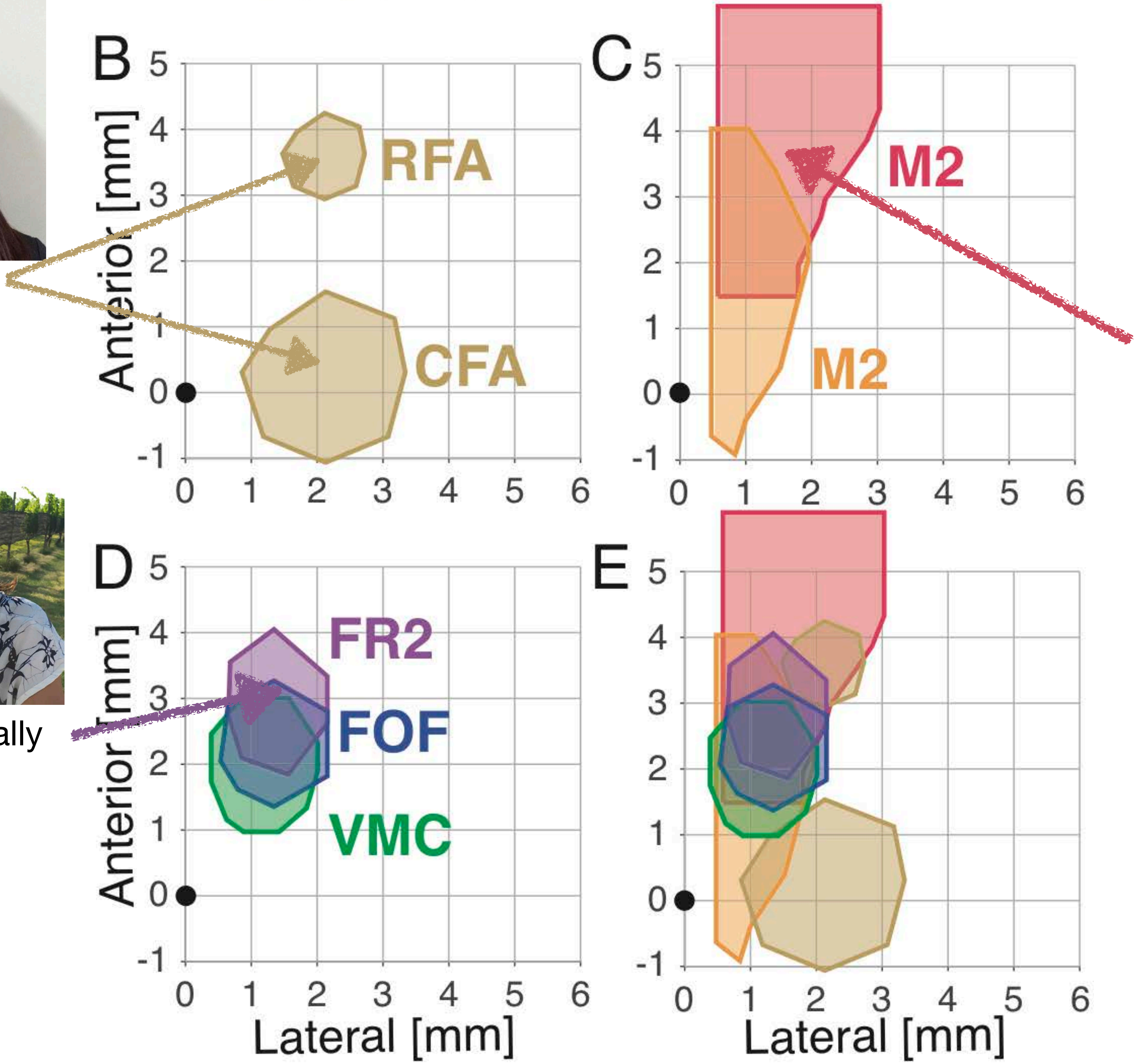
Tamawaga

Michele Insanally
Froemke Lab
NYU



