2021 Marmoset Community White Paper

I. Executive Summary

A. Marmosets are a Cornerstone Biomedical Model System

The common marmoset (*Callithrix jacchus*) has experienced unprecedented growth as an animal model in biomedical research across the United States and has now emerged as crucial engine for scientific discovery. *There are now more than 40 research colonies serving over 50+ Principal Investigators (PIs) in the United States.* Since the 2019 Marmoset Community White Paper, investment in marmoset research by the National Institutes of Health (NIH) has increased considerably, reflective of the growing interest in and importance of the marmoset model. The initial grassroots efforts by Investigators to champion this nonhuman primate are now being complemented by support from crucial funding agencies - such as the NIH - with both targeted investments in key infrastructure needed to further grow the model in the United States and an increase in support for investigator-initiated proposals. While continued support for these initial investments remain crucial for the field's continued growth, new areas of concern and opportunities for accelerating the model have presented themselves in parallel with the growth of marmoset use nationwide. Specific strategic investment is now needed by the NIH to address these issues and allow the marmoset model to realize its full potential as a cornerstone species able to accelerate the rate of discovery in biomedical research and better understand human disease.

This White Paper highlights both the advantages of marmoset monkeys for accomplishing the stated mission of the NIH and identifies the crucial, strategic investments needed to support and accelerate the impact of this model system for biomedical research.

B. Past NIH Investment in Marmoset Research

Over the past 5 fiscal years [2016-2020] the NIH has invested ~$156,000,000 in research involving marmosets. In FY2020, the NIH supported 54 grants with over $49,700,000 in funding from 9 different Institutes and the Office of the Director. FY 2020 was the highest level of financial support by the NIH for marmoset research and represented a ~40% increase in funding from the previous year (FY2019). While three marmoset-specific RFAs released by the NIH BRAIN Initiative for targeted investment in national infrastructure to support marmoset research contributed to the increased support, the prodigious rise in funding for this NHP model primarily reflects successful efforts to researchers to garner financial support through more standard investigator initiated funding mechanisms (i.e. NIH R01, R21, U01, R34 etc grants).

C. Recommendations & Priorities for Future NIH investment in Marmoset Research

The marmoset model has witnessed substantial growth over the past decade largely through grassroots, researcher-initiated projects. These foundational efforts are now being complemented by the NIH as marmosets are increasingly recognized as a keystone model organism for addressing NIH's stated goal to enhance health, lengthen life and reduce illness and disability in humans. As a nonhuman primate species with several unique reproductive, physiological and behavioral advantages, marmosets are uniquely positioned to accelerate progress to this end. We are presently at a crucial juncture in the development of the model; substantial investment by the NIH is needed to complement new core resources and infrastructure for the rapidly growing community of marmoset investigators that will facilitate an accelerated rate of discovery for human diseases.

Due to Covid-19, the biannual Marmoset PI meeting in April 2020 was cancelled and the community PIs gathered for a virtual meeting later the same year. in November. The goal of this

abbreviated meeting was to identify current bottlenecks for growth and the crucial resources needed to overcome these challenges. Based on input and feedback from the community, we have identified the following four resource priorities that require immediate investment from the NIH.

1. Investment in Developing Marmoset Behavioral Techniques & Technologies
2. Investment in Viral-based Gene-Editing Technologies in Marmosets.
3. Support for Cross-Institutional Training of Students/Post-Docs
4. Centralized Resource for Cataloging & Distributing Aging Marmosets

To address these issues, we recommend the NIH support the following identified priorities through several crucial RFA/PARs within the next year to foster the continued development of foundational infrastructure and resources for marmoset research to flourish in the United States.

D. Marmoset Community Initiatives

Grass roots efforts by marmoset investigators is a pivotal foundation of our community's future success. We have established both a website – www.marmohub.org – and a Slack workspace for PIs to coordinate efforts and facilitate communication across laboratories. During the 2020 Marmoset PI meeting, the community identified two new initiatives that have since been implemented in 2021.

1. Create a Forum for Sharing Methodological & Surgical Details.
2. Establish a Marmoset Journal Club.

E. Marmosets are a Keystone Model to Understand and Cure Human Disease in the 21st Century.

The principal long-term goal of the marmoset research community is to expand the use of this model organism in order to accelerate our rate of discovery for understanding human disease. The recommendations in this White Paper for immediate strategic investments by the NIH supporting crucial resources and infrastructure are needed to maximize the impact of marmosets as a cornerstone model organism to study human diseases. Marmosets offer unique opportunities to study and understand biomedical processes that have not been feasible to model in other nonhuman primates. The species' rapid development and aging, for example, make it possible to longitudinally examine diseases that afflict humans at specific times in life, both during ontogeny and senescence. Likewise, the small size and high fecundity provide logistical advantages for the development and implementation of next-generation gene-editing technologies. Furthermore, due to the notable similarities in their social behavior, cognition and communication with humans, as well as the shared functional brain architecture of all primates - this nonhuman primate species is uniquely suited to model the neuropsychological disorders that afflict humans. The marmoset model has the potential to transform our understanding of the myriad of genetic, physiological and environmental factors affecting human disease as a keystone biomedical model in the next chapter of scientific inquiry.

II. Introduction

A. The marmoset is establishing itself as a keystone animal model for biomedical research

The common marmoset (*Callithrix jacchus*) is a New World monkey that has been used as a model system in biomedical research for several decades. As outlined in the 2019 Marmoset Community White Paper, the use of marmosets has rapidly increased in the past decade. While only 7 marmoset colonies existed in the United States in 2008, nearly 40 colonies have been established by 2021 that support over 50+ Investigators. The growth of the marmoset model is also not restricted to the United States. In North America, two Institutions in Canada – Western University and McGill University – have heavily invested in marmoset research by building needed research infrastructure and establishing large breeding colonies that each support multiple Investigators. Biomedical research with marmosets has also continued to expand in Asia (China and Japan), Australia, UK, Europe (France, Germany) and Israel. The proliferation of marmosets on an international stage indicates that the model's ascension in the United States is not occurring in isolation, but rather reflects the broader recognition of the species' valuable and unique attributes as a powerful animal model for biomedical research on a global scale. Continued strategic investment in marmosets by the NIH will further demonstrate the United States' role as an international leader in nonhuman primate research.

The growing interest in marmosets both domestically and internationally stems from an awareness of the species scientific and logistical advantages that this species of New World primates offers biomedical research. For example, marmosets have a relatively short gestation of only ~150 days and typically birth fraternal twins, which establishes marmosets as having amongst the highest fertility of any primate (1). Likewise, marmoset development is notably rapid – reaching adulthood in ~14-18months and becoming aged at ~8yo (2, 3) Marmosets are similar in body size as rodents – weighing ~300-400g – making it possible for large populations to be housed in smaller facilities than larger primates. Yet in stark contrast to rodents, marmosets exhibit the shared physiological, behavioral and cognitive characteristics that distinguish primates from all other animals, including the core functional architecture and organization of our nervous system (4). This unique complement of characteristics affords the exciting opportunity to feasibly utilize a primate species to model many of the diseases that afflict humans, ranging from those that affect humans at specific times in life – including both developmentally and during aging – to neuropsychiatric disorders that impact uniquely primate properties of our brain.

A related advantage of marmosets has been the species' amenability to modern molecular gene-editing technologies. Following Dr. Erika Sasaki and colleague's pioneering work in marmosets demonstrating the first germline transmission of a transgene in a nonhuman primate (5) efforts to implement modern gene-editing technologies in marmosets have accelerated (6-8). This includes efforts to develop the most modern gene-editing approaches for use in marmosets, such as CRISPR (9-11), as well as viral based approaches that make it possible to more selectively target specific cell types and circuits in the brain (12-16) . These viral technologies include the intravenous delivery of AAV capsids designed to cross the blood-brain barrier in marmosets and are particularly promising because of their clear advantages for translational work (17). Researchers are increasingly leveraging the advantages of optogenetic and chemogenetic techniques to selectively manipulate circuits in the marmoset brain (18-21), while also implementing calcium-imaging approaches in an effort to better understand large populations of neurons in the marmoset brain (22-25). As this critical line of research and technical development continues to evolve, the promise of marmosets as primate model that can leverage genetic technologies is beginning to be realized.

B. The significance of marmosets as a NHP model in the 21st Century in the United States.

Rhesus monkeys have been and currently remain the dominant nonhuman primate model for biomedical research in the United States. For the past few decades, biomedical research in the US that uses macaques have relied on importing animals from international sources, primarily from China. Recently, the availability of these monkeys for import into the US has rapidly declined since China declared these animals a key resource and has invested heavily in expanding their own research using rhesus monkeys, including in the Neurosciences (https://www.economist.com/international/2021/07/24/attitudes-towards-experimenting-on-monkeys-are-diverging). Given the enormous expense domestically to produce large quantities of rhesus monkeys, it may not be feasible (or at least extremely difficult) to meet the research needs in the coming years. Owing to their small body size that allows for housing large numbers of animals in standard facilities, high fecundity and rapid development, marmosets are uniquely suited to fill this gap and emerge as an increasingly valuable primate model in the next decade. Efforts already underway to establish marmoset breeding centers in the US are strategically important to meet these growing needs. Because most individual marmoset laboratories also breed animals, these large-scale breeding centers can be complemented by animals made available from investigators across the country through a coordinated national effort.

C. Current Uses of Marmosets in Biomedical Research

Marmosets are utilized as animal models in a wide diversity of biomedical research disciplines, ranging from infectious disease to reproductive biology but neuroscience remains the dominant area in which this New World primate is used. The increasing interest in marmosets is also reflected in the notable rise in marmoset publications in the past two years. Using 'marmoset' as a keyword search in PubMed for each of the past two decades shows a steady increase in number of marmoset publications in peer-reviewed scientific journals (Figure 1). Over the past two years - 2019 and 2020 - the number of published papers on marmosets eclipsed 250 papers annually. Listed below are representative publications in marmosets over this time period. The selective list only encompasses peer-reviewed research papers in marmosets in high-profile scientific journals. Of note, the Representative Publications that reached this threshold in the 2019 Marmoset Community White paper were relatively limited. By contrast, several dozen manuscripts from a range of laboratories around the world are now evident. This trend indicates that not only are the number of marmoset publications increasing, including in more areas of scientific inquiry, but interest in marmoset research is likewise growing in the broader scientific communities.

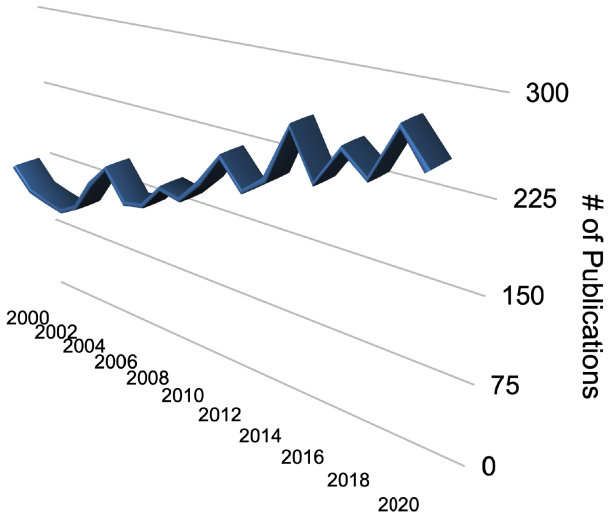

Figure 1. Plots the total number [#] of peer-reviewed publications with marmosets listed on PubMed each year from 2000-2020.

Representative Publications [2019-2020]

Systems Neuroscience.

- Spontaneous travelling cortical waves gate perception in behaving primates. (26)

Davis ZW, Muller L, Martinez-Trujillo J, Sejnowski T, Reynolds JH. Nature. 2020 Nov;587(7834):432-436.

- Spatial encoding in primate hippocampus during free navigation. (27)

Courellis HS, Nummela SU, Metke M, Diehl GW, Bussell R, Cauwenberghs G, Miller CT. PLoS Biol. 2019 Dec 9;17(12):e3000546.

- Arm movements induced by noninvasive optogenetic stimulation of the motor cortex in the common marmoset. (18)

Ebina T, Obara K, Watakabe A, Masamizu Y, Terada SI, Matoba R, Takaji M, Hatanaka N, Nambu A, Mizukami H, Yamamori T, Matsuzaki M. Proc Natl Acad Sci U S A. 2019 Nov 5;116(45):22844-22850. do

- Optimal features for auditory categorization. (28)

Liu ST, Montes-Lourido P, Wang X, Sadagopan S. Nat Commun. 2019 Mar 21;10(1):1302.

- Retinotopic specializations of cortical and thalamic inputs to area MT. (29)

Mundinano IC, Kwan WC, Bourne JA. Proc Natl Acad Sci U S A. 2019 Nov 12;116(46):23326-23331.

- Local homogeneity of tonotopic organization in the primary auditory cortex of marmosets. (24)

Zeng HH, Huang JF, Chen M, Wen YQ, Shen ZM, Poo MM. Proc Natl Acad Sci U S A. 2019 Feb 19;116(8):3239-3244.

- Contrast and luminance adaptation alter neuronal coding and perception of stimulus orientation. (30)

Ghodrati M, Zavitz E, Rosa MGP, Price NSC.Nat Commun. 2019 Feb 26;10(1):941.

- Submillimeter fMRI reveals a layout of dorsal visual cortex in macaques, remarkably similar to New World monkeys. (31)

Zhu Q, Vanduffel W.Proc Natl Acad Sci U S A. 2019 Feb 5;116(6):2306-2311.

- Insula serotonin 2A receptor binding and gene expression contribute to serotonin transporter polymorphism anxious phenotype in primates. (32)

Santangelo AM, Sawiak SJ, Fryer T, Hong Y, Shiba Y, Clarke HF, Riss PJ, Ferrari V, Tait R, Suckling J, Aigbirhio FI, Roberts AC. Proc Natl Acad Sci U S A. 2019 Jul 16;116(29):14761-14768.

- Face selective patches in marmoset frontal cortex. (33)

Schaeffer DJ, Selvanayagam J, Johnston KD, Menon RS, Freiwald WA, Everling S. Nat Commun. 2020 Sep 25;11(1):4856.

- Ventromedial prefrontal area 14 provides opposing regulation of threat and reward-elicited responses in the common marmoset. (34)

Stawicka ZM, Massoudi R, Horst NK, Koda K, Gaskin PLR, Alexander L, Santangelo AM, McIver L, Cockcroft GJ, Wood CM, Roberts AC. Proc Natl Acad Sci U S A. 2020 Oct 6;117(40):25116-25127.

- Divergence of rodent and primate medial frontal cortex functional connectivity. (35)

Schaeffer DJ, Hori Y, Gilbert KM, Gati JS, Menon RS, Everling S. Proc Natl Acad Sci U S A. 2020 Sep 1;117(35):21681-21689.

- The role of adaptation in generating monotonic rate codes in auditory cortex. (36)

Lee JH, Wang X, Bendor D.PLoS Comput Biol. 2020 Feb 18;16(2):e1007627.

- Over-activation of primate subgenual cingulate cortex enhances the cardiovascular, behavioral and neural responses to threat. (37)

Alexander L, Wood CM, Gaskin PLR, Sawiak SJ, Fryer TD, Hong YT, McIver L, Clarke HF, Roberts AC. Nat Commun. 2020 Oct 26;11(1):5386.

Molecular Neuroscience.

- Human-specific ARHGAP11B increases size and folding of primate neocortex in the fetal marmoset. (38)

Heide M, Haffner C, Murayama A, Kurotaki Y, Shinohara H, Okano H, Sasaki E, Huttner WB.Science. 2020 Jul 31;369(6503):546-550.

- Innovations present in the primate interneuron repertoire. (39)

Krienen FM, Goldman M, Zhang Q, C H Del Rosario R, Florio M, Machold R, Saunders A, Levandowski K, Zaniewski H, Schuman B, Wu C, Lutservitz A, Mullally CD, Reed N, Bien E, Bortolin L, Fernandez-Otero M, Lin JD, Wysoker A, Nemesh J, Kulp D, Burns M, Tkachev V, Smith R, Walsh CA, Dimidschstein J, Rudy B, S Kean L, Berretta S, Fishell G, Feng G, McCarroll SA. Nature. 2020 Oct;586(7828):262-269.

- Viral manipulation of functionally distinct interneurons in mice, non-human primates and humans. (13)

Vormstein-Schneider D, Lin JD, Pelkey KA, Chittajallu R, Guo B, Arias-Garcia MA, Allaway K, Sakopoulos S, Schneider G, Stevenson O, Vergara J, Sharma J, Zhang Q, Franken TP, Smith J, Ibrahim LA, M Astro KJ, Sabri E, Huang S, Favuzzi E, Burbridge T, Xu Q, Guo L, Vogel I, Sanchez V, Saldi GA, Gorissen BL, Yuan X, Zaghloul KA, Devinsky O, Sabatini BL, Batista-Brito R, Reynolds J, Feng G, Fu Z, McBain CJ, Fishell G, Dimidschstein J. Nat Neurosci. 2020 Dec;23(12):1629-1636.

Functional Neuroanatomy.

- Molecular Classification and Comparative Taxonomics of Foveal and Peripheral Cells in Primate Retina. (40)

Peng YR, Shekhar K, Yan W, Herrmann D, Sappington A, Bryman GS, van Zyl T, Do MTH, Regev A, Sanes JR. Cell. 2019 Feb 21;176(5):1222-1237.e22.

- Macroscale cortical organization and a default-like apex transmodal network in the marmoset monkey. (41)

Buckner RL, Margulies DS. Nat Commun. 2019 Apr 29;10(1):1976.

- A high-throughput neurohistological pipeline for brain-wide mesoscale connectivity mapping of the common marmoset. (42)

Lin MK, Takahashi YS, Huo BX, Hanada M, Nagashima J, Hata J, Tolpygo AS, Ram K, Lee BC, Miller MI, Rosa MG, Sasaki E, Iriki A, Okano H, Mitra P. Elife. 2019 Feb 5;8:e40042.

- Anatomical and functional investigation of the marmoset default mode network. (43)

Liu C, Yen CC, Szczupak D, Ye FQ, Leopold DA, Silva AC.Nat Commun. 2019 Apr 29;10(1):1975.

