

BIOGRAPHICAL SKETCH

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NAME: **Elena Borra**

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POSITION TITLE: **Associate Professor of Physiology**

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE (if applicable)	Completion Date MM/YYYY	FIELD OF STUDY
University of Parma (Italy)	MSc	03/2003	Pharmaceutical Chemistry and Technologies
University of Parma (Italy)	PhD	03/2008	Neuroscience
RIKEN Brain Science Institute (Japan)	One-year Internship	04/2008	Cortical organization and systematics
RIKEN Brain Science Institute (Japan)	Visiting researcher	04/2009	Cortical organization and systematics
University of Parma (Italy)	Postdoctoral	12/2012	Systems Neuroscience
Italian Institute of Technologies (Genova)	Postdoctoral	12/2013	Systems Neuroscience
University of Parma (Italy)	Researcher	12/2016	Neuroscience and Physiology

A. Personal Statement

I am an Associate Professor of Physiology, and my research is focused on the anatomo-functional definition of the cortical circuits involved in motor control and in cognitive motor functions. I have a background in pharmaceutical chemistry and in neuroanatomy and neurophysiology, with specific training and expertise in the neuroanatomy of the non-human primates. I worked on areal definition based on architectonical and connectional features of the inferior parietal, ventral premotor, and lateral prefrontal cortex in the macaque. During my internship at RIKEN Brain Science Institute and following collaboration with Kathleen Rockland, I worked on the issues of single axon reconstruction, cortical columnar organization, and on white matter neurons. With Giuseppe Luppino and Giacomo Rizzolatti I collaborated with Wim Vanduffel (KU Leuven, Belgium) for the definition of the action observation network in the macaque based on combination of neural tracers and fMRI data. More recently I got interested in the definition of large-scale (cortical and subcortical) networks in macaques, with classical anatomical and MRI-based techniques, and of their human counterparts, based on comparative considerations. Now I am working on the anatomo-functional definition of the cortico-basal ganglia connectivity underlying motor and cognitive motor functions in the non-human primate.

Ongoing and recently completed projects that I would like to highlight include:

11/2023-03/2026: MNESYS

PI of the project "MNESYS" #NEXTGENERATIONEU (NGEU) and funded by the Ministry of University and Research (MUR), National Recovery and Resilience Plan (NRRP), project MNESYS (PE0000006) – A Multiscale integrated approach to the study of the nervous system in health and disease (DN. 1553 11.10.2022.)

08/2019-08/2023: PRIN-MIUR 2017

2017KZNZLN_002 Performing Actions in a Changing Environment (PACE).

PI of the Parma Unit: Elena Borra, Coordinator of the project: Patrizia Fattori, University of Bologna.

07/2018-07/2021: Grant from the Canis Majoris Foundation (Madrid) for a collaboration project including the Multiarchitectonical study of the ventral premotor cortex in the human brain. PIs: Elena Borra, Giacomo Rizzolatti, Raul Aleu.

02/2013-02/2016: PRIN-MIUR 2010/2011

2010MEFNF7_005. Organizing and monitoring actions: from vision to motor control.

PI of the Parma Unit: Leonardo Fogassi, Coordinator of the project Claudio Galletti (University of Bologna)

Role: Co-investigator.

1) **Borra E**, Ichinohe N, Sato T, Tanifuji M, Rockland KS. 2010. Cortical connections to area TE in monkey: hybrid modular and distributed organization. *Cereb. Cortex* 20:257-270.

2) **Borra E**, Gerbella M, Rozzi S, Luppino G. 2015. Motor Cortex. in *Brain Mapping: An Encyclopedic Reference*, 2015, 2, pp.277–282.

3) **Borra E**, Luppino G. 2021. Comparative anatomy of the macaque and the human frontal oculomotor domain. *Neuroscience and Biobehavioral Reviews*, 126, 43–56

4) **Borra E**, Ballestrazzi G, Biancheri D, Caminiti R, Luppino G. 2024. Involvement of the claustrum in the cortico-basal ganglia circuitry: connectional study in the non-human primate. *Brain Struct Funct*. Jun;229(5):1143-1164. doi: 10.1007/s00429-024-02784-6.