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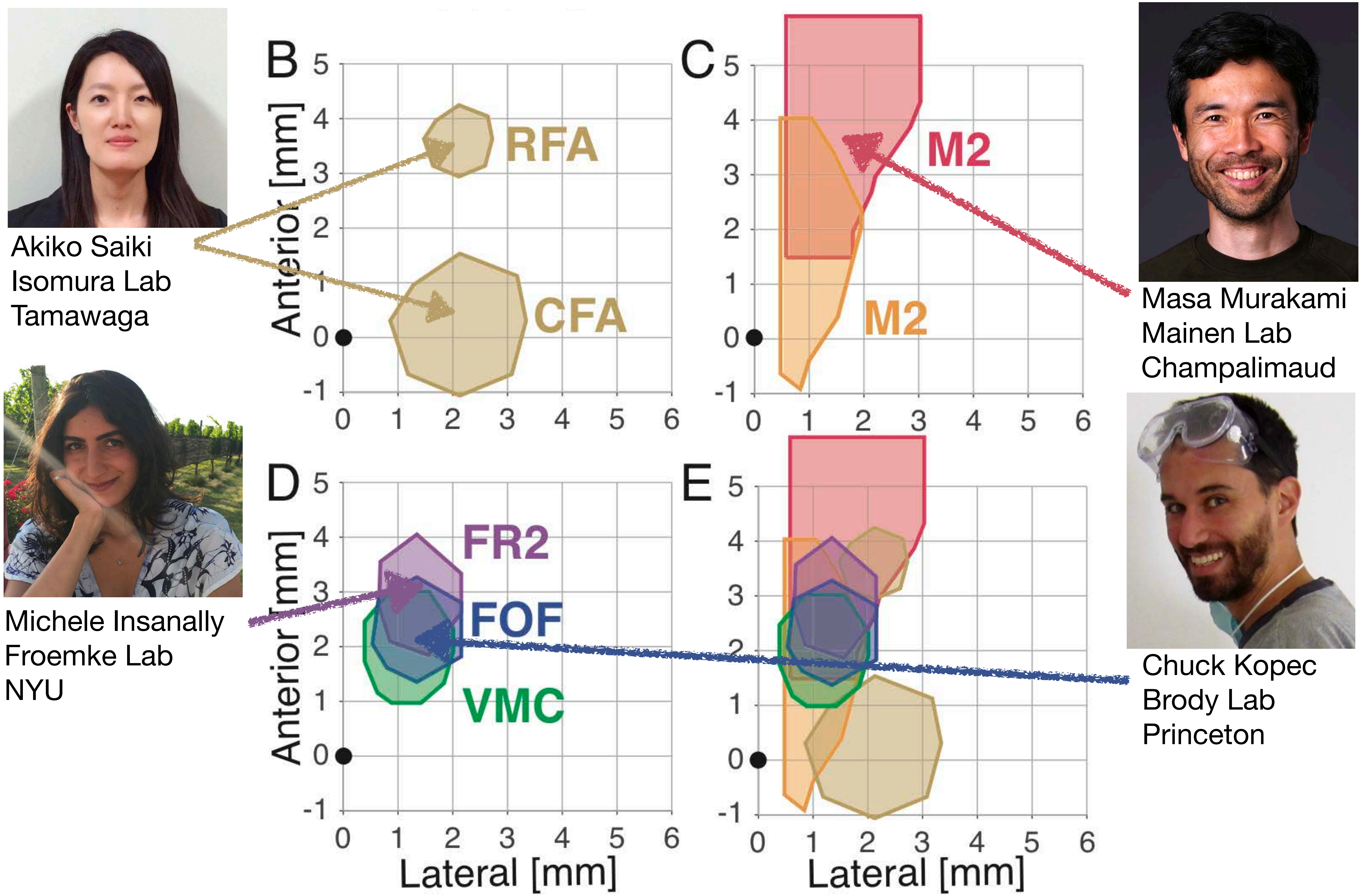