- A resource for the detailed 3D mapping of white matter pathways in the marmoset brain. (44)

Liu C, Ye FQ, Newman JD, Szczupak D, Tian X, Yen CC, Majka P, Glen D, Rosa MGP, Leopold DA, Silva AC. Nat Neurosci. 2020 Feb;23(2):271-280. d

- Open access resource for cellular-resolution analyses of corticocortical connectivity in the marmoset monkey. (45)

Majka P, Bai S, Bakola S, Bednarek S, Chan JM, Jermakow N, Passarelli L, Reser DH, Theodoni P, Worthy KH, Wang XJ, Wójcik DK, Mitra PP, Rosa MGP. Nat Commun. 2020 Feb 28;11(1):1133.

Behavior.

- Long-lasting vocal plasticity in adult marmoset monkeys. (46)

Zhao L, Rad BB, Wang X. Proc Biol Sci. 2019 Jun 26;286(1905):20190817.

- Cognitive control of complex motor behavior in marmoset monkeys. (47)

Pomberger T, Risueno-Segovia C, Gultekin YB, Dohmen D, Hage SR. Nat Commun. 2019 Aug 22;10(1):3796.

- Vocal state change through laryngeal development. (48)

Zhang YS, Takahashi DY, Liao DA, Ghazanfar AA, Elemans CPH. Nat Commun. 2019 Oct 9;10(1):4592.

- Vocal and locomotor coordination develops in association with the autonomic nervous system. (49)

Gustison ML, Borjon JI, Takahashi DY, Ghazanfar AA. Elife. 2019 Jul 16;8:e41853.

- Having Infants in the Family Group Promotes Altruistic Behavior of MarmosetMonkeys. (50)

Huang J, Cheng X, Zhang S, Chang L, Li X, Liang Z, Gong N. Curr Biol. 2020 Oct 19;30(20):4047-4055.e3.

- Theta Synchronization of Phonatory and Articulatory Systems in Marmoset Monkey Vocal Production. (51)

Risueno-Segovia C, Hage SR. Curr Biol. 2020 Nov 2;30(21):4276-4283.e3.

Disease Models.

- Fractionating Blunted Reward Processing Characteristic of Anhedonia by Over-Activating Primate Subgenual Anterior Cingulate Cortex. (52)

Alexander L, Gaskin PLR, Sawiak SJ, Fryer TD, Hong YT, Cockcroft GJ, Clarke HF, Roberts AC. Neuron. 2019 Jan 16;101(2):307-320.e6.

- Plasticity of the Mycobacterium tuberculosis respiratory chain and its impact on tuberculosis drug development. (53)

Beites T, O'Brien K, Tiwari D, Engelhart CA, Walters S, Andrews J, Yang HJ, Sutphen ML, Weiner DM, Dayao EK, Zimmerman M, Prideaux B, Desai PV, Masquelin T, Via LE, Dartois V, Boshoff HI, Barry CE 3rd, Ehrt S, Schnappinger D. Nat Commun. 2019 Oct 31;10(1):4970.

- Hominin-specific regulatory elements selectively emerged in oligodendrocytes and are disrupted in autism patients. (54)

Castelijns B, Baak ML, Timpanaro IS, Wiggers CRM, Vermunt MW, Shang P, Kondova I, Geeven G, Bianchi V, de Laat W, Geijsen N, Creyghton MP. Nat Commun. 2020 Jan 16;11(1):301.

- A high infectious simian adenovirus type 23 vector based vaccine efficiently protects common marmosets against Zika virus infection. (55)

Luo S, Zhao W, Ma X, Zhang P, Liu B, Zhang L, Wang W, Wang Y, Fu Y, Allain JP, Li T, Li C. PLoS Negl Trop Dis. 2020 Feb 12;14(2):e0008027. do

Innovative Methodology.

- Intracellular neuronal recording in awake nonhuman primates. (56)

Gao L, Wang X. Nat Protoc. 2020 Nov;15(11):3615-3631.

- Geometric deep learning enables 3D kinematic profiling across species and environments. (57)

Dunn TW, Marshall JD, Severson KS, Aldarondo DE, Hildebrand DGC, Chettih SN, Wang WL, Gellis AJ, Carlson DE, Aronov D, Freiwald WA, Wang F, Ölveczky BP. Nat Methods. 2021 May;18(5):564-573.

Here we outline the current use and advantages of marmosets for specific NIH Institutes, Centers, and Initiatives that support nonhuman primate research in order to further emphasize the unique advantages and broad potential of this species in the next chapter of biomedical research.

- Appendix 1 | NIH BRAIN Initiative
- Appendix 2 | NIH Office of Research Infrastructure Programs
- Appendix 3 | National Institute of Mental Health
- Appendix 4 | National Institute Neurological Disorders and Stroke
- Appendix 5 | National Institute Deafness and other Communication Disorders
- Appendix 6 | National Institute of Aging
- Appendix 7 | National Institute Child Health and Human Development
- Appendix 8 | National Eye Institute

III. Past NIH Investment in Marmoset Research

Funding support for marmoset research has increased over the past decade. The most dramatic increase has occurred over the past 5 years [2016-2020] in which the NIH has invested over $145M in marmoset research. Notably, FY2019 and 2020 represent the highest level of funding for marmosets by the NIH in history. A July 2021 search of NIH RePort Database using the term 'Marmoset' for 'Project Title' and 'Project Abstracts' revealed that in FY 2020 the NIH supported 54 projects with $49,700,000 in funding. Not only was this the highest annual funding for marmoset research by the NIH, but it was also a nearly 40% increase from FY2019 in which NIH supported 41 projects with $29,600,000 in funding. While some of this increase can be attributed to several infrastructure related marmoset-specific RFAs released by the NIH BRAIN Initiative that will be discussed below, these awards do not account for the precipitous increase in support by the NIH for marmoset research. Rather, the increase in funding relates primarily to investigator-initiated proposals using more traditional NIH funding mechanisms (i.e. R01, U01, R24, U24, R21 etc), including several young investigator training awards (i.e. F32, K99, etc).

As was previously noted in the 2019 Marmoset Community White Paper, NIAID supports nearly half of all NIH funding for rhesus monkeys, principally as animal models of various

infectious diseases and related vaccines (~$22M in FY2020). Though little funding had previously been reported by this Institute for marmoset research, in FY2020 NIAID supported 4 marmoset projects with ~$5M in research funding. This represents key investments in advancing marmosets as primate models of infectious disease.

One key advantage of marmosets is that their lifespan affords the opportunity to investigate questions related to ontogenetic and aging in nonhuman model (58). Noting this benefit, the National Institutes on Aging released *RFA-AG-20-0007 | Characterization of Marmosets as a Model of Aging and Age-Related Disease* in 2019. This award indicated the Institutes awareness that marmosets are a keystone model for understanding aging.

IV. Outcome of 2019 Community Priorities & Recommendations

The 2019 Marmoset Community White Paper outlined four following Recommendations & Priorities for NIH Investment. The first two focused on key infrastructure needs for marmoset research. Below we list each of these and the respective outcome of the NIH.

- Expansion of U.S. Marmoset Population.

The most significant concern amongst investigators in 2019 was a severe shortage of marmosets available for purchase in the United States. This issue was emphasized in the Community White Paper that year as the key bottleneck for the continued growth of the species as a cornerstone primate model. At the time there were no consistent supplier of marmosets in the country. In response to this concern, the NIH Brain Initiative released the following RFA intended to expand the marmosets available for purchase to Investigators: *RFA-MH-20-145 | Marmoset Colonies for Neuroscience Research*. Two grants were awarded in 2020, each of which comprised two separate sites. Together they established an integrated network of breeding centers– Johns Hopkins University (Baltimore, MD); Madison, WI; San Antonio, TX and San Diego, CA - strategically located near the major research hubs in the country to optimize transportation to these areas.

- Management of Genetic Diversity in Marmoset Populations.

A second related concern of the Marmoset Community at the 2019 PI meeting was the dearth of understanding about the genetic diversity and relatedness of marmosets in the country. This was considered significant both to maximize the genetic diversity of the US population and to identify natural gene mutations for modeling human disease. In response to this recommendation, the NIH Brain Initiative issued the following RFA: *RFA-MH-20-150 | Marmoset Coordination Center*. The mandate of this Coordination Center was not only to catalog and make available a myriad of population biometric data on marmosets to the community, but to maximize the genetic diversity of marmosets. In practice, this will occur by genotyping the marmosets in each of the aforementioned breeding colonies to facilitate the diversity of these populations, as well as individuals in laboratories throughout the US. This grant was awarded to the Oregon Regional Primate Center at OHSU (Portland, OR).

- Investment in Developing Gene-editing Technologies for Marmosets.

One of the key advantages of marmosets pertains to their amenability for developing and implementing next-generation genetic technologies. Indeed, the first demonstration in a nonhuman primate of germ-line transmission of a transgene in marmosets by Sasaki and colleagues (5) served to highlight the potential of this primate model for biomedical research. While progress developing further tools has continued since this initial report (59), it was noted

by the Marmoset Community at the 2019 PI meeting that further strategic investment was needed to accelerate this process. In 2020, the NIH BRAIN Initiative issued a RFA with due dates in 2020 and 2021 in response to this recommendation: *RFA-DA-21-006 | Tools for Germline Gene Editing in Marmosets*. The awards for the initial round of submissions are expected to be announced later in 2021.

- Support for Marmoset Training and Meetings.

The inaugural Marmoset Bioscience Symposium took place in Chicago, IL (October 2019) just prior to the annual Society for Neuroscience (SFN) meeting. The second Marmoset Bioscience Symposium was scheduled to take place in Washington, DC in 2020 prior to the SFN meeting, but due to Covid-19 it was held as a Virtual Conference. Each of these meetings was generously supported by the NIH in the form of a R13 conference grant.

V. Recommendations & Priorities for future NIH Investment in Marmoset Research.

The second Marmoset Principal Investigators meeting was planned for April 2020 in Boulder, Colorado. Due to the impacts of Covid-19, this meeting was cancelled. Alternatively, the Marmoset PIs convened for a virtual meeting on October 24th, 2020. The meeting was attended by 40 Investigators. The principal aim of this PI meeting is to [1] identify key bottlenecks facing marmoset research in the United States and [2] establish the strategic plans to address these issues. The investment by the NIH in key infrastructure to accelerate marmoset research in the US was noted as a crucial first step. Listed below are the most critical priorities discussed by the investigators at the 2020 PI meeting along with recommendations that should factor heavily for strategic plans in the next phase of marmoset research.

1. Investment in Developing Marmoset Behavioral Techniques & Technologies.

Owing to their relatively small body size (~300-400g), a notable advantage of marmosets for biomedical research is their amenability to a wide range of behavioral techniques. This ranges from traditional primate cognitive methodologies (i.e. Wisconsin card sorting task) to the use of modern computer vision technologies (i.e. DeepLabCut) to quantify fine biomechanical details in freely-moving animals across a range of contexts. Because of marmosets' suitability for freely-moving paradigms traditionally employed in other mammalian models (i.e. rodents) and more conventional restrained paradigms typical of primate research, marmosets are uniquely suited for powerful cross-species comparisons that identify critical points of shared and divergent processes. Marmosets' amenability to such a diverse catalog of behavioral approaches will undoubtedly remain a pivotal advantage of this species for biomedical research in the foreseeable future, particularly as disease models emerge using targeted gene manipulations.

We propose a two-fold critical investment in marmoset behavioral approaches. First, we recommend an investment to establish a core set of tasks that can be widely performed in marmoset laboratories. This would focus on testing a large corpus of marmosets on a focused set of tasks in order to establish normal distributions for adult marmosets. This foundational database could then be used to compare to marmosets in future experiments performed in laboratories with more limited sample sizes, as well as to compare against ontogenetic and developmental datasets. Second, we recommend a key investment to develop modern computational technologies for behavioral analysis in marmosets. This includes augmenting existing computer vision technologies, such as DeepLabCut, with software tools tailored to the

idiosyncrasies of marmosets, as well as the computational analysis and modeling tools that leverage these behavioral annotations towards unique insights into behavior and biomechanics. Such approaches have already proven invaluable to both quantify and model the fine details of behavior in other species that were not previously possible (60), and offer the opportunity to dissect natural behaviors at a more precise temporal resolution better aligned to the timescales of neural processes. As a result, these modern behavioral technologies are likely to become invaluable for quantitative behavioral phenotyping marmosets and identifying changes that emerge in marmoset disease models established through targeted gene manipulations. It is likely that some of these manipulations may result in more subtle, nuanced behavioral and/or cognitive processes that may not be identifiable with the relatively coarse phenotyping common in the analogous rodent research, particularly for the dynamics of primate social and cognitive processes.

Solution. One or more PAR/RFAs are needed to accelerate the advancement on marmoset behavioral techniques and technologies. Given the difficulty of funding pure behavioral research through more conventional NIH funding mechanisms, PAR/RFAs specifically for developing behavioral methodologies in marmosets would be particularly impactful to the field.

2. Investment in Viral-based Genetic Technologies in Marmosets.

The strategic investment in gene-editing technologies focused on germline transmission in marmosets by the NIH Brain Initiative is clearly critical to the field. However, viral-based gene-editing approaches remain a powerful and likely keystone technologies for marmoset research in the coming years. Practically speaking, the number of marmoset transgenic lines is almost certain to be dwarfed by the catalog available for other genetically tractable animal models (i.e. mice, zebrafish, etc) due to sheer cost of development and housing of these populations. As a result, viral-based approaches are likely to be critical to performing precise, functional genetic manipulations in marmosets to address a wide range of research questions in the coming years. While advances in these technologies continue to occur (12, 13), strategic investment is needed to accelerate this process and maximize its benefits for explicating the functional circuitry of the primate brain. Investing in these technologies as the marmoset model continues to grow would offer a key foundation to accelerate the rate of discovery for many years to come.

Solution. A Resource PAR/RFA is needed to directly fund the development and expansion of the molecular tool kit available for use in marmosets using viral based gene-editing technologies, including the intravenous delivery of AAV capsids because of their clear benefits for translational research with humans.

3. Support for Cross-Institutional Training of Students/Post-Docs.

The accelerated growth of marmoset research is unprecedented for any primate model organism. Because of the scarcity of marmoset laboratories a decade ago, the majority of researchers who have adopted marmosets as a model organism in recent years did not receive formal training during graduate school or post-doctoral periods. Instead, many new researchers previously gained their primary training either in rodents or macaque monkeys and have faced considerable challenges adapting their research program to marmosets. To address this issue, we propose immediate investment to support the cross-institutional training of new students and post-docs from established laboratories in the field.

Solution. A Resource PAR/RFA is needed that awards funds to graduate students and post-docs for the explicit purpose that they receive training in management, husbandry, surgical approaches, and experimental techniques. This funding would support training periods at Institutions with established marmoset laboratories and scientific leaders of different cutting-edge technologies to accelerate research efforts and reduce the need for single labs to develop approaches in isolation.

4. Centralized Resource for Cataloging and Distributing Aging Marmosets

One key advantage of marmosets as a biomedical model is their relatively rapid development and short lifespan. Marmosets are considered adults by 18-20months and aged by 8 years. As a result, they represent a powerful model in which to study and model the myriad of age-related diseases and disorders that afflict humans. Most laboratories focus on animals during their adult years ~2-7, As the number of marmoset colonies grow and expand, a critical infrastructure need for the community would be a centralized resource for cataloging aged animals across the country. Rather than euthanize animals when they reach an age at which they are no longer viable for experiments with adult age animals, the utility of these individuals can be maximized by making these individuals available to laboratories focused on questions of aging and age-related diseases. A present, there is no central mechanism available for Investigators to know of the availability and location of aged marmosets in the US. Rather Investigators rely on contacting colleagues to query the age and availability of animals. A centralized resource that governed aged marmosets would maximize animal use and minimize the number of animals used in research, an important ethical consideration for nonhuman primate use in biomedical research.

Solution. A Resource PAR/RFA is needed to establish and manage this database. A potential alternative is to expand the role of the Marmoset Coordination Center to include the capacity to catalog existing aged marmosets throughout the US and coordinate their distribution to laboratories in need of these animals.

VI. Marmoset Community Initiatives

During the PI meeting, the Community also identified initiatives that could be undertaken by the Investigators to further strengthen marmoset research. The following two projects were determined to address the most pressing concerns for the community.

1. Create a Forum for Sharing Methodological and Surgical Details.

The number of laboratories using marmosets has rapidly increased in the past 5-10years. Many of the new Investigators have little to no experience working with marmosets. To expedite the transition to marmoset and avoid unnecessary redundancy in technology development between laboratories, a strong suggestion at the 2020 Marmoset PI meeting was that we establish a forum for sharing details about methodological and surgical approaches in use across the marmoset community. This forum will serve as both a repository of existing knowledge about methodological and surgical details and as a place for community members to share experiences, ask questions and coordinate efforts across the country in an informal setting.

To this end, we began a monthly seminar series on Zoom in January 2021 organized by Drs. Yi Zhou and Steve Eliades. Each seminar is led by a single laboratory – PI and lab members - who describes in detail a novel methodological approach developed in that lab, including surgical details. These seminars are intended to be informal and a balance between presenting methodological details, asking questions and engaging in fruitful dialogues. These seminars have been highly successful and attended by 40-50 individuals. The seminar series will continue again in Fall 2021 for the academic year. This series has allowed remote interactions of marmoset PIs during COVID at zero cost with maximum gain, proving the effectiveness of grassroot community effort in advancing critical scientific activities during unprecedent circumstances.

2. Establish a Marmoset Journal Club for Students across Institutions.

As evidenced by the large number of scientific publications in high-impact journal outlined above in Representative Publications, the rate of publication for marmoset research has accelerated. To keep the Marmoset Community apprised of these advances, it was suggested at the 2020 Marmoset PI meeting that we establish a regular Journal Club. Each meeting would be led by the primary author of a scientific manuscript that was in review or recently published. The Journal Club is expected to meet monthly beginning in Fall 2021. These meetings will take place on Zoom and be organized by post-doctoral fellows from UC San Diego and Western University (Canada).

