

## **Sara Matias, Ph.D.**

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### **RESEARCH & TEACHING INTERESTS**

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I am a biomedical engineer with 15 years of experience in neuroscience research. I am interested in deciphering the role of the neuromodulators dopamine and serotonin in learning and cognitive flexibility. I use neurophysiology (two-photon imaging, large-scale electrophysiological recordings, optogenetics, chemogenetics, circuit mapping) and the machine learning framework of distributional reinforcement learning to elucidate the computational and neural circuit mechanisms through which neuromodulators enable learning and behavioral adaptability, which impact neuropsychiatric conditions, such as ADHD, addiction, depression, and anxiety. These brain mechanisms serve as inspiration for the development of advanced machine learning algorithms, particularly in reinforcement learning.

My research bridges the gap between biological and artificial intelligence and is integrated in the emerging field of NeuroAI.

### **RESEARCH EXPERIENCE**

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**2017 – present**    **Postdoctoral Research Associate in Neuroscience**, Department of Molecular and Cellular Biology, Center for Brain Science, Harvard University, Cambridge, MA, USA  
Faculty Advisor: Naohige Uchida, Professor  
Project: Distributional Reinforcement Learning in the Dopamine System

**2016 - 2017**        **Postdoctoral Fellow in Neuroscience**, Champalimaud Neuroscience Programme, Champalimaud Foundation, Lisbon, Portugal  
Faculty Advisor: Zachary F. Mainen, Principal Investigator, Director  
Project: The effect of serotonin neurons' inhibition on Reversal Learning

### **EDUCATION**

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**2015**                **Ph.D. in Bioengineering**, MIT-Portugal Program (Universidade de Lisboa, Universidade Nova de Lisboa, Universidade de Coimbra, Universidade do Minho), Portugal.  
Thesis: Dynamics of serotonergic neurons revealed by fiber photometry  
Faculty Advisor: Zachary F. Mainen

**2008**                **M.Sc. in Biomedical Engineering**, Instituto Superior Técnico (IST), Universidade Técnica de Lisboa, Lisbon, Portugal.

**2006**                **B.Sc. in Biomedical Engineering**, Instituto Superior Técnico (IST), Universidade Técnica de Lisboa, Lisbon, Portugal.

### **PUBLICATIONS**

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**In preparation**

**Matias S**, Campbell M, Xu S, Lowet A, Drugowitsch J, Uchida N (2025). Broadly-projecting mesolimbic dopamine neurons implement a distributional critic across the striatum.

#### Selected

1. Tolooshams B\*, **Matias S\***, Wu H, Temereanca S, Uchida N, Murthy VN, Masset P, Ba D (2025). Interpretable deep learning for deconvolutional analysis of neural signals. *Neuron*, 12:S0896-6273(25)00119-9. DOI: 10.1016/j.neuron.2025.02.006. PMID: 40081364
2. Lowet AS, Zheng Q, Meng M, **Matias S**, Drugowitsch J, Uchida N (2025). An opponent striatal circuit for distributional reinforcement learning. *Nature* 639, 717–726. DOI: 10.1038/s41586-024-08488-5
3. Lowet AS, Zheng Q, **Matias S**, Drugowitsch J, Uchida N (2020). Distributional Reinforcement Learning in the Brain. *Trends in Neurosciences*, 43 (12): 980-997. PMCID: PMC8073212.
4. **Matias S\***, Lottem E\*, Dugué GP, Mainen ZF (2017). Activity patterns of serotonin neurons underlying cognitive flexibility. *eLife*, 6:e20552. PMCID: PMC5360447. Data in the Dryad Repository with DOI: 10.5061/dryad.649nk.

