

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: **PEDRO PINHEIRO-CHAGAS**

eRA COMMONS USER NAME (credential, e.g., agency login): **PINHEIRO-CHAGAS.PEDRO**

POSITION TITLE: **ASSISTANT PROFESSOR**

EDUCATION/TRAINING (*Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.*)

INSTITUTION AND LOCATION	DEGREE (if applicable)	Completion Date MM/YYYY	FIELD OF STUDY
Federal University of Minas Gerais, Brazil	B.A	07/2010	Psychology
Federal University of Minas Gerais, Brazil	MASTER	07/2012	Neuroscience
Sorbonne University, France	Ph.D.	11/2017	Cognitive Neuroscience
Stanford University	Postdoctoral	03/2022	Cognitive Neuroscience

A. Personal Statement

As a cognitive neuroscientist, my ultimate goal is to contribute to the understanding of the cognitive algorithms of human learning and intelligence. My research focus on developing a mechanistic understanding of high level symbolic cognition with the ultimate goal of informing educational and health policies. More specifically, I investigate 1) the cognitive mechanisms and neural correlates of mathematical reasoning, 2) the development of mathematical cognition across childhood, and 3) how mathematical reasoning can be impaired by specific neurological pathologies. To investigate these questions that range multiple levels of analysis, I take an interdisciplinary approach, combining fine-grained behavioral measures, computational modelling, machine learning applied to neuroimaging (fMRI, intracranial EEG, MEG), intracranial electrical stimulation, and neuropsychology.

I have started my career studying the development of elementary mathematical concepts in typically and atypically developing children. During my undergraduate and master studies, I coordinated a large-scale collaborative study between Germany and Brazil on characterizing the neuropsychological and genetic profile of developmental dyscalculia. During my doctoral training at the CEA NeuroSpin Center – France, I started to become interested in solving one of the first most fundamental problems in experimental psychology, which is to parse and characterize the cascade of processing stages underlying mental operations and mapping them in brain networks. For that, I co-develop a method for measuring behavior in a continuous way (trajectory-tracking) and used it to reveal for the first time the covert processing stages of simple arithmetic operations. Next, I used a combination of magnetoencephalography (MEG) and machine learning to decode those processing stages and representational codes from brain activity. During my postdoctoral training, I used a combination of intracranial encephalography (iEEG) and electrical brain stimulation to study the fine-grained spatiotemporal dynamics of arithmetic processing and better understand the precise function of the main hubs of the math, how they communicate to each other and how they are causally linked to behavior performance.

Now as an Assistant Professor at the University of California, San Francisco (UCSF) affiliated to the UCSF Dyslexia Center, Memory and Aging Center (MAC) and Departments of Neurology and Neurological Surgery, my research program aims at characterizing the neural architecture and dynamics of human intelligence, with a focus on cognitive symbolic systems, such as **mathematics and language**. My research program aims at understanding how these systems develop and decline and how we can help.

B. Positions, Scientific Appointments, and Honors

ACADEMIC POSITIONS

2022-present Assistant Professor, University of California, San Francisco (UCSF) Memory and Aging Center
2018-2022 Postdoctoral Scholar, Stanford University, Department of Neurology and Neurological Sciences

PROFESSIONAL MEMBERSHIPS

Cognitive Neuroscience Society (2015-present)
Society for Neuroscience (2017-present)

AWARDS AND HONORS

France-Stanford Center for Interdisciplinary Studies (2020-2021)
Visiting Junior Scholar Fellowship granted by Stanford University, USA
7nd LASchool for Education Cognitive and Neural Sciences, Chile (2018)
Fellowship award granted by James S. McDonnell Foundation, USA
Program Science Without Borders (2013 – 2017)
Full Ph.D. scholarship
National Counsel of Technological and Scientific Development (CNPq), Brazil
2016 Kavli Summer Institute in Cognitive Neuroscience, USA (2016)
Fellowship award granted by the Kavli Foundation, USA
5nd LASchool for Education Cognitive and Neural Sciences, Chile (2015)
Fellowship award granted by James S. McDonnell Foundation, USA
4nd LASchool for Education Cognitive and Neural Sciences, Uruguay (2014)
Fellowship award granted by James S. McDonnell Foundation, USA
2nd LASchool for Education Cognitive and Neural Sciences, Argentina (2012)
Fellowship award granted by James S. McDonnell Foundation, USA
Program for Graduate Studies Sponsorships (2010 – 2012)
Coordination of Improvement of Higher Education Personnel (CAPES), Brazil
Undergraduate interchange program at UW Madison, USA (Fall 2008)
Full scholarship granted by Federal University of Minas Gerais, Brazil.
National Research Fellowship for Undergraduate Scientific Initiation Sponsorship (2006 – 2010)
National Counsel of Technological and Scientific Development (CNPq) , Brazil