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Appendix 1

National Institute of Health BRAIN Initiative

2021 Marmoset Community White Paper

Central to the mission of the BRAIN initiative is the creation and application of innovative technologies and gathering of information for understanding how individual cell types and complex neural circuits interact in space and time to generate normal brain function and dysfunction in the diseased brain. Priority research areas of the BRAIN Initiative include the generation of brain cell atlases, understanding circuit wiring, the function of specific cell types and circuits via causal manipulations, large scale multi-area interactions, and the link between brain function and behavior. Marmosets offer unique advantages for both developing new technologies and expanding our knowledge of the brain. As non-human primates, this New World species is within the same taxonomic family as humans (Order: Primates) and share the core brain architecture and broad behavioral repertoire. For example, marmosets have an extensively developed prefrontal cortex, and their motor control, sensory perception and social cognition is very similar to those of humans. In contrast to the more commonly used macaque monkey, however, they offer the advantage of a much smaller body (300-400gr in weight), a small lissencephalic brain, a shorter gestational period (5-6 months) and life span (8-12 yrs of age), a faster maturational period (sexual maturity is reached around 1.5 yrs of age), and high fecundity (producing litters of 2-3 offspring). These advantages make marmosets an ideal non-human primate species to address many goals of the BRAIN Initiative. For example, the fast maturation and high fecundity of the marmoset is a great advantage for the generation of transgenic lines. Indeed, recent advances in genetic engineering in marmosets have opened new pathways to study the brain, allowing modeling of disorders with a genetic component, such as Alzheimer's disease, Schizophrenia, Autism and Huntington's disease, in which mouse models have so far been unsuccessful in translation to humans. Moreover, the marmoset small brain size is ideal for studying circuit wiring and connectomics in a complex non-human primate brain that is several orders of magnitudes smaller than the macaque brain, whose large brain size still poses a big data challenge for computational tools. Additionally, in contrast to the large and convoluted macaque brain, the marmoset's small lissencephalic brain allows the accessibility needed for brain-wide, high resolution *in vivo* imaging techniques, such as two-photon microscopy.

Breadth of Current Research. There are several research questions within the BRAIN Initiative mission currently being addressed using the marmoset as a model species. Following the initial development of calcium imaging in the marmoset brain (23, 61, 62), several laboratories are applying this technique to image network dynamics in real time in behaving marmosets (63-65). Similarly, following the initial development of *in vivo* optogenetics in the marmoset (19), reports are rapidly accumulating on its application to study marmoset cortical function and behavior (66-69). These approaches will advance our knowledge of the neural basis of cognition and behavior, a major goal of the BRAIN Initiative. Studies are currently underway to produce a spatially specific catalog of cell types in the marmoset brain, using single-cell RNA sequencing; using this approach a recent study has profiled RNA expression in a large number of inhibitory neurons across several species, including marmosets (70). These approaches will pave the way for future studies of primate genetics and circuits. BRAIN Initiative funds have been, and continue to be, used successfully for the development of new viral tools for targeting specific cell types in the

non-human primate brain. For example, novel recombinant adeno-associated virus (rAAV) vectors that restrict gene expression to GABAergic interneurons in many vertebrate species including marmosets using the mDlx enhancer (16) or the h56D promoter (71) have recently been developed. Moreover, over the past year, two laboratories have developed viral vectors for selective transgene expression in specific inhibitory neuron subtypes (parvalbumin and somatostatin-positive interneurons) in marmoset cortex (71, 72). Studies of the auditory system have successfully leveraged the aforementioned advantages of marmosets to pioneer numerous neural recording and behavioral techniques to make new discoveries about the physiological mechanisms underlying sensory perception and social communication in the primate brain (73-86). More recently, researchers have also begun to take advantage of the marmoset natural tendency to orient towards visual stimuli, perform visual tasks, and the accessibility of the middle temporal (MT) visual area and frontal eye field on the cortical surface of this species, to study a diverse range of visual behaviors in marmosets (26, 87-93).

The Future. The marmoset is a unique model to investigate the non-human primate brain in ways that are not allowed by other primate species. Promising future research areas are briefly discussed below. First, the marmoset small lissencephalic brain is ideally suited for the development of wide-field calcium imaging to enable imaging of millions of neurons across cortical layers and multiple brain areas. Future efforts are directed towards increasing the width and depth capabilities of imaging in this primate species Second, the marmoset small brain size is also ideal for the development of large-scale manipulations of cortical circuit activity, to understand interareal interactions. Future efforts are directed towards developing large-area manipulations throughout the cortical depth, and performing spatiotemporally patterned photostimulation to mimic the spatiotemporal patterns of neuronal activity. Third, efforts are under way to couple single-cell RNA sequencing with behavioral studies in marmoset (as previously done in mouse (94)), to establish computational tools that allow linking gene expression in specific cell types to behaviorally relevant circuits in a primate. Fourth, current and future efforts are under way for further development of viral tools for cell specific targeting in non-human primate brains; for example, rAAV vectors that can specifically infect additional subtypes of inhibitory neurons in marmoset cortex, beyond those recently reported. Finally, a revolution in understanding the human brain in health and disease will require non-invasive real-time mapping of neurotransmitter and calcium signaling. New vasoactive imaging probes with high sensitivity and resolution have been developed in rodents (95, 96) and are currently being developed for marmosets.

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Appendix 2

National Institutes Office of the Director
Office of Research Infrastructure Programs

2021 Marmoset Community White Paper

The core mission of the Office of Research Infrastructure Programs (ORIP) within the Office of Director (OD) is to advance the NIH mission by supporting research infrastructure and research-related resource programs and by coordinating NIH's science education efforts. Specifically, ORIP's Strategic Plan supports the NIH-Wide Strategic Plan by funding the "scientific human and physical resources that will help to ensure the Nation's capability to prevent disease." ORIP awards grants to support research resources, such as animal models of human disease and state-of-the-art biomedical instrumentation. ORIP plans, organizes, and conducts workshops, both independently and in collaboration with NIH Institutes and Centers, to identify and pursue scientific opportunities. ORIP supports research-training opportunities for veterinary scientists to capitalize on their distinct perspective and expertise based in a deep understanding of comparative medicine and insight into animal models of human diseases. In the last several decades, the mouse system has been a powerful model for medical research due to, in large part, an array of sophisticated gene-editing techniques to manipulate the mouse genome and strategies for cell-type specific, inducible, or spatiotemporal regulation. However, considerable anatomical, physiological, cognitive, and behavioral differences between mice and humans limit the degree to which insights from mouse models shed light on human diseases. This is reflected in the high number of failed clinical trials for drugs that were effective in treating mouse models of human disease. Thus, non-human primates (NHPs) may serve as better models for studying human disease with the macaque being the traditional choice. However, the common marmoset (*Callithrix jacchus*) has emerged recently as a complementary species with advantageous characteristics over the macaque. First, marmosets share with other primates, including humans, similar physiology, brain organization, and sophisticated social and cognitive behaviors. For example, like humans, marmosets are diurnal and housed in social groups consistent with the size and composition of groups in the wild. This is particularly important because the range of sophisticated social and cognitive behaviors that emerge naturally within social groups can be effectively studied under more controlled laboratory conditions. Second, marmosets are among the shortest-lived NHPs with small body size and strong reproductive power, making them highly economical and scalable for housing and generating the number of marmosets needed for preclinical evaluation. Third, in contrast to rhesus macaques, marmosets are free of Herpes B viruses, making the species safer to work with. Finally, technologies for generating genetically modified marmosets have already been developed, and their short generation time represents a distinct advantage for creating and expanding transgenic lines over larger nonhuman primate species.

Breadth of Current Research. Ongoing research in the marmoset is focused on modeling various human diseases and investigating in a wide range of systems and at multiple levels of analysis, including infectious disease, aging, Alzheimer's disease, Parkinson disease, Schizophrenia, Huntington's disease and multiple sclerosis. Furthermore, the marmoset has been used to develop a model system to evaluate various gene-editing approaches and strategies for gene therapy. Research efforts are also ongoing to characterize the effects of pharmacological and life-style interventions on health span in the marmoset.

The Future. ORIP can play an essential role in addressing numerous resources issues that impede the progress in using marmosets as a biomedical model. Here are some examples. First, one of major bottlenecks in using marmosets to model human disease is the extreme short supply of marmosets available for sale to research community. Second, the genetic diversity of marmoset population in this country is largely unknown. The information is critical in better maintaining high population diversity and modeling human disease. For example, it will be extremely informative to know the divergence and frequency of marmoset alleles relevant to human mutations such as major risk factors ApoE and Trem2 for AD and other diseases. As marmosets are purposely kept as out-bred to maintain diversity, the

database will provide information to understand (97) the extent of genetic diversity and ancestral relationship of different populations; (98) assist the analysis of fidelity of genome following gene editing and (8) facilitate the genome-based interpretation and comparisons of variations in phenotypes across different populations. Third, it is not known if immunological reagents and protocols for analytic experiments in the marmoset are available. Database for these reagents and, if needed, developing these reagents will become critical for the success of modeling human disease. Fourth, it is critical to develop genetic viral tools that work in the marmoset. Fifth, it will be important to develop and standardize a suit of state-of-art behavioral tests for marmosets Sixth, it will be advantageous to establish an aging marmoset colony and its related resources for the community. Finally, ORIP can offer workshops to advance above endeavors and disseminate the resulting resources.

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Appendix 3

National Institute of Mental Health

2021 Marmoset Community White Paper

The core mission of the National Institute of Mental Health (NIMH) is to transform the understanding and treatment of mental illness through basic and clinical research. Traditionally, research funded by the NIMH has taken advantage of three main species – namely the mouse, the macaque monkey, and the human. This combination has led to a series of important discoveries that has gradually expanded our understanding of how the brain supports a range of higher cognitive processes. However, progress towards understanding and treating mental health and behavioral disorders has slowed, marking the need for a substantial paradigm shift in the scientific approach toward more human-relevant experimental-models. The recent emphasis on the common marmoset as a promising model for neuroscience heralds a broadening of experimental paradigms to study brain mechanisms of cognition, including those whose failure underlies prevalent mental disorders. Traditionally, research in cognitive neuroscience has also taken advantage of the three aforementioned main species: the mouse, the macaque monkey, and the human. This has led to a series of important discoveries, gradually transforming our understanding of how the brain supports a range of higher cognitive processes. The marmoset adds new and important dimensions to our understanding of brain function, with great relevance to mental health and disease within an animal model whose brain shares many of its primate specializations with the human. Importantly, new experimental opportunities are rooted in marmosets' gregarious social behavior, which, together with their relative ease in breeding and handling, invite investigation into interactive and developmental aspects of primate cognition. Marmosets are particularly well suited for studying the brain in paradigms involving interactive social behavior. Several aspects of their behavior closely resemble that of humans, including their cooperative foraging and defense, reciprocal communication, and allomaternal rearing of offspring. The marmoset brain shares many of its primate features with the human brain, including specializations for social perception and vocal communication. These scientific factors, together with practical considerations such as the relative ease in breeding and handling marmosets compared to macaques, opens the door to a range of naturalistic experimental paradigms. Recent advances in miniaturization and telemetry make it possible to measure and manipulate brain circuits during natural social exchanges, such as affiliative, competitive, and reproductive behaviors. Further, the marmoset is an ideal species for studying mechanisms of prenatal and postnatal brain development relevant to mental illness. Similar to other primates, marmoset brain development diverges from other mammals by the inclusion of additional zones of neural progenitors, the preservation of neural stem cells after birth, and an unusually protracted childhood during which the brain matures slowly amid abundant social experience. The systematic investigation into the anatomy and physiology of primate brain development and its bearing on cognition, from the cellular and molecular processes in the embryo to the brain's circuit development during critical periods in early life, requires a high degree of control over a species' reproductive biology, breeding, rearing, and weaning. Marmosets breed easily in captivity and can be housed in multigenerational families that cooperate in the rearing of infants. Moreover, marmosets exhibit routine twinning, typically with two reproductive cycles each year, with offspring reaching sexual maturity at the age of eighteen months. Together, these factors provide a much needed opportunity to study unique features of primate brain development whose failure is suspected to be at the core of psychiatric disorders.

Breadth of research. In the past several decades, marmosets have been used in experimental neuropsychology programs to study aspects of executive function (99, 100) and emotion (101, 102). This work has demonstrated that the organization of the prefrontal cortex is similar to that found in macaques and humans. In parallel, systematic mapping studies of the sensory systems have illustrated that the

cortical blueprint of the marmoset is also fundamentally similar to that of the macaque and human (103-106). Additional work has demonstrated specializations in the marmoset brain for the perception of faces (33, 107, 108), the production and perception of vocal behavior (78, 83, 85, 86, 109-111), and more recently begun to uncover circuits underlying curiosity driven behavior (112). Technological advances in optical imaging using genetically encoded calcium indicators (25, 113), as well as viral based optogenetic approaches (18-20) have rapidly begun to import technology developed in the mouse into the marmoset. This, together with emerging transgenic methods (5-7), chronic wireless recordings (114, 115) and interactive behavioral paradigms (116, 117), have expanded conceptions of the types of experiments currently feasible in nonhuman primates.

Future. Future marmoset research holds great promise both for increasingly precise basic science research into cognitive circuits, as well as the generation of primate models of neuropsychiatric disease. In both cases, the creation of transgenic animals is likely to figure prominently into the research. For basic scientific research, transgenic animals will serve as valuable tools for experiments in the domains of both neurodevelopment and social interaction, providing, for example, cell-type specific reporters indicating activity level or maturation state. The recent generation of transgenic marmosets expressing genetically encoded calcium indicators at the NIH (7) is an important step in enabling chronic *in vivo* monitoring of neural activity using high-resolution optical imaging. Regarding translational neuropsychiatric research, preclinical models are beginning to yield deeper understanding into underlying mechanisms and potential treatments for autism spectrum disorder (118), depression (52), stress response (119), and fear memory relevant for PTSD in humans (120). In the creation of disease models, transgenic animals will enable translational studies aimed at understanding the complex neural mechanisms of human brain function, with the ultimate goal of molecular targeting for pharmacotherapy and brain stimulation. Taken together, the remarkable similarities between marmosets' brain architecture and cognitive and social capacities with humans, as well as the species wide array of cutting-edge molecular and genetic tools, this primate model provides a promising bridge between basic science research and clinical psychiatry.

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Appendix 4

National Institute of Neurological Disorders and Stroke

2021 Marmoset Community White Paper

The core mission of the National Institute of Neurological Disorders and Stroke (NINDS) is twofold. First, NINDS seeks fundamental knowledge about the brain and nervous system.Second, NINDS aims to use that knowledge to reduce the burden of neurologicaldiseases. In support of its mission, NINDS performs and funds basic, translational, and clinical neuroscience research on more than 600 neurological diseases afflicting humans, including genetic diseases (e.g., Huntington's disease; muscular dystrophy), developmental disorders (e.g., cerebral palsy), neurodegenerative diseases (e.g., Parkinson's disease; Alzheimer's disease; multiple sclerosis), metabolic diseases (e.g., Gaucher's disease), cerebrovascular diseases (e.g., stroke; vascular dementia), trauma (e.g., spinal cord and head injury), convulsive disorders (e.g., epilepsy), infectious diseases (e.g., AIDS dementia) and brain tumors. Common marmosets (*Callithrix jacchus*) offer unique,powerful advantages to both components of the NINDS mission. In support of the first component, marmosets are particularly well suited for neuroanatomical and functional brain studies, as their brains retain the typical anatomical and functional organization of the primate brain. A significant advantage is that the marmoset is a lissencephalic primate, which greatly facilitates the mapping of functional brain areas by neuroimaging techniques, such as fMRI and optical imaging, as well as by electrophysiology, with high spatial resolution. In support of the second component, marmosets are excellent models of neurological disorders. Unlike rodents, marmosets are outbred, and every individual isgenetically different. Further, the marmoset brain has a gray-to-white matter ratio comparable to humans, which strongly facilitates modeling diseases such as multiple sclerosis and small vessel disease. The species also exhibits the breadth of cognitive sophistication that distinguishes primates from other taxonomic groups. Finally, gene-edited marmosets can be generated with an intergeneration time and establishment of transgenic lines 2-3 times faster than other primate species, which makes marmosets bethe ideal primate species for the development of genetically engineered lines. For all of the aforementioned reasons, marmosets are poised to be a central player to advance the core mission of the NINDS.

Breadth of Current Research. Marmosets are currently being used to elucidate pathogenetic mechanisms of multiple sclerosis (121-125). Marmoset models of MS haveclinicopathologic correlation patterns, lesion heterogeneity, immunologic mechanisms, and disease markers more closely mimic the human condition. Marmoset models of stroke (126, 127) have been developed as the marmoset brain features cell types and behavioral deficits that most closely mimic human stroke. Marmosets are advantageous models of neurodegenerative diseases due to their many anatomical, functional, metabolic, and social similarities with humans. Marmosets are an ideal model in longitudinal studies of cognitive decline (128), and the recent evidence that aging marmosets shows the biological hallmarks for Alzheimer's disease, including amyloid-beta (129-131), hyperphosphorylated tau, and dystrophic microglia (132, 133), strongly elevates the marmoset as a superior model for the study of aging and age-related diseases (134). Transgenic marmoset models of stroke (135), Parkinson's disease (136), polyglutamine diseases (137), spinocerebellar ataxia (138), and severe combined immunodeficiency (139) have been developed to allow better modeling of neurological disorders. Meanwhile, we know more about the organization of the primate brain thanks to the very high-resolution anatomical, neurophysiological, and functional imaging efforts being made in marmosets, with the development of brain atlases based on MRI (140-143), gene-expression (144), and neuronal connections (145, 146). Finally, the use of high-resolution fMRI for mapping sensory and social regions of the marmoset brain (147-150), resting-state brain networks (151, 152), and neurophysiological, behavioral (153) and calcium imaging (62, 154, 155) studies in freely-moving marmosets are significantly advancing our understanding of marmoset behavior in ways to understand their changes due to neurological disorders.

The Future. There's a bright future for biomedical research, as marmosets are poised tomake a tremendous, potentially revolutionary contribution both to our currentunderstanding of brain anatomy and function and to the causes and mechanisms of neurological disorders. The small marmoset brain allows, for the first time in a primate species, the integration of whole-brain morphological (MRI, fMRI, and neuronal tracing) studies performed at the microscale with cell-specific gene expression. This will enable the construction of a comprehensive atlas/database that will contain completely novel knowledge about the primate brain. The development of genetic-engineering techniquesin marmosets will enable the study of a broad range of neurological and neuropsychiatricdisorders as well as spur the development of precision medicine and gene-therapy approaches to manage and treat these diseases. In particular, being among the shortest-lived primate species, marmosets are uniquely suited to provide crucial information about primate brain development and about the mechanisms of neurodegenerative diseases inwhich aging is a major comorbidity and contributing factor.