#### Additional Published Research

5. Qian L\*, Burrell M\*, Hennig JA, **Matias S**, Murthy VN, Gershman SJ, Uchida N (2025). Prospective contingency explains behavior and dopamine signals during associative learning. *Nature Neuroscience*. DOI: 10.1038/s41593-025-01915.
6. Amo R, **Matias S**, Yamanaka A, Tanaka KF, Uchida N, Watabe-Uchida M (2022). A gradual temporal shift of dopamine responses mirrors the progression of temporal difference error in machine learning. *Nature Neuroscience*, 25 (8), 1082-1092. PMCID: PMC9624460.
7. Correia PA, **Matias S**, Mainen ZF (2017). Stereotaxic adeno-associated virus injection and cannula implantation in the dorsal raphe nucleus of mice. *Bio-protocol*, 7 (18), e2549-e2549. PMCID: PMC5633075.
8. Lopes G, Bonacchi N, Frazão J, Neto JP, Atallah BV, Soares S, Moreira L, **Matias S**, Itskov PM, Correia PA, Medina RE, Calcaterra L, Dreosti E, Paton JJ, Kampff AR (2015). Bonsai: an event-based framework for processing and controlling data streams. *Frontiers in neuroinformatics*, 9. PMCID: PMC4389726.
9. Tecuapetla F, **Matias S**, Dugué GP, Mainen ZF, Costa RM (2014). Balanced activity in basal ganglia projection pathways is critical for contraversive movements. *Nature Communications*, 5:4315. PMCID: PMC4102112.
10. Dugué GP, Lörincz ML, Lottem E, Audero E, **Matias S**, Correia PA, Léna C, Mainen ZF (2014). Optogenetic recruitment of dorsal raphe serotonergic neurons acutely decreases mechanosensory responsivity in behaving mice. *PloS One*, 9(8): e105941. PMCID: PMC4141837
11. Figueira JR, Almeida-Dias J, **Matias S**, Roy B, Carvalho MJ, Plancha CE (2011). Electre Tri-C, a multiple criteria decision aiding sorting model applied to assisted reproduction. *International Journal of Medical Informatics*, 80(4). PMID: 21295515.

Complete list of published work in MyBibliography:

<https://www.ncbi.nlm.nih.gov/myncbi/sara.pinto%20dos%20santos%20matias.1/bibliography/public/>

## PRESENTATIONS

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### Invited Talks

1. *Upcoming*: Tolooshams B\*, **Matias S\***, Wu H, Temereanca S, Uchida N, Murthy VN, Masset P, Ba D (2025). Interpretable deep learning for deconvolutional analysis of neural signals. Learning Club, Computational Machinery of Cognition, 2025, TU Dresden, Germany
2. **Matias S**, Dugué DP, Lottem E, Audero E, Vassilevskaia T, Mainen ZF (2013). Long-term monitoring of genetically defined neuronal populations in freely behaving rodents through an optical fiber. Donders Discussions 2013, Nijmegen, Netherlands.

#### Conference Talks

3. *Upcoming*: **Matias S**, Campbell M, Xu S, Lowet A, Drugowitsch J, Uchida N (2025). Broadly-projecting mesolimbic dopamine neurons implement a distributional critic across the striatum. The 48<sup>th</sup> Annual Meeting of the Japan Neuroscience Society, Niigata, Japan.
4. **Matias S**, Campbell M, Xu S, Lowet A, Drugowitsch J, Uchida N (2025). Broadly-projecting mesolimbic dopamine neurons implement a distributional critic across the striatum. Frontiers in NeuroAI Symposium, Kempner Institute - For the study of natural and artificial intelligence at Harvard University, Allston, Boston, MA, USA.
5. **Matias S**, Figueira JR, Carvalho MJ, Plancha CE (2009). A Multiple Criteria Decision Aiding Assignment Methodology for Assisted Reproductive Technology. The 23<sup>rd</sup> European Conference on Operational Research, Bonn, Germany.