INVITED TALKS

Arithmetic encoding in the human brain at Dronkers Lab - UC Berkeley. 09/06/2019
Arithmetic encoding in the human brain at Knight Lab - UC Berkeley. 21/05/2021
Arithmetic encoding in the human brain at Math Thinking Lab - Tel Aviv University. 17/06/2020.
Math encoding in the human brain at Rich Ivry's CognAc Lab - UC Berkeley. 03/11/2020.
Tracking the Neurocognitive Mechanisms of Arithmetic at the Steve Piantadosi's The Computation and Language Lab - UC Berkeley. 11/12/2019.
Spatiotemporal dynamics of arithmetic processing in the human brain at the Cognitive and Cognitive Neuroscience - Psychology Department , UW Madison. 10/17/2019.
Tracking the Neurocognitive Mechanisms of Arithmetic at the FriSem – Stanford University. 05/24/2019.
Modulating visuospatial attention with electrical brain stimulation. Conte Center for Active Sensing retreat, Columbia University, NYC. 05/14/2019.
Tracking the Neurocognitive Mechanisms of Arithmetic at the Knight Lab - UC Berkeley. 06/06/2019.
Tracking the Neurocognitive Mechanisms of Arithmetic. Jay McClelland's Lab - Stanford University. 04/23/2019.
Finger tracking reveals the covert stages of mental arithmetic. Laboratory of behavioral and cognitive neuroscience, Stanford University, USA. 07/17/2016.
The approximate number system and arithmetic achievement. Cognitive Neuroscience Sector, SISSA - International School for Advanced Studies, Trieste, Italy. 07/16/2012.
Developmental dyscalculia in school aged children: population screening and characterization of cognitive and genetic molecular aspects. Section Neuropsychology, Department of Neurology, RWTH Aachen University, Aachen, Germany. 02/18/2011.

PROFESSIONAL SERVICE

Ad-hoc reviewer for scientific journals

Nature Neuroscience, Nature Communications, Current Biology, PNAS, Journal of Neuroscience, Cortex, NeuroImage, Scientific Reports, Cognition, Developmental Psychology, Developmental Science, Learning and Individual Differences, Vision Research, Journal of Vision, PLoS One, Journal of Numerical Cognition.

C. Contributions to Science

My full list of publications is available at My NCBI and Google Scholar:

<https://www.ncbi.nlm.nih.gov/myncbi/1ZS9pYc6Ym55T4/bibliography/public/>

<https://scholar.google.com/citations?user=XVsftdsAAAAJ&hl>

1. Development of mathematical concepts in typically and atypically developing children.

To understand how mathematical abilities are acquired by children with typical and atypical developmental trajectories, and which basic cognitive abilities predict math achievement, I co-lead a large cohort project in Brazil. We investigated the hypotheses that numbers are represented intuitively in the form of a "*mental number line*" (with variable precision across children) and that arithmetic calculations constitute movements along this spatially organized representation. In a series of studies, we found that the acuity of children's *approximate number system* is tightly associated with formal mathematics and might constitute the basis for developmental dyscalculia. Complementary, we found that the visuospatial attention system is increasingly recruited across the first three years of formal schooling during successful procedural arithmetic calculations⁷, specifically simple additions and subtractions. We recently confirmed the association between visuospatial abilities and mental addition by demonstrating that the vast majority of math active sites in the lateral parietal cortex show overlapping responses during both visuospatial and arithmetic tasks. Importantly, responses during arithmetic processing were greatest in sites along the IPS that had preference to contralateral, instead of ipsilateral hemifield, a classic signature of the visuospatial system. In a French cohort initiative, we corroborated these cross-sectional findings, showing that visuospatial skills at 5 years old longitudinally predicted addition and subtraction scores, but not multiplication at 11 years old. Conversely, language skills significantly predicted later multiplication scores, but not addition or subtraction, suggesting that at least some components of math reasoning rely on language. In sum, these results have elucidated several of the required basic cognitive abilities that support the development of math reasoning in children. Now, as a faculty of the UCSF Dyslexia center, I am interested in understanding the neurocognitive mechanisms underlying the co-occurrence of dyslexia and dyscalculia. For that, we developed a comprehensive math cognition battery (the UCSF Dyscalculia Subtyping), which has the capacity to separate math deficits in different domains (number processing, calculation procedures, fact retrieval and visuospatial/geometric reasoning).