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Appendix 5

National Institute of Deafness and Other Communication Disorders

2021Marmoset Community White Paper

The core mission of the National Institute of Deafness and Other Communication Disorders (NIDCD) to understand normal and disordered processes of hearing, balance, taste, smell, voice, speech and language as well as to improve the treatment of communication impairment and other sensory disorders. The common marmoset (*Callithrix jacchus*) has contributed significantly to research designed to address these key issues for several decades and will remain a cornerstone model to significantly advance the core missions of the NIDCD in the years to come. With their complex and human-like social behavior and brain organization, marmosets are an ideal model for studies of normal and disordered hearing. As a non-human primate with hearing ranges and auditory brain structures similar to that of humans, marmosets can provide greater insight into basic mechanisms of hearing than studies in more evolutionarily distant rodent models can. Moreover, because they can be easily bred and raised in laboratory conditions, have an average lifespan of 10 years, and exhibit age-related hearing loss, marmosets provide a unique opportunity to longitudinally study the effects of development and aging upon hearing over the entire lifespan. Because they are amenable to genetic manipulation, and close genetic similarities, marmosets may provide a better understanding of genetic causes of hearing loss and their rehabilitation. Marmosets are also one of the few non-human mammalian models of vocal communication. Even in the laboratory colony, marmosets are highly social primates in constant interactive vocal contact with each other facilitated by the ability to be kept in natural social and family groups. As a result, marmosets can provide critical insight into normal mechanisms of communication, the evolutionary origins of speech, and disorders in communication that can arise from deafness, neurologic disease, or social isolation. Thus marmosets have substantial potential to understand the critical interplay between hearing and vocal communication and the development of novel strategies to prevent and treat disorders stemming from hearing loss. Notably, work in the marmoset auditory system was the first to leverage the many advantages of this model organism to explore core questions of systems neuroscience research with nonhuman primates, such as sensory coding in neocortex (156) and the cortical basis of vocal communication (78, 157, 158). The potential of the marmoset model also extends beyond hearing, and offers opportunities to explore less well investigated facets of the NIDCD mission. As prolific scent markers, marmosets are amenable to studying the neural mechanisms of olfaction in a non-human primate. As a species that naturally moves rapidly in three dimensions and relies more heavily on head than eye movements (159), marmosets are potentially useful in studying both the peripheral and central aspects of the vestibular system, in particular less-well understood encoding of gravity and tilt.

Breadth of Current Research. Recent work in marmosets has begun to address many fundamental questions central to the mission of the NIDCD. In basic hearing research, neural recordings in the marmoset auditory cortex by Bendor and Wang (81) have localized a pitch-selective brain area, answering a long-standing question in auditory perception and physiology. Marmosets also exhibit human-like pitch perceptual patterns (73). Marmosets are beginning to be used to understand therapies for hearing loss, having recently become a model species for studying the neural effects of Cochlear Implants, revealing critical similarities and differences from normal sensory processing (74). Marmosets have also shown recent advances in our understanding of hearing loss genetics, with recent studies of the marmoset cochlea showing patterns of hearing-related gene expression that are distinct from that in mice and more similar to humans (160), thus suggesting marmosets may be a better model for genetic hearing loss. Furthermore, recent evidence has now shown that marmosets, like humans, exhibit age-related hearing loss (161). Marmosets are also proving themselves to be an excellent model for vocal communication and its disorders (78, 109). Marmosets engage in cooperative, turn-taking vocal conversations with rules similar to that of human communication (162, 163). Some evidence also

suggests that infant marmosets babble, similarly to human babies, and their vocal development may be dependent, in part, on interactions with their parents (164-166). Like humans, marmosets use their hearing to help them control their vocalizations on a moment-to-moment basis, and can exhibit long-lasting vocal plasticity, evidence of the intimate relationship between hearing and vocal production, (111) with implications for human speech and vocal disorders. Marmosets are also able to learn and detect artificial grammars, and ability that may be an ancestral trait for the evolution of language (167).

The Future. Marmosets are uniquely suited for future advances in our understanding of critical open questions in disordered hearing and communication. For example, what are the long-term effects of hearing loss and hearing restoration on the brain and what are the mechanisms by which this can contribute to cognitive decline? This association has garnered significant recent interest and attention, but the underlying mechanisms remain uncertain. Because of marmosets' lifespan, reproductive patterns, and social behavior, they are an ideal model for studying age-related hearing loss and its consequences on cognitive decline and social isolation that have been revealed as critically important in humans. Furthermore, marmosets would be amenable to more rapid testing of hearing or other rehabilitation to determine its effects on future age-related changes. Second line of critical forthcoming research pertains to genetic and neuroanatomical origins of speech and other vocal communication disorders. Although marmosets do not possess human language, their vocalizations exhibit many similarities and they are the only non-human primate species in which vocal communication can readily be studied in the laboratory, including greater homology with humans than other non-primate research models. When combined with the potential for genetic manipulations and longitudinal studies during development, marmosets are an ideal model for understanding these disorders and potential therapies.

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Appendix 6

National Institute of Aging

2021 Marmoset Community White Paper

The core mission of the National Institute of Aging (NIA) is to support and conduct genetic, biological, clinical, behavioral, and social research on aging. Common marmosets (*Callithrix jacchus*) share with other primates, including humans, many aspects of physiology, a complex brain organization, and sophisticated social and cognitive behaviors, facilitating translational research on human conditions. With an average lifespan of about 10 years and a maximum lifespan of 21, marmosets are also among the shortest-lived anthropoid primates. This characteristic makes them uniquely suited for studies of aging, as the dynamics of the aging process can be studied longitudinally throughout the entire lifespan, an approach not feasible in more long-lived primates. Thus, marmoset models of human aging have the potential to advance the NIA mission in multiple areas. First, the short lifespan of the marmoset provides the opportunity to track the progression of normal aging and age-related disorders and study their underlying mechanisms in order to achieve better prevention and prognosis. Interestingly, marmosets develop several age-related changes of specific relevance to human late-life phenotypes. For example, they exhibit age-related declines in basic biological markers, such as a decrease in lean muscle mass, that are similar to those observed in humans. They also show a marked age-related increase in cancers, amyloidosis, pathogenic tau accumulation, diabetes and renal diseases, typical of human late-life disorders. Many aspects of functional decline during normative aging in marmosets are also similar to those of humans, with marmosets exhibiting hearing loss as well as declines in cognitive and motor function with increased age. Aging is the greatest risk factor for many diseases including Alzheimer's Disease (AD), and understanding how age-related changes at both the system and cellular levels predispose the primate brain to these diseases will be critical to developing effective prevention and treatment strategies. Of particular interest, aged marmosets spontaneously develop β-amyloid deposition and tauopathies, both implicated in the pathogenesis of AD. Because the high rate of failure in AD clinical trials has been ascribed, in part, to the inadequacy of rodent models that recapitulate only limited aspects of AD pathology, these features of marmoset biology position the species as an excellent primate model for advancing our understanding of AD. In addition, advances in genetic engineering are leading to the generation of genetically modified marmosets as models for AD and other age-related neurodegenerative conditions, such as Parkinson's disease. Thus, the marmoset has substantial potential for the development of novel strategies to prevent and treat neurological diseases of aging. Moreover, because the marmoset is a highly social primate who forms long-lasting bonds and can be maintained in a social group in the laboratory, it should also prove particularly valuable to study social influences on the aging process and their impact on the pathogenesis of age-associated diseases. Finally, this short-lived primate offers the opportunity to test the safety and efficacy of interventions against age-related burden in a compressed time-frame relative to long-term studies in macaques or humans, thus allowing for the evaluation of specific interventions to extend human healthspan.

Breadth of research. Recent work in the marmoset has documented age-related changes in a wide range of biological systems (168), including the microbiome (169) immune system (170) and metabolome (171), likely to have important consequences for aging trajectories. At the CNS level, efforts are ongoing to characterize age-related changes in the marmoset brain (172, 173), associated changes in perception, cognition and motor function (174, 175), and their neuroendocrine mechanisms (176, 177). A rapidly growing area of research focuses on developing genetically modified marmosets to model AD (178), Parkinson's disease (11) and other age-related brain disorders (8). Capitalizing on the relatively short lifespan of the marmoset, research evaluating the effects of pharmacological (e.g, rapamycin, (179) metformin and acarbose (180)) and environmental (e.g., exercise (181)) interventions on healthspan in this species is underway.

Future. Offering key advantages for aging research, the marmoset provides a unique model to advance our understanding of aging at multiple levels of analysis. Studies focused on the basic biology of aging will help elucidate how age-related changes in immune function, mitochondrial function, DNA damage repair and epigenetic processes may increase the brain's vulnerability to neurodegeneration. Complementary *in vitro* studies of marmoset neuron and astrocyte cultures (182) will enable better understanding of the basic processes involved in aging and neurodegenerative disorders. At the system level, advances in neuroscience techniques applicable to behaving marmosets, such as chemogenetics, optogenetics, 2-photon imaging, and high field functional MRI, will be critical to identify the neural changes that underlie perceptual and cognitive deficits in healthy and pathological aging. Longitudinal studies integrating behavioral, physiological and neural assessments in naturally aging marmosets, marmosets with induced pathology, and genetically modified models for neurodegenerative diseases will provide better tools for understanding the mechanisms underlying neurodegeneration and designing new treatment strategies with high translational potential to humans. The marmoset will also be an ideal animal model to study the effects of early life interventions (e.g., diet, caloric restriction) on the development of late-life diseases. Finally, the rich social behavior of the marmoset, now amenable to functional neuroimaging (108), will offer the opportunity to study the mechanisms by which social influences impact the aging process. Given the unique advantages of the marmoset model for advancing fundamental questions of human aging, we urge NIA to support aging marmoset colonies, to facilitate their distribution to Investigators and to support marmoset aging research.

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Appendix 7

National Institute of Child Health and Human Development

2021 Marmoset Community White Paper

The principal mission of the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) is to ensure that every person is born healthy, that women suffer no harmful effects from the reproductive process, that children have the chance to fulfill their potential to live healthy and productive lives free from disease, and the well-being of all people through optimal rehabilitation. Animal models of disease have significantly contributed to the quests meeting the NICHD mission. The common marmoset (*Callithrix jacchus*) – a small monomorphic New World monkey – has a number of critical advantages to accelerate the rate of discovery in this research area. Like other primates, marmosets share the core physiological properties and brain architecture with humans. However, it is the species' small size, short life span, high fecundity, and human-like social structure that distinguish them from other primates and make them a particularly powerful biomedical model of child health and human development. Adult common marmosets average 300-450 grams, about the weight of a rat. They are reproductively competent at approximately 1.5 years of age, produce litters of 2-3 offspring every 5-6 months, and are considered aged at 8-12 years of age. The small size and fast life history of marmosets represents an advantage in many types of studies, including those involving reproduction, child-rearing, child health, impact of early life interventions, chronic disease effects, and testing compounds for which only small volumes may be affordably available. In particular, within a 5-year grant period, a marmoset can be followed from its own conception through to adulthood and reproduction in its offspring. Furthermore, the frequent production of twins and triplets enables study designs that can effectively control for genetic contribution by using siblings in different study groups. In addition, common marmosets are cooperative breeders with shared parenting responsibilities, a social structure very similar to humans. This similarity facilitates use of the common marmoset to model parenting and family effects on child development. Tools that further enhance the value of this species include complete sequencing, assembly, and annotation of the marmoset genome, generation of iPS cells, and production of transgenic marmosets – the first successful production of a transgenic nonhuman primate with germline transmission. For transgenic production, the fast maturation and high fecundity of the marmoset is a great advantage. The use of marmosets may bring transgenic line production within an acceptable financial range for areas of interest to NICHD in which the primate is a particularly compelling model such as autism spectrum disorder, Fragile X syndrome, and osteogenesis imperfecta.

Breadth of Current Research. Ongoing common marmoset research covers many areas of interest to NICHD. Several studies (183, 184) have documented a greatly diminished role for ovarian estradiol in metabolism and have established the relationship between estradiol depletion and diminished negative feedback in the development of polycystic ovarian syndrome (PCOS). A group of studies (185-188) have described marmoset pediatric obesity and its metabolic consequences as well as the role of both developmental programming and the establishment of feeding phenotypes during weaning on the development of pediatric obesity. Rutherford and colleagues (189-192) have taken advantage of litter size variation in marmosets to model the effects of varying intrauterine environments on developmental programming on a female's future reproductive success. Ongoing studies are investigating the role of dietary fat, puberty, and metabolism in the development of adolescent mood disorders. Pryce and colleagues established a model for examining the impact of separation on infant attachment and affective behavior during early development (193). This work has led to the further development of the model by French and colleagues (194-196), who have examined the role of oxytocin in modulating mate-guarding behavior and reunion affiliation following social separation in an attempt to understand the critical behavioral processes that contribute to the preservation of long-lasting relationships. Marmosets are a well-established model for vocal development. Their cooperative breeding system has been a major asset in research showing the crucial role of social interaction in vocal development (164-166, 197).

Importantly, there is evidence that marmosets are appropriate models for both autism (198, 199) and Zika virus infection (200).

The Future. The marmoset is a unique and valuable nonhuman primate model to investigate human development throughout the entire life process. Given their short lifespan and their short generation time, they are particularly important for evaluating the impact of developmental processes and programming on future generations. The development of tools allowing assessment of neurobehavioral developmental milestones (201, 202) and brain development from infancy to adulthood (203) will greatly facilitate this work, as will the ability to create transgenic models. There is great potential for the development of genetically modified models for diseases that have dramatic impacts on child health and development, such as autism spectrum disorder and Fragile X syndrome. Given the emergence of devastating neotropical diseases, such as Zika, we also anticipate increasing interest in marmoset disease models, particularly for diseases endemic to marmoset natural habitats and that may have prolonged latencies or unexpected later life effects. Finally, there is increasing appreciation for the role of social interactions in disease development and this is an area in which marmosets are a particularly valuable model over other potential models due to their human-like family structure.

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Appendix 8

National Eye Institute

2021 Marmoset Community White Paper

The core mission of the National Eye Institute (NEI) is to support research on the mechanisms underlying visual perception, from the early stages of processing in the eye to downstream processes in the lateral geniculate nucleus, primary visual and extrastriate cortex, and including areas involved in higher order visual processes such as visual attention and the control of eye movements. Natural selection has endowed primates, including humans, with specializations that affect visual processing in all these areas such as, critically, the fovea. The primate fovea has an outsized impact on the way visual information is processed, not simply because it yields higher acuity than any other mammal, leading to fine spatial form (shape) processing (204), but because it fundamentally changes how primates use their eyes to acquire information about the world. The primate brain has a network of oculomotor areas (205) and efficient strategies for moving the eyes so that the fovea is rapidly positioned over targets of interest. Rapid eye movements (saccades), are made two to three times every second as the brain samples the visual scene, and these signals are smoothly integrated across time so that it looks to the observer as though a wide visual field is seen crisply during a period of viewing. The areas governing the planning of saccades also play a critical role in the deployment of visuospatial attention, which strongly influences visual processing (206). Eye movements are also critical for visuo-motor manipulations during tool use and face recognition during social interactions. Relative to other mammals, primate vision is defined by these specializations along the full extent of the visual pathway from enhanced low-level retinal processing through high-level visual abilities. Thus vision research in non-human primates affords clear advantages over rodents. Both Old- and New-world monkeys have critical roles to play in the study of primate vision, but marmosets have several practical advantages: they are economical to house and easy to handle, and lack B-virus, making them safer to work with. Further, as detailed below, the marmoset has additional advantages over other primate models for vision research in multiple areas:

Development **-** Their short developmental timescale (reaching sexual maturity ~3x faster than macaques) allows study of postnatal development in the early visual system, and they offer interesting opportunities for developmental studies of color vision, as they exhibit genetic polymorphisms that affect the long-wavelength sensitive cones, yielding both dichromats (all males, some females) and some trichromats (some females) (207).

Mapping - The lissencephalic brain of the marmoset places multiple areas (such as V2, MT, face patches in IT, FEF) on the surface of the brain, where they are readily accessible for laminar recordings, array recordings, intrinsic imaging, fluorescent calcium imaging, and surface-based optogenetics (19, 20, 23, 25, 113, 208). The smaller brain of the marmoset makes large-scale mapping more efficient. Studies in Japan have already shown the promise of large-scale mapping techniques such as diffusion tensor imaging and widefield imaging.

Behavior – Like macaques, marmosets readily accept head restraint, a prerequisite for some approaches to electrophysiology and imaging (209) and can readily perform tasks requiring sensory discrimination (91). Marmosets make saccadic and smooth pursuit eye movements (87, 90) and preserve the use of eye movements to explore visual scenes and the relationship between saccadic velocity and displacement (91-93). Marmosets naturally exhibit a rich visuo-social behavior that in many respects parallels human.

Disease – Treatments for debilitating diseases like blindness and retinal degeneration benefit from studying animals whose retinae are similar to those of humans. Marmosets, macaques, and humans have very similar foveal cone densities though marmosets have higher cone density in the visual periphery (210). The rapid reproductive cycle of the marmoset and lower cost of housing relative to the macaque is an advantage when testing novel treatments such as gene therapy and neuroprosthetics where costs may be prohibitive in a macaque.