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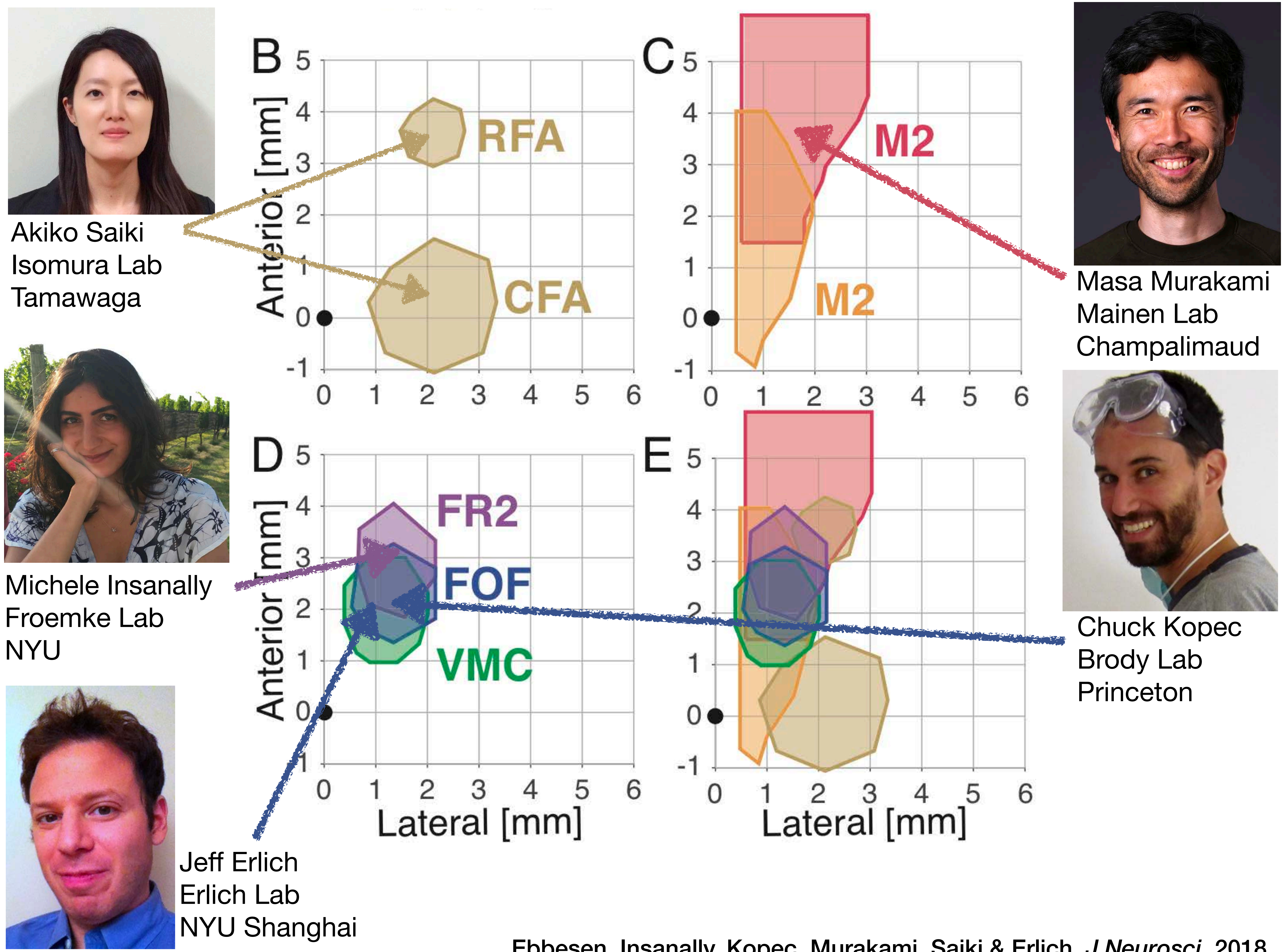

