Institution: University of Cambridge

Unit of Assessment: 4 – Psychology, Psychiatry and Neuroscience

1: Unit context and structure, research and impact strategy

1.1 Context and Structure

We benefit society through a deeper understanding of the brain and mind over the life course from childhood to old age, in health and disease.

We pursue this mission by:

- Promoting research within and between the linked disciplines of Psychology, Psychiatry and Neuroscience.
- Recruiting and retaining excellent people at all levels of seniority, from students to senior faculty.
- Actively stimulating inter-disciplinary innovation as part of our organisational culture of openness, diversity, inclusivity and team science.

Our scientific strategy is explicitly and pervasively translational – with many active collaborations between “basic” and “clinical” research groups established across the whole community of brain and mind scientists in Cambridge. Our research bridges the full range of neuroscientific scales and experimental modalities required to encompass the complexities of the brain and the mind: from genetic and molecular mechanisms, through cell biology and network neuroscience, to behavioural science and cognitive psychology, in model organisms and humans. We leverage our strengths in biological and normative human neuroscience to achieve significant impact on major global health challenges in mental health, dementia, and many other brain and neurodevelopmental disorders.

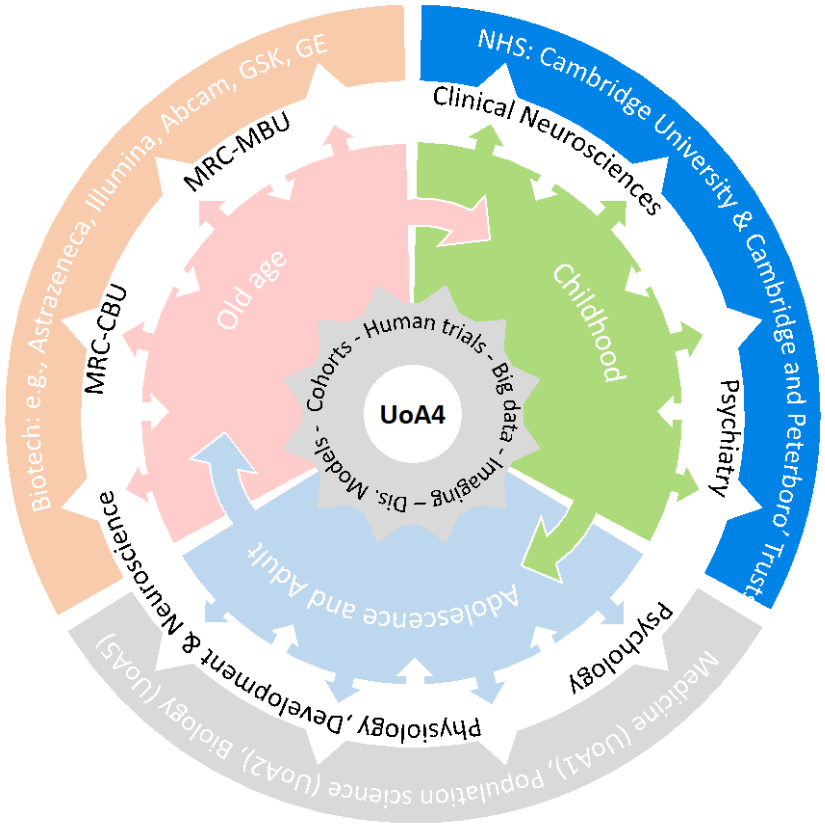


Figure 1. UoA4 in Cambridge: Psychology, Psychiatry and Neuroscience across the life course. *Central grey circle shows our major shared infrastructure surrounded by concentric circles representing our organization across the life course, our departmental organization and some of our key external partners (see below for abbreviations).*

Childhood: It is critical to understand the contributions of nature and nurture during the earliest period of brain and mind development, the related disorders of childhood, and their implications for mental health in later life. Combining novel psychometric and behavioural approaches with remote monitoring, brain imaging, and neurophysiology, we study normal early child development, with particular expertise in learning and the development of speech, hearing and language, and how these cognitive processes intersect with social behaviour and educational attainment. Genetics, mitochondrial and cell biology, in animal models and large clinical bioresources, are central to our work on understanding, diagnosis and treatment of autistic spectrum disorders and rare neuro-genetic or metabolic diseases of the developing nervous system.

Adolescence and adult life: The adolescent period from puberty to ~25 years old is a time of high risk for many mental health and neurodevelopmental disorders. We use cognitive psychology and computational psychiatry, combined with translational magnetic resonance imaging (MRI), to map underlying developmental trajectories of neurocognitive networks or connectomes, in young people and animal models. We use epidemiology, social psychology and digital technologies to resolve the complex intersection of biomedical and psychosocial factors in determining health and social outcomes of adolescence. This deep foundation of normative developmental neuroscience, combined with broad analysis of the population and social context of adolescence, informs clinically-facing research, directly addressing the strategic national challenge of children and young people's mental health, including studies of depression, anxiety, psychosis, addiction and eating behaviour.

Throughout adolescence and into adult life, auto-immune and neuro-inflammatory brain disorders are increasingly recognised as important causes of morbidity and multi-morbidity. We use epidemiological, genetic and experimental medicine studies to identify the causal mechanisms for neuro-immune disorders and brain inflammation. We develop new neuroimaging and blood biomarkers, and intensive bedside monitoring technologies, for precise diagnosis and evaluation

of clinical status, including a major focus on the most critically ill patients. We continue to build on our proven track record of translating novel insights about immune targets into clinically impactful new therapeutics for demyelinating disease, traumatic brain injury (TBI), auto-antibody mediated encephalitis and psychosis, and inflammation-related depression. This strategic focus has enabled us to respond rapidly and effectively to the acute challenges of understanding and mitigating the impact of SARS-CoV2 infection on the brain.

Old Age: The period from adulthood to old age is associated with major normative developmental changes in the brain and mind, and the greatest risk for dementia, neurodegenerative and cerebrovascular disorders. We use cognitive neuroscience, neuroimaging and epidemiology to define trajectories of healthy brain ageing. Complementary clinical programmes are based on local, national and international cohorts of healthy volunteers and patients that strongly inform laboratory studies of the genetic, molecular and cellular mechanisms of neurodegeneration. The over-arching emphasis is translational, from the genetic and environmental origins of disease, early detection and diagnosis, through to the development of novel therapeutics, including stem cell-derived regenerative interventions. We aim to modify the natural history of progressively disabling disorders - such as Alzheimer's disease, Parkinson's disease, Huntington's disease, fronto-temporal dementias - and to prevent strokes or improve the outcomes of cerebrovascular disease.