Breadth of Current Research. The breadth of research related to the mission of NEI Eye currently underway in marmosets is notable, ranging from disease modeling of the visual periphery to higher level visual processing. For example, myopia (nearsightedness) is a prevalent disease of the eye that affects >20% of the human population and can develop throughout life. Work has been done in marmosets studying how corrective optics early in development can affect the evolution of nearsightedness (Troilo & Judge, *Vision Research* 1993). Ongoing work in marmoset is studying the genetic markers and the molecular signaling pathways involved in myopia so that potential therapeutic targets can be identified (211). Recent work in marmosets has also begun to show how interactions between cortical areas affect visual processing elucidating the long-debated role of cortical feedback in vision. Using novel optogenetic techniques for circuit dissection, the specific effects of long-range projections from V2 on V1 function were demonstrated advancing on work using more classical techniques in macaques (20). Moreover, visual face processing is important in primate social interactions and developmental prosopagnosia and autism are examples of specific disorders of face recognition afflicting a large fraction of the human population. Marmosets are highly social (4) and, like humans, are highly attentive to faces (91, 93) because they convey meaningful social information (212) and exhibit specialized regions for face processing in high-level visual cortex (107). Studies of this face-patch network are poised to expand with ongoing efforts to developed transgenic marmoset models of autism disorder. Close parallels are being established between marmoset and human visual and oculomotor behavior, including comparable performance on object recognition tasks (213) and motion perception (105). The Frontal Eye Fields, which play a critical part in oculomotor planning have been functionally characterized in marmoset, (214) helping to establish the marmoset as a model for studying eye movements (215). Advances are being made in studying foveal vision in marmoset and there is evidence for pre-saccadic enhancement in marmost V1(216). Marmosets were key to the discovery that traveling waves occur in the extrastriate visual cortex in the awake state, and that these waves strongly regulate sensitivity to visual stimuli (26). Detection and tracking of these waves in Area MT was only possible because unlike macaque MT, which is at the bottom of the Superior Temporal Sulcus, in marmoset MT rests on the surface of the largely lissencephalic marmoset cortex.

The Future. As a rapidly emerging model system, marmosets are likely to play a critical role in elucidating the intricacies of the primate visual system for decades to come and increase the range of studies for which the species is employed. Marmosets, for example, are an attractive species for studying diseases with a developmental component because of their fast life cycle and high reproduction rates (217). The rapid sexual maturation of marmosets (18 months) will be critical for studying schizophrenia, autism-spectrum disorders, and attention-deficit hyperactivity disorder in which psychopathology is manifest in childhood. Furthermore, visual deficits, particularly in the M pathway of early vision are well documented in schizophrenia and can be studied in marmosets as well as studying oculomotor, face processing, and visual attention deficits in autism. Marmosets are the shortest-lived anthropoid primates, with a typical lifespan of 9–12 years as compared with 25–40 years for rhesus macaques. Their shorter lifespan makes them better suited to longitudinal studies of age-related vision loss. Finally, an acute need exists throughout neuroscience for means of targeting the elements of cortical circuits in the non-human primate. Viral targeting strategies have been developed for highly selective expression of proteins, such as opsins in non-genetically engineered species, and validated in marmoset (12, 13, 16). The benefits of the development of these capacities, both through the establishment of genetically engineered Cre and Flp lines and through the development of enhanced viral targeting capacities (16) will be particularly impactful in the visual system due to the over 50 years of foundational research on visual circuits.

Authors
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Literature Cited

1. Tardif SD, Smucny DA, Abbott DH, Mansfield K, Schultz-Darken N, Yamamoto ME. Reproduction in captive common marmosets (Callithrix jacchus). Comparative Medicine. 2003;53:364-8.
2. Yamamoto M. From dependence to sexual maturity: the behavioural ontogeny of Callitrichidae. In: Rylands AB, editor. Marmosets and Tamarins: Systematics, Behavior and Ecology. London: Oxford University Press; 1993. p. 235-54.
3. Schiel N, Souto A. The common marmoset: An overview of its natural history, ecology and behavior. Developmental Neurobiology. 2017;77:244-62.
4. Miller CT, Freiwald W, Leopold DA, Mitchell JF, Silva AC, Wang X. Marmosets: A Neuroscientific Model of Human Social Behavior. Neuron. 2016;90:219-33.
5. Sasaki E, Suemizu H, Shimada A, Hanazawa K, Oiwa R, Kamioka M, Tomioka I, Sotomaru Y, Hirakawa R, Eto R, Siozawa S, Maeda T, Ito M, Ito R, Kito C, Yagihashi C, Kawai K, Miyoshi H, Tanioka Y, Tamaoki N, Habu S, Okano H, Nomura T. Generation of transgenic non-human primates with germline transmission. Nature. 2009;459:523-7.
6. Sato K, Oiwa R, Kumita W, Henry R, Sakuma T, Ryoji I, Nozu R, Inoue T, Katano I, Sato K, Okahara N, Okahara J, Shimizu Y, Yamamoto M, Hanazawa K, Kawakami T, Kametani Y, Suzuki R, Takahashi TT, Weinstein E, Yamamoto T, Sakakibara Y, Habu S, Hata J, Okano H, Sasaki E. Generation of a nonhuman primate model of severe combined immunodeficiency using highly efficient genome editing. Cell stem cell. 2016;19:127-38.
7. Park JE, Zhang XF, Choi S, Okahara J, Sasaki E, Silva AC. Generation of transgenic marmosets expressing genetically encoded calcium indicators. Scientific Reports. 2016;6:34931.
8. Feng G, Jensen FE, Greely HT, Okano H, Treue S, Roberts AC, Fox JG, Caddick S, Poo M-m, Newsome WT, Morrison JH. Opportunities and limitations of genetically modified nonhuman primate models for neuroscience research. PNAS. 2020;117(39):24022-31. doi: 10.1073/pnas.2006515117.
9. Kumita W, Sato K, Suzuki Y, Kurotaki Y, Harada T, Zhou Y, Kishi N, Sato K, Aiba A, Sakakibara Y, Feng G, Okano H, Sasaki E. Efficient generation of Knock-in/Knock-out marmoset embryo via CRISPR/Cas9 gene editing. Scientific Reports. 2019;9(1):12719. doi: 10.1038/s41598-019-49110-3.
10. Yoshimatsu S, Okahara J, Sone T, Takeda Y, Nakamura M, Sasaki E, Kishi N, Shiozawa S, Okano H. Robust and efficient knock-in in embryonic stem cells and early-stage embryos of the common marmoset using the CRISPR-Cas9 system. Scientific Reports. 2019;9(1):1528. doi: 10.1038/s41598-018-37990-w.
11. Vermilyea SC, Babinski A, Tran N, To S, Guthrie S, Kluss JH, Schmidt JK, Wiepz GJ, Meyer MG, Murphy ME, Cookson MR, Emborg ME, Golos TG. In Vitro CRISPR/Cas9-Directed Gene Editing to Model LRRK2 G2019S Parkinson's Disease in Common Marmosets. Scientific Reports. 2020;10(1):3447. doi: 10.1038/s41598-020-60273-2.
12. Mehta P, Kreeger L, Wylie DC, Pattadkal JJ, Lusignan T, Davis MJ, Turi GF, Li W-K, Whitmire MP, Chen Y, Kajs BL, Seidemann E, Priebe NJ, Losonczy A, Zemelman BV. Functional Access to Neuron Subclasses in Rodent and Primate Forebrain. Cell reports. 2019;26(10):2818-32.e8. doi: https://doi.org/10.1016/j.celrep.2019.02.011.
13. Vormstein-Schneider D, Lin JD, Pelkey KA, Chittajallu R, Guo B, Arias-Garcia MA, Allaway K, Sakopoulos S, Schneider G, Stevenson O, Vergara J, Sharma J, Zhang Q, Franken TP, Smith J, Ibrahim LA, M astro KJ, Sabri E, Huang S, Favuzzi E, Burbridge T, Xu Q, Guo L, Vogel I, Sanchez V, Saldi GA,

Gorissen BL, Yuan X, Zaghloul KA, Devinsky O, Sabatini BL, Batista-Brito R, Reynolds J, Feng G, Fu Z, McBain CJ, Fishell G, Dimidschstein J. Viral manipulation of functionally distinct interneurons in mice, non-human primates and humans. Nature Neuroscience. 2020;23(12):1629-36. doi: 10.1038/s41593-020-0692-9.
14. Watakabe A, Sadakane O, Hata K, Ohtsuka M, Takaji M, Yamamori T. Application of viral vectors to the study of neural connectivities and neural circuits in the marmoset brain. Developmental Neurobiology. 2017.
15. Watakabe A, Ohtsuka M, Kinoshita M, Takaji M, Isa K, Mizukami H, Ozawa K, Isa T, Yamamori T. Comparative analyses of adeno-associated viral vector serotypes 1,2,5,8, and 9 in marmoset, mouse and macaque cerebral cortex. . Neuroscience Research. 2015;93:144-57.
16. Dimidschtein J, Chen Q, Temblay R, Rogers SL, Saldi G, Guo L, Xu Q, Liu RC, Lu C, Chu J, Avery M, Rashid M, Baek M, Jacob A, Smith G, Wilson D, Kosche G, Kuglikov I, Rusielwicz T, Kotak V, Mowery T, Anderson S, Callaway EM, Dasen J, Fitzpatrick D, Fossati V, Long MA, Noggle S, Reynolds JH, Sanes DH, Rudy B, Feng G, Fishell G. A viral strategy for targeting and manipulating interneurons across vertebrate species. . Nature Neuroscience. 2016;19:1743-9.
17. Flytzanis NC, Goeden N, Goertsen D, Cummins A, Pickel J, Gradinaru V. Broad gene expression throughout the mouse and marmoset brain after intravenous delivery of engineered AAV capsids. bioRxiv. 2020:2020.06.16.152975. doi: 10.1101/2020.06.16.152975.
18. Ebina T, Obara K, Watakabe A, Masamizu Y, Terada S-I, Matoba R, Takaji M, Hatanaka N, Nambu A, Mizukami H, Yamamori T, Matsuzaki M. Arm movements induced by noninvasive optogenetic stimulation of the motor cortex in the common marmoset. PNAS. 2019;116(45):22844-50. doi: 10.1073/pnas.1903445116.
19. MacDougall M, Nummela SU, Coop S, Disney AA, Mitchell JF, Miller CT. Optogenetic photostimulation of neural circuits in awake marmosets. J Neurophys. 2016;116:1286-94.
20. Nurminen L, Merlin S, Bijanzadeh M, Federer F, Angelucci A. Top-down feedback controls spatial summation and response amplitude in primate visual cortex. Nature Communications. 2018;9(1):2281. doi: 10.1038/s41467-018-04500-5.
21. Mimura K, Nagai Y, Inoue K-i, Matsumoto J, Hori Y, Sato C, Kimura K, Okauchi T, Hirabayashi T, Nishijo H, Yahata N, Takada M, Suhara T, Higuchi M, Minamimoto T. Chemogenetic activation of nigrostriatal dopamine neurons in freely moving common marmosets. bioRxiv. 2021:2021.01.29.428749. doi: 10.1101/2021.01.29.428749.
22. Yamada Y, Matsumoto Y, Okahara N, Mikoshiba K. Chronic multiscale imaging of neuronal activity in the awake common marmoset. Scientific Reports. 2016;6(1):35722. doi: 10.1038/srep35722.
23. Sadakane O, Masamizu Y, Watakabe A, Terada S, Ohtsuka M, Takaji M, Mizukami H, Ozawa K, Kawasaki H, Matsuzaki M, Yamamori T. Long-term Two-photon Calcium Imaging of neuronal populations with subcellular resolution in adult non-human primates. . Cell reports. 2015;13:1989-99.
24. Zeng H-h, Huang J-f, Chen M, Wen Y-q, Shen Z-m, Poo M-m. Local homogeneity of tonotopic organization in the primary auditory cortex of marmosets. PNAS. 2019;116(8):3239-44. doi: 10.1073/pnas.1816653116.
25. Santisakultarm TP, Kresbergen CJ, Bandy DK, Ide DC, Choi S, Silva AC. Two-photon imaging of cerebral hemodynamics and neural activity in awake and anesthetized marmosets. . Journal of Neuroscience Methods. 2016;271:55-64.
26. Davis ZW, Muller L, Martinez-Trujillo J, Sejnowski T, Reynolds JH. Spontaneous travelling cortical waves gate perception in behaving primates. Nature. 2020;587(7834):432-6. Epub 2020/10/09. doi: 10.1038/s41586-020-2802-y. PubMed PMID: 33029013; PMCID: PMC7677221.

27. Courellis HS, Nummela SU, Metke M, Diehl G, Bussell R, Cauwenberghs G, Miller CT. Spatial encoding in primate hippocampus during free-navigation. PLOS Biology 2019;17(12):e3000546. doi: https://doi.org/10.1371/journal. pbio.3000546.
28. Liu ST, Montes-Lourido P, Wang X, Sadagopan S. Optimal features for auditory categorization. Nature Communications. 2019;10(1):1302. doi: 10.1038/s41467-019-09115-y.
29. Mundinano I-C, Kwan WC, Bourne JA. Retinotopic specializations of cortical and thalamic inputs to area MT. PNAS. 2019;116(46):23326-31. doi: 10.1073/pnas.1909799116.
30. Ghodrati M, Zavitz E, Rosa MGP, Price NSC. Contrast and luminance adaptation alter neuronal coding and perception of stimulus orientation. Nature Communications. 2019;10(1):941. doi: 10.1038/s41467-019-08894-8.
31. Zhu Q, Vanduffel W. Submillimeter fMRI reveals a layout of dorsal visual cortex in macaques, remarkably similar to New World monkeys. PNAS. 2019;116(6):2306-11. doi: 10.1073/pnas.1805561116.
32. Santangelo AM, Sawiak SJ, Fryer T, Hong Y, Shiba Y, Clarke HF, Riss PJ, Ferrari V, Tait R, Suckling J, Aigbirhio FI, Roberts AC. Insula serotonin 2A receptor binding and gene expression contribute to serotonin transporter polymorphism anxious phenotype in primates. PNAS. 2019;116(29):14761-8. doi: 10.1073/pnas.1902087116.
33. Schaeffer DJ, Selvanayagam J, Johnston KD, Menon RS, Freiwald WA, Everling S. Face selective patches in marmoset frontal cortex. Nature Communications. 2020;11(1):4856. doi: 10.1038/s41467-020-18692-2.
34. Stawicka ZM, Massoudi R, Horst NK, Koda K, Gaskin PLR, Alexander L, Santangelo AM, McIver L, Cockcroft GJ, Wood CM, Roberts AC. Ventromedial prefrontal area 14 provides opposing regulation of threat and reward-elicited responses in the common marmoset. PNAS. 2020;117(40):25116-27. doi: 10.1073/pnas.2009657117.
35. Schaeffer DJ, Hori Y, Gilbert KM, Gati JS, Menon RS, Everling S. Divergence of rodent and primate medial frontal cortex functional connectivity. PNAS. 2020;117(35):21681-9. doi: 10.1073/pnas.2003181117.
36. Lee JH, Wang X, Bendor D. The role of adaptation in generating monotonic rate codes in auditory cortex. PLOS Computational Biology. 2020;16(2):e1007627. doi: 10.1371/journal.pcbi.1007627.
37. Alexander L, Wood CM, Gaskin PLR, Sawiak SJ, Fryer TD, Hong YT, McIver L, Clarke HF, Roberts AC. Over-activation of primate subgenual cingulate cortex enhances the cardiovascular, behavioral and neural responses to threat. Nature Communications. 2020;11(1):5386. doi: 10.1038/s41467-020-19167-0.
38. Heide M, Haffner C, Murayama A, Kurotaki Y, Shinohara H, Okano H, Sasaki E, Huttner WB. Human-specific ARHGAP11B increases size and folding of primate neocortex in the fetal marmoset. Science. 2020;369:546-50.
39. Krienen FM, Goldman M, Zhang Q, C. H. del Rosario R, Florio M, Machold R, Saunders A, Levandowski K, Zaniewski H, Schuman B, Wu C, Lutservitz A, Mullally CD, Reed N, Bien E, Bortolin L, Fernandez-Otero M, Lin JD, Wysoker A, Nemesh J, Kulp D, Burns M, Tkachev V, Smith R, Walsh CA, Dimidschstein J, Rudy B, S. Kean L, Berretta S, Fishell G, Feng G, McCarroll SA. Innovations present in the primate interneuron repertoire. Nature. 2020;586(7828):262-9. doi: 10.1038/s41586-020-2781-z.
40. Peng Y-R, Shekhar K, Yan W, Herrmann D, Sappington A, Bryman GS, van Zyl T, Do MTH, Regev A, Sanes JR. Molecular Classification and Comparative Taxonomics of Foveal and Peripheral Cells in Primate Retina. Cell. 2019;176(5):1222-37.e22. doi: https://doi.org/10.1016/j.cell.2019.01.004.

