

NeuroView

Brainhack: Developing a culture of open, inclusive, community-driven neuroscience

Rémi Gau,^{1,76,*} Stephanie Noble,^{2,76} Katja Heuer,^{3,4,76} Katherine L. Bottenhorn,^{5,76} Isil P. Bilgin,^{6,7,76} Yu-Fang Yang,^{8,76} Julia M. Huntenburg,^{9,76} Johanna M.M. Bayer,^{10,11,76} Richard A.I. Bethlehem,^{12,13,76} Shawn A. Rhoads,¹⁴ Christoph Vogelbacher,¹⁵ Valentina Borghesani,¹⁶ Elizabeth Levitis,^{17,18} Hao-Ting Wang,^{19,20,21} Sofie Van Den Bossche,²² Xenia Kobeleva,^{23,24} Jon Haitz Legarreta,²⁵ Samuel Guay,²⁶ Selim Melvin Atay,²⁷ Gael P. Varoquaux,^{28,29} Dorien C. Huijser,^{30,31} Malin S. Sandström,³² Peer Herholz,³³ Samuel A. Nastase,³⁴ AmanPreet Badhwar,^{16,35,36} Guillaume Dumas,^{37,38} Simon Schwab,³⁹ Stefano Moia,^{40,41} Michael Dayan,⁴² Yasmine Bassil,⁴³ Paula P. Brooks,³⁴ Matteo Mancini,^{20,44,45} James M. Shine,⁴⁶ David O'Connor,⁴⁷ Xihe Xie,⁴⁸ Davide Poggiali,⁴⁹ Patrick Friedrich,⁵⁰

(Author list continued on next page)

¹Institute of Psychology, Université Catholique de Louvain, Louvain la Neuve, Belgium

²Radiology & Biomedical Imaging, Yale University, New Haven CT, USA

³Center for Research and Interdisciplinarity, Université of Paris, Paris, France

⁴Department of Neuropsychology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

⁵Department of Psychology, Florida International University, Miami, FL, USA

⁶Biomedical Engineering, Cybernetics, University of Reading, Reading, UK

⁷Allied Health Professions Institute, University of the West of England, Bristol, UK

⁸Department of Psychology, University of Würzburg, Würzburg, Germany

⁹Systems Neuroscience Lab, Champalimaud Research, Lisbon, Portugal

¹⁰Centre for Youth Mental Health, University of Melbourne, Melbourne, Australia

¹¹Orygen Youth Health, Melbourne, Australia

¹²Autism Research Centre, Department of Psychiatry, University of Cambridge, Cambridge, UK

¹³Brain Mapping Unit, Department of Psychiatry, University of Cambridge, Cambridge, UK

¹⁴Department of Psychology, Georgetown University, Washington DC, USA

¹⁵Laboratory for Multimodal Neuroimaging, Department of Psychiatry and Psychotherapy, University of Marburg, Marburg, Germany

¹⁶Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal, Université de Montréal, Montréal, QC, Canada

¹⁷Section on Developmental Neurogenetics, National Institute of Mental Health, Bethesda, MD, USA

¹⁸Centre for Medical Image Computing, Department of Computer Science, University College London, London, UK

¹⁹Sackler Centre for Consciousness Science, University of Sussex, Brighton, UK

²⁰Department of Neuroscience, Brighton and Sussex Medical School, University of Sussex, Brighton, UK

²¹Sussex Neuroscience, University of Sussex, Brighton, UK

²²Department of Data Analysis, Faculty of Psychology and Educational Sciences, Ghent University, Ghent, Belgium

²³Department of Neurology, University of Bonn, Bonn, Germany

²⁴German Center for Neurodegenerative Diseases (DZNE), Bonn, Germany

²⁵Computer Science, Université de Sherbrooke, Sherbrooke, QC, Canada

²⁶Université de Montréal, Montréal, QC, Canada

(Affiliations continued on next page)

Brainhack is an innovative meeting format that promotes scientific collaboration and education in an open, inclusive environment. This NeuroView describes the myriad benefits for participants and the research community and how Brainhacks complement conventional formats to augment scientific progress.

Introduction

Social factors play a crucial role in the advancement of science. New findings are discussed and theories emerge through social interactions, which usually take place within local research groups and at academic events such as conferences, seminars, or workshops. This system tends to amplify the voices of a select subset of the community—especially more established researchers—thus limiting opportunities for the larger com-

munity to contribute and connect. Brainhack (<https://brainhack.org/>) events (or Brainhacks for short) complement these formats in neuroscience with decentralized 2- to 5-day gatherings, in which participants from diverse backgrounds and career stages collaborate and learn from each other in an informal setting. The Brainhack format was introduced in a previous publication (Cameron Craddock et al., 2016; Figures 1A and 1B). It is inspired by the hackathon model (see

glossary in Table 1), which originated in software development and has gained traction in science as a way to bring people together for collaborative work and educational courses. Unlike many hackathons, Brainhacks welcome participants from all disciplines and with any level of experience—from those who have never written a line of code to software developers and expert neuroscientists. Brainhacks additionally replace the sometimes-competitive context of traditional



Anibal S. Heinsfeld,^{53,54} Lydia Riedl,⁵¹ Roberto Toro,^{3,52} César Caballero-Gaudes,⁴⁰ Anders Eklund,^{55,56,57} Kelly G. Garner,^{58,59,60} Christopher R. Nolan,⁶¹ Damion V. Demeter,⁶² Fernando A. Barrios,⁶³ Junaid S. Merchant,^{64,65} Elizabeth A. McDevitt,³⁴ Robert Oostenveld,^{66,67} R. Cameron Craddock,⁶⁸ Ariel Rokem,⁶⁹ Andrew Doyle,⁷⁰ Satrajit S. Ghosh,^{71,72} Aki Nikolaidis,⁷³ Olivia W. Stanley,^{74,75} and Eneko Uruñuela^{40,41} The Brainhack Community

²⁷Neuroscience and Neurotechnology, Middle East Technical University, Ankara, Turkey

²⁸Parietal, INRIA, Saclay, France

²⁹Montréal Neurological Institute, McGill University, Montréal, QC, Canada

³⁰Erasmus School of Social and Behavioural Sciences, Erasmus University Rotterdam, Rotterdam, the Netherlands

³¹Developmental and Educational Psychology, Leiden University, Leiden, the Netherlands

³²INCF, Karolinska Institute, Stockholm, Sweden

³³NeuroDataScience - ORIGAMI laboratory, Faculty of Medicine and Health Sciences McGill University Montréal, QC Canada

³⁴Princeton Neuroscience Institute, Princeton University, Princeton, NJ, USA

³⁵Multimics Investigation of Neurodegenerative Diseases (MIND) Lab, Université de Montréal, Montréal, QC, Canada

³⁶Département de Pharmacologie et Physiologie, Université de Montréal, Montréal, QC, Canada

³⁷Department of Psychiatry, Université de Montréal, Montréal, QC, Canada

³⁸Mila, Université de Montréal, Montréal, QC, Canada

³⁹Department of Biostatistics & Center for Reproducible Science, University of Zurich, Zurich, Switzerland

⁴⁰Basque Center on Cognition, Brain and Language, San Sebastián-Donostia, Spain

⁴¹University of the Basque Country (EHU UPV), San Sebastián-Donostia, Spain

⁴²Human Neuroscience Platform, Fondation Campus Biotech Geneva, Geneva, Switzerland

⁴³Graduate Division of Biological & Biomedical Sciences, Emory University, Atlanta, GA, USA

⁴⁴Cardiff University Brain Research Imaging Centre, Cardiff University, Cardiff, UK

⁴⁵NeuroPoly Lab, Polytechnique Montréal, Montréal, QC, Canada

⁴⁶Faculty of Medicine and Health, The University of Sydney, Sydney, Australia

⁴⁷Department of Biomedical Engineering, Yale University, New Haven, CT, USA

⁴⁸Department of Neuroscience, Weill Cornell Medicine, New York City, NY, USA

⁴⁹Padova Neuroscience Center, University of Padova, Padova, Italy

⁵⁰Institute of Neuroscience and Medicine, Brain & Behaviour (INM-7), Research Centre Jülich, Jülich, Germany

⁵¹Department of Psychiatry and Psychotherapy, Philipps Universität, Marburg, Germany

⁵²Neuroscience Department, Institut Pasteur, Paris, France

⁵³Computational Neuroimaging Lab, University of Texas at Austin, Austin, TX, USA

⁵⁴Department of Computer Science, University of Texas at Austin, Austin, TX, USA

⁵⁵Department of Biomedical Engineering, Linköping University, Linköping, Sweden

⁵⁶Department of Computer and Information Science, Linköping University, Linköping, Sweden

⁵⁷Center for Medical Image Science and Visualization (CMIV), Linköping University, Linköping, Sweden