5) Simone L, Caruana F, **Borra E**, Del Sorbo S, Jezzini A, Rozzi S, Luppino G, Gerbella M. Anatomic-functional organization of insular networks: From sensory integration to behavioral control. *Prog Neurobiol*. 2025 247:102748. doi: 10.1016/j.pneurobio.2025.102748.

B. Positions, Scientific Appointments, and Honors

2021– Associate Professor of Physiology, Department of Medicine and Surgery, University of Parma

2021 – Reviewing Editor, *Brain Structure and Function* (BSAF); Associate Editor, *Frontiers in Systems Neuroscience*

2017 – Member of the board of the PhD school of Neuroscience (University of Modena-Reggio Emilia and University of Parma)

2016 Co-organizer Workshop: “Different elements of primate neural networks in the connectome era” Erice, Sicily, June 26-30, 2017 (sponsor: University of Parma)

2014 – 2016 Researcher (tenure track) Department of Neuroscience, University of Parma

2014 – 2016 Lecturer of Physiology in courses of the School of Medicine

2013 Post-doctoral fellow at the Italian Institute of Technology (IIT, Genova), Brain Center for Motor and Social Cognition

2008 – 2012 Post-doctoral fellow, Department of Neuroscience, University of Parma

2008 – 2009 Visitor Scientist at RIKEN BSI

2007 – 2008 Intern at RIKEN Brain Science Institute (Japan)

Invited talks and conference talks (2019-2025)

2025, May: TractAnat Club seminar, Online https://tractography.io/tractanat_club/

2024, November: invited speaker at the International Society of Intraoperative Neurophysiology (ISIN) Congress, Barcellona, Spain.

2024, September: invited speaker at the ICPBR Summer School, Shanghai, Cina

2024, March: invited member of the Tract-Anat retreat for the constitution of the International Society of Tractography. Ajaccio, Corsica (FR).

2021, invited seminar for CNS Seminars, Anatomic-functional Organisation of the Grasping Network in the Primate Brain, online and on youtube <https://www.clinicalneuroanatomyseminars.com/>

2019, January: “Large scale cortical networks for controlling motor and cognitive functions” Departamento De Anatomía, Histología Y Neurociencia, Facultad de Medicina, Universidad Autónoma de Madrid.

2019, October: “Large scale cortical networks for motor and cognitive motor functions in primates”, 29/10/2019 (Tokyo Metropolitan Institute of Medical Science) and 30/10/2019 (Kyoto University)

2019: "Comparative considerations on the anatomo-functional organization of the premotor and caudal prefrontal cortex in macaques and humans". Workshop: Brain and behavioral evolution in primates. September 25-29, 2019 Erice, Sicily, Italy.

C. Contributions to Science

1. Architectonic and Connectional organization of the inferior parietal cortex

In my doctoral thesis I addressed the issue of the organization of the inferior parietal lobule (IPL) based on cortico-cortical connectivity in combination with electrophysiological and architectonic data. The results highlighted a rostro-caudal organization of the IPL, hosting areas differentially involved in controlling mouth-, hand-, and eye-related motor behavior and in cognitive motor functions. With Kathleen Rockland, we also described direct connections of the IPL to V1 and V2 potentially contributing to attention and active vision. Our studies contributed to the definition of a macaque IPL cortical map, which now represents a framework of reference for defining IPL areas in the human brain.