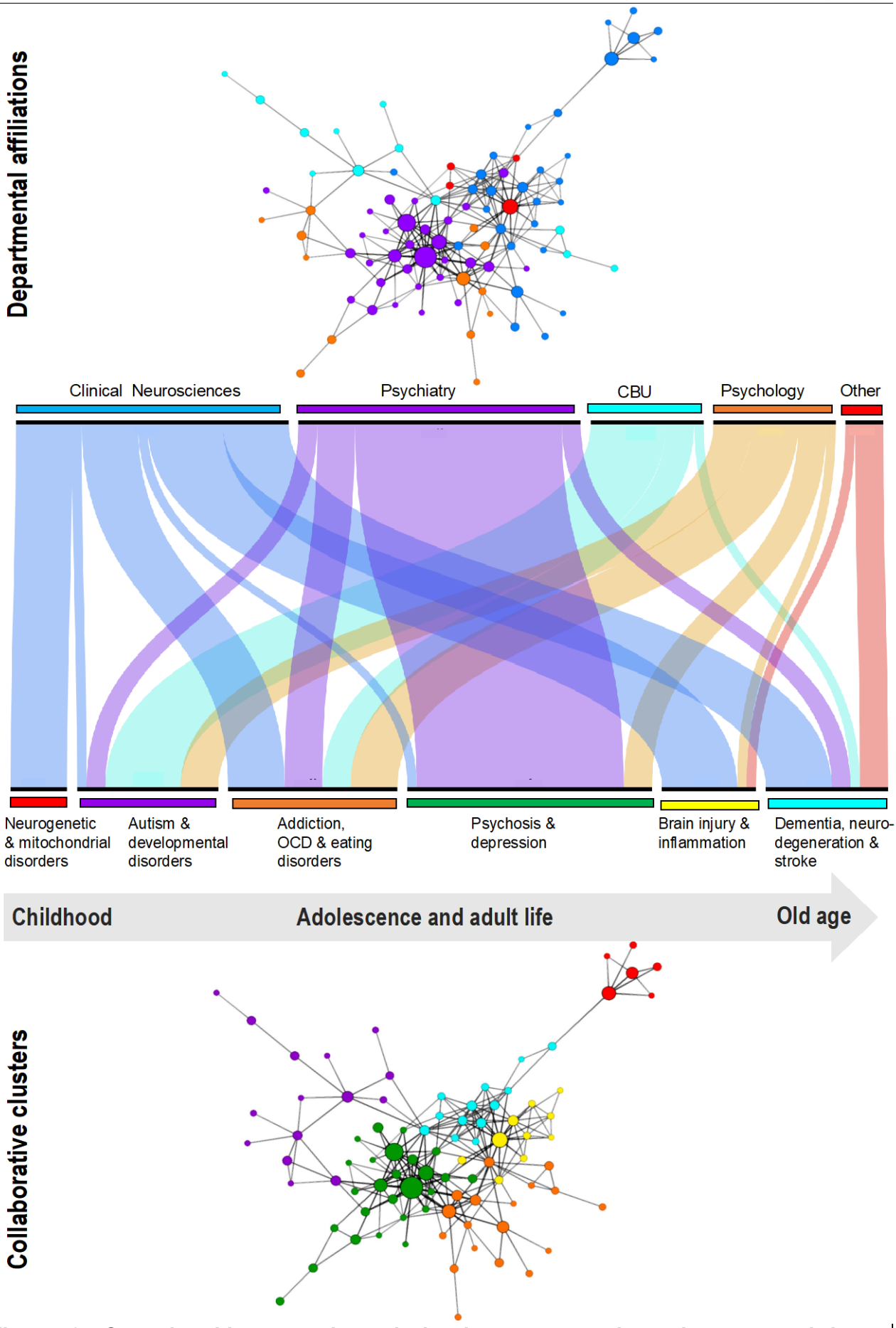


Figure 2. Co-authorship network analysis demonstrates the coherence and inter-disciplinarity of Psychology, Psychiatry and Neuroscience research in Cambridge.

(Top) Each node in the network represents a member of the 157 research staff returned in UoA4 and the links between nodes represent co-authorship of our 377 research outputs. The size of each node is proportional to the number of returned papers co-authored by each individual and the colour represents their administrative affiliation to one of five Departmental groups in the University (Clinical Neurosciences, including the MRC MBU; Psychiatry; the MRC Cognition and Brain Sciences Unit (CBU); Psychology; and Other Departments (Medicine, Physiology, Development & Neuroscience, and Music). (Bottom) The same co-authorship network is shown with the nodes differently coloured to represent 6 collaborative clusters, identified by data-driven analysis of co-authorships of returned papers. Each cluster has produced a major proportion of the research outputs returned by UoA4. (Centre) The alluvial diagram shows how these 6 collaborative research clusters have self-organized within and between the 5 Departments to produce inter-disciplinary, basic-to-clinical translational research. Each cluster is labelled according to its focus on the major mental health and/or brain disorders occurring in childhood, adolescence and adulthood, or old age.

The research community of **157** staff returned as UoA4 represents ***three Schools*** (Biological Sciences; Clinical Medicine; and Arts and Humanities), ***six Departments*** (Clinical Neurosciences; Medicine; Music; Psychiatry; Psychology and Physiology, Development and Neuroscience) including ***four embedded Research Council University Institutes/Units*** (MRC Cognition and Brain Sciences Unit [MRC CBU]; UK Dementia Research Institute Cambridge [UK DRI]; MRC Mitochondrial Biology Unit [MRC-MBU]; the MRC-Wellcome Cambridge Stem Cell Institute [CSCI]), with close links to the MRC Laboratory of Molecular Biology (MRC-LMB). This grouping forms an integral part of the wider Cambridge community of brain and mind scientists, with complementary research activity also returned in UoA1 and UoA5, which is comprehensively coordinated through the Cambridge Neuroscience Interdisciplinary Research Centre (IRC).

1.2 Achievements since REF2014

A transformational strategy was implemented following REF2014 with ***a single focus on cross disciplinary integration***. Driven by our research community, this approach was endorsed by an international external strategic review (2016) and the creation of Cambridge Neuroscience IRC by the University in 2017, supported by an annual budget. Together this has enabled a coherent approach to recruitment and the development of research infrastructure, transforming the Cambridge environment.

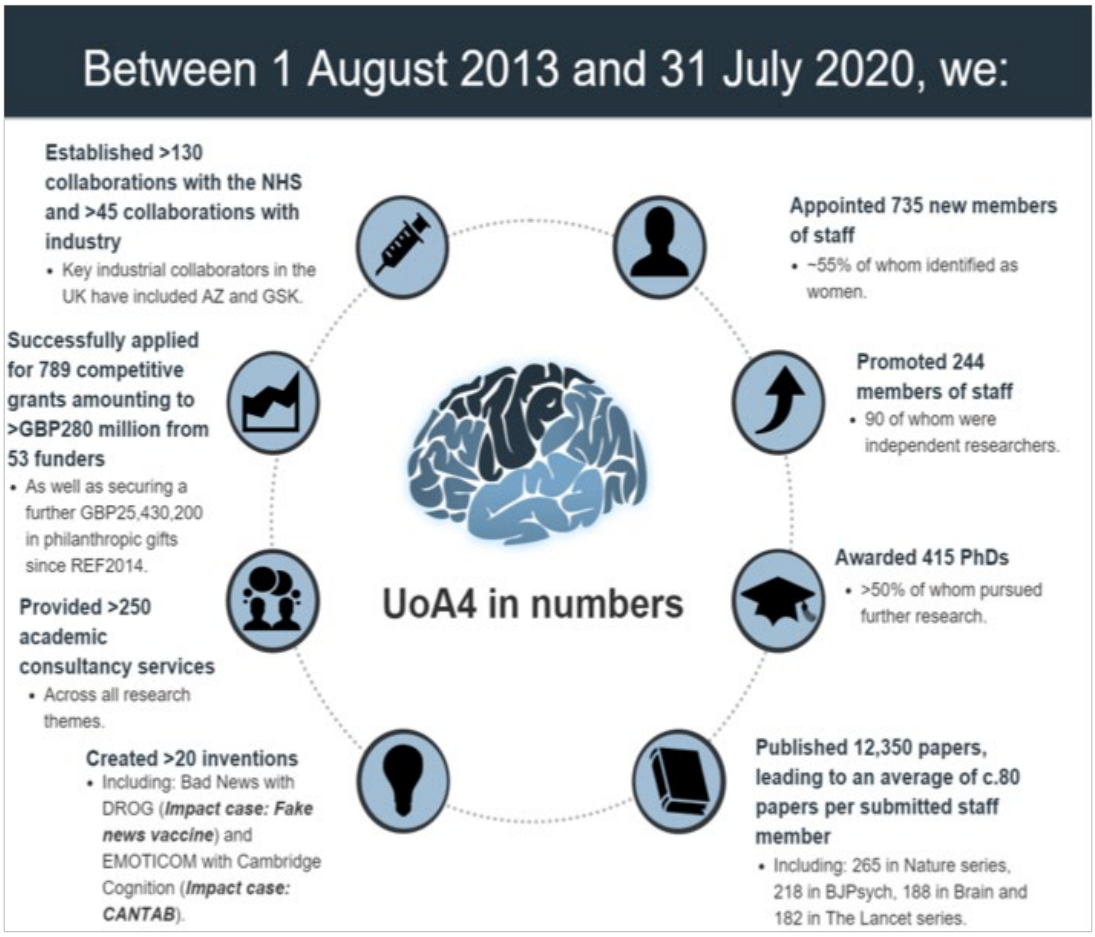


Figure 3. UoA4 in numbers Key activities between 1 August 2013 and 31 July 2020.

Our achievements directly align with the strategic priorities highlighted in our REF2014 submission as follows:

1.2.1 Strategic recruitment bridging biology, medicine, the physical and social sciences

Since 2014 we have recruited senior and junior academic staff to directly address our research strategy. The following examples include ***9 Professors and 24 junior independent Fellowships since REF2014*****,** in addition to University Lectureships and other Fellowships across UoA4.

Senior recruits since REF2014:

Childhood:

- Tamsin Ford (Professor of Child and Adolescent Psychiatry, 2019, from the University of Exeter) investigates children's mental health and the delivery of NHS services for young people's mental health.
- Mark Johnson (Professor of Experimental Psychology and Head of Department of Psychology, 2017, from UK Medical Research Council) studies brain and behaviour in infancy and its relationship to autism and ADHD.

Adolescence and adult life:

- Manohar Bance (Professor of Otology and Skull Base Surgery, 2017 from Dalhousie University, Canada) studies the biophysical and anatomical properties of the ear underpinning the design of cochlear implants, working with industry, engineering and computer science.
- Sarah-Jayne Blakemore (Professor of Psychology, 2019, from UCL) studies the development of social cognition and decision making in the human adolescent brain.

- Patrick Chinnery (Professor of Neurology and Head of Department of Clinical Neurosciences, 2015, from Newcastle University) studies the origin and treatment of inherited neurological diseases particularly involving mitochondria.
- Rita Horvath (Clinical Director of Research, 2018, from Newcastle University) studies protein synthesis within mitochondria as a disease mechanism explaining tissue selectivity.
- Petra Vértes (University Lecturer in Network Neuroscience, 2019, from Queen Mary, University of London) uses graph theory and other methods from statistical physics to analyse brain networks (connectomes) in humans and *C. elegans*.
- Debi Vickers (MRC Senior Fellowship, 2018, from UCL) bridges psychology, physics and engineering to improve hearing in cochlear implant users.