#### Selected posters and abstracts

- 2025 - **Matias S**, Campbell M, Xu S, Lowet A, Drugowitsch J, Uchida N. Broadly-projecting mesolimbic dopamine neurons implement a distributional critic across the striatum. Computational and Systems Neuroscience (COSYNE) Conference, Montreal, Canada.
- 2025 - Campbell M, Ra Y, Xu S, **Matias S**, Watabe-Uchida M, Uchida N. Minimal neural circuit elements for dopaminergic temporal difference learning. Computational and Systems Neuroscience (COSYNE) Conference, Montreal, Canada.
- 2025 - Burrell M, Qian L, Hennig J, **Matias S**, Murthy V, Gershman S, Uchida N. Temporal difference learning models explain behavior and dopamine during contingency degradation. Computational and Systems Neuroscience (COSYNE) Conference, Montreal, Canada.
- 2025 - Costa V, **Matias S**, Tolooshams B, Masset P, Uchida N, Ba D. Sparse autoencoders for mechanistic insights on neural computation in naturalistic experiments. Computational and Systems Neuroscience (COSYNE) Conference, Montreal, Canada.
- 2025 - Kamath T, Lodder B, Bilsel E, Green I, **Matias S**, Capelli P, Raghubardayal M, Legister J, Tjahjono N, Scott E, Berrios Wallace J, Tian L, Uchida N, Watabe-Uchida M, Sabatini B. Hunger modulates exploration through dopamine signaling at the tail of striatum. Computational and Systems Neuroscience (COSYNE) Conference, Montreal, Canada.
- 2023 - Tolooshams B, **Matias S**, Wu H, Uchida N, Murthy VN, Masset P, Ba D. Interpretable deep learning for deconvolution of multiplexed neural signals. Computational and Systems Neuroscience (COSYNE) Conference, Montreal, Canada.
- 2022 - Lowet A, Zheng Q, **Matias S**, Uchida N, Drugowitsch J. Distributional Value Coding in the Striatum. RLDM The Multi-disciplinary Conference on Reinforcement Learning and Decision Making, Brown University in Providence, Rhode Island, USA.
- 2022 - Lowet A, Zheng Q, **Matias S**, Uchida N, Drugowitsch J. A striatal probabilistic population code for reward underlies distributional reinforcement learning. Computational and Systems Neuroscience (COSYNE) Conference, Lisbon, Portugal.
- 2019 - **Matias S**, Uchida N. Characterization of Dopamine and Striatal Neuron's Responses during Associative Learning. 19th Human Frontier Science Program Meeting, Tsukuba, Japan.

- 2016 - **Matias S**, Lottem E, Dugué DP, Mainen ZF. Serotonin and dopamine neurons signal distinct prediction errors during reversal learning. Computational and Systems Neuroscience (COSYNE) Conference, Salt Lake City, Utah, USA.
- 2015 - **Matias S**, Lottem E, Dugué DP, Mainen ZF. Encoding of reward prediction errors by serotonin neurons revealed by bulk fluorescence recordings. Motivational Circuits in Natural and Learned Behaviors, Janelia Farm Research Campus, Virginia, USA.
- 2015 - **Matias S**, Lottem E, Dugué DP, Mainen ZF. Encoding of reward prediction errors by serotonin neurons revealed by bulk fluorescence recordings. Computational and Systems Neuroscience (COSYNE) Conference, Salt Lake City, Utah, USA.
- 2014 - **Matias S**, Lottem E, Dugué DP, Mainen ZF. Long-term monitoring of serotonergic neuronal activity in behaving mice through an optical fiber 9th Federation of European Neuroscience Societies Forum, Milan, Italy.
- 2012 - **Matias S**, Dugué DP, Lottem E, Mainen ZF. Long-term monitoring of genetically defined neuronal populations in freely behaving rodents through and optical fiber. 42nd Annual Meeting of the Society for Neuroscience, New Orleans, Louisiana, USA.
- 2009 - **Matias S**, Figueira JR, Carvalho MJ, Plancha CE. A Multiple Criteria Decision Aiding Assignment Methodology for Assisted Reproductive Technology. 69th Meeting of the Euro Working Group Multiple Criteria Decision Aiding, Brussels, Belgium.

## TEACHING & ADVISING EXPERIENCE

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### Teaching Assistant

Responsibilities included developing new class materials, leading class discussions, grading all assignments, and meeting with students individually

- The Discipline of Neuroscience (NEUROBIO2015B), Spring 2023, Graduate Program in Neuroscience, Harvard Medical School, MA, USA.

### Guest lecturer

- Distributional Reinforcement Learning in the Brain, Neuro120 – Introduction to Computational Neuroscience course, Harvard University. Cambridge, Spring 2025.
- Imaging and fiber-photometry techniques in Systems Neuroscience. MIT-Portugal Program, Neuroscience Module, Champalimaud Neuroscience Programme, Lisbon, Portugal. Spring 2014.

### Instructor

- 2023 - 2025 Animal Learning Theories. Neurobiology Course, Scienspur, MA, USA.