- a) **Borra E**, Rockland KS. 2011. Projections to early visual areas V1 and V2 in the calcarine fissure from parietal association areas in the macaque. *Front. Neuroanat.* 5:35.
- b) **Borra E**, Belmalih A, Calzavara R, Gerbella M, Murata A, Rozzi S, Luppino G. 2008. Cortical connections of the macaque anterior intraparietal (AIP) area. *Cereb. Cortex* 18:1094-1111.
- c) Gregoriou GG, **Borra E**, Matelli M, Luppino G. 2006. Architectonic organization of the inferior parietal convexity of the macaque monkey. *J. Comp. Neurol.* 496:422-451.
- d) Rozzi S, Calzavara R, Belmalih A, **Borra E**, Gregoriou GG, Matelli M, Luppino G. 2006. Cortical connections of the inferior parietal cortical convexity of the macaque monkey. *Cereb. Cortex* 16:1389-1417.

2. Architectonic and Connectional Organization of the ventral premotor cortex

During my PhD and postdoc, I contributed to the study of the architectonic and connectional features of the ventral premotor cortex, in particular of the cortical and subcortical connectivity of the various subdivisions of the macaque area F5 and of its neighboring areas. In this cortical sector, the hand- and mouth-related cortical sectors display characteristic cortical and subcortical connections, suggesting different roles in action control. Based on our studies, we proposed a map of the ventral premotor cortex, which is an important framework of reference for human functional and tractographic studies. More recently, in collaboration with the Canis Majoris Foundation (Madrid), I collected some preliminary data on the distribution of SMI-32 immunoreactive neurons in the human primary motor and ventral premotor cortex.

- a) Gerbella M, Belmalih A, **Borra E**, Rozzi S, Luppino G. 2011. Cortical connections of the anterior (F5a) subdivision of the macaque ventral premotor area F5. *Brain Struct. Funct.* 216:43-65.
- b) **Borra E**, Belmalih A, Gerbella M, Rozzi S, Luppino G. 2010. Projections of the hand field of the macaque ventral premotor area F5 to the brainstem and spinal cord. *J. Comp. Neurol.* 518: 2570-2591.
- c) Belmalih A, **Borra E**, Contini M, Gerbella M, Rozzi S, Luppino G. 2009. Multimodal architectonic subdivision of the rostral part (area F5) of the macaque ventral premotor cortex. *J. Comp. Neurol.* 512:183-217.
- d) Belmalih A, **Borra E**, Contini M, Gerbella M, Rozzi S, Luppino G. 2007. A multiarchitectonic approach for the definition of functionally distinct areas and domains in the monkey frontal lobe. *Journal of Anatomy* 211:199-211.

3. Architectonic and Connectional organization of the ventrolateral prefrontal cortex

First guided by indirect data on the connectivity of parietal and premotor areas, and then based on injections of neural tracers in architectonically defined lateral prefrontal areas, we explored the connectional organization of this cortical sector. Specifically, we identified an intermediate sector of the lateral prefrontal cortex involved in the cortical network for controlling hand actions, adjacent to a more caudal mosaic of oculomotor areas and a more rostral cortical sector likely involved in higher-order control of behavior. The connectivity of these prefrontal areas/sectors compared to that of the parietal and frontal areas, suggested the existence of large-scale cortical networks of highly interconnected territories, jointly involved in specific motor and cognitive motor functions.

- a) **Borra E**, Ferroni CG, Gerbella M, Giorgetti V, Mangiaracina C, Rozzi S, Luppino G. 2019. Rostro-caudal Connectional Heterogeneity of the Dorsal Part of the Macaque Prefrontal Area 46. *Cereb Cortex*. 29:485-504. doi: 10.1093/cercor/bhx332
- b) Gerbella M, **Borra E**, Rozzi S, Tonelli S, Luppino G. 2013. Connectional heterogeneity of the ventral part of the macaque area 46. *Cereb. Cortex* 23:967-87.
- c) **Borra E**, Gerbella M, Rozzi S, Luppino G. 2011. Anatomical evidence for the involvement of the macaque ventrolateral prefrontal area 12r in controlling goal-directed actions. *J. Neurosci*. 31:12351-63.
- d) Gerbella M, Belmalih A, **Borra E**, Rozzi S, Luppino G. 2010. Cortical connections of the macaque caudal ventrolateral prefrontal areas 45A and 45B. *Cereb. Cortex* 20:141-168.