41. Buckner RL, Margulies DS. Macroscale cortical organization and a default-like apex transmodal network in the marmoset monkey. Nature Communications. 2019;10(1):1976. doi: 10.1038/s41467-019-09812-8.
42. Lin MK, Takahashi YS, Huo B-X, Hanada M, Nagashima J, Hata J, Tolpygo AS, Ram K, Lee BC, Miller MI, Rosa MGP, Sasaki E, Iriki A, Okano H, Mitra P. A high-throughput neurohistological pipeline for brain-wide mesoscale connectivity mapping of the common marmoset. eLife. 2019;8:e40042. doi: 10.7554/eLife.40042.
43. Liu C, Yen CC-C, Szczupak D, Ye FQ, Leopold DA, Silva AC. Anatomical and functional investigation of the marmoset default mode network. Nature Communications. 2019;10(1):1975. doi: 10.1038/s41467-019-09813-7.
44. Liu C, Ye FQ, Newman JD, Szczupak D, Tian X, Yen CC-C, Majka P, Glen D, Rosa MGP, Leopold DA, Silva AC. A resource for the detailed 3D mapping of white matter pathways in the marmoset brain. Nature Neuroscience. 2020;23(2):271-80. doi: 10.1038/s41593-019-0575-0.
45. Majka P, Bai S, Bakola S, Bednarek S, Chan JM, Jermakow N, Passarelli L, Reser DH, Theodoni P, Worthy KH, Wang X-J, Wójcik DK, Mitra PP, Rosa MGP. Open access resource for cellular-resolution analyses of corticocortical connectivity in the marmoset monkey. Nature Communications. 2020;11(1):1133. doi: 10.1038/s41467-020-14858-0.
46. Zhao L, Rad BB, Wang X. Long-lasting vocal plasticity in adult marmoset monkeys. Proceedings of the Royal Society B: Biological Sciences. 2019;286(1905):20190817. doi: doi:10.1098/rspb.2019.0817.
47. Pomberger T, Risueno-Segovia C, Gultekin YB, Dohmen D, Hage SR. Cognitive control of complex motor behavior in marmoset monkeys. Nature Communications. 2019;10(1):3796. doi: 10.1038/s41467-019-11714-8.
48. Zhang YS, Takahashi DY, Liao DA, Ghazanfar AA, Elemans CPH. Vocal state change through laryngeal development. Nature Communications. 2019;10(1):4592. doi: 10.1038/s41467-019-12588-6.
49. Gustison ML, Borjon JI, Takahashi DY, Ghazanfar AA. Vocal and locomotor coordination develops in association with the autonomic nervous system. eLife. 2019;8:e41853. doi: 10.7554/eLife.41853.
50. Huang J, Cheng X, Zhang S, Chang L, Li X, Liang Z, Gong N. Having Infants in the Family Group Promotes Altruistic Behavior of Marmoset Monkeys. Current Biology. 2020;30(20):4047-55.e3. doi: https://doi.org/10.1016/j.cub.2020.07.045.
51. Risueno-Segovia C, Hage SR. Theta Synchronization of Phonatory and Articulatory Systems in Marmoset Monkey Vocal Production. Current Biology. 2020;30(21):4276-83.e3. doi: https://doi.org/10.1016/j.cub.2020.08.019.
52. Alexander L, Gaskin PLR, Sawiak SJ, Fryer TD, Hong YT, Cockcroft GJ, Clarke HF, Roberts AC. Fractionating Blunted Reward Processing Characteristic of Anhedonia by Over-Activating Primate Subgenual Anterior Cingulate Cortex. Neuron. 2019;101(2):307-20.e6. doi: https://doi.org/10.1016/j.neuron.2018.11.021.
53. Beites T, O'Brien K, Tiwari D, Engelhart CA, Walters S, Andrews J, Yang H-J, Sutphen ML, Weiner DM, Dayao EK, Zimmerman M, Prideaux B, Desai PV, Masquelin T, Via LE, Dartois V, Boshoff HI, Barry CE, Ehrt S, Schnappinger D. Plasticity of the Mycobacterium tuberculosis respiratory chain and its impact on tuberculosis drug development. Nature Communications. 2019;10(1):4970. doi: 10.1038/s41467-019-12956-2.
54. Castelijns B, Baak ML, Timpanaro IS, Wiggers CRM, Vermunt MW, Shang P, Kondova I, Geeven G, Bianchi V, de Laat W, Geijsen N, Creyghton MP. Hominin-specific regulatory elements selectively emerged in oligodendrocytes and are disrupted in autism patients. Nature Communications. 2020;11(1):301. doi: 10.1038/s41467-019-14269-w.

55. Luo S, Zhao W, Ma X, Zhang P, Liu B, Zhang L, Wang W, Wang Y, Fu Y, Allain J-P, Li T, Li C. A high infectious simian adenovirus type 23 vector based vaccine efficiently protects common marmosets against Zika virus infection. PLOS Neglected Tropical Diseases. 2020;14(2):e0008027. doi: 10.1371/journal.pntd.0008027.
56. Gao L, Wang X. Intracellular neuronal recording in awake nonhuman primates. Nature Protocols. 2020;15(11):3615-31. doi: 10.1038/s41596-020-0388-3.
57. Dunn TW, Marshall JD, Severson KS, Aldarondo DE, Hildebrand DGC, Chettih SN, Wang WL, Gellis AJ, Carlson DE, Aronov D, Freiwald WA, Wang F, Ölveczky BP. Geometric deep learning enables 3D kinematic profiling across species and environments. Nature Methods. 2021;18(5):564-73. doi: 10.1038/s41592-021-01106-6.
58. Tardif SD, Mansfield KG, Ratnam R, Ross CN, Ziegler TE. The marmoset as a model of aging and age-related disease. ILAR journal/ National Research Council, Institute of Laboratory Animal Resources. 2011;52:54-65.
59. Okano H. Current Status of and Perspectives on the Application of Marmosets in Neurobiology. Ann Rev Neurosci. 2021;44(1):27-48. doi: 10.1146/annurev-neuro-030520-101844. PubMed PMID: 34236888.
60. Calhoun AJ, Pillow JW, Murthy M. Unsupervised identification of the internal states that shape natural behavior. Nature Neuroscience. 2019;22(12):2040-9. doi: 10.1038/s41593-019-0533-x.
61. Ding R, Liao X, Li J, Zhang J, Wang M, Guang Y, Qin H, Li X, Zhang K, Liang S, Guan J, Lou J, Jia H, Chen B, Shen H, Chen X. Targeted Patching and Dendritic Ca2+ Imaging in Nonhuman Primate Brain in vivo. Scientific Reports. 2017;7(1):2873. doi: 10.1038/s41598-017-03105-0.
62. Yamada Y, Matsumoto Y, Okahara N, Mikoshiba K. Chronic multiscale imaging of neuronal activity in the awake common marmoset. Sci Rep. 2016;6:35722. Epub 2016/10/28. doi: 10.1038/srep35722. PubMed PMID: 27786241; PMCID: PMC5082371.
63. Ebina T, Masamizu Y, Tanaka YR, Watakabe A, Hirakawa R, Hirayama Y, Hira R, Terada SI, Koketsu D, Hikosaka K, Mizukami H, Nambu A, Sasaki E, Yamamori T, Matsuzaki M. Two-photon imaging of neuronal activity in motor cortex of marmosets during upper-limb movement tasks. Nat Commun. 2018;9(1):1879. Epub 2018/05/16. doi: 10.1038/s41467-018-04286-6. PubMed PMID: 29760466; PMCID: PMC5951821.
64. Zeng HH, Huang JF, Chen M, Wen YQ, Shen ZM, Poo MM. Local homogeneity of tonotopic organization in the primary auditory cortex of marmosets. Proc Natl Acad Sci U S A. 2019;116(8):3239-44. Epub 2019/02/06. doi: 10.1073/pnas.1816653116. PubMed PMID: 30718428; PMCID: PMC6386663.
65. Kondo T, Saito R, Otaka M, Yoshino-Saito K, Yamanaka A, Yamamori T, Watakabe A, Mizukami H, Schnitzer MJ, Tanaka KF, Ushiba J, Okano H. Calcium Transient Dynamics of Neural Ensembles in the Primary Motor Cortex of Naturally Behaving Monkeys. Cell Rep. 2018;24(8):2191-5 e4. Epub 2018/08/23. doi: 10.1016/j.celrep.2018.07.057. PubMed PMID: 30134178.
66. Ebina T, Obara K, Watakabe A, Masamizu Y, Terada SI, Matoba R, Takaji M, Hatanaka N, Nambu A, Mizukami H, Yamamori T, Matsuzaki M. Arm movements induced by noninvasive optogenetic stimulation of the motor cortex in the common marmoset. Proc Natl Acad Sci U S A. 2019;116(45):22844-50. Epub 2019/10/23. doi: 10.1073/pnas.1903445116. PubMed PMID: 31636197; PMCID: PMC6842633.
67. Macknik SL, Alexander RG, Caballero O, Chanovas J, Nielsen KJ, Nishimura N, Schaffer CB, Slovin H, Babayoff A, Barak R, Tang S, Ju N, Yazdan-Shahmorad A, Alonso JM, Malinskiy E, Martinez-Conde S. Advanced Circuit and Cellular Imaging Methods in Nonhuman Primates. J Neurosci. 2019;39(42):8267-74. Epub 2019/10/18. doi: 10.1523/JNEUROSCI.1168-19.2019. PubMed PMID: 31619496; PMCID: PMC6794937.

68. Nurminen L, Merlin S, Bijanzadeh M, Federer F, Angelucci A. Top-down feedback controls spatial summation and response amplitude in primate visual cortex. Nature Commun. 2018;9:2281.
69. Tremblay S, Acker L, Afraz A, Albaugh DL, Amita H, Andrei AR, Angelucci A, Aschner A, Balan PF, Basso MA, Benvenuti G, Bohlen MO, Caiola MJ, Calcedo R, Cavanaugh J, Chen Y, Chen S, Chernov MM, Clark AM, Dai J, Debes SR, Deisseroth K, Desimone R, Dragoi V, Egger SW, Eldridge MAG, El-Nahal HG, Fabbrini F, Federer F, Fetsch CR, Fortuna MG, Friedman RM, Fujii N, Gail A, Galvan A, Ghosh S, Gieselmann MA, Gulli RA, Hikosaka O, Hosseini EA, Hu X, Huer J, Inoue KI, Janz R, Jazayeri M, Jiang R, Ju N, Kar K, Klein C, Kohn A, Komatsu M, Maeda K, Martinez-Trujillo JC, Matsumoto M, Maunsell JHR, Mendoza-Halliday D, Monosov IE, Muers RS, Nurminen L, Ortiz-Rios M, O'Shea DJ, Palfi S, Petkov CI, Pojoga S, Rajalingham R, Ramakrishnan C, Remington ED, Revsine C, Roe AW, Sabes PN, Saunders RC, Scherberger H, Schmid MC, Schultz W, Seidemann E, Senova YS, Shadlen MN, Sheinberg DL, Siu C, Smith Y, Solomon SS, Sommer MA, Spudich JL, Stauffer WR, Takada M, Tang S, Thiele A, Treue S, Vanduffel W, Vogels R, Whitmire MP, Wichmann T, Wurtz RH, Xu H, Yazdan-Shahmorad A, Shenoy KV, DiCarlo JJ, Platt ML. An Open Resource for Non-human Primate Optogenetics. Neuron. 2020;108(6):1075-90 e6. Epub 2020/10/21. doi: 10.1016/j.neuron.2020.09.027. PubMed PMID: 33080229.
70. Krienen FM, Goldman M, Zhang Q, R CHDR, Florio M, Machold R, Saunders A, Levandowski K, Zaniewski H, Schuman B, Wu C, Lutservitz A, Mullally CD, Reed N, Bien E, Bortolin L, Fernandez-Otero M, Lin JD, Wysoker A, Nemesh J, Kulp D, Burns M, Tkachev V, Smith R, Walsh CA, Dimidschstein J, Rudy B, L SK, Berretta S, Fishell G, Feng G, McCarroll SA. Innovations present in the primate interneuron repertoire. Nature. 2020;586(7828):262-9. Epub 2020/10/02. doi: 10.1038/s41586-020-2781-z. PubMed PMID: 32999462; PMCID: PMC7957574.
71. Mehta P, Kreeger L, Wylie DC, Pattadkal JJ, Lusignan T, Davis MJ, Turi GF, Li WK, Whitmire MP, Chen Y, Kajs BL, Seidemann E, Priebe NJ, Losonczy A, Zemelman BV. Functional Access to Neuron Subclasses in Rodent and Primate Forebrain. Cell Rep. 2019;26(10):2818-32 e8. PubMed PMID: 30840900.
72. Vormstein-Schneider DC, Lin JD, Pelkey KA, Chittajallu R, Guo B, Arias Garcia M, Sakopoulos S, Stevenson O, Schneider G, Zhang Q, Sharma J, Franken TP, Smith J, Vogel I, Sanchez V, Ibrahim LA, Burbridge T, Favuzzi E, Saldi GA, Xu Q, Guo L, Yuan X, Zaghloul KA, Sabri E, Goldberg EM, Devinsky O, Batista-Brito R, Reynolds J, Feng G, Fu Z, McBain CJ, Fishell GJ, Dimidschstein J. Viral manipulation of functionally distinct interneurons in mice, non-human primates and humans. Nat Neurosci. 2020;23:1629-36. doi: http://dx.doi.org/10.1101/808170.
73. Song X, Osmanski MS, Guo Y, Wang X. Complex pitch perception mechanisms are shared by humans and a New World monkey. PNAS. 2016;113:781-6.
74. Johnson LA, Della Santina CC, Wang X. Selective Neuronal Activation by Cochlear Implant Stimulation in Auditory Cortex of Awake Primate. The Journal of Neuroscience. 2016;36:12468-84.
75. Zhou Y, Wang XW. Spatially extended forward suppression in primate auditory cortex. European Journal of Neuroscience. 2014;39:919-33.
76. Issa EB, Wang X. Altered neural responses to sounds in primate primary auditory cortex. J Neurosci. 2011;31:2965-73.
77. Bendor DA, Wang X. Neural coding of periodicity in marmoset auditory cortex. J Neurophys. 2010;103:1809-22.
78. Eliades SJ, Wang X. Neural substrates of vocalization feedback monitoring in primate auditory cortex. Nature. 2008;453:1102-6.
79. Bendor DA, Wang X. Neural response properties of the primary, rostral and rostrotemporal core fields in the auditory cortex of marmoset monkeys. J Neurophys. 2008;100:888-906.
80. Wang X, Lu T, Snider RK, Liang L. Sustained firing in auditory cortex evoked by preferred stimuli. Nature. 2005;435:341-6.

81. Bendor DA, Wang X. The neuronal representation of pitch in primate auditory cortex. Nature. 2005;436:1161-5.
82. Gao L, Kostlan K, Wang Y, Wang X. Distinct Subthreshold Mechanisms Underlying Rate-Coding Principles in Primate Auditory Cortex. Neuron. 2016;91(4):905-19. doi: https://doi.org/10.1016/j.neuron.2016.07.004.
83. Roy S, Zhao L, Wang X. Distinct neural activities in premotor cortex during natural vocal behaviors in a New World primate, the common marmoset (Callithrix jacchus). J Neurosci. 2016;36:12168-79.
84. Toarmino CR, Yen CC, Papoti D, Bock NA, Leopold D, Miller CT, Silva AC. Functional magnetic resonance imaging of auditory cortical fields in awake marmosets. Neuroimage. 2017;162:86-92.
85. Nummela S, Jovanovic V, de la Mothe LA, Miller CT. Social context-dependent activity in marmoset frontal cortex populations during natural conversations. . J Neurosci. 2017;37:7036-47.
86. Miller CT, Thomas AW, Nummela S, de la Mothe LA. Responses of primate frontal cortex neurons during natural vocal communication. J Neurophys. 2015;114:1158-71.
87. Mitchell J, Priebe N, Miller CT. Motion dependence of smooth eye movements in the marmoset. J Neurophys. 2015;113:3954-60.
88. Ghodrati M, Zavitz E, Rosa MGP, Price NSC. Contrast and luminance adaptation alter neuronal coding and perception of stimulus orientation. Nat Commun. 2019;10(1):941. Epub 2019/02/28. doi: 10.1038/s41467-019-08894-8. PubMed PMID: 30808863; PMCID: PMC6391449.
89. Mundinano IC, Kwan WC, Bourne JA. Retinotopic specializations of cortical and thalamic inputs to area MT. Proc Natl Acad Sci U S A. 2019;116(46):23326-31. Epub 2019/10/30. doi: 10.1073/pnas.1909799116. PubMed PMID: 31659044; PMCID: PMC6859338.
90. Samonds JM, Geisler WS, Priebe NJ. Natural image and receptive field statistics predict saccade sizes. Nature Neuroscience. 2018;21(11):1591-9. doi: 10.1038/s41593-018-0255-5.
91. Mitchell J, Reynolds J, Miller CT. Active vision in marmosets: A model for visual neuroscience. J Neurosci. 2014;34:1183-94.
92. Knöll J, Pillow JW, Huk AC. Lawful tracking of visual motion in humans, macaques, and marmosets in a naturalistic, continuous, and untrained behavioral context2018;115(44):E10486-E94. doi: 10.1073/pnas.1807192115 %J Proceedings of the National Academy of Sciences.
93. Nummela SU, Jutras MJ, Wixted JT, Buffalo EA, Miller CT. Recognition Memory in Marmoset and Macaque Monkeys: A Comparison of Active Vision. J Cog Neurosci. 2019;31:1318-28.
94. Moffitt JR, Bambah-Mukku D, Eichhorn SW, Vaughn E, Shekhar K, Perez JD, Rubinstein ND, Hao J, Regev A, Dulac C, Zhuang X. Molecular, spatial and functional single-cell profiling of the hypothalamic preoptic region2018:eaau5324. doi: 10.1126/science.aau5324 %J Science.
95. Okada S, Bartelle BB, Li N, Breton-Provencher V, Lee JJ, Rodriguez E, Melican J, Sur M, Jasanoff A. Calcium-dependent molecular fMRI using a magnetic nanosensor. Nature Nanotechnology. 2018;13(6):473-7. doi: 10.1038/s41565-018-0092-4.
96. Hai A, Cai LX, Lee T, Lelyveld VS, Jasanoff A. Molecular fMRI of Serotonin Transport. Neuron. 2016;92(4):754-65. doi: https://doi.org/10.1016/j.neuron.2016.09.048.
97. Goodroe AE, Fitz C, Power ML, Colman RJ, Capuano III S, Ziegler TE. Evaluation of vitamin D3 metabolites in Callithrix jacchus (common marmoset). Am J Primatol. 2020;82(6):e23131. doi: https://doi.org/10.1002/ajp.23131.
98. Singh DK, Singh B, Ganatra SR, Gazi M, Cole J, Thippeshappa R, Alfson KJ, Clemmons E, Gonzalez O, Escobedo R, Lee T-H, Chatterjee A, Goez-Gazi Y, Sharan R, Gough M, Alvarez C, Blakley A, Ferdin J, Bartley C, Staples H, Parodi L, Callery J, Mannino A, Klaffke B, Escareno P, Platt RN, Hodara V, Scordo J, Gautam S, Vilanova AG, Olmo-Fontanez A, Schami A, Oyejide A, Ajithdoss DK, Copin R, Baum A, Kyratsous C, Alvarez X, Ahmed M, Rosa B, Goodroe A, Dutton J, Hall-Ursone S, Frost PA, Voges AK, Ross CN, Sayers K, Chen C, Hallam C, Khader SA, Mitreva M, Anderson TJC, Martinez-