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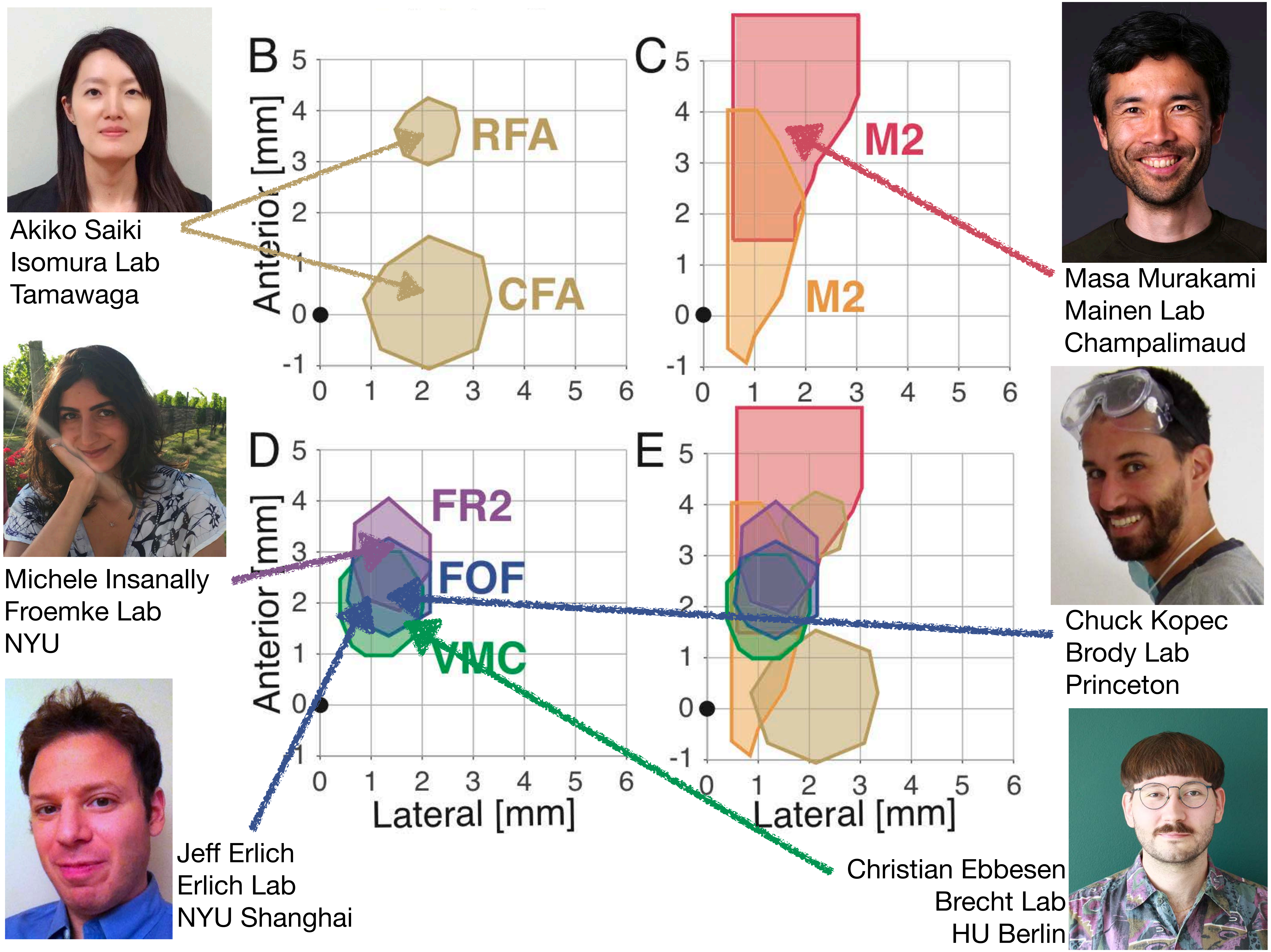

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E
Lateral [mm]
Akiko Saiki
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NYU
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2:15 PM - 2:35 PM **180.04 - Neural substrates of action timing decisions**
M. Murakami; Champalimaud Research, University of Yamanashi, Chuo-shi, JAPAN.

2:35 PM - 2:55 PM **180.05 - Nominally non-responsive frontal cortical cells encode behavioral variables via ensemble consensus-building**
M. Insanally; New York University, NY, NY.

2:55 PM - 3:15 PM **180.06 - In vivo spiking dynamics and encoding of forelimb movements in rat M1/M2**
A. Saiki; Neurobiology, Northwestern University, Evanston, IL.

3:15 PM - 3:35 PM **180.07 - Spatio-temporal receptive fields in the rodent frontal orienting field**
J. C. Erlich; Institute of Brain and Cognitive Science, NYU Shanghai, Shanghai, CHINA.

3:35 PM - 4:00 PM **180.08 - Closing Remarks**

Rolls-Royce *Merlin* V-12 Aircraft Engine, 1933