4. Networks organization

The connectivity of temporal, parietal, frontal and prefrontal cortical sectors functionally involved in hand actions, suggests the existence of a large-scale cortical network, which represents a neural substrate for interfacing perceptual, cognitive, and hand-related sensorimotor processes for controlling hand actions based on object identity, goals, and memory-based or contextual information and for the contribution of motor signals to cognitive motor functions. This same network processes also information about hand action observation (mirror system). Similarly, architectonic, connectional, and functional data have provided evidence for a functionally specialized large-scale cortical network involving temporal, parietal, and frontal areas for exploratory oculomotor behavior and gaze recognition. Based on the comparison of macaque connectional and functional data with data from human studies, it is possible to argue that there is clear evidence also for human counterparts of these large-scale networks.

- a) Howells H, Simone L, **Borra E**, Fornia L, Cerri G, Luppino G. 2020. Reproducing macaque lateral grasping and oculomotor networks using resting state functional connectivity and diffusion tractography. *Brain Struct Funct*. 2020 Nov;225(8):2533-2551. doi: 10.1007/s00429-020-02142-2.
- b) Caminiti R, **Borra E**, Visco-Comandini F, Battaglia-Mayer A, Averbeck BB, Luppino G. 2017. Computational Architecture of the Parieto-Frontal Network Underlying Cognitive-Motor Control in Monkeys. *eNeuro*. eCollection 2017 Jan-Feb. doi: 10.1523/ENEURO.0306-16.2017.
- c) **Borra E**, Gerbella M, Rozzi S, Luppino G. 2017. The macaque lateral grasping network: A neural substrate for generating purposeful hand actions. *Neurosci Biobehav Rev*. 75:65-90.
- d) Nelissen K, **Borra E**, Gerbella M, Rozzi S, Luppino G, Vanduffel W, Rizzolatti G, Orban GA. 2011. Action observation circuits in the macaque monkey cortex. *J. Neurosci*. 31:3743-56.

5. Cortico-subcortical interactions

The results on large-scale networks organization, drove my interest towards the possible involvement of subcortical structures. The parietal, frontal and prefrontal hand-related areas send convergent projections to the deep layers of the superior colliculus and to specific sectors of the striatum, suggesting a specific information processing also in these structures. Furthermore, injections of neural tracers in the striatum showed also some previously, almost neglected, features of the corticostriatal connectivity, suggesting more complex modes of information processing in the basal ganglia for different motor and nonmotor functions and opening new questions on the general architecture of the corticostriatal circuitry.

- a) **Borra E**, Rizzo M, Gerbella M, Rozzi S, Luppino G. 2021. Laminar Origin of Corticostriatal Projections to the Motor Putamen in the Macaque Brain. *J Neurosci*. 2021 Feb 17;41(7):1455-1469. doi: 10.1523/JNEUROSCI.1475-20.2020
- b) **Borra E**, Biancheri D, Rizzo M, Leonardi F, Luppino G. 2022. Crossed Corticostriatal Projections in the Macaque Brain. *J Neurosci*. 42(37):7060-7076. doi: 10.1523/JNEUROSCI.0071-22.2022.
- c) Gerbella M, Borra E, Mangiaracina C, Rozzi S, Luppino G. 2016. Corticostriate Projections from Areas of the "Lateral Grasping Network": Evidence for Multiple Hand-Related Input Channels. *Cereb. Cortex* 26:3096-3115
- d) **Borra E**, Gerbella M, Rozzi S, Tonelli S, Luppino G. 2014. Projections to the superior colliculus from inferior parietal, ventral premotor, and ventrolateral prefrontal areas involved in controlling goal-directed hand actions in the macaque. *Cereb. Cortex* 24:1054-65.

Complete List of Published Work in My Bibliography

<https://www.ncbi.nlm.nih.gov/myncbi/elena.borra.2/bibliography/public/>