- a) **Pinheiro-Chagas P**, Wood G, Knops A, Krinzinger H, Lonnemann J, Starling-Alves I, Willmes K, Haase VG. In how many ways is the approximate number system associated with exact calculation? PLoS One. 2014 Nov 19;9(11):e111155. doi: 10.1371/journal.pone.0111155. PMID: 25409446; PMCID: PMC4237330.
- b) **Pinheiro-Chagas P**, Didino D, Haase VG, Wood G, Knops A. The Developmental Trajectory of the Operational Momentum Effect. Front Psychol. 2018 Jul 17;9:1062. doi: 10.3389/fpsyg.2018.01062. PMID: 30065673; PMCID: PMC6056750.
- c) Guez, A., Piazza, M., **Pinheiro-Chagas, P.**, Peyre, H., Heude, B., & Ramus, F. (2022). Preschool language and visuospatial skills respectively predict multiplication and addition/subtraction skills in middle school children. *Developmental Science*, 00, e13316. <https://doi.org/10.1111/desc.13316>
- d) Pedemonte, B. (...), **Pinheiro-Chagas, P.**, (...) *et al.* A novel approach to subtypes of developmental dyscalculia. (under revision).

2. Neurocognitive algorithms of elementary mathematics. During my doctoral training with Stanislas Dehaene at the CEA NeuroSpin Center – France, we started to characterize the neurocognitive algorithms of arithmetic. In our first study using our recently developed finger-tracking method, we showed that even simple additions and subtractions rely on quantity manipulation and are computed by a stepwise displacement on a spatially organized mental number line, starting with the larger operand and incrementally adding or subtracting the smaller operand. Using a combination of MEG and time resolved decoding, we provided a first comprehensive picture of a cascade of unfolding processing stages underlying arithmetic calculation and decision-making at a single-trial level. Finally, in collaboration with Josef Parvizi, my postdoctoral mentor at Stanford University, we used iEEG to characterize a detailed temporal and individual anatomical information

about the ways in which different brain regions are engaged in the subsecond scale to perform mathematical tasks that requires the integration of information across multiple cognitive functions.

- a) **Pinheiro-Chagas P**, Dotan D, Piazza M, Dehaene S. Finger Tracking Reveals the Covert Stages of Mental Arithmetic. *Open Mind (Camb)*. 2017 Feb 1;1(1):30-41. doi: 10.1162/OPMI_a_00003. PMID: 30931419; PMCID: PMC6436574.
- b) **Pinheiro-Chagas P**, Daitch A, Parvizi J, Dehaene S. Brain Mechanisms of Arithmetic: A Crucial Role for Ventral Temporal Cortex. *J Cogn Neurosci*. 2018 Dec;30(12):1757-1772. doi: 10.1162/jocn_a_01319. Epub 2018 Jul 31. PMID: 30063177; PMCID: PMC6355388.
- c) **Pinheiro-Chagas P**, Piazza M, Dehaene S. Decoding the processing stages of mental arithmetic with magnetoencephalography. *Cortex*. 2019 May;114:124-139. doi: 10.1016/j.cortex.2018.07.018. Epub 2018 Jul 31. PMID: 30177399; PMCID: PMC6542658.
- d) Liu N*, **Pinheiro-Chagas P***, Sava-Segal C, Kastner S, Chen Q, Parvizi J. Overlapping Neuronal Population Responses in the Human Parietal Cortex during Visuospatial Attention and Arithmetic Processing. *J Cogn Neurosci*. 2021 Nov 5;33(12):2548-2558. doi: 10.1162/jocn_a_01775. PMID: 34407190; PMCID: PMC8713653.
- e) *Pinheiro-Chagas, P.*, Chen, F., Sabetfakhri, N. et al. Direct intracranial recordings in the human angular gyrus during arithmetic processing. *Brain Structure and Function* (2022). <https://doi.org/10.1007/s00429-022-02540-8>

3. Methodological advances, open science and equity. Because of the interdisciplinary nature of my research program, I have developed and improved advanced methods to measure behavior and model brain activity, which are all open source and publicly available, notably: trajectory tracking (<https://trajtracker.com/>), a full iEEG preprocessing and analysis toolbox (https://github.com/pinheirochagas/lbcn_preproc), methods for MEG multivariate decoding using machine learning (https://github.com/pinheirochagas/Calc_MEG), and a toolbox to convert iEEG data into the Neurodata Without Borders data standard (https://github.com/pinheirochagas/lbcn_nwb). I am also actively engaged on initiatives to promote open and reproducible science, such as the BrainHack community, as well as on actions to foster a more inclusive scientific environment for traditionally underrepresented groups.