Old age:

- Matthew Lambon-Ralph (Director of the MRC CBU, 2018, from the University of Manchester) harnesses multiple methodologies to secure convergent insights on semantic cognition, aphasia, and recovery, rehabilitation and neuroplasticity, including in dementia.
- Giovanna Mallucci (van Geest Professor of Neurosciences, 2014, from MRC Toxicology Unit, now Associate Director UK Dementia Research Institute, 2017) works on the molecular mechanisms of neurodegeneration to develop new treatments for dementia.

Junior independent external Fellowships since REF2014:

Childhood:

- Fabian Grabenhorst, 2017 is a Wellcome Trust Henry Dale fellow studying the neural mechanisms underlying reward-based decisions in individual neurons of old-world monkeys.
- Sarah Lloyd-Fox (UKRI Future Leader Fellow, 2019) is investigating early brain function in the perinatal period to understand how neurodevelopmental trajectories relate to poverty.
- Jelle van den Ameele (Wellcome Intermediate Fellow, 2020) is a neurologist from the Gurdon Institute, studying metabolism in brain development.

Adolescence and adult life:

- Damiano Barone (NIHR Clinical Lecturer, 2019) is a neurosurgeon developing the next generation of neural bioelectronics to treat spinal cord injury.
- Aya Ben Yakov Breslav (Royal Society Dorothy Hodgkin Research Fellow, 2019) investigates brain mechanisms underlying encoding of new episodic memories.
- Samuel Chamberlain (Wellcome Trust Intermediate Clinical Fellow, 2017) is a psychiatrist investigating the mechanisms of compulsive disorders through experimental medicine.
- Rocco Chiou (Sir Henry Wellcome Fellow, 2018) studies how the brain enables humans to perceive the world and transform perception into knowledge.
- Alex Clarke (Wellcome Henry Dale Fellow, 2019) is examining how the environment changes the dynamics of visual and semantic activity in the brain.
- Hannah Clarke, 2016 holds an MRC fellowship to develop a schizophrenia model in new world monkeys to understand the role of hippocampal-prefrontal circuits.
- Tobias Goehring (MRC Career Development Fellow, 2020) studies the perception of speech for people with hearing loss in everyday life.
- Rebecca Jackson (British Academy Fellow, 2018) is building a computational model of semantic cognition that includes both representation and control processes.
- Golam Khandaker (Wellcome Trust Intermediate Clinical Fellow, 2017) is a psychiatrist investigating shared immune mechanisms of depression and cardiovascular disease.
- Andras Lakatos (MRC Clinician Scientist, 2017) is a neurologist developing brain organoids to understand and treat amyotrophic lateral sclerosis.
- Rebecca Lawson (Wellcome Trust Henry Dale Fellow, 2018) studies how humans learn to build adaptive expectations about the world, other people and the self.
- Romy Lorenz (Sir Henry Wellcome Fellow, 2018) is a cognitive neuroscientist developing brain-computer interfaces.
- Mary-Ellen Lynall (MRC Clinical Research Fellow, 2019) is a psychiatrist investigating the neuroimmunology of treatment-resistant depression.

- Luca Peruzzotti-Jametti (Wellcome Trust Intermediate Fellow, 2020) is a neurologist recruited from Milan studying the role of metabolism in immune regulation in multiple sclerosis.
- Jasper Poort (Wellcome Trust Henry Dale Fellow, 2019) investigates selective vision and attention at a cellular level.
- Roni Tibon (British Academy Fellow, 2017). Recruited from Baruch Lvcher School of Psychology, Israel, investigates how memory works using behavioural and imaging techniques.

Old age:

- Edward Avezov (UK DRI Fellow, 2018) is developing an interdisciplinary programme to understand how fundamental cellular processes contribute to neurodegeneration.
- Gabriel Balmus (UK DRI Fellow, 2018) was recruited from Wellcome Trust Sanger Institute to understand how neurons are protected from harm during ageing.
- Will McEwan (Wellcome Trust Henry Dale Fellow, then UK DRI Fellow, 2016) was recruited from the MRC-LMB working on the molecular mechanisms of dementia.
- Li Su (Alzheimer's Research UK Fellow, 2018) is a computer scientist developing novel methods of imaging analysis to study psychiatric and late-life degenerative disorders.
- Caroline Williams-Gray (MRC Clinician Scientist, 2018) is a neurologist studying the role of inflammation in Parkinson's disease.

1.2.2 Major expansion of our research infrastructure

Our research infrastructure has expanded substantially since REF2014 through integrated applications to government funders, industry, charities and benefactors, matched by University investment.

Highlights include:

Childhood:

- Transfer of MRC MBU into the University (Department of Clinical Neurosciences) to consolidate critical mass in mitochondrial and genetic disorders of childhood (MRC and the UoC, GBP23m over five years, 2016).
- BabyLab (2018, Johnson, Lawson, Lloyd-Fox, GBP500k).
- Building strengths in researching diverse family forms (Wellcome Trust, GBP1.5m, 2018)
- New early-life cohort in Cambridge (MRC, GBP2.4m, 2019).

Adolescence and adulthood:

- Establishing the Cambridge-NTU CREATE Centre on Learning and Individualised Cognition funded by the National Research Foundation Singapore (GBP12.5m) to promote research in the neuroscience of lifelong learning.
- Establishing the NIHR Global Health Research Group on Neurotrauma (NIHR, GBP1.7m, 2017).
- Hosting the NIHR Applied Research Collaborations (ARC) East of England, in partnership with Cambridgeshire & Peterborough NHS Foundation Trust (NIHR, GBP9m, 2019).

Old age:

- Co-location of chemists, biologists and clinicians studying dementia in the UK Dementia Research Institute Cambridge Centre (UK DRI, GBP15m, 2017) and ARUK *ALBORADA* Drug Development Institute (GBP12m, 2016).
- Cambridge Centre for Parkinson Plus (philanthropic gift, USD20m, 2018).

Cross-theme:

- Transfer of MRC CBU into the University to consolidate critical mass in cognitive, mental health and developmental disorders over the life course (2018, GBP5.5m/year).

- NIHR Biomedical Research Centre - Brain and Mind 'Supertheme' with joint clinical research infrastructure focused on electronic health care records, neuro-immunology, biobanking and imaging platforms (NIHR, GBP12m, 2017).
- Co-location of patient facing translational researchers in psychology, psychiatry, neuro-cognition, and hearing loss in shared clinical facilities (2014).
- High Performance Hub for Clinical Informatics (MRC Clinical Research Infrastructure Award, GBP2m, 2014)
- Comprehensive human brain imaging facilities installed at the Wolfson Brain Imaging Centre, including 7 Tesla MRI and MRI/PET scanners (MRC Clinical Research Infrastructure Award, GBP15m, 2014).
- Translational Neuroimaging Laboratory for small animals including marmosets and rodents with 9.4T MRI and PET facilities (University, GBP2.5m, 2016).

1.2.3 Scientific discoveries

Many of our discoveries span both fundamental and translational science. The examples chosen demonstrate the breadth and diversity of our research since REF2014 both within and beyond the remit of our submitted impact case studies. All have been critically dependent on our integrated, cross-disciplinary approach.

Highlights include:

Childhood:

- Goswami's research identified the importance of temporal rhythm processing for the understanding of language and acquisition of reading in young children and then used this knowledge to design interventions for dyslexia (*Front Hum Neurosci* 2015).
- Longitudinal studies showed associations between very early infant brain and cognitive data and mid-childhood autism outcomes (Johnson, *Molecular Autism* 2017).
- Using exome and whole genome sequencing to diagnose rare inherited neurological disorders enabling genetic counselling and prenatal diagnosis in the NHS (Chinnery, Horvath, incl. *JAMA* 2014, *Science* 2019).

Adolescence and adult life:

- Jones provided a population-based prediction tool to NHS commissioners to support the implementation of the 2016 NHS Access and Waiting Time Standard (***Impact: PsyMaptic***).
- Bullmore, Jones and colleagues used MRI to elucidate mechanisms of adolescent brain development and their relationship to cognitive and genetic risks for OCD and schizophrenia (*Nature Neuroscience* 2019) in collaboration with UCL.
- Coles showed that disease-modifying therapies in multiple sclerosis slow conversion to the secondary progressive stage of the illness which causes the most disability (*JAMA* 2019, ***Impact: Alemtuzumab***).
- RESCUEicp (Hutchinson et al, incl. *NEJM* 2016, 2019) showed that decompressive craniectomy in traumatic brain injury patients with raised intracranial pressure leads to a major reduction in mortality (***Impact: TBI***).
- Dalgleish developed psychological interventions to treat depression based on understanding normal brain function (*Lancet* 2015, ***Impact: Mindfulness***).
- Markus led the first randomised controlled trial (RCT) studying carotid artery dissection, accounting for 25% of strokes in young adults, showing equivalent benefits from aspirin and anticoagulants (*JAMA Neurol* 2019).