⁵⁸Queensland Brain Institute, The University of Queensland, St Lucia, Australia

⁵⁹School of Psychology, University of Birmingham, Birmingham, UK

⁶⁰School of Psychology, The University of Queensland, St Lucia, Australia

⁶¹School of Psychology, University of New South Wales, Sydney, Australia

⁶²Psychology Department, The University of Texas at Austin, Austin, TX, USA

⁶³Instituto de Neurobiología, Universidad Nacional Autónoma de México, Querétaro, Mexico

⁶⁴Neuroscience and Cognitive Science Program, University of Maryland, College Park, MD, USA

⁶⁵Department of Psychology, University of Maryland, College Park, MD, USA

⁶⁶Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, the Netherlands

⁶⁷NatMEG, Karolinska Institutet, Stockholm, Sweden

⁶⁸Department of Diagnostic Medicine, The University of Texas at Austin Dell Medical School, Austin, TX, USA

⁶⁹Psychology and eScience Institute, University of Washington, Seattle, WA, USA

⁷⁰McGill Centre for Integrative Neuroscience, McGill University, Montréal, QC, Canada

⁷¹McGovern Institute for Brain Research, MIT, Cambridge, MA, USA

⁷²Department of Otolaryngology - Head and Neck Surgery, Harvard Medical School, Boston, MA, USA

⁷³Center for the Developing Brain, Child Mind Institute, New York City, NY, USA

⁷⁴Centre for Functional and Metabolic Mapping, University of Western Ontario, London, ON, Canada

⁷⁵Department of Medical Biophysics, University of Western Ontario, London, ON, Canada

⁷⁶These authors contributed equally

*Correspondence: remi.gau@uclouvain.be

<https://doi.org/10.1016/j.neuron.2021.04.001>

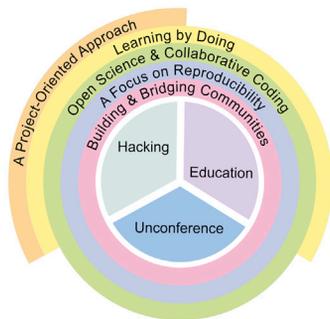
hackathons with a purely collaborative one and also feature informal dissemination of ongoing research through unconferences.

In the following NeuroView, we aim to address two key questions about the

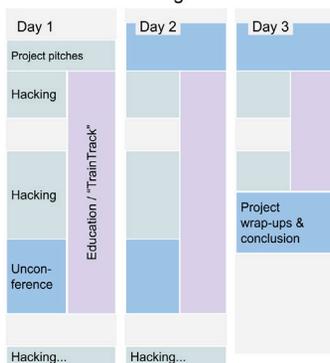
merits of a Brainhack. First, how do participants benefit from attending a Brainhack event? Second, what is the relevance and importance of Brainhacks for neuroscience more broadly? To answer these questions, we discuss the

five defining Brainhack features: (1) a project-oriented approach that fosters active participation and community-driven problem-solving; (2) learning by doing, which enables participants to gain more intensive training, particularly

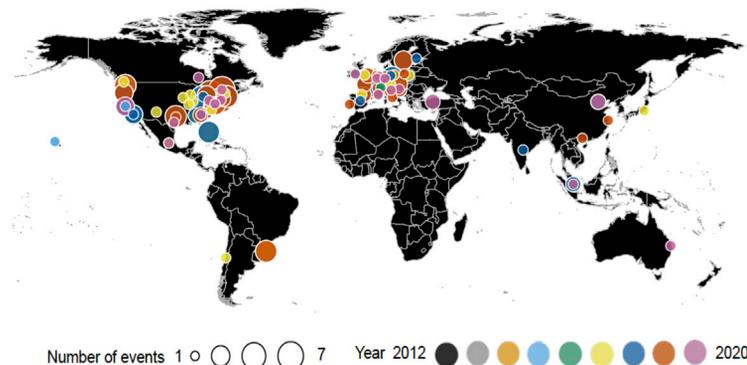
A Anatomy of a Brainhack



B Timeline of a Single Event



C Brainhack Cartography



D Brainhack Timeline

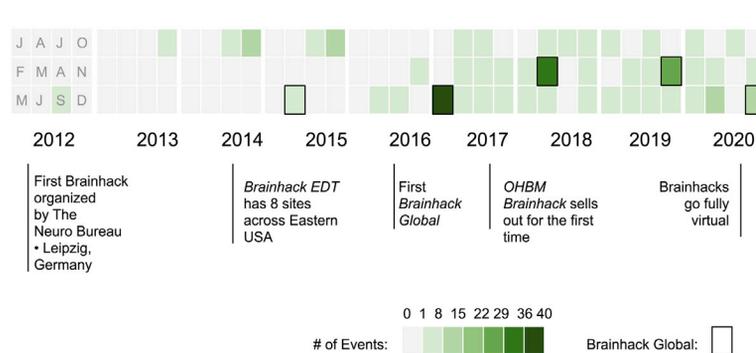


Figure 1. Brainhack in time and space

(A) Anatomy of a Brainhack shows how the components of Brainhack events relate to overarching topics that lead to scientific and professional opportunities in neuroscience. (B) Timeline of a single event describes the typical daily schedule throughout a Brainhack. Project work and educational activities occur simultaneously interspersed with unconferences. (C) Brainhack cartography displays cities across the world that have hosted a Brainhack. Marker color indicates the year in which each city hosted its first Brainhack, and marker size indicates the number of events hosted in each city. (D) The Brainhack timeline displays the number of events per month since the inaugural Brainhack in September 2012, along with notable happenings throughout the years. Months are only denoted in the first year with a single letter; this ordering is repeated for all subsequent years. See the latest version of this figure at http://brainhack.org/brainhack_jupyter_book/neuroview_figure.html.

in computational methods; (3) training in open science and collaborative coding, which helps participants become more effective collaborators; (4) focus on reproducibility, which leads to more robust scientific research; and (5) accelerated building and bridging of communities, which encourages inclusivity and seamless collaboration between researchers at different career stages. Altogether, Brainhacks and similar formats are increasingly recognized as a new way of providing academic training and conducting research that extends traditional settings. These events foster a new research culture that celebrates open science, collaboration, and diversity, unlocking opportunities for scientific progress.

A project-oriented approach

Brainhacks are fundamentally centered on attendee-led projects. At the beginning of each Brainhack, participants pitch project ideas and form teams to realize some of these ideas during the “hacking” sessions (Figure 1B). The teams are dynamic, and their composition can change throughout the course of a project. As participants group themselves based on their common interest in a question, method, goal, or idea, interdisciplinary teams naturally emerge. Each participant can hone diverse skills by playing an active part in multiple projects. This format avoids the scientific silos that often arise when scientists connect over a specific methodological or conceptual approach. Brainhack projects promote

the flow of information between specialized domains within the multidisciplinary field of neuroscience.

The project-oriented structure of Brainhack enables everyone to be an active participant at the event, with contributions taking a variety of forms. Importantly, the term “hacking” is not used to refer to coding in particular but to describe an intensive form of work, eschewing strict conventions and often targeted at prototyping an idea within a short period of time. Participants are therefore not required to have coding skills to make meaningful contributions. An example of an impactful project that did not focus on coding is Open Brain Consent (<https://open-brain-consent.readthedocs.io/en/stable/>; [Banner et al., 2021](#)). This project

Table 1. Glossary of selected terminology

Term	Definition
Open Science	Movement and practices within science aimed at increasing the transparency, accessibility, diversity, and inclusivity of scientific practices and output. This is often reflected in open science practices, such as publishing open access manuscripts; making research data findable, accessible, interoperable, and reusable (FAIR); and open sourcing code and software, etc.
Hackathon	The term hackathon is a portmanteau of “hacking” and “marathon.” Traditionally, it is an event in which people and teams gather to collaboratively work on projects over the course of multiple days. These events often historically feature competitions between teams. Brainhacks instead emphasize collaboration over competition.
Hacking	In this context, hacking does not indicate trying to break into computer systems by breaching security. Instead, it refers to tinkering with a system to better understand its working and subsequently laying a foundation for its advancement.
Unconference	This refers to a short session in which participants either present their research or prompt a discourse on any topic of interest in an informal setting. The content of an unconference may be decided impromptu and is often inspired by ongoing team discussions during the course of the Brainhack.
TrainTrack	A series of educational workshops that run in parallel with the projects enabling attendees to acquire specific skills during the course of their projects. The content of TrainTrack ranges from tutorials teaching skills useful to successfully navigate diverse projects in the Brainhack (such as code version control using Git) to more generalized education relevant to neuroscientific research (like MATLAB, BIDS, etc.).

Terms highlighted here either are defined in a unique way for this community or are important for appreciating the text. For detailed definitions, see [Cameron Craddock et al. \(2016\)](#) and the Brainhack Jupyter Book Glossary (http://brainhack.org/brainhack_jupyter_book/glossary.html).

developed consent form templates for the collection and sharing of human neuroimaging data, incorporating data protection standards such as the General Data Protection Regulation (GDPR) of the European Union. The consent forms can be used in ethics approval procedures to ensure that the collected data are shareable while the participants’ privacy is protected.