Sobrido L, Patterson JL, Turner J, Torrelles JB, Dick EJ, Brasky K, Schlesinger LS, Giavedoni LD, Carrion R, Kaushal D. Responses to acute infection with SARS-CoV-2 in the lungs of rhesus macaques, baboons and marmosets. Nature Microbiology. 2021;6(1):73-86. doi: 10.1038/s41564-020-00841-4.
99. Dias R, Robbins TW, Roberts AC. Dissociation in prefrontal cortex of affective and attentional shifts. Nature. 1996;380:69-72.
100. Clarke HF, Walker SC, Dalley JW, Robbins TW, Roberts AC. Cognitive Inflexibility after Prefrontal Serotonin Depletion Is Behaviorally and Neurochemically Specific. Cerebral Cortex. 2007;17(1):18-27. doi: 10.1093/cercor/bhj120.
101. Roberts AC. Primate orbitofrontal cortex and adaptive behaviour. Trends in Cognitive Sciences. 2006;10(2):83-90. doi: https://doi.org/10.1016/j.tics.2005.12.002.
102. Roberts AC, Wallis JD. Inhibitory control and affective processing in the prefrontal cortex: Neuropsychological studies in the marmoset. Cerebral Cortex. 2000;10:252-62.
103. Solomon SG, Rosa MGP. A simpler primate brain: The visual system of the marmoset monkey. Frontiers in Neural Circuits. 2014;8(96):1-24.
104. Kaneko T, Takemura H, Pestilli F, Silva AC, Ye FQ, Leopold DA. Spatial organization of occipital white matter tracts in the common marmoset. Brain Structure and Function. 2020;225(4):1313-26. doi: 10.1007/s00429-020-02060-3.
105. Cloherty SL, Yates JL, Graf D, DeAngelis GC, Mitchell JF. Motion Perception in the Common Marmoset. Cerebral Cortex. 2019;30(4):2659-73. doi: 10.1093/cercor/bhz267.
106. Ma L, Selvanayagam J, Ghahremani M, Hayrynen LK, Johnston KD, Everling S. Single-unit activity in marmoset posterior parietal cortex in a gap saccade task. J Neurophys. 2020;123(3):896-911. doi: 10.1152/jn.00614.2019. PubMed PMID: 31967927.
107. Hung CC, Yen CC, Ciuchta JL, Papoti D, Bock NA, Leopold DA, Silva AC. Functional mapping of face-selective regions in the extrastriate visual cortex of the marmoset. The Journal of neuroscience : the official journal of the Society for Neuroscience. 2015;35(3):1160-72. doi: 10.1523/JNEUROSCI.2659-14.2015. PubMed PMID: 25609630; PMCID: 4300322.
108. Cléry JC, Hori Y, Schaeffer DJ, Menon RS, Everling S. Neural network of social interaction observation in marmosets. eLife. 2021;10:e65012. doi: 10.7554/eLife.65012.
109. Eliades SJ, Miller CT. Marmoset vocal communication: Neurobiology and behavior. Developmental Neurobiology. 2017;77(3):286-99.
110. Tsunada J, Eliades SJ. Dissociation of Unit Activity and Gamma Oscillations during Vocalization in Primate Auditory Cortex. The Journal of Neuroscience. 2020;40(21):4158-71. doi: 10.1523/jneurosci.2749-19.2020.
111. Eliades SJ, Tsunada J. Auditory cortical activity drives feedback-dependent vocal control in marmosets. Nature Communications. 2018;9(1):2540. doi: 10.1038/s41467-018-04961-8.
112. Tian X, Silva AC, Liu C. The Brain Circuits and Dynamics of Curiosity-Driven Behavior in Naturally Curious Marmosets. Cerebral Cortex. 2021;31(9):4220-32. doi: 10.1093/cercor/bhab080.
113. Kondo T, Saito R, Otaka M, Yoshino-Saito K, Yamanaka A, Yamamori T, Watakabe A, Mizukami H, Schnitzer MJ, Tanaka KF, Ushiba J, Okano H. Calcium Transient Dynamics of Neural Ensembles in the Primary Motor Cortex of Naturally Behaving Monkeys. Cell reports. 2018;24(8):2191-5.e4. doi: 10.1016/j.celrep.2018.07.057.
114. Walker JD, Pirschel F, Sundiang M, Niekrasz M, MacLean JN, Hatsopoulos NG. Chronic wireless neural population recordings with common marmosets. Cell reports. 2021;36(2):109379. doi: https://doi.org/10.1016/j.celrep.2021.109379.
115. Roy S, Wang X. Wireless multi-channel single unit recording in freely moving and vocalizing primates. Journal of Neuroscience Methods. 2012;203:28-40.

116. Toarmino C, Wong L, Miller CT. Audience affects decision-making in a marmoset communication network. Biology Letters. 2017;13:20160934.
117. Miller CT, Thomas AW. Individual recognition during bouts of antiphonal calling in common marmosets. Journal of Comparative Physiology A. 2012;198:337-46.
118. Mimura K, Oga T, Sasaki T, Nakagaki K, Sato C, Sumida K, Hoshino K, Saito K, Miyawaki I, Suhara T, Aoki I, Minamimoto T, Ichinohe N. Abnormal axon guidance signals and reduced interhemispheric connection via anterior commissure in neonates of marmoset ASD model. NeuroImage. 2019;195:243-51. doi: https://doi.org/10.1016/j.neuroimage.2019.04.006.
119. Ash H, Smith TE, Buchanan-Smith HM. The long-term impact of infant rearing background on the behavioural and physiological stress response of adult common marmosets (Callithrix jacchus). Applied Animal Behaviour Science. 2021;234:105169. doi: https://doi.org/10.1016/j.applanim.2020.105169.
120. Philippens IHCHM, Draaisma L, Baarends G, Krugers HJ, Vermetten E. Ketamine treatment upon memory retrieval reduces fear memory in marmoset monkeys. European Neuropsychopharmacology. 2021;50:1-11. doi: https://doi.org/10.1016/j.euroneuro.2021.04.004.
121. Donadieu M, Kelly H, Szczupak D, Lin JP, Song Y, Yen CCC, Ye FQ, Kolb H, Guy JR, Beck ES, Jacobson S, Silva AC, Sati P, Reich DS. Ultrahigh-resolution MRI Reveals Extensive Cortical Demyelination in a Nonhuman Primate Model of Multiple Sclerosis. Cereb Cortex. 2021;31(1):439-47. Epub 2020/09/10. doi: 10.1093/cercor/bhaa235. PubMed PMID: 32901254; PMCID: PMC7947170.
122. Perez-Munoz ME, Sugden S, Harmsen HJM, t Hart BA, Laman JD, Walter J. Nutritional and ecological perspectives of the interrelationships between diet and the gut microbiome in multiple sclerosis: Insights from marmosets. iScience. 2021;24(7):102709. Epub 2021/07/24. doi: 10.1016/j.isci.2021.102709. PubMed PMID: 34296070; PMCID: PMC8282968.
123. Werneburg S, Jung J, Kunjamma RB, Ha SK, Luciano NJ, Willis CM, Gao G, Biscola NP, Havton LA, Crocker SJ, Popko B, Reich DS, Schafer DP. Targeted Complement Inhibition at Synapses Prevents Microglial Synaptic Engulfment and Synapse Loss in Demyelinating Disease. Immunity. 2020;52(1):167-82 e7. Epub 2019/12/31. doi: 10.1016/j.immuni.2019.12.004. PubMed PMID: 31883839; PMCID: PMC6996144.
124. Lefeuvre JA, Guy JR, Luciano NJ, Ha SK, Leibovitch E, Santin MD, Silva AC, Jacobson S, Lehericy S, Reich DS, Sati P. The spectrum of spinal cord lesions in a primate model of multiple sclerosis. Mult Scler. 2020;26(3):284-93. Epub 2019/02/08. doi: 10.1177/1352458518822408. PubMed PMID: 30730246; PMCID: PMC6685769.
125. Lee NJ, Ha SK, Sati P, Absinta M, Nair G, Luciano NJ, Leibovitch EC, Yen CC, Rouault TA, Silva AC, Jacobson S, Reich DS. Potential role of iron in repair of inflammatory demyelinating lesions. J Clin Invest. 2019;129(10):4365-76. Epub 2019/09/10. doi: 10.1172/JCI126809. PubMed PMID: 31498148; PMCID: PMC6763243.
126. Le Friec A, Desmoulin F, Demain B, Davoust C, Robert L, Duval T, Remy F, Cirillo C, Loubinoux I. A Reproducible New Model of Focal Ischemic Injury in the Marmoset Monkey: MRI and Behavioural Follow-Up. Transl Stroke Res. 2021;12(1):98-111. Epub 2020/04/07. doi: 10.1007/s12975-020-00804-1. PubMed PMID: 32249405.
127. Teo L, Boghdadi AG, de Souza M, Bourne JA. Reduced post-stroke glial scarring in the infant primate brain reflects age-related differences in the regulation of astrogliosis. Neurobiol Dis. 2018;111:1-11. Epub 2017/12/06. doi: 10.1016/j.nbd.2017.11.016. PubMed PMID: 29203280.
128. Rothwell ES, Freire-Cobo C, Varghese M, Edwards M, Janssen WGM, Hof PR, Lacreuse A. The marmoset as an important primate model for longitudinal studies of neurocognitive aging. Am J Primatol. 2021:e23271. Epub 2021/05/22. doi: 10.1002/ajp.23271. PubMed PMID: 34018622.

129. Ludlage E, Murphy CL, Davern SM, Solomon A, Weiss DT, Glenn-Smith D, Dworkin S, Mansfield KG. Systemic AA amyloidosis in the common marmoset. Vet Pathol. 2005;42(2):117-24. Epub 2005/03/09. doi: 10.1354/vp.42-2-117. PubMed PMID: 15753464.
130. Geula C, Nagykery N, Wu CK. Amyloid-beta deposits in the cerebral cortex of the aged common marmoset (Callithrix jacchus): incidence and chemical composition. Acta Neuropathol. 2002;103(1):48-58. Epub 2002/02/12. doi: 10.1007/s004010100429. PubMed PMID: 11837747.
131. Palazzi X, Switzer R, George C. Natural occurrence of amyloid-Abeta deposits in the brain of young common marmosets (Callithrix jacchus): a morphological and immunohistochemical evaluation. Vet Pathol. 2006;43(5):777-9. Epub 2006/09/13. doi: 10.1354/vp.43-5-777. PubMed PMID: 16966460.
132. Sharma G, Huo A, Kimura T, Shiozawa S, Kobayashi R, Sahara N, Ishibashi M, Ishigaki S, Saito T, Ando K, Murayama S, Hasegawa M, Sobue G, Okano H, Hisanaga SI. Tau isoform expression and phosphorylation in marmoset brains. J Biol Chem. 2019;294(30):11433-44. Epub 2019/06/07. doi: 10.1074/jbc.RA119.008415. PubMed PMID: 31171723; PMCID: PMC6663862.
133. Rodriguez-Callejas JD, Fuchs E, Perez-Cruz C. Evidence of Tau Hyperphosphorylation and Dystrophic Microglia in the Common Marmoset. Front Aging Neurosci. 2016;8:315. Epub 2017/01/10. doi: 10.3389/fnagi.2016.00315. PubMed PMID: 28066237; PMCID: PMC5177639.
134. Tardif SD, Mansfield KG, Ratnam R, Ross CN, Ziegler TE. The marmoset as a model of aging and age-related diseases. ILAR J. 2011;52(1):54-65. Epub 2011/03/18. doi: 10.1093/ilar.52.1.54. PubMed PMID: 21411858; PMCID: PMC3775658.
135. Park JE, Silva AC. Generation of genetically engineered non-human primate models of brain function and neurological disorders. Am J Primatol. 2019;81(2):e22931. Epub 2018/12/27. doi: 10.1002/ajp.22931. PubMed PMID: 30585654; PMCID: PMC6463491.
136. Okano H, Kishi N. Investigation of brain science and neurological/psychiatric disorders using genetically modified non-human primates. Curr Opin Neurobiol. 2018;50:1-6. Epub 2017/11/11. doi: 10.1016/j.conb.2017.10.016. PubMed PMID: 29125958.
137. Tomioka I, Ishibashi H, Minakawa EN, Motohashi HH, Takayama O, Saito Y, Popiel HA, Puentes S, Owari K, Nakatani T, Nogami N, Yamamoto K, Noguchi S, Yonekawa T, Tanaka Y, Fujita N, Suzuki H, Kikuchi H, Aizawa S, Nagano S, Yamada D, Nishino I, Ichinohe N, Wada K, Kohsaka S, Nagai Y, Seki K. Transgenic Monkey Model of the Polyglutamine Diseases Recapitulating Progressive Neurological Symptoms. eNeuro. 2017;4(2). Epub 2017/04/05. doi: 10.1523/ENEURO.0250-16.2017. PubMed PMID: 28374014; PMCID: PMC5368386.
138. Tomioka I, Nagai Y, Seki K. Generation of Common Marmoset Model Lines of Spinocerebellar Ataxia Type 3. Front Neurosci. 2020;14:548002. Epub 2020/10/20. doi: 10.3389/fnins.2020.548002. PubMed PMID: 33071733; PMCID: PMC7542094.
139. Sato K, Oiwa R, Kumita W, Henry R, Sakuma T, Ito R, Nozu R, Inoue T, Katano I, Sato K, Okahara N, Okahara J, Shimizu Y, Yamamoto M, Hanazawa K, Kawakami T, Kametani Y, Suzuki R, Takahashi T, Weinstein EJ, Yamamoto T, Sakakibara Y, Habu S, Hata J, Okano H, Sasaki E. Generation of a Nonhuman Primate Model of Severe Combined Immunodeficiency Using Highly Efficient Genome Editing. Cell Stem Cell. 2016;19(1):127-38. Epub 2016/07/05. doi: 10.1016/j.stem.2016.06.003. PubMed PMID: 27374787.
140. Liu C, Yen CC, Szczupak D, Tian X, Glen D, Silva AC. Marmoset Brain Mapping V3: Population multi-modal standard volumetric and surface-based templates. Neuroimage. 2021;226:117620. Epub 2020/12/12. doi: 10.1016/j.neuroimage.2020.117620. PubMed PMID: 33307224; PMCID: PMC7908070.
141. Liu C, Ye FQ, Newman JD, Szczupak D, Tian X, Yen CC, Majka P, Glen D, Rosa MGP, Leopold DA, Silva AC. A resource for the detailed 3D mapping of white matter pathways in the marmoset brain.

Nat Neurosci. 2020;23(2):271-80. Epub 2020/01/15. doi: 10.1038/s41593-019-0575-0. PubMed PMID: 31932765; PMCID: PMC7007400.
142. Liu C, Ye FQ, Yen CC, Newman JD, Glen D, Leopold DA, Silva AC. A digital 3D atlas of the marmoset brain based on multi-modal MRI. Neuroimage. 2018;169:106-16. Epub 2017/12/07. doi: 10.1016/j.neuroimage.2017.12.004. PubMed PMID: 29208569; PMCID: PMC5856608.
143. Woodward A, Hashikawa T, Maeda M, Kaneko T, Hikishima K, Iriki A, Okano H, Yamaguchi Y. The Brain/MINDS 3D digital marmoset brain atlas. Sci Data. 2018;5:180009. Epub 2018/02/14. doi: 10.1038/sdata.2018.9. PubMed PMID: 29437168; PMCID: PMC5810420.
144. Shimogori T, Abe A, Go Y, Hashikawa T, Kishi N, Kikuchi SS, Kita Y, Niimi K, Nishibe H, Okuno M, Saga K, Sakurai M, Sato M, Serizawa T, Suzuki S, Takahashi E, Tanaka M, Tatsumoto S, Toki M, U M, Wang Y, Windak KJ, Yamagishi H, Yamashita K, Yoda T, Yoshida AC, Yoshida C, Yoshimoto T, Okano H. Digital gene atlas of neonate common marmoset brain. Neurosci Res. 2018;128:1-13. Epub 2017/11/08. doi: 10.1016/j.neures.2017.10.009. PubMed PMID: 29111135.
145. Majka P, Bednarek S, Chan JM, Jermakow N, Liu C, Saworska G, Worthy KH, Silva AC, Wojcik DK, Rosa MGP. Histology-Based Average Template of the Marmoset Cortex With Probabilistic Localization of Cytoarchitectural Areas. Neuroimage. 2021;226:117625. Epub 2020/12/11. doi: 10.1016/j.neuroimage.2020.117625. PubMed PMID: 33301940.
146. Majka P, Bai S, Bakola S, Bednarek S, Chan JM, Jermakow N, Passarelli L, Reser DH, Theodoni P, Worthy KH, Wang XJ, Wojcik DK, Mitra PP, Rosa MGP. Open access resource for cellular-resolution analyses of corticocortical connectivity in the marmoset monkey. Nat Commun. 2020;11(1):1133. Epub 2020/03/01. doi: 10.1038/s41467-020-14858-0. PubMed PMID: 32111833; PMCID: PMC7048793.
147. Clery JC, Hori Y, Schaeffer DJ, Menon RS, Everling S. Neural network of social interaction observation in marmosets. Elife. 2021;10. Epub 2021/04/01. doi: 10.7554/eLife.65012. PubMed PMID: 33787492; PMCID: PMC8024015.
148. Schaeffer DJ, Liu C, Silva AC, Everling S. Magnetic Resonance Imaging of Marmoset Monkeys. ILAR J. 2021. Epub 2021/02/26. doi: 10.1093/ilar/ilaa029. PubMed PMID: 33631015.
149. Clery JC, Hori Y, Schaeffer DJ, Gati JS, Pruszynski JA, Everling S. Whole brain mapping of somatosensory responses in awake marmosets investigated with ultra-high-field fMRI. J Neurophysiol. 2020;124(6):1900-13. Epub 2020/10/29. doi: 10.1152/jn.00480.2020. PubMed PMID: 33112698.
150. Yen CC, Papoti D, Silva AC. Investigating the spatiotemporal characteristics of the deoxyhemoglobin-related and deoxyhemoglobin-unrelated functional hemodynamic response across cortical layers in awake marmosets. Neuroimage. 2018;164:121-30. Epub 2017/03/10. doi: 10.1016/j.neuroimage.2017.03.005. PubMed PMID: 28274833; PMCID: PMC5587354.
151. Hori Y, Schaeffer DJ, Yoshida A, Clery JC, Hayrynen LK, Gati JS, Menon RS, Everling S. Cortico-Subcortical Functional Connectivity Profiles of Resting-State Networks in Marmosets and Humans. J Neurosci. 2020;40(48):9236-49. Epub 2020/10/25. doi: 10.1523/JNEUROSCI.1984-20.2020. PubMed PMID: 33097633; PMCID: PMC7687060.
152. Liu C, Yen CC, Szczupak D, Ye FQ, Leopold DA, Silva AC. Anatomical and functional investigation of the marmoset default mode network. Nat Commun. 2019;10(1):1975. Epub 2019/05/01. doi: 10.1038/s41467-019-09813-7. PubMed PMID: 31036814; PMCID: PMC6488610.
153. Yabumoto T, Yoshida F, Miyauchi H, Baba K, Tsuda H, Ikenaka K, Hayakawa H, Koyabu N, Hamanaka H, Papa SM, Hirata M, Mochizuki H. MarmoDetector: A novel 3D automated system for the quantitative assessment of marmoset behavior. J Neurosci Methods. 2019;322:23-33. Epub 2019/04/05. doi: 10.1016/j.jneumeth.2019.03.016. PubMed PMID: 30946879; PMCID: PMC8014948.