Old age:

- Mallucci discovered the role of cold-shock proteins, particularly RBM3, in neuroprotection through their effect on synaptic structural plasticity and synapse regeneration (*Nature* 2015).
- Kourtzi and Rowe established 7 Tesla magnetic resonance spectroscopy (MRS) techniques to measure GABA for discovery and translational studies providing insights into perceptual decision making and dementia (*Nature Comms* 2019).

- Franklin worked with physicist Chalut to show that mechanical properties of the stem cell niche drive stem cell ageing which can be by-passed using gene editing (*Nature 2019*).
- St George Hyslop showed low complexity/intrinsically disordered domains of proteins such as FUS and αSYN drive their reversible condensation into liquid:liquid droplets in health, ageing and neurodegenerative diseases (*Neuron* 2015*; Cell* 2018, 2019).
- Halai and Lambon Ralph established the use of machine learning and multimodal imaging measures for the prediction of language and cognitive impairments in post-stroke aphasia (*Nature Human Behaviour, 2020*).

1.2.4 Commercial translation

Since 2014 we have established **45** major new industry collaborations and contracted **250** academic consultancy agreements.

Highlights include:

Childhood:
- Goswami has developed a computer-assisted reading intervention, launched in 2018, which has been commercialised by Cambridge Enterprise and is now available on iOS, Android and Windows devices (GraphoGame Rime, incl. *Reading Research Quarterly* 2013).

Adolescence and adult life:
- Establishment of companies to develop therapies for myelopathy, including BitBio, which now employ over 100 staff (raised over GBP10m, Kotter).
- Quethera, a gene therapy programme for glaucoma, and its subsequent acquisition by Astellas (GBP85m in 2018, Martin and Osborne).
- NIMA – an academic-industrial consortium for target validation, biomarker discovery and experimental medicine in early clinical development of new immune-modulatory drugs for treatment of depression and Alzheimer's disease, was funded by the Wellcome Trust and several major pharma companies (Janssen, Pfizer, Lundbeck and GSK; GBP8.75m).

Old age:
- CANTAB cognitive profiling to detect early dementia and monitor treatments built on normal life-course data (GBP39.7m since 2013, Robbins and Sahakian, incl. *Brain* 2014, ***Impact: CANTAB***).

1.2.5 Translation into public policy and understanding

In addition to our work responding to the COVID-19 pandemic (4.2.4), *highlights include:*

Childhood:
- Golombok has shown that children from diverse family forms experience high quality parenting and show low levels of emotional and behavioural problems; she has actively engaged in policy discussions and contributed to policy and legislation changes in the UK, USA, France, Germany and the Netherlands (*Develop Psychol* 2017; ***Impact: New family forms***).
- Chinnery advised the Chief Medical Officer (CMO) on the use of whole genome sequencing to diagnose rare diseases in the NHS, was co-author of the CMO annual report *Generation Genome* (2016), and gave Science Select Committee evidence (2017), linked to underpinning science (*Nature* 2020).

Adolescence and adult life:
- Ewing developed the Carer Support Needs Assessment Tool intervention (CSNAT-i) which has been implemented into practice in 168 organisations across 15 countries (*PloS One* 2015, 2017; ***Impact: CSNAT***).

- Fletcher used digital gaming technology to reduce the stigma of mental health disorders, shaping national policy (*Proc Natl Acad Sci* 2015, ***Impact: Hellblade***).
- Van der Linden developed a 'vaccine' against fake news which has had significant uptake among international governments, including the UK Foreign and Commonwealth Office and the US Homeland Security (*Science* 2017, ***Impact: Fake news vaccine***).

Old age:

- Barker's work on Parkinson's disease has also had a significant effect on public understanding of the disease through the TRANSEURO Network which brings together researchers, clinicians and patient stakeholders (*Nature* 2018), leading to first-in-human trials of embryonic stem cell derived dopamine (STEM-PD) (*Nature Med* 2019).

1.3 Impact Strategy

Since REF2014 we have translated our discoveries into clinical practice across all of the main research domains. Many are now embedded in the NHS and have been adopted internationally, and include contemporary digital technologies, pharmaceuticals and cell therapies. This has been possible by focusing our energy on ***three key impact incubators*** developed to facilitate impact across the breadth of our research:

1.3.1 Fostering an interdisciplinary research culture

Interdisciplinary research underpins our impact strategy, including the free and open exchange of knowledge and methodologies at all levels in the organisation, from PhD students to Professors, within and across our research clusters – all focused on addressing unmet clinical and societal needs. Pathways to impact are embedded in all stages of our research cycle and the research training we offer to junior scientists.

1.3.2 Building successful partnerships

Interdisciplinarity naturally lends itself to collaborative research. We seek to foster successful partnerships across our research clusters, the broader University, and external organisations in order to achieve our underpinning mission. Our collaborative successes (**Figure 2**) are underpinned by the co-location of our researchers with key collaborators across two main sites: central Cambridge and the Cambridge Biomedical Campus on the south-western edge of the city. Critically, our two main sites are very close, facilitating easy interdisciplinary work and cross-fertilisation of ideas between researchers. In addition, long before the COVID-19 lockdown, we had invested in and embraced videoconferencing, enabling effective cross-campus collaborations on a daily basis.

1.3.3 Building our capacity for impact

Our researchers' capacity to generate impact is dependent on two core elements:

- ***Infrastructure:*** Through a coordinated series of successful grant applications, we have obtained major new equipment underpinning Neuroscience, Psychology and Psychiatry research across the whole city (1.2.2). New activity has been catalysed by targeted investment from philanthropy, matched by the University, to catalyse cross-disciplinary research activities, particularly at the interface of discovery and translation in collaboration with Engineering, Chemistry, Maths and Computer Science.
- ***Operational support:*** Expert advice is available through the Office of Translational Research, Cambridge Academy of Therapeutic Sciences and the Milner Institute as well as a range of training opportunities for all staff to ensure that our researchers are equipped to deliver impact, including regular training events for postdoctoral scientists.

1.4 Fostering an interdisciplinary research culture

Our approach to interdisciplinary research complements both our ***impact*** (1.3) and ***people*** (2) ***strategies*** so that we are able to recruit, nurture and retain excellent researchers who forge successful translational partnerships.

1.4.1 Impact strategy and interdisciplinary research

In building our capacity for impact, we also enhance our opportunity for interdisciplinary research, creating a virtuous circle fuelled by scientific discovery. Our investment in infrastructure, and especially in ***cross-cutting technologies and platforms***, has facilitated interdisciplinarity across our three research clusters.

Key examples include:

- Well-established and well-characterised regional and national cohorts of healthy participants and patient groups spanning the life course from birth to old age (**Box 7**), contributing to research efforts locally, nationally and internationally.
- Data Study groups and postgraduate training within the Alan Turing Institute and HDR-UK to promote computational and data science in discovery neuroscience and mental health.
- Model experimental systems, including: organisms (Drosophila, zebrafish, rodents, non-human primates); and human induced pluripotent cell models (hiPSC) in partnership with the NIHR iPSC hub and HipSci consortium (http://www.hipsci.org/), enabling world-leading brain and spinal cord organoid development in close partnership with the MRC-LMB (**Box 9**).
- Campus-wide access to University- and MRC-supported High Performance Computing (GBP40m, 2015), underpinning computational modelling of neural and cognitive function, image analysis, genomic and bioinformatic analysis.
- Clinical research facilities underpinned by the NIHR Cambridge Biomedical Research Centre Brain and Mind 'Supertheme' (GBP12m, 2017) providing cross-campus translational infrastructure and integrated health-care and educational data informatics.
- Comprehensive structural and functional brain imaging research platforms for humans and animals including human 7-Tesla MRI and PET/MRI (2015, GBP15m MRC Capital Infrastructure), and small animal MRI and PET within new (GBP60m, 2018) centralised animal facilities (**Box 8**).
- Single cell genomic and transcriptomic platforms (GBP7m MRC Capital Infrastructure, 2015) underpinning our role in the GBP10m MRC-Wellcome Chan-Zuckerberg Single Cell Atlas (2019).
- Translational and applied methodologies underpinned by the NIHR ARC East of England (GBP9m, 2019).

1.4.2 People strategy and interdisciplinary research

Our ***recruitment strategy*** prioritises links between biology, medicine, the physical and social sciences specifically to address major unmet medical and societal needs. Since REF2014, our senior recruitment has mapped directly to our life-course research themes (1.2.1).

We actively promote interdisciplinarity through our commitment to ***training and sustainability*** by mentoring and hosting early-career physicists, chemists, mathematicians and computer scientists within our research themes, and by new appointments to Lecturer and senior academic positions. In addition, we encourage co-supervision of PhD students, and pro-actively ***recruit, mentor and empower*** junior scientists to drive cross-collaboration through early leadership roles within research groups and departmental executives.

1.5 Open research

Underpinned by our ***mission***, ***impact strategy*** and ***approach to interdisciplinary research***, we have made significant advances in fostering an open research environment.

1.5.1 Open access publication

96.15% of the 377 outputs we return here are compliant with the REF open access policy and have been made open access via the Green Route (uploaded on www.repository.cam.ac.uk). Most of our researchers have also adopted Plan U and are depositing preprints in *BioRxiv* and *MedRxiv*. Our successes in open access publication were achieved by embedding a network of champions across UoA4, supported administratively to make open access publication as easy as possible.