Unlike some traditional hackathons, there is no competitive element to Brainhacks. The focus is on collective and community-driven work, making the events more welcoming for inexperienced participants. Neither the level of completeness nor the publication potential determines the success of a project. Instead, Brain-

hacks emphasize the value of collaborating, exploring unconventional ideas, group thinking, and building tools that benefit the community. Exemplary of these values is a project that originated at the first Brainhack in 2012: The Brain Catalogue (<https://braincatalogue.org/>) provides magnetic resonance (MR) brain images of a range of different species and allows multiple users to view and segment them on the web simultaneously. Its successor, BrainBox (<https://brainbox.pasteur.fr/>), has evolved to enable real-time collaborative segmentation of any MR image accessible online ([Heuer et al., 2016](#)). BrainBox has been used in many subsequent Brainhack projects, research collaborations, and sci-

ence outreach events. Similarly, braindr (<https://braindr.us>) fosters citizen science while solving visual quality control for massive datasets ([Keshavan et al., 2019](#)). This app enables anyone to contribute to scientific progress by swiping left or right on brain images to classify them as clean or corrupted. The project originated from a hackathon in 2017, was extended in a Brainhack project in 2018, and recently led to the development of the extensible SwipesforScience (<https://swipesforscience.org/>) citizen science template.

Many Brainhack projects take on a life of their own and grow beyond a single event. The open science approach embraced by the Brainhack community makes it easier for anyone to contribute to or take the lead in pushing projects forward beyond their initial creation. For example, the Autism Gradients project (<https://github.com/rb643/Autism-Gradients>), exploring the cortical hierarchy in individuals with autism, was conceptualized at Brainhack Global 2016. It was subsequently picked up by another group, who expanded the original idea and invited the initial Brainhack team to collaborate. This resulted in a peer-reviewed publication ([Hong et al., 2019](#)), multiple follow-up projects, two exchange grants, and international workshops (Autism workshop at INSAR and gradient workshop at OHBM) on the same topic. Another example is the development of Nighres (<https://nighres.readthedocs.io/en/latest/>), a Python package for processing high-resolution neuroimaging data. The initial project spanned two Brainhacks in 2016 and resulted in a toolbox (https://github.com/juhuntenburg/laminar_python) that made algorithms for layer-specific analysis of the cortex easier to install and use. This sparked the development of the full Nighres package, with a broader range of functions and various contributors across several Brainhacks. Nighres has been presented in a peer-reviewed publication ([Huntenburg et al., 2018](#)), is actively maintained, and has been used and cited in multiple studies. Some projects transcend the domain of brain sciences; for example, DueCredit (<https://github.com/ducredit/ducredit>) is a project promoting citable code that emerged at Brainhack OHBM 2015 and is now used in molecular dynamics, geophysics, and

other sciences. Many more projects have been part of Brainhacks over the years, attracting users and developers and evolving together with the community. An expanding list lives in the accompanying Jupyter Book (http://brainhack.org/brainhack_jupyter_book/overview.html).

All these examples highlight how the project-oriented approach of Brainhacks encourages active participation and interdisciplinary collaboration that can reach beyond a single event. The projects directly benefit participants, who can explore new ideas in a stimulating setting, leverage their projects for career advancement, and gain new skills by collaborating with experienced researchers and developers. Brainhack projects also contribute to the progress of the wider neuroscience community by fostering exchange across scientific silos, resulting in multi-disciplinary tools, community-driven guidelines and reference data, and traditional publication output.

Learning by doing

Alongside projects, educational activities lie at the heart of Brainhacks. Such activities include informal teaching between project teammates, theoretical discussions in self-organized groups, un-conference presentations, and structured workshops on a particular tool or topic. A recent format for major Brainhack events is the TrainTrack, entirely education-focused sessions that run in parallel with project work (Figures 1A and 1B). This format lowers the entry barrier for new participants, enabling them to build relevant skills and familiarize themselves with the structure and environment of a Brainhack before diving into their first project. The variety of educational approaches supports different ways of learning. Furthermore, the informal nature of these activities empowers participants to be proactive about learning and asking for help.

Brainhack instructors strive to share their materials with the scientific community, including recorded presentations, slide decks, or interactive tutorials. For example, all the materials developed for the TrainTrack of OHBM Brainhack 2020 have been made publicly available under a permissive license so as to encourage reuse, redistribution, and reproduction of the content. Educational content devel-

oped for Brainhacks covers a range of topics, including analytical and statistical methods (e.g., machine learning, data preprocessing), reproducible workflows (e.g., automated pipelines, automated data standardization, version control, software containers), and other relevant concepts (e.g., preregistration, p-hacking). Brainhacks represent an ideal place to showcase neuroscientific tools in the form of presentations or training sessions. These sessions are designed to be hands on and interactive as they typically feature small groups having active discussions. Participants are explicitly encouraged to adopt what they learned at a Brainhack event to their own context and to improve the teaching material with their own ideas.

Skills learned at Brainhacks are not constrained to those of a technical nature; the event format provides a unique opportunity for early career researchers to develop transferable skills such as teamwork and leadership. Project teams are often interdisciplinary, allowing participants to practice communicating beyond their own field. Everyone is encouraged to propose and lead their own projects, and the informal structure of the events often empowers more junior participants to also take on a leadership role. The growing pool of training materials provides a ready route to extend teaching opportunities to any member of the community, including trainees. Such experiences are rare for early career researchers, but crucial for their advancement given that they can potentially mold future interests, boost the quality of their research, and widen their scientific horizons. Altogether, the broad range of scientific and professional training opportunities equips participants with a skill set that can be applicable across many domains and career stages and may therefore open up a greater range of career opportunities.

Open science and collaborative coding

Despite the increasingly central role of programming in neuroscience research, formal training in coding is not common in the neuroscience curriculum. In addition, code is seldom shared across more than a few labs and too often read and executed by only a single individual. As a result, many scripts and workflows are

hard to reuse and share and may contain undiscovered errors (Merali, 2010).

By putting cross-disciplinary collaboration at its heart, Brainhacks have brought awareness to the need for usability, reusability, and long-term maintenance of tools. This comes with a shift of efforts, from individuals creating tools for their own needs to a community actively contributing to an existing resource, solving the aforementioned issues. Practices such as writing good code and documentation, improving code readability, performing basic version control, working collaboratively on a codebase on GitHub, GitLab, or BitBucket, and using appropriate open licenses have become essential within the community. These open practices and tools facilitate community-driven development and ensure that tools are available to all researchers, fostering global inclusivity. Brainhacks have highlighted the utility of producing a variety of research deliverables other than scientific papers (such as software, tutorials, workflows, and datasets), a concept that is increasingly endorsed by publishing venues such as F1000, RIO, eLife, Aperature, and others over the years.

Mastering collaborative programming skills enables Brainhack participants to contribute to open research objects that affect the wider scientific community. It can also make them more efficient at conducting their own research; for example, skills such as version control can be transferred to their own research group and foster more seamless collaboration among lab members. The wider neuroscience community benefits from the creation of transparent, reproducible tools and from researchers equipped with the skills to maintain and extend them.

A focus on reproducibility

In line with their open, transparent, and collaborative nature, Brainhacks promote increased awareness of the importance of reproducible practices that integrate easily into research workflows. In addition to the coding practices mentioned above, an important aspect of reproducibility is data sharing. Public datasets are featured extensively in Brainhack projects and training sessions because they are ideal for testing out new ideas or learning how to use a new tool. First-time users thus experiment with these datasets and

related tools under the guidance of expert users, which lowers the barrier to working with public data in the future. This approach establishes open data sharing as a standard practice and teaches participants how to curate their own data and metadata to make them accessible and reusable by others.

Resources that help researchers handle their data in a reproducible fashion are integral to Brainhacks; many of these have been introduced to the Brainhack community through structured efforts from the Center for Reproducible Neuroimaging Computation (Kennedy et al., 2019). For example, many projects and trainings use DataLad (<https://www.datalad.org/>), a tool that not only lets participants version-control their own data but also helps them find, access, share, and work with increasingly large publicly available datasets. Similarly, a growing number of projects build on the Brain Imaging Data Structure (BIDS; <https://bids.neuroimaging.io/>; Gorgolewski et al., 2016), a community standard for the organization of brain imaging data and metadata founded with the International Neuroinformatics Coordinating Facility (INCF; <https://www.incf.org/>). Introducing participants to data standards, such as BIDS, in the environment of a Brainhack allows them to experience the benefits of a unified data organization and provides them with the skillset to use these formats in their own research. Additionally, past Brainhacks have highlighted best practices in neuroimaging data analysis as defined by the Committee on Best Practice in Data Analysis and Sharing (COBIDAS guidelines for MRI [<http://www.humanbrainmapping.org/files/2016/COBIDASreport.pdf>] as well as for EEG and MEG [<https://osf.io/a8dhn/>]). By creating a scientific culture around open and standardized data, metadata, and methods, as well as detailed documentation and reporting, Brainhacks promote fundamental building blocks of a more efficient and reliable scientific research process.