154. Yamamori T. Functional visualization and manipulation in the marmoset brain using viral vectors. Curr Opin Pharmacol. 2021;60:11-6. Epub 2021/07/20. doi: 10.1016/j.coph.2021.06.004. PubMed PMID: 34280704.
155. Santisakultarm TP, Kersbergen CJ, Bandy DK, Ide DC, Choi SH, Silva AC. Two-photon imaging of cerebral hemodynamics and neural activity in awake and anesthetized marmosets. J Neurosci Methods. 2016;271:55-64. Epub 2016/07/10. doi: 10.1016/j.jneumeth.2016.07.003. PubMed PMID: 27393311; PMCID: PMC5003758.
156. Wang X. Cortical Coding of Auditory Features. Ann Rev Neurosci. 2018;41(1):527-52. doi: 10.1146/annurev-neuro-072116-031302. PubMed PMID: 29986161.
157. DiMattina C, Wang X. Virtual vocalization stimuli for investigating neural representations of species-specific vocalizations. J Neurophys. 2006;95:1244-62.
158. Wang X, Merzenich MM, Beitel R, Schreiner CE. Representations of species-specific vocalizations in the primary auditory cortex of the common marmoset: temporal and spectral characteristics. J Neurophys. 1995;74:2685-706.
159. Pandey S, Simhadri S, Zhou Y. Rapid head movements in common marmosets. iScience. 2020;23:100837. doi: 10.1016/j.isci.2020.100837
.
160. Hosoya M, Fujioka M, Ogawa K, Okano H. Distinct Expression Patterns Of Causative Genes Responsible For Hereditary Progressive Hearing Loss In Non-Human Primate Cochlea. Scientific Reports. 2016;6:22250. doi: 10.1038/srep22250
https://www.nature.com/articles/srep22250#supplementary-information.
161. Sun Z, Cheng Z, Gong N, Xu Z, Jin C, Wu H, Tao Y. Neural presbycusis at ultra-high frequency in aged common marmosets and rhesus monkeys. Aging. 2021;13(9):12587-606. doi: 10.18632/aging.202936.
162. Takahashi D, Narayanan D, Ghazanfar AA. Coupled oscillator dynamics of vocal turn-taking in monkeys. Current Biology. 2013;23:2162-8.
163. Miller CT, Wang X. Sensory-motor interactions modulate a primate vocal behavior: antiphonal calling in common marmosets. Journal of Comparative Physiology A. 2006;192:27-38.
164. Gultekin YB, Hage SR. Limiting parental feedback disrupts vocal development in marmoset monkeys. Nature Communications. 2017;8:14046. doi: 10.1038/ncomms14046.
165. Gultekin YB, Hage SR. Limiting parental interaction during vocal development affects acoustic call structure in marmoset monkeys. Science Advances. 2018;4.
166. Chow C, Mitchell J, Miller CT. Vocal turn-taking in a nonhuman primate is learned during ontogeny. Proceedings of the Royal Society, B. 2015;282:210150069.
167. Reber SA, Šlipogor V, Oh J, Ravignani A, Hoeschele M, Bugnyar T, Fitch WT. Common marmosets are sensitive to simple dependencies at variable distances in an artificial grammar. Evolution and Human Behavior. 2019;40(2):214-21. doi: https://doi.org/10.1016/j.evolhumbehav.2018.11.006.
168. Ross CN. Marmosets in Aging Research. In: Fox JG, Marini RP, Wachtman LM, Tardif SD, Mansfield K, editors. The Common Marmoset in Captivity and Biomedical Research Academic Press; 2019. p. 355-76.
169. Reveles KR, Patel S, Forney L, Ross CN. Age-related changes in the marmoset gut microbiome. Am J Primatol. 2019;81(2):e22960. doi: https://doi.org/10.1002/ajp.22960.
170. Mietsch M, Paqué K, Drummer C, Stahl-Hennig C, Roshani B. The aging common marmoset's immune system: From junior to senior. Am J Primatol. 2020;82(6):e23128. doi: https://doi.org/10.1002/ajp.23128.
171. Hoffman JM, Tran V, Wachtman LM, Green CL, Jones DP, Promislow DEL. A longitudinal analysis of the effects of age on the blood plasma metabolome in the common marmoset, Callithrix

jacchus. Experimental Gerontology. 2016;76:17-24. doi: https://doi.org/10.1016/j.exger.2016.01.007.
172. Freire-Cobo C, Edler MK, Varghese M, Munger E, Laffey J, Raia S, In SS, Wicinski B, Medalla M, Perez SE, Mufson EJ, Erwin JM, Guevara EE, Sherwood CC, Luebke JI, Lacreuse A, Raghanti MA, Hof PR. Comparative neuropathology in aging primates: A perspective. Am J Primatol.n/a(n/a):e23299. doi: https://doi.org/10.1002/ajp.23299.
173. Rodriguez-Callejas JD, Fuchs E, Perez-Cruz C. Evidence of Tau Hyperphosphorylation and Dystrophic Microglia in the Common Marmoset. Frontiers in Aging Neuroscience. 2016;8(315). doi: 10.3389/fnagi.2016.00315.
174. Phillips KA, Watson CM, Bearman A, Knippenberg AR, Adams J, Ross C, Tardif SD. Age-related changes in myelin of axons of the corpus callosum and cognitive decline in common marmosets. Am J Primatol. 2019;81(2):e22949. doi: https://doi.org/10.1002/ajp.22949.
175. Sadoun A, Rosito M, Fonta C, Girard P. Key periods of cognitive decline in a nonhuman primate model of cognitive aging, the common marmoset (Callithrix jacchus). Neurobiology of Aging. 2019;74:1-14. doi: https://doi.org/10.1016/j.neurobiolaging.2018.10.003.
176. Garber PA, McKenney A, Bartling-John E, Bicca-Marques JC, De la Fuente MF, Abreu F, Schiel N, Souto A, Phillips KA. Life in a harsh environment: the effects of age, sex, reproductive condition, and season on hair cortisol concentration in a wild non-human primate. PeerJ. 2020;8:e9365. doi: 10.7717/peerj.9365.
177. Gervais NJ, Remage-Healey L, Starrett JE, Pollack DJ, Mong JA, Lacreuse A. Adverse effects of aromatase inhibition on the brain and behavior in a non-human primate. . J Neurosci. 2019;In Press.
178. Sato K, Sasaguri H, Kumita W, Inoue T, Kurotaki Y, Nagata K, Mihira N, Sato K, Sakuma T, Yamamoto T, Tagami M, Manabe R, Ozaki K, Okazaki Y, Saido TC, Sasaki E. A non-human primate model of familial Alzheimer's disease. bioRxiv. 2020:2020.08.24.264259. doi: 10.1101/2020.08.24.264259.
179. Sills AM, Artavia JM, DeRosa BD, Ross CN, Salmon AB. Long-term treatment with the mTOR inhibitor rapamycin has minor effect on clinical laboratory markers in middle-aged marmosets. Am J Primatol. 2019;81(2):e22927. doi: https://doi.org/10.1002/ajp.22927.
180. Fernandez E, Ross C, Liang H, Javors M, Tardif S, Salmon AB. Evaluation of the pharmacokinetics of metformin and acarbose in the common marmoset. Pathobiology of Aging & Age-related Diseases. 2019;9(1):1657756. doi: 10.1080/20010001.2019.1657756.
181. Phillips KA, Hambright MK, Hewes K, Schilder BM, Ross CN, Tardif SD. Take the monkey and run. Journal of Neuroscience Methods. 2015;248:27-31. doi: https://doi.org/10.1016/j.jneumeth.2015.03.023.
182. Dorigatti AO, Hussong SA, Hernandez SF, Sills AM, Salmon AB, Galvan V. Primary neuron and astrocyte cultures from postnatal Callithrix jacchus: a non-human primate in vitro model for research in neuroscience, nervous system aging, and neurological diseases of aging. GeroScience. 2021;43(1):115-24. doi: 10.1007/s11357-020-00284-z.
183. Bethea CL, Reddy AP, Flowers M, Shapiro RA, Colman RJ, Abbott DH, Levine JE. High fat diet decreases beneficial effects of estrogen on serotonin-related gene expression in marmosets. Progress in Neuro-Psychopharmacology and Biological Psychiatry. 2015;58:71-80. doi: https://doi.org/10.1016/j.pnpbp.2014.11.008.
184. Kraynak M, Flowers MT, Shapiro RA, Kapoor A, Levine JE, Abbott DH. Extraovarian gonadotropin negative feedback revealed by aromatase inhibition in female marmoset monkeys2017;313(5):E507-E14. doi: 10.1152/ajpendo.00058.2017. PubMed PMID: 28679622.
185. Power ML, Ross CN, Schulkin J, Ziegler TE, Tardif SD. Metabolic consequences of the early onset of obesity in common marmoset monkeys2013;21(12):E592-E8. doi: doi:10.1002/oby.20462.

186. Riesche L, Tardif SD, Ross CN, deMartelly VA, Ziegler T, Rutherford JN. The common marmoset monkey: avenues for exploring the prenatal, placental, and postnatal mechanisms in developmental programming of pediatric obesity2018;314(5):R684-R92. doi: 10.1152/ajpregu.00164.2017. PubMed PMID: 29412686.
187. Ross CN, Power ML, Artavia JM, Tardif SD. Relation of Food Intake Behaviors and Obesity Development in Young Common Marmoset Monkeys2013;21(9):1891-9. doi: doi:10.1002/oby.20432.
188. Tardif SD, Power ML, Ross CN, Rutherford JN. Body mass growth in common marmosets: Toward a model of pediatric obesity2013;150(1):21-8. doi: doi:10.1002/ajpa.22110.
189. Rutherford JN, deMartelly VA, Layne Colon DG, Ross CN, Tardif SD. Developmental Origins of Pregnancy Loss in the Adult Female Common Marmoset Monkey (Callithrix jacchus). PLOS ONE. 2014;9(5):e96845. doi: 10.1371/journal.pone.0096845.
190. Rutherford JN, Tardif SD. Developmental Plasticity of the Microscopic Placental Architecture in Relation to Litter Size Variation in the Common Marmoset Monkey (Callithrix jacchus). Placenta. 2009;30(1):105-10. doi: https://doi.org/10.1016/j.placenta.2008.10.010.
191. Narapareddy L, Wildman DE, Armstrong DL, Weckle A, Bell AF, Patil CL, Tardif SD, Ross CN, Rutherford JN. Maternal weight affects placental DNA methylation of genes involved in metabolic pathways in the common marmoset monkey (Callithrix jacchus). Am J Primatol. 2020;82(3):e23101. doi: https://doi.org/10.1002/ajp.23101.
192. Rutherford JN, Ross CN, Ziegler T, Burke LA, Steffen AD, Sills A, Layne Colon D, deMartelly VA, Narapareddy LR, Tardif SD. Womb to womb: Maternal litter size and birth weight but not adult characteristics predict early neonatal death of offspring in the common marmoset monkey. PLOS ONE. 2021;16(6):e0252093. doi: 10.1371/journal.pone.0252093.
193. Dettling AC, Feldon J, Pryce CR. Repeated parental deprivation in the infant common marmoset (callithrix jacchus, primates) and analysis of its effects on early development. Biological Psychiatry. 2002;52(11):1037-46. doi: https://doi.org/10.1016/S0006-3223(02)01460-9.
194. Cavanaugh J, Mustoe A, French JA. Oxytocin regulates reunion affiliation with a pairmate following social separation in marmosets2018;80(10):e22750. doi: doi:10.1002/ajp.22750.
195. Cavanaugh J, Mustoe A, Womack SL, French JA. Oxytocin modulates mate-guarding behavior in marmoset monkeys. Horm Behav. 2018;106:150-61. doi: https://doi.org/10.1016/j.yhbeh.2018.10.009.
196. Taylor JH, Carp SB, French JA. Vasopressin, but not oxytocin, modulates responses to infant stimuli in marmosets providing care to dependent infants. Dev Psychobio. 2020;62(7):932-40. doi: https://doi.org/10.1002/dev.21892.
197. Koshiba M, Watarai-Senoo A, Karino G, Ozawa S, Kamei Y, Honda Y, Tanaka I, Kodama T, Usui S, Tokuno H. A Susceptible Period of Photic Day-Night Rhythm Loss in Common Marmoset Social Behavior Development. Frontiers in Behavioral Neuroscience. 2021;14(219). doi: 10.3389/fnbeh.2020.539411.
198. Nakako T, Murai T, Ikejiri M, Hashimoto T, Kotani M, Matsumoto K, Manabe S, Ogi Y, Konoike N, Nakamura K, Ikeda K. Effects of lurasidone on ketamine-induced joint visual attention dysfunction as a possible disease model of autism spectrum disorders in common marmosets. Behav Brain Res. 2014;274:349-54. doi: https://doi.org/10.1016/j.bbr.2014.08.032.
199. Santana-Coelho D, Layne-Colon D, Valdespino R, Ross CC, Tardif SD, O'Connor JC. Advancing Autism Research From Mice to Marmosets: Behavioral Development of Offspring Following Prenatal Maternal Immune Activation. Frontiers in Psychiatry. 2021;12(1295). doi: 10.3389/fpsyt.2021.705554.

200. C.Y. C, C. S-SM, J. B, T. L, S. Y, M. T, V. H, L. P, S. S, G. Y, L. G, S. T, J. P. Experimental zika virus inoculation in a new world monkey model reproduces key features of the human infection. Scientific Reports. 2017;7(1):17126.
201. Ausderau KK, Dammann C, McManus K, Schneider M, Emborg ME, Schultz-Darken N. Cross-species comparison of behavioral neurodevelopmental milestones in the common marmoset monkey and human child2017;59(7):807-21. doi: doi:10.1002/dev.21545.
202. Ash H, Ziegler TE, Colman RJ. Early learning in the common marmoset (Callithrix jacchus): Behavior in the family group is related to preadolescent cognitive performance. Am J Primatol. 2020;82(8):e23159. doi: https://doi.org/10.1002/ajp.23159.
203. Sawiak SJ, Shiba Y, Oikonomidis L, Windle CP, Santangelo AM, Grydeland H, Cockcroft G, Bullmore ET, Roberts AC. Trajectories and Milestones of Cortical and Subcortical Development of the Marmoset Brain From Infancy to Adulthood. Cerebral Cortex. 2018;28(12):4440-53. doi: 10.1093/cercor/bhy256.
204. Kirk EC, Kay RF. The Evolution of High Visual Acuity in the Anthropoidea. In: Ross CF, Kay RF, editors. Anthropoid Origins: New Visions. Boston, MA: Springer US; 2004. p. 539-602.
205. Krauzlis RJ. The Control of Voluntary Eye Movements: New Perspectives2005;11(2):124-37. doi: 10.1177/1073858404271196. PubMed PMID: 15746381.
206. Reynolds JH, Chelazzi L. ATTENTIONAL MODULATION OF VISUAL PROCESSING2004;27(1):611-47. doi: 10.1146/annurev.neuro.26.041002.131039. PubMed PMID: 15217345.
207. Jacobs GH, Neitz J, Crognale M. Color vision polymorphism and its photopigment basis in a callitrichid monkey (Saguinus fuscicollis). Vision Res. 1987;27(12):2089-100. doi: https://doi.org/10.1016/0042-6989(87)90123-4.
208. Nassi Jonathan J, Avery Michael C, Cetin Ali H, Roe Anna W, Reynolds John H. Optogenetic Activation of Normalization in Alert Macaque Visual Cortex. Neuron. 2015;86(6):1504-17. doi: https://doi.org/10.1016/j.neuron.2015.05.040.
209. Mitchell JF, Leopold DA. The marmoset monkey as a model for visual neuroscience. Neuroscience Research. 2015;93:20-46.
210. Troilo D, Rowland HC, Judge SJ. Visual optics and retinal cone topography in the common marmoset (Callithrix jacchus). Vision Res. 1993;33(10):1301-10. doi: https://doi.org/10.1016/0042-6989(93)90038-X.
211. Tkatchenko TV, Troilo D, Benavente-Perez A, Tkatchenko AV. Gene expression in response to optical defocus of opposite signs reveals bidirectional mechanism of visually guided eye growth. PLOS Biology. 2018;16(10):e2006021. doi: 10.1371/journal.pbio.2006021.
212. Kemp C, Kaplan G. Facial expressions in common marmosets (Callithrix jacchus) and their use by conspecifics. Animal Cognition. 2013;16:773-88.
213. Kell AJE, Bokor SL, Jeon Y-N, Toosi T, Issa EB. Marmoset invariant object recognition behavior mirrors that of humans and macaques at fine scale. bioRxiv. 2020:2020.10.19.345561. doi: 10.1101/2020.10.19.345561.
214. Yates J, Coop S, Sarch G, Wu R-J, Butts D, Rucci M, Mitchell J. Beyond fixation: foveal receptive field estimation in freely viewing primates. Journal of Vision. 2020;20(11):1470-. doi: 10.1167/jov.20.11.1470.
215. Selvanayagam J, Johnston KD, Schaeffer DJ, Hayrynen LK, Everling S. Functional Localization of the Frontal Eye Fields in the Common Marmoset Using Microstimulation. The Journal of Neuroscience. 2019;39(46):9197-206. doi: 10.1523/jneurosci.1786-19.2019.
216. Yates JL, Coop SH, Mitchell JF. V1 neurons tuned for high spatial frequencies show pre-saccadic enhancement. Journal of Vision. 2019;19(10):254a-a. doi: 10.1167/19.10.254a.

217. Homman-Ludiye J, Bourne JA. The marmoset: An emerging model to unravel the evolution and development of primate neocortex. Developmental Neurobiology. 2017;In Press.