1.5.2 Open science

Through our international leadership in open science, our staff have championed new initiatives in the global community including publishing about open access approaches (https://doi.org/10.3389/fncom.2012.00094) and the introduction of pre-registration posters at several international conference (https://doi.org/10.1016/j.tics.2018.01.008). Orben leads a University-wide lecture course on robust and open science that is attended by many of our junior investigators and graduate students (https://www.amyorben.com/docs/syllabus.pdf).

1.5.3 Open platforms

As part of our commitment to impact and interdisciplinarity, we provide open online research data and web resources for the international science community.

Examples include:

- CamCAN (www.can-can.org) is a population-derived cohort of nearly 3000 healthy volunteers across the adult lifespan, with detailed lifestyle, cognitive, genetic and brain-imaging data (MRI and MEG) on a subset of 700 that have been used by over 800 researchers around the world to study ageing, contributing to >100 peer-reviewed papers.
- The NIHR BRC 'Supertheme' in Brain and Mind Health has adopted the RedCap platform enabling data sharing across and beyond the campus in a standardised format, promoting data sharing and adoption of high-level data governance standards consistently across all research groups.
- Leadership of national and international efforts promoting open access to genomic data, including creation of world-leading cohorts recallable by genotype for translational research. Through the NIHR BioResource – Rare Diseases (https://bioresource.nihr.ac.uk/using-our-bioresource/our-cohorts/rare-diseases/) we have provided sequence data on >13,000 patients with rare diseases as a research resource and to accelerate translation to clinical diagnosis of new genetic disorders globally.

1.6 Research integrity and reproducibility

The highest levels of research integrity and reproducibility are central to our ***mission***, underpin our ***impact strategy***, and are aligned with the University's core principles in research integrity and with Universities UK's *Concordat to Support Research Integrity*. UoA4 has also made an important contribution to understanding reproducibility in neuroscience and psychology research (**Box 1**).

Box 1: Understanding research reproducibility

Szucs' work has informed how to improve the statistical power and replicability of neuroscience and mental health research. By mining >3000 published papers from psychology, neuroscience and medical journals, he demonstrated the importance of increasing sample sizes to improve reporting accuracy (*PLoS Biology 2017*).

1.6.1 Maintaining the highest standards in all aspects of research

Since REF2014, we have made it a strategic priority to foster a culture that actively addresses research integrity including:

- Increasing awareness that irreproducibility is a serious issue. We have arranged visits by high profile external experts to give lectures and lead workshops, and regularly consider this at governance and strategy meetings.
- Providing training and support in appropriate statistical methods and data analytics to all our researchers, and mandating such training for PhD students.
- Promoting scrutiny of primary data in all supervisory and research group meetings.

Each Department has a named staff member responsible for monitoring and reporting on research governance which constitutes a key element of core business for our departmental executives. We also provide individual researchers with administrative support in order to promote research integrity and ensure appropriate ethical standards are upheld, with support from the Research Strategy Office.

1.6.2 Ensuring research is conducted to the highest standards
Our research proposals and conduct are subject to internal and external review to ensure that we adhere to all relevant standards. University Research Ethics Committees review research proposals using healthy human participant data. All animal research is reviewed both before commencement, and after completion, by the University Animal Welfare and Ethical Review Body (AWERB) including scientists, veterinarians and lay persons with a particular focus on the 3R's (reduction, refinement and replacement). We have an integrated approach with our two main NHS partners who act as the sponsor for our patient-facing research aligned with policies of the Health Research Authority and the Medicines and Healthcare products Regulatory Agency (MHRA).

1.6.3 Maintaining a culture of integrity with strong governance, best practice and support for the development of researchers
We host Data Champions who promote Findable Accessible Interoperable and Reusable (FAIR) research principles at a local level, and expert professional staff who provide guidance at the levels of UoA4 and the University. This holistic top-down and bottom-up approach helps to facilitate an environment in which research integrity and reproducibility are core values. As a signatory of the San Francisco Declaration on Research Assessment (DORA), we are committed to ensuring that our approach to measuring scientific output avoids inappropriate metrics and all staff recruitment, evaluation and promotion processes have been reformed accordingly.

1.7 Future strategic priorities

Since REF2014 we have successfully created a sustainable, diverse, cross-disciplinary research community capitalising on state-of-the art research infrastructure. This has enabled us to consolidate and expand our three age-related research themes to tackle the emerging global challenges of brain and mental health disorders.

Our three strategic priorities are:

1.7.1 Developing a sustainable, supportive research culture
We will promote a free-thinking "ideas factory" – the most valuable asset being people, regardless of career level – who conceive, drive, and deliver research through their vision, imagination, and intellectual energy. We will embrace a 'bottom up' culture, enabling scientists at all stages to develop and promote their own ideas. Central to this is the promotion of equality, diversity, openness and integrity through networks (**Box 2**) specifically designed to enable a research environment that is inclusive and accommodates the disparate working practices and environments of our diverse staff.

1.7.2 Nurturing the next generation of interdisciplinary researchers
We are committed to developing the next generation of interdisciplinary researchers at all career levels from PhD through to independence and seniority. This will be achieved through personalised independent mentorship, annual progress reviews, and cross-disciplinary partnerships to sponsor external fellowship applications (including peer review and mock interviews). Evidence of our success comes from the high ratio of PhD students to staff **(>2:1**),

and the number of successful external fellowship awards which span multiple disciplines, accounting for **15%** of our **157** returned staff.

1.7.3 Developing our estate to promote further multi-disciplinarity

We have mature plans to revitalise buildings for Psychology, Psychiatry and Neuroscience researchers with a central hub supporting University-wide spokes. Underpinned by GBP1.2m funding (Gatsby Foundation matched by the University), the University Planning Committee has approved (2018) the re-development of six acres of land on the Cambridge Biomedical Campus (Forvie site) to host inter-disciplinary research teams: the Cambridge Hub for Integrated Neuroscience and Mental Health (beginning 2023).

Phase 1 will co-locate: (1) clinicians, chemists and physicists working to develop new radiopharmaceuticals and other technologies for brain molecular imaging; (2) informaticians working on “big data” in neuroscience and mental health from backgrounds in computer science, statistics, mathematics and bioinformatics; (3) and clinical research space for human volunteer and patient research including experimental medicine and other interventional studies. Phase 2 will co-locate ‘wet’ experimental labs, bringing neurodegeneration, dementia and neuroinflammation groups together on one site, thus consolidating our expertise in molecular, cellular and systems neuroscience.

The Forvie site is immediately adjacent to Cambridge University Hospitals NHS Trust (CUH), where the UK Government has committed GBP100m (2018) to develop a new Children’s Hospital and Research Institute over the next five years (completion 2025). This will accommodate physical and mental health services for children and young people (CUH and Cambridge and Peterborough NHS Foundation Trust), co-located with a new 5,000 m^2 research institute accommodating UoA4 research clusters in childhood and adolescence in close proximity to cognate UoA1 research strengths in paediatrics and young people’s medicine.

2: People

Our people strategy is a central tenet in achieving our ***mission*** enabling us to address our ***future priorities***. Through a comprehensive programme of recruitment and development, our people strategy aims to ***sustainably grow our research community*** and ensure that our world-class researchers are able to ***deliver research with societal impact***. All activity is always underpinned by ***equality, diversity and inclusion*** and the core principles of the ***UK Concordat to Support the Career Development of Researchers***.

2.1 Equality, Diversity and Inclusion (EDI) Strategy

Our approach to EDI is at the heart of our people strategy, as we seek to create a research environment with a supportive and inclusive culture. Our returned staff provide leadership in this domain across the University: notably by Aigbirhio, who jointly chairs the UoC BAME staff network, and also advises the MRC and UKRI (**Box 2**). Local champions develop 'bottom-up' initiatives to promote diversity, supported "top-down' by departmental and UoC resources.

2.1.1 Recognition of advances in EDI

Our advances in EDI have been recognised by the award of the ***ATHENA Swan Silver Award*** to the School of Clinical Medicine in 2018 and the ***Race Equality Charter Bronze Award*** in 2019 to the University. In UoA4, we are focused on improving working culture across departments, following the employee journey, and introducing specific actions including mandatory Equality and Diversity training and continually improving communications and inclusivity.

2.1.2 Organisational support for EDI

Our staff provide leadership for the University-wide ***Equality, Diversity and Inclusion Governance Group*** which promotes EDI to ensure fair processes for recruitment, funding applications, and further development opportunities for all staff. We contribute to the ***Equality Champions network*****,** further enabling grassroots involvement in EDI. This network of >100 staff at all levels of seniority is responsible for information dissemination and collation and embedding of good practice. Our commitment to EDI is reflected by the appointment of an ***EDI Coordinator*** who is responsible for progressing the ATHENA Swan Action Plan, providing support for various staff networks, and organising career development and events to improve the working culture for all staff.