Building and bridging communities

All aspects of Brainhacks discussed above build upon an active commitment to a diverse, inclusive, and non-hierarchically organized community. This commitment has been formalized in a

Code of Conduct that aims to ensure a safe and welcoming environment for participants from all backgrounds. The Code of Conduct is discussed at the beginning of a Brainhack, and adherence is monitored throughout the event. There have also been dedicated efforts to raise awareness about equity, diversity, and inclusivity, such as a recent panel discussion at Brainhack Ontario 2020. While far from perfect or bias-free, we feel that the Brainhack community itself is continuously growing more diverse in terms of race, ethnicity, gender identity and expression, sexual orientation, career stage, and other aspects of personal background and identity. The enthusiastically inclusive culture helps members hold each other to a standard of mutual respect that empowers individuals from typically underrepresented groups to claim their space and take on central roles in the community.

Brainhacks are designed to promote intensive networking. The project-oriented and decentralized setting puts participants on an equal footing regardless of backgrounds and career stage. Unconferences provide a unique opportunity for people interested in the same topic to meet and discuss, sometimes sparking new collaborations. Working in small groups during projects, workshops, and unconferences over the course of several days encourages frequent interactions that often go deeper than relatively short encounters at traditional conferences. These interactions contribute to building lasting collaborations that bridge across disciplines, research contexts, career stages, and geographical borders. Sometimes they lead to job opportunities, grant proposals, new ideas, and new projects. Often, they turn into friendships. We firmly believe that growing this diverse community and insisting on a culture of collaboration and inclusivity has untold benefits for the retention and well-being of all scientists doing brain research.

In addition to year-round locally organized Brainhacks, Brainhack Global has emerged as a major yearly initiative that has sparked numerous simultaneous events around the world (Figures 1C and 1D). The focus on open collaboration through virtual spaces throughout the years meant that the community had the infrastructure, knowledge, and motivation to go fully virtual in 2020, ac-

commodating restrictions due to the COVID-19 pandemic, budget constraints, and increased awareness of the climate cost of travel. The general format of project-oriented, community-building events has gained traction in the field of neuroscience and beyond. Large initiatives such as the Human Brain Project, Neurodata Without Borders, and the Society for the Improvement of Psychological Science have also chosen hackathons as a primary work format. Summer schools like the ABCD-ReproNim course, NeuroHackademy, the ABCD Workshop and the Brainhack School are based on the same principles as the original Brainhack events. Brainhacks have been organized with other communities such as Network Neuroscience (<https://netscisociety.net/home>), thereby forming a bridge with those communities. Many Brainhack community members also play active roles in like-minded initiatives such as the Open Science Special Interest Group (<https://ossig.netlify.app/>) of OHBM or Neuromatch Academy (<https://arxiv.org/abs/2012.08973>), among others. Thus, a community of individuals and practices has emerged that transports the benefits and values of the Brainhack format far beyond any individual event or organization. Brainhacks are spreading to an increasingly wide community, because their non-hierarchical, self-organizing structure enables individuals to organize a Brainhack anywhere in the world (Figure 1C), while events are kept financially accessible. An online community with more than 4,000 members and 500 channels uses the Mattermost messaging platform to provide continuity across time and space. Posts range from questions about a specific resource to job openings and discussions about research ethics, and anyone can join regardless of having attended a Brainhack. The community evolves with every new member and their ideas, and many members become local advocates for the principles of open and collaborative science in their home institutions.

Conclusion and future directions

Brainhacks complement traditional academic settings and offer additional opportunities for participants to achieve their scientific and professional goals. The focus on building a community that promotes

open science and inclusivity has naturally led to better coding practices, more reproducible methods, accelerated knowledge dissemination, and ample opportunities for collaboration. Brainhacks differ from many scientific meetings, as they are more project oriented, are less formal, and have broadened the notion of what constitutes successful outputs in science. Within neuroscience, Brainhacks have the potential to evolve beyond their initial focus on neuroimaging data and include more projects on theory, hardware, and different types of neural data. With a growing global community and an iteratively improving format (Figure 1D), Brainhacks provide a successful template that can be extended to other scientific fields. Nearly a decade of successful Brainhacks have already brought about positive change for individual researchers and the field as a whole in the form of improved skills, reusable resources, new collaborations, and a diverse and inclusive community.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at <https://doi.org/10.1016/j.neuron.2021.04.001>.

CONSORTIA

The Brainhack Community includes Nasim Anousheh, Aurina Arnatkeviciute, Guillaume Auzias, Dipankar Bachar, Elise Bannier, Ruggero Basanisi, Arshitha Basavaraj, Marco Bedini, Pierre Bellec, R. Austin Benn, Kathryn Berluti, Steffen Bollmann, Saskia Bollmann, Claire Bradley, Jesse Brown, Augusto Buchweitz, Patrick Callahan, Micaela Y. Chan, Bramsh Q. Chandio, Theresa Cheng, Sidhant Chopra, Ai Wern Chung, Thomas G. Close, Etienne Combrisson, Giorgia Cona, R. Todd Constable, Claire Cury, Kamalaker Dadi, Pablo F. Damasceno, Samir Das, Fabrizio De Vico Fallani, Krista DeStasio, Erin W. Dickie, Lena Dorfschmidt, Eugene P. Duff, Elizabeth DuPre, Sarah L. Dziura, Nathalia B. Esper, Oscar Esteban, Shreyas Fadnavis, Guillaume Flandin, Jessica E. Flannery, John Flournoy, Stephanie J. Forkel, Alexandre R. Franco, Saampras Ganesan, Siyuan Gao, José C. García Alanis, Eleftherios Garyfallidis, Tristan Glatard, Enrico Glerean, Javier Gonzalez-Castillo, Cassandra D. Gould van Praag, Abigail S. Greene, Geetika Gupta, C. Alice Hahn, Yaroslav O. Halchenko, Daniel Handwerker, Thomas S. Hartmann, Valérie Hayot-Sasson, Stephan Heunis, Felix Hoffstaedt, Daniela M. Hohmann, Corey Horien, Horea-Ioan Ioanas, Alexandru D. Iordan, Chao Jiang, Michael Joseph, Jason Kai, Agah Karakuzu, David N. Kennedy, Anisha Keshavan, Ali R. Khan, Gregory Kiar, P. Christiaan Klink, Vincent Koppelmans, Serge Koudoro, Angela R. Laird,

Georg Langs, Marissa L. Laws, Roxane Licandro, Sook-Lei Liew, Tomislav Lipic, Krisanne Litinas, Daniel J. Lurie, Désirée Lussier, Christopher R. Madan, Lea-Theresa Mais, Sina Mansour L., J.P. Manzano-Patron, Dimitra Maoutsa, Matheus Marcon, Daniel S. Margulies, Giorgio Marinato, Daniele Marinazzo, Christopher J. Markiewicz, Camille Maumet, Felipe Meneguzzi, David Meunier, Michael P. Milham, Kathryn L. Mills, Davide Momi, Clara A. Moreau, Aysha Motala, Iska Moxon-Emre, Thomas E. Nichols, Dylan M. Nielson, Gustav Nilsson, Lisa Novello, Caroline O'Brien, Emily Olafson, Lindsay D. Oliver, John A. Onofrey, Edwina R. Orchard, Kendra Oudyk, Patrick J. Park, Mahboobeh Parsapoor, Lorenzo Pasquini, Scott Peltier, Cyril R. Pernet, Rudolph Pienaar, Pedro Pinheiro-Chagas, Jean-Baptiste Poline, Anqi Qiu, Tiago Quendera, Laura C. Rice, Joscelin Rocha-Hidalgo, Saige Rutherford, Matthias Scharinger, Dustin Scheinost, Deena Shariq, Thomas B. Shaw, Viviana Siless, Molly Simmonite, Nikoloz Sirmpilatze, Hayli Spence, Julia Sprenger, Andrija Stajduhar, Martin Szinte, Sylvain Takerkart, Angela Tam, Link Tejavibulya, Michel Thiebaut de Schotten, Ina Thome, Laura Tomaz da Silva, Nicolas Traut, Lucina Q. Uddin, Antonino Vallesi, John W. VanMeter, Nandita Vijayakumar, Matteo Visconti di Oleggio Castello, Jakub Vohryzek, Jakša Vukojević, Kirstie Jane Whitaker, Lucy Whitmore, Steve Wideman, Suzanne T. Witt, Hua Xie, Ting Xu, Chao-Gan Yan, Fang-Cheng Yeh, B.T. Thomas Yeo, and Xi-Nian Zuo.