### Pedagogical Training

- 2021: Undergraduate Mentoring Workshop - Faculty of Arts and Sciences, Harvard University
- 2024: Mentor Training for SURFiN fellows - Simons Foundation

### Advising Experience

6 undergraduate students at Harvard University: 2018, 2019, 2021, 2022, 2023, 2024

2 master students at Harvard University: 2018, 2024

5 graduate students at Harvard University: 2018, 2019, 2021, 2023, 2024

## FELLOWSHIPS & AWARDS

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### **Fellowships**

- 2018 - Human Frontier Science Program Long-term Postdoctoral Fellowship (LT00801/2018).  
2008 - Portuguese Foundation for Science and Technology (Fundação para a Ciência e Tecnologia) Ph.D. fellowship (SFRH / BD / 43072 / 2008)

### **Academic Recognition**

- 2021 - Harvard Brain Science Initiative Young Scientist Transitions Award.  
2021 - Graduate Women in Science Honorable Mention, USA

### **Research Grants**

- 2022 - NARSAD Young Investigator Grant, Brain and Behavior Research Foundation (grant #30035), NY, USA

### **Travel awards**

- 2025 – *Upcoming*: Japan Neuroscience Society Neuroscience2025 travel award, to attend The 48<sup>th</sup> Annual Meeting of the Japan Neuroscience Society, Niigata, Japan  
2020 - WIST Fund (Women in Science Travel Fund) grant for COVID-19 Relief on unanticipated childcare expenses.  
2015 - Convergent Science Network of Biomimetics and Neurotechnology travel award to attend the OIST Computational Neuroscience Summer Course in Okinawa, Japan.  
2015 - Janelia Farm Research Campus travel award to attend the conference on Motivational Circuits in Natural and Learned Behaviors Janelia Farm Research Campus, Virginia, USA.

## **ADVANCED TRAINING**

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- 2023 - Research Seminar Course: Beyond “Don’t Be Evil”: Embedding your research in social contexts, Program on Science, Technology and Society, Harvard Kennedy School (John F. Kennedy School of Government), MA, USA.  
2018 - Neuroimaging Techniques Winter Course, Max Planck Florida Institute for Neuroscience, Florida, USA.  
2015 - OIST Computational Neuroscience Course (OCNC 2015), Okinawa Institute of Science and Technology, Okinawa, Japan.  
2011 - Optical Imaging and Electrophysiological Recording in Neuroscience, Paris School of Neuroscience, Paris, France.

## **PROFESSIONAL SERVICE**

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### **Committee Experience**

- 2021 - Symposium organizer (with Balázs Hangya, Ph.D., Institute of Experimental Medicine, Hungarian Academy of Sciences, Budapest, Hungary): *Learning by Reinforcement*. FENS FRM (Federation of European Neuroscience Societies Regional Meeting), Krakow, Poland.

### **Educational Outreach**

- 2014            Producer and presenter of a science communication 3-day program about the brain on dance through multiple dance workshops and the science communication platform Ar | Respire Connosco.  
2011 - 2015    Founding member of the organization of the Ar events. Ar (<http://ar.neuro.fchampalimaud.org/>) is a series of interactive science communication events organized by students of the Champalimaud Neuroscience Programme aiming at

- sharing the wonders and advances of science and technology with the general public, in an approachable and fun format.
- 2013 Neuroscience to school - educational outreach in local schools to demonstrate concepts relevant in neuroscience research.
- 2011 - 2012 Founding member and producer of the first edition of the E3 Forum - Education, Employment and Entrepreneurship ([www.e3forum.org](http://www.e3forum.org)). The E3 Forum is a MIT Portugal students' initiative to foster synergies between students, the Academia, Industry, entrepreneurs, and policy makers in Portugal.
- 2007 - 2008 President of the Board of NEBM-IST.
- 2004 Founding member of NEBM-IST – Núcleo de Engenharia Biomédica do IST - a Biomedical Engineering Students' Association that organizes and promotes a wide range of activities for students at my undergraduate university, IST in Lisbon, Portugal, as well as outreach activities.

### Professional memberships

- 2021 - Member, Portuguese Society for Neuroscience, Portugal
- 2021 - Member, ALBA Network
- 2020 - Member, Graduate Women in Science, USA
- 2009 - Member, Society for Neuroscience, USA

### CAREER BREAKS

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- 09/2016 - 03/2017 Maternity leave
- 05/2021 - 08/2021 Maternity leave

### REFERENCES

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- Dr. Naoshige Uchida, [uchida@mcb.harvard.edu](mailto:uchida@mcb.harvard.edu), Professor, Harvard University
- Dr. Zachary F. Mainen, [zmainen@neuro.fchampalimaud.org](mailto:zmainen@neuro.fchampalimaud.org), Group Leader, Champalimaud Foundation
- Dr. Demba Ba, [demba@seas.harvard.edu](mailto:demba@seas.harvard.edu), Professor, Harvard University
- Dr. Rui M. Costa, [rc3031@columbia.edu](mailto:rc3031@columbia.edu), Group Leader, President and CEO, Allen Institute