- a) Dotan D, **Pinheiro-Chagas P**, Al Roumi F, Dehaene S. Track It to Crack It: Dissecting Processing Stages with Finger Tracking. *Trends Cogn Sci*. 2019 Dec;23(12):1058-1070. doi: 10.1016/j.tics.2019.10.002. Epub 2019 Nov 1. PMID: 31679752.
- b) Gau, R., Noble, S., (...) Brainhack Community (**Pinheiro-Chagas, P.**) (2021). Brainhack: Developing a culture of open, inclusive, community-driven neuroscience. *Neuron*, 109(11), 1769–1775. <https://doi.org/10.1016/j.neuron.2021.04.001>
- c) Llorens, A., Tzovara, A., (...), **Pinheiro-Chagas, P.**, ... Dronkers, N. F. (2021). Gender bias in academia: A lifetime problem that needs solutions. *Neuron*, 109(13), 2047–2074. <https://doi.org/10.1016/j.neuron.2021.06.002>
- d) **NeuroCausal**: An open data sharing and metadata synthesis platform for clinical data. <https://neurocausal.github.io/>

4. Decline of cognitive abilities in neurogenerative pathologies. I recently started a line of research in primary progressive aphasia (PPA), via a collaboration with Dr. Marilu Gorno Tempini from UCSF. We are going to investigate a possible dissociation in different domains of math processing in two variants of primary progressive aphasia (PPA): the semantic variant (svPPA), which is characterized by anterior temporal atrophy and associated with loss of object conceptual knowledge; and the logopenic variant (lvPPA), characterized by temporoparietal atrophy (close to the main hubs of the math network) and associated with phonological deficits, including pseudoword reading that requires a concatenation procedure. Based on the pattern of brain atrophy and the associated known symptomatology, we predict that svPPA patients will show conceptual deficits in arithmetic principles and rules, but intact calculation abilities. Conversely, lvPPA patients will show impairments in calculation, but preserved knowledge of arithmetic principles and rules. I am also collaborating with Rich Ivry from UC Berkeley on a similar project investigating patients with spinocerebellar ataxia (SCA, characterized by lesions in the cerebellum), and Parkinson's disease (PD, characterized by lesions in the basal ganglia). Our preliminary results suggest that the cerebellum is crucial for calculation iterative procedures (stepwise displacement along the mental number line), while the basal ganglia is important for executive functions that require the orchestration of multiple computational steps in multi-digit calculations.

- a) Saban W, **Pinheiro-Chagas P**, Piantadosi S, Ivry R. (Under Review) Distinct Contributions of the Cerebellum and Basal Ganglia to Arithmetic Procedures.
- b) **NeuroCausal**: An open data sharing and metadata synthesis platform for clinical data.
<https://neurocausal.github.io/>

5. Brain networks dynamics

In addition to my primary original work, I maintain a network of active collaborations with multidisciplinary scientist to investigate the brain function at multiple levels of cognitive and behavioral processing. We study brain activity from the very early sensory input to very late decision making in even social or emotional domains. Our goal is to acquire a universal understanding of the functional architecture of the human brain with millisecond and millimeter precision using a multimodal approach that includes intracranial electroencephalography (iEEG), functional MRI (fMRI), and intracranial electrical stimulation (iES).

- a) Tan, K., Daitch, A., **Pinheiro-Chagas, P.** Fox, KCR., Parvizi, P., Lieberma, M. (2022) Electrocorticographic evidence of a common neurocognitive sequence for mentalizing about the self and others, Nature communications 13 (1), 1- 17.
- b) Parvizi, J. Braga, RM., Kucyi, A., Veit, M., Perry, C., **Pinheiro-Chagas, P.**, Zeineh, M., van Staalduinen, EK., Henderson, J., Markert, M. (2021) Altered sense of self during seizures in the posteromedial cortex. PNAS, 118 (29), e2100522118.
- c) Stieger, J., **Pinheiro-Chagas, P.**, Fang, Y., Perry, C., Contreras, D., Chen, Q., Hugendar, J., Buch, V. Parvizi, J. (under review in Nature) Cross regional oscillatory mechanisms of autobiographical memory retrieval in the human brain