ACKNOWLEDGMENTS

The present manuscript is part of a growing community effort to collate Brainhack-related insights and expertise into a Jupyter Book (http://brainhack.org/brainhack_jupyter_book/) that will serve as a centralized set of resources for the community; we acknowledge all the individuals who contributed and will make ongoing contributions to these resources. A pre-print version of the present manuscript is available as part of the Jupyter Book. Moreover, we would like to acknowledge all Brainhack organizers, supporters, presenters, and participants for their contribution to growing and maintaining this community. The benefits described in this manuscript would not be possible without them. We also thank all institutions, labs, and organizations who have helped this community grow, meet in stimulating environments, and add an excellent educational resource pool and agenda. With an expanding community, Brainhack's support network keeps growing, and we thank all labs and individual researchers for their dedication and expertise offered to this community (see http://brainhack.org/brainhack_jupyter_book/acknowledgments.html for a full list of individual acknowledgments; an updated list will be maintained in the Jupyter Book). Grants and funding bodies: This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 867458 awarded to Julia M. Huntenburg; from ANR-19-DATA-0025 NeuroWebLab for Katja Heuer, Roberto Toro, and Nicholas Traut; and from NIH K00MH122372 for Stephanie Noble. The Brainhack Community member list and

contributions of the different authors are detailed at http://brainhack.org/brainhack_jupyter_book/contributors.html. Our crediting system is described here: http://brainhack.org/brainhack_jupyter_book/neuroview_authorship-agreement.html.

DECLARATION OF INTERESTS

Anisha Keshavan is an employee of Octave Bioscience.

REFERENCES

- Bannier, E., Barker, G., Borghesani, V., Broeckx, N., Clement, P., Emblem, K.E., Ghosh, S., Glerean, E., Gorgolewski, K.J., Havu, M., et al. (2021). The Open Brain Consent: Informing research participants and obtaining consent to share brain imaging data. *Hum. Brain Mapp.* 42, 1945–1951, <https://doi.org/10.1002/hbm.25351>.
- Cameron Craddock, R., Margulies, D.S., Bellec, P., Nolan Nichols, B., Alcauter, S., Barrios, F.A., Burnod, Y., Cannistraci, C.J., Cohen-Adad, J., De Leener, B., et al. (2016). Brainhack: a collaborative workshop for the open neuroscience community. *Gigascience* 5, 16, <https://doi.org/10.1186/s13742-016-0121-x>.
- Gorgolewski, K.J., Auer, T., Calhoun, V.D., Craddock, R.C., Das, S., Duff, E.P., Flandin, G., Ghosh, S.S., Glatard, T., Halchenko, Y.O., et al. (2016). The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments. *Sci. Data* 3, 160044, <https://doi.org/10.1038/sdata.2016.44>.
- Heuer, K., Ghosh, S.S., Robinson Sterling, A., and Toro, R. (2016). Open Neuroimaging Laboratory. *Research Ideas and Outcomes* 2, e9113, <https://doi.org/10.3897/rio.2.e9113>.
- Hong, S.-J., Vos de Wael, R., Bethlehem, R.A.I., Larivière, S., Paquola, C., Valk, S.L., Milham, M.P., Di Martino, A., Margulies, D.S., Smallwood, J., and Bernhardt, B.C. (2019). Atypical functional connectome hierarchy in autism. *Nat. Commun.* 10, 1022, <https://doi.org/10.1038/s41467-019-08944-1>.
- Huntenburg, J.M., Steele, C.J., and Bazin, P.-L. (2018). Nighres: processing tools for high-resolution neuroimaging. *Gigascience* 7, <https://doi.org/10.1093/gigascience/giy082>.
- Kennedy, D.N., Abraham, S.A., Bates, J.F., Crowley, A., Ghosh, S., Gillespie, T., Goncalves, M., Grethe, J.S., Halchenko, Y.O., Hanke, M., et al. (2019). Everything Matters: The ReprNim Perspective on Reproducible Neuroimaging. *Front. Neuroinform.* 13, 1, <https://doi.org/10.3389/fninf.2019.00001>.
- Keshavan, A., Yeatman, J.D., and Rokem, A. (2019). Combining Citizen Science and Deep Learning to Amplify Expertise in Neuroimaging. *Front. Neuroinform.* 13, 29, <https://doi.org/10.3389/fninf.2019.00029>.
- Merali, Z. (2010). Computational science: ...Error. *Nature* 467, 775–777, <https://doi.org/10.1038/467775a>.

Supplemental information

Brainhack: Developing a culture of open, inclusive, community-driven neuroscience

Rémi Gau, Stephanie Noble, Katja Heuer, Katherine L. Bottenhorn, Isil P. Bilgin, Yu-Fang Yang, Julia M. Huntenburg, Johanna M.M. Bayer, Richard A.I. Bethlehem, Shawn A. Rhoads, Christoph Vogelbacher, Valentina Borghesani, Elizabeth Levitis, Hao-Ting Wang, Sofie Van Den Bossche, Xenia Kobeleva, Jon Hartz Legarreta, Samuel Guay, Selim Melvin Atay, Gael P. Varoquaux, Dorien C. Huijser, Malin S. Sandström, Peer Herholz, Samuel A. Nastase, AmanPreet Badhwar, Guillaume Dumas, Simon Schwab, Stefano Moia, Michael Dayan, Yasmine Bassil, Paula P. Brooks, Matteo Mancini, James M. Shine, David O'Connor, Xihe Xie, Davide Poggiali, Patrick Friedrich, Anibal S. Heinsfeld, Lydia Riedl, Roberto Toro, César Caballero-Gaudes, Anders Eklund, Kelly G. Garner, Christopher R. Nolan, Damion V. Demeter, Fernando A. Barrios, Junaid S. Merchant, Elizabeth A. McDevitt, Robert Oostenveld, R. Cameron Craddock, Ariel Rokem, Andrew Doyle, Satrajit S. Ghosh, Aki Nikolaidis, Olivia W. Stanley, Eneko Uruñuela, and The Brainhack Community

Supplementary Materials

We would like to thank all labs and individual researchers for their dedication and expertise offered to this community. These include (in alphabetical order): Allen Institute for Brain Science (Organization for Human Brain Mapping (OHBM) 2013), Amazon Web Services (OHBM 2013, OHBM 2014, Boston 2014, AMX 2015, Atlanta 2019), Athinoula A. Martinos Center for Biomedical Imaging (Boston 2014), Basque Center on Cognition, Brain and Language (Donostia 2018, 2019, 2020), Basque Government - Ikerbilerak grants (Donostia 2019), Biomedical Zone - Ryerson University (Canadian Association for Neuroscience - Association Canadienne des Neurosciences (CAN-ACN) 2019), Brain Institute of Rio Grande do Sul (Porto Alegre 2016–2019), Brain Vision LLC (ATL 2019), Canadian Consortium on Neurodegeneration in Aging (Montreal 2017), Centre for Addiction and Mental Health (Global Toronto 2017–2019, Global Ontario 2020), Center for Advanced Brain Imaging (Atlanta 2019), Centre for Aging + Brain Health Innovation, Baycrest (Global Toronto 2019, Global Ontario 2020), Center for Intelligent Imaging (San Francisco 2019), Center for Translational Research in Neuroimaging & Data Science (Atlanta 2019), Champalimaud Centre for the Unknown (Global Lisbon 2019), Child Mind Institute, Inc. (New York City 2014, Eastern Daylight Time 2014, Americas 2015, New York City 2015, Mexico 2015, Vienna 2016, Washington D.C. 2017, Global 2017, New York City 2017–2019, PRIMatE Data Exchange 2019), Canadian Open Neuroscience Platform (OHBM 2019, 2020; Global Montreal 2019, 2020, Global Toronto 2019, 2020, CAN-ACN 2019), Center for Open Neuroscience and Center for Cognitive Neuroscience at the Department of Psychological and Brain Sciences of Dartmouth College (Global Dartmouth 2017, 2018), Compute Ontario/SciNet (Global Toronto 2017, 2018, CAN-ACN 2019), Cognixion (CAN-ACN 2019), Donders Institute, the Netherlands (OpenMR Benelux 2020), Florida International University Center for Imaging Science (Miami EDT 2014, Miami Global 2017), ElementAI (Deep Brainhack 2017), Fetal-Neonatal Neuroimaging and Developmental Science Center, Boston Children's Hospital (Boston 2019), Frontiers (OHBM 2014), Frontiers in Neuroscience (OHBM 2013), George Washington Center for Healthcare Innovation and Policy Research (Washington D.C. 2017), Georgia State University Research Foundation (Atlanta 2019), Georgia Tech College of Sciences (Atlanta 2019), Georgetown University Center for Functional and Molecular Imaging (Washington D.C. 2019), Georgetown University Department of Psychology (Washington D.C. 2019, 2020), Georgetown University Methods Lab (Washington D.C. 2019, 2020), Healthy Brains for Healthy Lives (Deep Brainhack 2017), Gordon Museum of Pathology (Brainhack London 2017), Inria (Global Rennes 2018, Global Western France 2019), Intel Labs (Princeton 2019), International Neuroinformatics Coordinating Facility [INCF] (SfN 2012, ABA 2012, OHBM 2013–2016, OHBM 2020, Leiden 2014, Mexico 2015, NWB 2015, Neuroimaging Data Model 2015, 3xABBigNeuron 2015 (2xCambridge, 1xJanelia), ABBigNeuron 2016, Global Stockholm 2017–2019, Montreal 2018, NI 2019), INCF Belgian Node (Belgian Node Hackathon 2014), INCF Czech Node (Czech Node Hackathon 2019), INCF Japan Node (Brain Atlas Hackathon 2015, NIX&odML Hackathon 2016–2018, 2020), Institut Pasteur (Paris 2016, Paris: Anatomy 2016, Global Paris 2017, 2018), Interaxon/Muse (CAN-ACN 2019, Global Toronto 2019), IRISA (Global Rennes 2018, Global Western France 2019), Karl-Franzens-Universität Graz (Vienna 2016), La Paillasse (Global Paris 2017), Ludmer Centre for Neuroinformatics & Mental Health (Open Science Hackathon 2019, OHBM 2018–2020; INCF 2018; Global Montreal 2017–2020), Marburg University (Marburg 2019, 2020), MATRICE (Paris 2013), Max Planck Institute for Cognitive and Brain Sciences (Leipzig 2012), McGill Centre for Integrative Neuroscience (Deep Brainhack 2017, Global 2017, OHBM 2018), McGill University, University of Montreal, Concordia University, Polytechnique Montreal (Montreal Brainhack School 2018–20), Microsoft Azure (OHBM 2015), Mozilla Lab Paris (Paris: Lesions 2017), National Institutes of Health (Washington D.C. 2017), NeuroMod (Global Montreal 2019; OHBM 2019, 2020), Neukom Institute (Global Dartmouth 2017, 2018), Neurohackademy (2016–2020), NeurotechX