Box 2: Black, Asian and Minority Ethnic groups in UoA4

Aigbirhio co-chairs the University BAME network, supporting the wider BAME activities across the University. As a black African Professor, he is a powerful role model promoting increased diversity in HEIs. The two key aims of the BAME network are to increase the proportion of black staff members, who are notably underrepresented; and to increase the low proportion of BAME staff in senior academic grades. In recent years this has included an event held by MRC CBU as part of wider discussions and events to identify issues that pertain to BAME neuroscientists in areas of recruitment and retention, obtaining grants, publications, mentorship, networking and promotions. Our staff make a major contribution to the African in STEM group established in Cambridge.

2.1.3 Supporting staff and students with protected characteristics

To develop a diverse scientific leadership, we support staff with protected characteristics to conduct productive research. As with other elements of our people strategy, this benefits from tiered and complementary elements at each level of the University structure:

- ***Institutional support*:** University-organised ***Diversity Networks*** enable staff with protected characteristics to develop communities beyond academic boundaries and encourage a sense of inclusivity. UoA4 has demonstrated leadership at the institutional-level as Aigbirhio co-chairs the University ***BAME Network*** (**Box 2)** and Astle is a Committee member of the ***LGBT+ Network***.
- ***Local support***: We run focus group sessions for LGBT+ staff and for those with 'invisible' disabilities or relapsing-recurring health conditions. The School's ***Academic Women's Forum*** provides peer support and mentoring opportunities for female research staff across the biomedical disciplines.

2.1.4 Support mechanisms

The University EDI strategy includes the following key elements:

- ***Flexible working arrangements*:** Our full-time staff all work flexibly on an informal basis with additional opportunity for formal flexible working arrangements. All annual leave is at individual discretion, and compassionate, parental, care and sick leave are all available.
- ***Remote working arrangements*:** Efficient remote working has underpinned our COVID-19 response, which we intend to continue to some degree following the pandemic. The University Information Service provides staff with multiple options for remote working, including VPN servers.
- The University has also launched an initiative in collaboration with the organisation ***My Family Care***, as part of its commitment to support all its staff. This includes emergency childcare, school holiday cover and back-up adult and elderly dependent relative care.
- ***Supporting staff returning from leave*:** The ***University Returning Carers' Scheme*** supports academic activity and builds up the research profiles of our staff returning from a period away from work. Staff can benefit from attendance at UK and international conferences, short-term research support, attendance at training courses and/or equipment purchase.
- Staff with caring responsibilities benefit from the ***Supporting Parents and Carers @ Cambridge Network (SPACE)*** providing information and informal opportunities to meet others and share experiences.
- ***Supporting staff wellbeing*:** In conjunction with the University's overall Wellbeing Strategy, we launched the Raising Mental Health Awareness Programme in early 2015 to embed a culture of dignity in mental health that supports employees' well-being.

2.2 Recruitment Strategy

Our recruitment strategy actively promotes ***interdisciplinarity, diversity*** and ***sustainability*** at all levels to address unmet clinical and societal needs. We are committed to the long-term support of successful research fellows through planned retirements and endowed tenured positions.

We have recruited strategically to senior posts across our research themes including 16 senior positions, **43%** of whom identify as women. Within the ***Childhood*** theme, developmental cognitive neuroscience and child psychiatry has been strengthened through the appointments of Johnson, Lawson, and Lloyd-Fox; and neurogenetics through Chinnery, Horvath and Yu-Wai-Man. We have built critical mass across ***Adolescence and adult life*** in translational hearing research by winning two of only three MRC Senior Hearing Fellows nationally (Vickers and Hughes), in psychology and psychiatry by the professorial appointments of Blakemore and Ford, and in network neuroscience through the appointment of Vértes. There has also been major recruitment within the ***Old age*** cluster, as Mallucci leads the UKDRI Cambridge Hub, and Coleman leads the Van Geest Centre for Brain Repair.

2.2.1 Recruiting early career researchers (ECRs)

Since 2014, UoA4 has recruited over 300 ECRs, who now constitute **37%** of our overall research staff. **56%** of our ECRs identify as women and **11%** are employed on clinical contracts. **16%** are funded through external fellowships, including **24** awarded since REF2014 (see 1.2.1), accounting for **15%** of our returned staff. For clinical academic ECRs see 2.3.4.

2.2.2 Recruitment processes

Our recruitment processes align with our commitment to EDI. We ensure that all recruitment panel members have completed the University's EDI and unconscious bias training modules, and are proportionately gender-balanced to ensure sufficient representation whilst ensuring that staff with protected characteristics are not overburdened. We use LinkedIn and other social media to advertise opportunities widely and to attract high-calibre candidates.

2.3 Staff Development

We are committed to ensuring that researchers are able to develop their full potential through professional and career development aligned with the ***Researcher Development Concordat***, incorporating the following examples:

2.3.1 Institutional development opportunities

The University hosts a comprehensive range of research, teaching, and leadership training schemes open to all staff, including: three levels of leadership training for mid-career and senior academics; project management, communications and management training courses; public engagement and impact training; and active bystander, anti-bullying and harassment training courses.

All staff holding the post of University Lecturer or above have access to sabbatical leave for one term for every six terms of service. This has been an effective way for investigators to rejuvenate their research programme, often by visiting laboratories in other countries to establish new collaborations and/or develop new methodologies which are subsequently made available to other laboratories in Cambridge.

Box 3: Sabbatical – the experience of James Rowe

My sabbatical was actively encouraged. It was an invigorating experience which has had a significant impact on my research. I spent three months in Copenhagen, shorter visits to UCSF, Cologne and Bonn and presentations in Nice, Washington, and several UK sites. I could work in greater depth with longstanding collaborators, their students and ECRs at the Danish Research Centre for Magnetic Resonance (with special expertise in ultrahigh field 7T MRI), and the Neurobiology Research Unit (with special expertise in PET and psychopharmacology). The space and flexibility afforded by the sabbatical enabled me to focus on writing – including a successful Wellcome Investigator Award and some long overdue key papers. My visit to the extraordinary Memory and Ageing Centre in UCSF was inspiring. I was warmly welcomed to the Global Brain Health Initiative events, to see and hear the amazing range of innovation and creativity to work for brain health in the context of poverty, oppression, and discrimination. In specialist clinics we could compare and discuss best practice models for care and translational research. Much of what I saw and learnt has informed our work in the Cambridge Centre for Frontotemporal Dementia and Centre for Parkinson-Plus.

2.3.2 Local development opportunities

Our ***induction, probation and appraisal programme*** includes both online and in-person induction modules. In our 2018 staff survey, **73%** of staff said their local induction provides them with the information to do their job effectively. Termly welcome events have proved successful in welcoming new staff to the University. Attendees have particularly valued the presence of senior school staff as a symbol of their commitment to generosity, kindness and inclusion within the institution.

Completion of probations currently sits at **91%**, and the annual appraisal completion rate is currently at **87%** with **72%** of staff in the 2019 Staff Survey confirming their appraisal was productive. In light of the ongoing pandemic, appraisal forms have been amended to acknowledge the impact on both clinical and non-clinical researchers.

2.3.3 Development opportunities for ECRs

Our ECRs comprise a diverse, international network of 37 post-doctoral Fellows and 194 Research Associates. Our ECRs benefit from the staff development system (2.4.1), but we also recognise that ECRs face specific challenges including: career instability or limited short-term contracts; geographic mobility – an expectation that individuals will move institutions frequently; and limited funding and future career opportunities. These challenges are further complicated for clinically practising ECRs who balance research and clinical training. Evidence of our commitment to ECRs is shown in **Box 4**, and by the fact that **20%** of our returned staff are externally funded ECRs.

Box 4: Mentoring Early Career Researchers – the experience of Caroline Williams Gray

As Clinical Lecturer I benefited from protected research time alongside clinical neurology training. This allowed me to build a research portfolio to support future applications for independent fellowships, whilst at the same time juggling the demands of NHS clinical duties and raising two young children. The mentorship I received throughout this time provided an ideal balance between academic support and encouragement to transition towards independence. Within 4 years I had established my own research team, investigating the role of the immune system in Parkinson's disease. Cross-disciplinary support from senior colleagues in neurodegeneration (Barker), neuroimmunology (Coles and Jones), basic immunology (Clatworthy UoA1) and Chemistry (Klenerman UoA8) was invaluable in enabling me to prepare a successful fellowship application to the MRC, leading to a Clinician Scientist award in 2018. Balancing a clinical and academic career with the demands of family life is an ongoing challenge, requiring a flexible approach. However, my Department continues to be hugely supportive, facilitating my transition to full independence as Principal Research Associate, and Chief Investigator of the first clinical trial of an immunosuppressant therapy for Parkinson's disease.

We have devised and delivered a comprehensive support network to ensure all ECRs reach their full potential:

- ***Induction, probation and appraisal:*** We offer all ECRs a bespoke induction programme at the start of their contracts designed to orientate them to local procedures, policies, personnel, sources of help and information, location of key equipment, and to sign-post neutral and impartial confidantes. Robust probation processes and annual appraisal exercises are also in place to ensure alignment between the expectations and responsibilities of staff and their line-managers.