(Deep Brainhack 2017), NIH BD2K Center (1U54EB020406-01) Big Data for Discovery Science (USC, PI: Toga) (Los Angeles 2015, 2016), NIH BD2K Center (1U54EB020403-01) Enigma Center for Worldwide Medicine, Imaging, and Genomics (USC, PI: Thompson)(Los Angeles 2015, 2016), NIH BD2K Centers-Coordinating Center Hackathon Grant (Vienna 2016, Los Angeles 2016), NIH BD2K Supplement for NCANDA (3U01AA021697-04S1) and NCANDA: Data Analysis Component (5U01AA021697-04) (SRI International, PI: Pohl) (OHBM 2015, Mexico 2015), NVIDIA (Atlanta 2019), Ontario Brain Institute (Global Toronto 2017, 2019, CAN-ACN 2019, Global Ontario 2020), Opereason Analytics Inc. (Global Toronto 2019), Organization for Human Brain Mapping (OHBM 2013–2020), OHBM Australian chapter (OHBM 2020), OpenfMRI (OHBM 2016), OpenNeuro (OHBM 2020), Open Science Initiative University Marburg (Marburg 2018–2020), PNC - Padova Neuroscience Center (Padova 2018, 2019, 2020), Pontifical Catholic University of Rio Grande do Sul (Porto Alegre 2016–2019), Princeton University Department of Psychology Langfeld Fund (Princeton 2019), Quebec Bioimaging Network (Montreal 2014-15, 2017-19, OHBM 2020), ReproNim: Center for Reproducible Neuroimaging Computation (NIH-NIBIB P41 EB019936 (Los Angeles 2016, New York City 2020, Princeton 2019), Rotman Research Institute - Baycrest (Global Toronto 2019, Global Ontario 2020), Siemens (Paris 2013), Sticker Giant (Atlanta 2019), Toronto Neuroimaging Facility, Dept of Psychiatry, University of Toronto (Global Toronto 2019, Global Ontario 2020), Unité de Neuroimagerie Fonctionnelle, Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal (Montreal 2014-15), UNIQUE (OHBM 2020), University of Alabama at Birmingham (UAB 2017–2019), University of Miami Flipse Funds (Miami 2015), USC Viterbi School of Engineering (Los Angeles 2016), USC Stevens Neuroimaging and Informatics Institute (Los Angeles 2016), The University of Texas at Austin Dell Medical School (Global 2018), University of Warsaw (Warsaw 2017, 2019, 2020 (cancelled)), University of Zurich (Zurich 2018, 2019), Medical University of Vienna (Vienna 2016, 2019), Wellcome Centre for Integrative Neuroimaging (OHBM 2020), Wellcome Trust (OHBM 2016, Global Warwick 2017, PRIMatE Data Exchange 2019), WinAIML (Global Toronto 2019), Womanium (Washington D.C. 2017), The Neuro Bureau (Leipzig 2012, OHBM 2015, Washington D.C. 2017), University of Washington eScience Institute (Global 2016, 2019), and Yale University - MRRC and Biolmage Suite Web funds (Global 2018, 2019). An updated list of acknowledgments is available [here](#).

Consortium

The Brainhack community:

Nasim Anousheh¹, Aurina Arnatkeviciute², Guillaume Auzias³, Dipankar Bachar³, Elise Bannier⁴, Ruggero Basanisi³, Arshitha Basavaraj⁵, Marco Bedini⁶, Pierre Bellec^{7,8}, R. Austin Benn⁹, Kathryn Berluti¹⁰, Steffen Bollmann^{11,12}, Saskia Bollmann¹², Claire Bradley¹³, Jesse Brown¹⁴, Augusto Buchweitz¹⁵, Patrick Callahan¹⁶, Micaela Y. Chan¹⁷, Bramsh Q. Chandio¹⁸, Theresa Cheng¹⁹, Sidhant Chopra², Ai Wern Chung²⁰, Thomas G. Close^{21,22}, Etienne Combrisson³, Giorgia Cona²³, R. Todd Constable^{24,25}, Claire Cury²⁶, Kamalaker Dadi²⁷, Pablo F. Damasceno²⁸, Samir Das²⁹, Fabrizio De Vico Fallani^{30,31}, Krista DeStasio³², Erin W. Dickie^{33,34}, Lena Dorfschmidt³⁵, Eugene P. Duff³⁶, Elizabeth DuPre³⁷, Sarah L. Dziura³⁸, Nathalia B. Esper¹⁵, Oscar Esteban³⁹, Shreyas Fadnavis⁴⁰, Guillaume Flandin⁴¹, Jessica E. Flannery⁴², John Flournoy⁴³, Stephanie J. Forkel^{44,45}, Alexandre R. Franco^{46,47,48}, Saampras Ganesan^{49,50}, Siyuan Gao⁵¹, José C. García Alanis⁵², Eleftherios Garyfallidis¹, Tristan Glatard⁵³, Enrico Glerian^{54,55}, Javier Gonzalez-Castillo⁵⁶, Cassandra D. Gould van Praag^{57,58}, Abigail S. Greene⁵⁹, Geetika Gupta^{60,61}, C. Alice Hahn⁶², Yaroslav O. Halchenko⁶³, Daniel Handwerker⁶⁴, Thomas S. Hartmann⁶⁵, Valérie Hayot-Sasson⁵³, Stephan Heunis⁶⁶, Felix Hoffstaedter^{67,68}, Daniela M. Hohmann⁶⁹, Corey Horien⁵⁹, Horea-Ioan Ioanas^{70,71}, Alexandru D. Iordan⁷², Chao Jiang⁷³, Michael Joseph⁷⁴, Jason Kai⁷⁵, Agah Karakuzu^{76,77}, David N. Kennedy⁷⁸, Anisha Keshavan^{79,80,81}, Ali R. Khan⁸², Gregory Kiar⁸³, P. Christiaan Klink⁸⁴, Vincent Koppelmans⁸⁵, Serge Koudoro¹, Angela R. Laird⁸⁶, Georg Langs^{87,88}, Marissa L. Laws⁸⁹, Roxane Licandro^{90,91}, Sook-Lei Liew⁹², Tomislav Lipic⁹³, Krisanne Litinas⁹⁴, Daniel J Lurie⁹⁵, Désirée Lussier⁸, Christopher R. Madan⁹⁶, Lea-Theresa Mais⁹⁷, Sina Mansour L.⁵⁰, J.P. Manzano-Patron⁹⁸, Dimitra Maoutsa⁹⁹, Matheus Marcon¹⁰⁰, Daniel S. Margulies^{101,102}, Giorgio Marinato⁶, Daniele Marinazzo¹⁰³, Christopher J. Markiewicz¹⁰⁴, Camille Maumet²⁶, Felipe Meneguzzi¹⁰⁰, David Meunier³, Michael P. Milham⁴⁷, Kathryn L. Mills^{19,105}, Davide Momi¹⁰⁶, Clara A. Moreau^{107,108}, Aysha Motala¹⁰⁹, Iska Moxon-Emre¹¹⁰, Thomas E. Nichols^{111,112}, Dylan M. Nielson¹¹³, Gustav Nilsson^{114,115}, Lisa Novello⁶, Caroline O'Brien¹¹⁶, Emily Olafson¹¹⁷, Lindsay D. Oliver¹¹⁸, John A. Onofrey^{119,120}, Edwina R. Orchard², Kendra Oudyk³⁷, Patrick J. Park¹²¹, Mahboobeh Parsapoor^{122,123,124}, Lorenzo Pasquini¹²⁵, Scott Peltier⁹⁴, Cyril R. Pernet^{126,127}, Rudolph Pienaar^{128,129}, Pedro Pinheiro-Chagas¹³⁰, Jean-Baptiste Poline^{37,131}, Anqi Qiu¹³², Tiago Quendera¹³³, Laura C. Rice^{134,135}, Joscelin Rocha-Hidalgo¹⁰, Saige Rutherford¹³⁶, Mathias Scharinger¹³⁷, Dustin Scheinost¹¹⁹, Deena Shariq¹³⁸, Thomas B. Shaw¹², Viviana Siless¹³⁹, Molly Simmonite⁷², Nikoloz Sirmipilatzé¹⁴⁰, Hayli Spence¹⁴¹, Julia Sprenger³, Andrija Stajduhar^{142,143}, Martin Szinte³, Sylvain Takerkart³, Angela Tam¹⁴⁴, Link Tejavibulya¹⁴⁵, Michel Thiebaut de Schotten^{146,147}, Ina Thome⁶⁹, Laura Tomaz da Silva¹⁰⁰, Nicolas Traut^{148,149}, Lucina Q. Uddin¹⁵⁰, Antonino Vallesi^{151,152}, John W. VanMeter^{153,154}, Nandita Vijayakumar¹⁵⁵, Matteo Visconti di Oleggio Castello¹³¹, Jakub Vohryzek⁵⁸, Jakša Vukojević¹⁵⁶, Kirstie Jane Whitaker¹⁵⁷, Lucy Whitmore¹⁹, Steve Wideman^{158,159}, Suzanne T. Witt¹⁶⁰, Hua Xie³⁸, Ting Xu⁴⁷, Chao-Gan Yan^{161,162}, Fang-Cheng Yeh¹⁶³, B.T. Thomas Yeo¹⁶⁴, Xi-Nian Zuo^{165,166,167}

¹Intelligent Systems Engineering, Indiana University, Bloomington, IN, USA, ²Turner Institute for Brain and Mental Health, Monash University, Melbourne, Australia, ³Institut de Neurosciences de la Timone UMR 7289, CNRS - Aix-Marseille University, Marseille, France, ⁴Empenn ERL U 1228 IRISA UMR 6074, CHU Rennes, Univ Rennes, Inria, CNRS, Inserm,

Rennes, France, ⁵Data Science and Sharing Team, National Institute of Mental Health, Bethesda, MD, USA, ⁶Center for Mind Brain Sciences (CIMeC), University of Trento, Trento, Italy, ⁷Psychology Department, Université de Montréal, Montréal, QC, Canada, ⁸Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal, Université de Montréal, Montréal, QC, Canada, ⁹Centro Nacional de Investigaciones Cardiovasculares (CNIC), Madrid, Spain, ¹⁰Department of Psychology, Georgetown University, Washington D.C., USA, ¹¹School of Information Technology and Electrical Engineering, The University of Queensland, Brisbane, Australia, ¹²Centre for Advanced Imaging, The University of Queensland, Brisbane, Australia, ¹³Queensland Brain Institute, The University of Queensland, St Lucia, Australia, ¹⁴Department of Neurology, University of California, San Francisco, San Francisco, CA, USA, ¹⁵Brain Institute of Rio Grande do Sul, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil, ¹⁶Memory and Aging Center, University of California, San Francisco, San Francisco, CA, USA, ¹⁷Center for Vital Longevity, School of Behavioral and Brain Sciences, University of Texas at Dallas, Dallas, TX, USA, ¹⁸Department of Intelligent Systems Engineering, Indiana University, Bloomington, IN, USA, ¹⁹Department of Psychology, University of Oregon, Eugene, OR, USA, ²⁰Fetal-Neonatal Neuroimaging and Developmental Science Center, Boston Children's Hospital, Harvard Medical School, Boston, MA, USA, ²¹School of Biomedical Engineering, The University of Sydney, Sydney, Australia, ²²National Imaging Facility, Sydney, Australia, ²³Department of General Psychology, University of Padova, Padova, Italy, ²⁴Yale Magnetic Resonance Research Center, Yale University, New Haven, CT, USA, ²⁵School of Medicine, Yale University, New Haven, CT, USA, ²⁶Empenn ERL U 1228 IRISA UMR 6074, Univ Rennes, Inria, CNRS, Inserm, Rennes, France, ²⁷Parietal, INRIA, Saclay, France, ²⁸Center for Intelligent Imaging, University of California, San Francisco, San Francisco, CA, USA, ²⁹McGill Centre for Integrative Neuroscience, Montreal Neurological Institute-Hospital, Montréal, QC, Canada, ³⁰ARAMIS team, INRIA, Paris, France, ³¹Paris Brain Institute, Sorbonne Universités, Inserm 1127, Cnrs 7225, AP-HP, Paris, France, ³²University of Oregon, Eugene, OR, USA, ³³Krembil Centre from Neuroinformatics, Centre for Addiction and Mental Health, Toronto, ON, Canada, ³⁴Department of Psychiatry, University of Toronto, Toronto, ON, Canada, ³⁵Brain Mapping Unit, Department of Psychiatry, University of Cambridge, Cambridge, UK, ³⁶University of Oxford, Oxford, UK, ³⁷NeuroDataScience - ORIGAMI laboratory, Faculty of Medicine and Health Sciences, McGill University, Montréal, QC, Canada, ³⁸Department of Psychology, University of Maryland, College Park, MD, USA, ³⁹Department of Radiology, Lausanne University Hospital, University of Lausanne, Lausanne, Switzerland, ⁴⁰Indiana University, Bloomington, IN, USA, ⁴¹Wellcome Centre for Human Neuroimaging, University College London, London, UK, ⁴²Department of Psychology and Neuroscience, University of North Carolina, Chapel Hill, NC, USA, ⁴³Department of Psychology, Harvard University, Cambridge, MA, USA, ⁴⁴CNRS UMR 5293 Institut des Maladies Neurodégénératives, Bordeaux, France, ⁴⁵Department Neuroimaging, Institute of Psychiatry, Psychology and Neurosciences, King's College London, London, UK, ⁴⁶Center for Biomedical Imaging and Neuromodulation, Nathan Kline Institute, Orangeburg, NY, USA, ⁴⁷Center for the Developing Brain, Child Mind Institute, New York City, NY, USA, ⁴⁸Department of Psychiatry, NYU Grossman School of Medicine, New York City, NY, USA, ⁴⁹Systems Neuroscience, Melbourne Neuropsychiatry Centre, Melbourne, Australia, ⁵⁰Department of Biomedical Engineering, The University of Melbourne, Melbourne, Australia, ⁵¹Yale University, New Haven, CT, USA, ⁵²Department of Psychology, Philipps Universität, Marburg, Germany, ⁵³Department of Computer Science and Software Engineering, Concordia University, Montréal, QC, Canada, ⁵⁴Department of Neuroscience