- ***Mentoring***: Each research cluster mentors ECRs through to success with their first national competitive grant application, including cross-disciplinary 'mock' interviews by experienced investigators. Once appointed, host departments provide start-up packages (typically GBP200k) to junior faculty in partnership with the Isaac Newton Trust.
- ***Postdoc Academy:*** All postdoctoral researchers are member of the Postdoc Academy (2.5.3).

The fruitfulness of this strategy is evidenced both by our success in securing external fellowships (1.2) and by the future career progression of Cambridge ECRs. For example, in 2020, 4 ECRs from the Department of Psychiatry were appointed to full professorial positions elsewhere in the UK and Europe (Chamberlain, Southampton; Khandaker, Bristol; Li, Sheffield; van Harmelen, Leiden).

2.3.4 Development opportunities for clinical staff including aspiring academic clinicians
45% of our 157 returned staff are clinically qualified. Clinical research appraisals differ slightly from the standard academic appraisal by being with the relevant NHS/Public Health England appraisal. We promote proactive job planning to ensure that research time is protected for clinical academic trainees.

Since REF2014 we have hosted **36** NIHR Academic Foundation Programme junior doctors, **40** NIHR Academic Clinical Fellows, and **14** NIHR Academic Clinical Lecturers. The majority remain committed to academic medicine either in training, with subsequent research fellowships (26%), or in tenured academic positions in the UK and globally.

2.3.5 Supporting Category C staff
We are committed to integrating and developing clinical academics and NHS-employed active researchers. The 20 Category C staff returned in UoA4 play a critical role in delivering our strategy through the delivery of our research, the realisation of research impact, and the mentorship of ECRs.

2.3.6 Promotion
The University runs a CV-mentoring scheme for Senior Academic Promotion candidates and schools and departments run local workshops for both academics and researchers before annual promotion cycles. This strategy has delivered notable successes for UoA4, including four staff promotions to Senior Lecturer, nine to Reader, and 12 to Professor, since REF2014.

In addition, the University offers several staff reward opportunities. For example, the annual Vice-Chancellor's Impact and Engagement Awards provide recognition of impact achievements for researchers and professional services staff. Seven UoA4 staff submitted entries to the 2020 Awards with Hutchinson and Menon awarded the prize for Established Researcher (***Impact case: TBI***).

We also recognise and reward our professional support staff through an annual awards scheme.

2.4 Postgraduate Research (PGR) Students

We host a rich collaborative training environment for **305** students currently registered for PGR degrees, comprising **266** PhD and **39** MPhil students, supervised by our **157** Category A and **9** Category C returned staff.

2.4.1 Recruiting PGR students
Students are recruited from across the UK and internationally, with >95% securing competitive awards from external funding sources including MRC and BBSRC doctoral training awards, Industry CASE studentships, Gates Trust, NIH-Cambridge, Cambridge Trust, Wellcome Trust, Pinsent Darwin Fund, British Heart Foundation, Cambridge College Studentships, EU ITN and NIHR. The process of PGR student recruitment is competitive (5:1 over-subscribed), with interviews held for University-wide doctoral training schemes and by host labs.

We are committed to the principles of widening participation, and employ a number of recruitment strategies to ensure that we are able to select from the widest possible pool of candidates:

- ***External communications*:** We use a variety of online and in-print tools to publicise training opportunities for candidates across the UK and the world. We have strong national and international research connections to ensure that candidates around the world are familiar with our training opportunities**.**
- ***Experiential elements*:** We deploy 'on-site' experiential events to provide candidates with an experience of what host institutions are like. These include summer internship programmes that provide external candidates with opportunities and experiences similar to those of internal applicants, negating biases towards internal applicants; and a postgraduate Open Day allowing external applicants to visit our sites and meet potential supervisors.
- ***Recruiting students with protected characteristics***: We are determined to recruit and support the best students, irrespective of their disabilities (see **Box 5**). This recruitment is facilitated greatly by the **University's Disability Resource Centre** providing support for offer holders who have disclosed a disability at application and throughout their PhD.

2.4.2 Ensuring successful completion

Our students benefit from a three-tiered, fully-integrated support system:

Box 5: Supporting students with disabilities

A PhD student hosted in the Kotter laboratory scored the highest academically, but a previous spinal cord injury meant that he was unable to perform independent laboratory work on the project of his choice. The host departments provided a research assistant and implemented many building adaptations to allow him to pursue his ambitions, supporting his computational training which allows him to independently analyse complex datasets generated for his project by the research assistant under his supervision. The student has the mindset and talent to become a scientific leader, and we are committed to giving him the best chances for his career.

- ***Colleges*:** Our Colleges provide graduate students with an exceptionally supportive environment and peer-group, including central accommodation, social space, and pastoral support from a non-academic Graduate Tutor.
- ***Departments***: Host departments provide academic support including a PhD supervisory team, senior PhD coordinators, and administrative support. Progress is continually monitored through regular meetings, data presentations and written annual reports. Each student has two independent mentors who see them at least annually, overseen by Departmental Graduate Tutors. The ultimate responsibility for our students is held by the Heads of Departments, who monitor progress every academic term through an on-line reporting system.
- ***Graduate School of Life Sciences (GSLS)*:** All our students are members of the GSLS, a joint endeavour between the Schools of Clinical Medicine and Biological Sciences. This provides a parity of supervision, support and assessment for all graduate students, facilitates collaboration across life sciences research, and provides bespoke training.
  - The GSLS Core Skills Training Programme is available to first year students and provides them with foundation skills to improve their research, aid them in the completion of key milestones in their degree, and help them make the most of other training opportunities in future.
  - The GSLS Research Development Programme requires students to map their progress across 15 essential competencies within four interconnected areas, namely: research enterprise, career progression, personal effectiveness, and engaging others.

2.4.3 Supporting skills development and preparation for careers

We recognise our responsibility to nurture the next generation of research leaders. In addition to direct supervision and personal mentorship, our approach includes the following:

- ***Promoting a neuroscience community*:** We promote scientific networking and support through the Cambridge Neuroscience IRC, which hosts a regular seminar programme and the Cambridge 'Postdoc Neuroscience Network' (PNN) (**Box 6**).
- ***Postdoc Academy*:** This offers direct support to all post-doctoral scientists, including: welcome, induction and orientation advice on arrival in Cambridge; a comprehensive range of professional development and training activities, including leadership and entrepreneurship, delivered in partnership with an international consortium; a bespoke mentoring programme; advocacy and support for the community of post-doctoral scientists on relevant university and national policies, such as the Research Culture agenda; connections to life beyond Cambridge through employers, other partners and a postdoc alumni scheme. The Academy also works with and supports the three grassroots postdoctoral organisations in the University and the Postdoc Chairs' Network to broaden their reach.
- ***Student-led conferences*:** We provide resources and funding for student-organised conferences and away days which provide our PGR students with key organisational, communication and presentation skills, as well as the opportunity to consider a wide range of potential career pathways.
- ***Skills workshops:*** We host a number of workshops and training opportunities for PGR students within the Unit alongside those studying at other institutions. For example, MRC CBU hosts workshops for MatLab and Python training, as well as imaging analysis for MRI, for PGR students across the region.
- ***Career planning*:** During the course of their studies, PGR students are supported in preparing for their future careers. For example, we host networking events where students have the opportunity to meet with alumni who have pursued a range of career paths.

Box 6: Postdoc Neuroscience Network (PNN)

The PNN directly supports interdisciplinary research, collaboration, knowledge transfer, communication and career development for our junior scientists. The annual symposium was delivered virtually in 2020. Topics covered across the two days included mental health of early career researchers; funding and policy; the impact of COVID-19 on early career development; diversity and racism in academia; open science and credibility; and career progression. The event was attended by ~120 delegates.

2.4.4 Outcome measures

We have awarded **415** PhDs since 2014. From August 2013 to August 2017, **36%** of our 170 PhD graduates directly proceeded to further post-doctoral research positions in Universities or Industry.

3: Income, infrastructure and facilities

3.1 Income

Our aim is to maintain a balanced portfolio of research funding that draws on diverse sources (3.1.1 to 3.1.4), sustaining the research community and enhancing critical mass within research groups spanning the life course. We generate income through:

- Seeking ***long-term strategic funding*** across our three ***research themes*** (1.2) through effective communication to facilitate large grant applications at national and international levels.
- Promoting ***interdisciplinary awards*** (1.4).
- Encouraging and supporting ***individual funding applications***, and placing particular emphasis on mentoring early career researchers to secure external fellowship awards (2.4.3).

Our ***within-year research spend has more than doubled*** since REF2014 (**Figure 4**), reaching ***GBP44m*** in 2019-2020. Our funding portfolio is secured from diverse sources including relevant Research Councils within UKRI, NIHR, the Wellcome Trust and other major charities, including Alzheimer's Research UK and Parkinson's UK. The spike of increased funding in 2015/16 represents the major capital investment in human neuroimaging and high-performance computing facilities funded by MRC Clinical Research Infrastructure awards.