and Biomedical Engineering, Aalto University, Espoo, Finland, ⁵⁵International Laboratory of Social Neurobiology, Institute of Cognitive Neuroscience, National Research University Higher School of Economics, Moscow, Russia, ⁵⁶Section on Functional Imaging Methods, National Institutes of Health, Bethesda, MD, USA, ⁵⁷Wellcome Centre for Integrative Neuroimaging, University of Oxford, Oxford, UK, ⁵⁸Department of Psychiatry, University of Oxford, Oxford, UK, ⁵⁹Interdepartmental Neuroscience Program, Yale School of Medicine, New Haven, CT, USA, ⁶⁰Department of Psychology, Western University, London, ON, Canada, ⁶¹Brain and Mind Institute, Western University, London, ON, Canada, ⁶²Department of Radiology and Biomedical Imaging, Yale School of Medicine, New Haven, CT, USA, ⁶³Center for Open Neuroscience, Department of Psychological and Brain Sciences, Dartmouth College, Hanover, NH, USA, ⁶⁴Section on Functional Imaging Methods, National Institute of Mental Health, Bethesda, MD, USA, ⁶⁵Philipps Universität, Marburg, Germany, ⁶⁶Department of Electrical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands, ⁶⁷Institute of Neuroscience and Medicine, Brain & Behaviour (INM-7), Research Centre Jülich, Jülich, Germany, ⁶⁸Institute of Systems Neuroscience, Medical Faculty, Heinrich-Heine University Duesseldorf, Duesseldorf, Germany, ⁶⁹Laboratory for Multimodal Neuroimaging, Department of Psychiatry and Psychotherapy, University of Marburg, Marburg, Germany, ⁷⁰Biological Engineering, MIT, Cambridge, MA, USA, ⁷¹D-ITET, ETH Zurich, Zurich, Switzerland, ⁷²Department of Psychology, University of Michigan, Ann Arbor, MI, USA, ⁷³Key Laboratory of Behavioral Sciences, Institute of Psychology, Chinese Academy of Sciences, Beijing, China, ⁷⁴Campbell Family Mental Health Research Institute, Centre for Addiction and Mental Health, Toronto, ON, Canada, ⁷⁵Department of Medical Biophysics, University of Western Ontario, London, ON, Canada, ⁷⁶NeuroPoly Lab, Institute of Biomedical Engineering, Montréal, QC, Canada, ⁷⁷Montreal Heart Institute, Université de Montréal, Montréal, QC, Canada, ⁷⁸University of Massachusetts Medical School, Worcester, MA, USA, ⁷⁹Octave Bioscience, Menlo Park, CA, USA, ⁸⁰eScience Institute, University of Washington, Seattle, WA, USA, ⁸¹Institute for Learning and Brain Science, University of Washington, Seattle, WA, USA, ⁸²Department of Medical Biophysics, Western University, London, ON, Canada, ⁸³Montréal Neurological Institute, McGill University, Montréal, QC, Canada, ⁸⁴Department of Vision & Cognition, Netherlands Institute for Neuroscience, Amsterdam, The Netherlands, ⁸⁵Department of Psychiatry, University of Utah, Salt Lake City, UT, USA, ⁸⁶Department of Physics, Florida International University, Miami, FL, USA, ⁸⁷CIR Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Vienna, Austria, ⁸⁸CSAIL, MIT, Cambridge, MA, USA, ⁸⁹Center for the Study of Learning, Georgetown University Medical Center, Washington D.C., USA, ⁹⁰Medical University of Vienna, Vienna, Austria, ⁹¹TU Wien, Vienna, Austria, ⁹²Stevens Neuroimaging and Informatics Institute, University of Southern California, Los Angeles, CA, USA, ⁹³Laboratory for Machine Learning and Knowledge Representation, Ruder Boskovic Institute, Zagreb, Croatia, ⁹⁴Functional MRI Laboratory, University of Michigan, Ann Arbor, MI, USA, ⁹⁵Department of Psychology, University of California, Berkeley, Berkeley, CA, USA, ⁹⁶Psychology, University of Nottingham, Nottingham, UK, ⁹⁷University of Marburg, Marburg, Germany, ⁹⁸Radiological Sciences & Sir Peter Mansfield Imaging Centre, University of Nottingham, Nottingham, UK, ⁹⁹Institute of Software Engineering and Theoretical Computer Science, Technical University of Berlin, Berlin, Germany, ¹⁰⁰School of Technology, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil, ¹⁰¹CNRS, Paris, France, ¹⁰²INCC UMR 8002, Université de Paris, Paris, France, ¹⁰³Department of Data Analysis, Ghent University, Ghent, Belgium, ¹⁰⁴Department of Psychology, Stanford University, Stanford, CA, USA, ¹⁰⁵PROMENTA Research Center,

Department of Psychology, University of Oslo, Oslo, Norway, ¹⁰⁶Department of Neuroscience, Imaging and Clinical Sciences, University G. d'Annunzio of Chieti, Chieti, Italy, ¹⁰⁷Human Genetics and Cognitive Functions, Pasteur Institute, Paris, France, ¹⁰⁸Université de Montréal, Montréal, QC, Canada, ¹⁰⁹Department of Psychology, University of Western Ontario, London, ON, Canada, ¹¹⁰Child, Youth and Family Service, Centre for Addiction and Mental Health, Toronto, ON, Canada, ¹¹¹Big Data Institute, University of Oxford, Oxford, UK, ¹¹²WIN-FMRIB, University of Oxford, Oxford, UK, ¹¹³Section of Clinical and Computational Psychiatry (Comp Ψ), National Institute of Mental Health, Bethesda, MD, USA, ¹¹⁴Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden, ¹¹⁵Department of Psychology, Stockholm University, Stockholm, Sweden, ¹¹⁶Department of Neuroscience, Georgetown University, Washington D.C., USA, ¹¹⁷Department of Neuroscience, Weill Cornell Medicine, New York City, NY, USA, ¹¹⁸Centre for Addiction and Mental Health, Toronto, ON, Canada, ¹¹⁹Department of Radiology & Biomedical Imaging, Yale School of Medicine, New Haven, CT, USA, ¹²⁰Department of Urology, Yale School of Medicine, ¹²¹Engineering, University of Western Ontario, London, ON, Canada, ¹²²Computer Science Department, University of Toronto, Toronto, ON, Canada, ¹²³Vector Institute for Artificial Intelligence, Toronto, ON, Canada, ¹²⁴Women in Artificial Intelligence & Machine Learning (WinAIML), Montréal, QC, Canada, ¹²⁵Neurology Department, Memory and Aging Center, University of California, San Francisco, San Francisco, CA, USA, ¹²⁶Centre for Clinical Brain Sciences, University of Edinburgh, Edinburgh, UK, ¹²⁷Neurobiology Research Unit, Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark, ¹²⁸Radiology, Boston Children's Hospital, Harvard Medical School, Boston, MA, USA, ¹²⁹Radiology, Harvard Medical School, Boston, MA, USA, ¹³⁰Stanford University, Stanford, CA, USA, ¹³¹Helen Wills Neuroscience Institute, University of California, Berkeley, Berkeley, CA, USA, ¹³²Department of Biomedical Engineering, National University of Singapore, Singapore, Singapore, ¹³³Champalimaud Research, Lisbon, Portugal, ¹³⁴Neuroscience, American University, Washington D.C., USA, ¹³⁵Neurology, Johns Hopkins University, Baltimore, MD, USA, ¹³⁶Department of Psychiatry, University of Michigan, Ann Arbor, MI, USA, ¹³⁷German Linguistics & Fine Arts Science, Institute of German Linguistics, University of Marburg, Marburg, Germany, ¹³⁸University of Maryland, College Park, MD, USA, ¹³⁹Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School, Boston, MA, USA, ¹⁴⁰Functional Imaging Laboratory, German Primate Center - Leibniz Institute for Primate Research, Göttingen, Germany, ¹⁴¹Section on Molecular Neurobiology, National Institute of Child and Human Development, Bethesda, MD, USA, ¹⁴²Croatian Institute for Brain Research, School of Medicine, University of Zagreb, Zagreb, Croatia, ¹⁴³Andrija Stampar School of Public Health, School of Medicine, University of Zagreb, Zagreb, Croatia, ¹⁴⁴Perceiv Research Inc., Montréal, QC, Canada, ¹⁴⁵Interdepartmental Neuroscience Program, Yale University, New Haven, CT, USA, ¹⁴⁶Brain Connectivity and Behaviour Laboratory, Sorbonne Universities, Paris, France, ¹⁴⁷Groupe d'Imagerie Neurofonctionnelle, Institut des Maladies Neurodégénératives- UMR 5293, CNRS, CEA University of Bordeaux, Bordeaux, France, ¹⁴⁸Human Genetics and Cognitive Functions, Institut Pasteur, Paris, France, ¹⁴⁹Center for Research and Interdisciplinarity, University of Paris, Paris, France, ¹⁵⁰Department of Psychology, University of Miami, Coral Gables, FL, USA, ¹⁵¹Department of Neuroscience & Padova Neuroscience Center, University of Padova, Padova, Italy, ¹⁵²IRCCS San Camillo Hospital, Venice, Italy, ¹⁵³Department of Neurology, Georgetown University, Washington D.C., USA, ¹⁵⁴Center for Functional and Molecular Imaging, Georgetown University Medical Center, Washington D.C., USA, ¹⁵⁵School of Psychology, Deakin University, Melbourne,

Australia, ¹⁵⁶University psychiatric hospital Vrače, Zagreb, Croatia, ¹⁵⁷Tools, Practices and Systems Research Programme, Alan Turing Institute, London, UK, ¹⁵⁸Neurobiology - Comprehensive Neuroscience Center, University of Alabama at Birmingham, Birmingham, AL, USA, ¹⁵⁹CNC, University of Alabama at Birmingham, Birmingham AL, USA, ¹⁶⁰BrainsCAN, University of Western Ontario, London, ON, Canada, ¹⁶¹CAS Key Laboratory of Behavioral Science, Institute of Psychology, Beijing, China, ¹⁶²International Big-Data Center for Depression Research, Chinese Academy of Sciences, Beijing, China, ¹⁶³Department of Neurological Surgery, University of Pittsburgh, Pittsburgh, PA, USA, ¹⁶⁴Department of Electrical and Computer Engineering, Centre for Sleep & Cognition & Centre for Translational MR Research, National University of Singapore, Singapore, Singapore, ¹⁶⁵State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, China, ¹⁶⁶National Basic Public Science Data Center, Chinese Academy of Sciences, Beijing, China, ¹⁶⁷School of Education Sciences, Nanning Normal University, Nanning, China