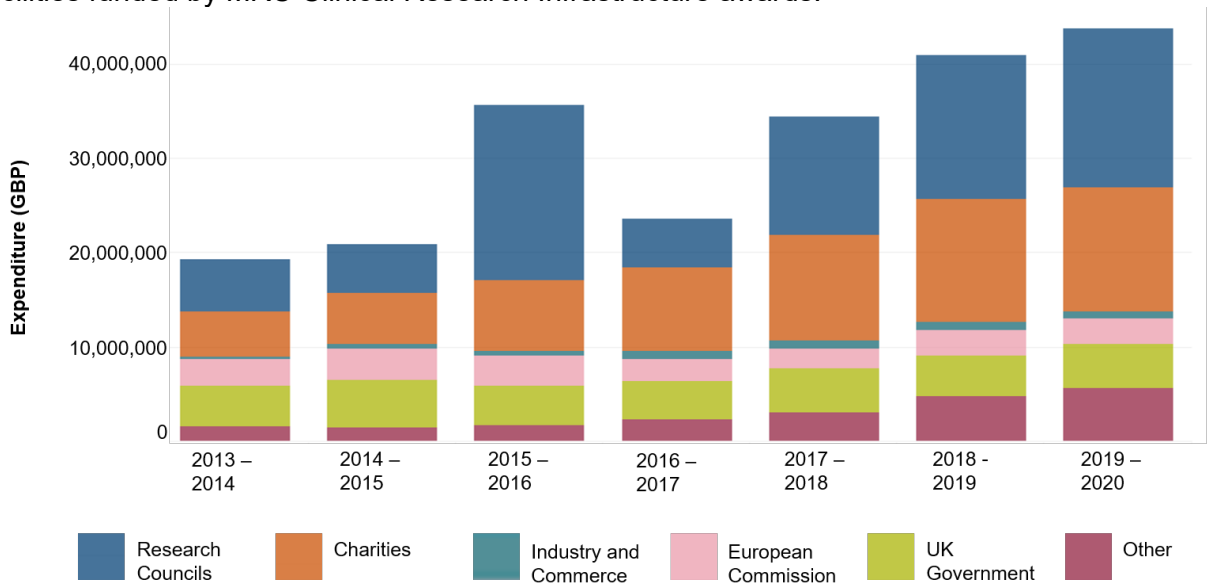


Figure 4. Cambridge UoA4 research grant expenditure in 2014-2020

3.1.1 Personal funding

We have established a supportive culture for ***personal Fellowship*** applications which involves early peer review of draft applications and subsequent mock interviews. Of the **157** mandatory returned individuals, **52 (35%)** were supported by personal Fellowships during the 2014-2020 REF assessment period. Major awards >GBP1.75m are shown below.

3.1.2 National and international funding applications

We proactively engage all researchers in strategic national and international funding applications.

Major examples where we lead or co-lead include:

- Dementias Platform UK (GBP20m, 2015, renewed 2020).
- Alzheimer's Research UK – *ALBORADA Dementia Drug Discovery Institute* (GBP12m, 2016).
- MRC UK PET/MRI Network (GBP15m, 2016).
- NIHR Translational BioResource for Common and Rare Diseases (GBP37m, 2016).

- UK Dementia Research Institute Cambridge (GBP15m, 2017).
- MRC 7T MRI brain imaging network (GBP15m, 2020).
- CNS-COVID (GBP2.3m, 2020).
- National Research Foundation Singapore, CREATE Programme in the Science of Learning: Centre for Learning and Individualized Cognition (GBP12.5m, 2020).

3.1.3 Philanthropic funding

Working with dedicated fundraisers within the University Development and Alumni Relations Office, we have secured ***GBP25m in philanthropic gifts since REF2014***. This has underpinned major new cross-disciplinary research programmes, including fund raising for the Cambridge Hub for Integrative Neuroscience and Mental Health. University and philanthropic funds have been used to match major equipment awards which provide our core facilities in genomics, cell biology, high resolution light and electron microscopy, human brain physiology, brain imaging, brain stimulation, data storage and computation and linked health care informatics.

Major gifts include:

- Mitochondrial ageing (2016-2021, GBP3m).
- Cambridge Centre for Parkinson's Plus (2017-2022, USD20m).
- Gatsby Foundation (2018, GBP0.6m) – for development of the Cambridge Hub for Integrative Neuroscience and Mental Health.
- Gnodde Goldman Sachs Gives (2019, GBP5.6m) – for research in Alzheimer's disease and endowment of a new Professorship in Neuroinformatics.
- Autism Research Trust (2020, GBP3.6m) – for endowment of a new Professorship in Autism Research.

3.1.4 Key awards

Competitive research awards **>GBP1.75m** during the review period include the following:

***National Institute for Health Research*:**

- 2014-2019; renewed 2019 NIHR ARC East of England core (PI:Jones) **GBP1.8m**
- 2017-2022 NIHR Cambridge Biomedical Research Centre:
  - Neurodegeneration theme (PI: Barker) **GBP4.7m**
  - Neuroscience theme (PI: Chinnery) **GBP1.9m**
  - Mental health theme (PI: Bullmore) **GBP2.1m**
- 2017-2022 NIHR BioResource for Translational Research (PI: Chinnery with Bradley) **GBP37m**
- 2017-2023 NIHR Global Health Research Group (PI: Hutchinson) **GBP1.7m**
- 2019-2024 NIHR ARC East-of-England (PI:Jones) **GBP8m**

***Wellcome Trust*:**

- 2014-2019 Fronto-striatal systems in impulsive-compulsive disorders (PI: Robbins) **GBP2.9m**
- 2014-2019 Restoring brain function (PI: Rowe) **GBP1.9m**
- 2015-2022 NIMA: Neuroimmunology of Mood Disorders and Alzheimer's Disease consortium; with matching funds from Janssen, Pfizer, Lundbeck and GSK (PI: Bullmore) **GBP8.7m.**
- 2016-2021 Fractionating the functions of primate ventromedial prefrontal cortex of relevance to depression (PI: Roberts) **GBP2m**
- 2017-2022 Neural reward mechanisms (PI: Schultz) **GBP4.4m**
- 2017-2022 Lipid droplets and hydrogels in health and disease (PI: St.George-Hyslop) **GBP2.5m**
- 2018-2023 Nuclear genomic control of mitochondrial DNA heteroplasmy in humans: population genetics and disease (PI: Chinnery) **GBP2.2m.**
- 2018-2023 Using auditory evoked electrophysiological measures for improving auditory perception. (PI: Vickers) **GBP1.75m**
- 2019-2024 Common variant genetics of autism (PI: Baron-Cohen) **GBP3.1m**

***MRC/UKRI*:**

- 2015-2016 A new collaborative ultra-high field MRI facility for dementia and neuroscience research (PI: Rowe, Co-I: Bullmore, Henson, Carpenter) **GBP6.9m.**
- 2015-2016 Innovative technologies for stratified medicine (PI: Maxwell, Co-I: Bullmore) **GBP14.6m**
- 2015-2021 Identification of the higher-order cognitive mechanisms by which prefrontal and anterior cingulate circuits regulate negative emotion (PI: Roberts) **GBP2.1m.**
- 2015-2016 UKDP: Integrated DEmentiA research environment (IDEA) (PI: O'Brien, Co-I: Aigbirhio, Carpenter and Rowe) **GBP4.2m**
- 2016-2021 Neurobehavioural mechanisms of addiction: vulnerability, circuits and drug memories (PI: Everitt, Co-I: Dalley, Milton and Robbins) **GBP3.2m.**
- 2016-2022 A randomised placebo-controlled trial of immunotherapy in patients with psychosis associated with anti-neuronal membrane antibodies (SINAPPS 2) (PI: Coles, Co-I: Jones) **GBP2.1m**
- 2017-2022 MRC CBU renewal (PI: Gathercole) **GBP15.9m**
- 2017-2022 UK Dementia Research Institute: Cambridge hub (PI: Mallucci): **GBP10m**
- 2018-2023 The Pluripotent Stem Cells and Engineered Cell (PSEC) Hub (PI: Barker) **GBP4.1m**
- 2019-2024 GCRF Global Mental Health grant: Scalable transdiagnostic early assessment of mental health (STREAM) (Co-I: Johnson) **GBP4.1m**
- 2019-2024 Human neurocognitive development: Early-stage processing, modifiers and outcomes (PI: Johnson) **GBP2.7 m**

***European Union and other international*:**

- 2015-2020 Investigating mathematical talent in autism (PI: Baron-Cohen) Templeton Foundation **GBP1.8m**
- 2016-2020 Oscillatory rhythmic entertainment and the foundations of language acquisition (PI: Goswami) EU **GBP2m**
- 2018-2023 Neuronal regulation of CNS plasticity (PI: Karadottir) EU **GBP1.7m**
- 2018-2023 EU Innovative Medicines Initiative 2, Call 10: EU-Aims 2- TRIALS. (Co-Is: Johnson and Jones – infants task and EEG/eye tracking biomarkers; Baron-Cohen) EU120m, **GBP0.8m** to Cambridge.
- National Research Foundation Singapore, CREATE Programme in the Science of Learning in collaboration with NTU: Centre for Learning and Individualized Cognition (PI: Kourtzi), **GBP12.5m**

3.2 Major Infrastructure and Facilities

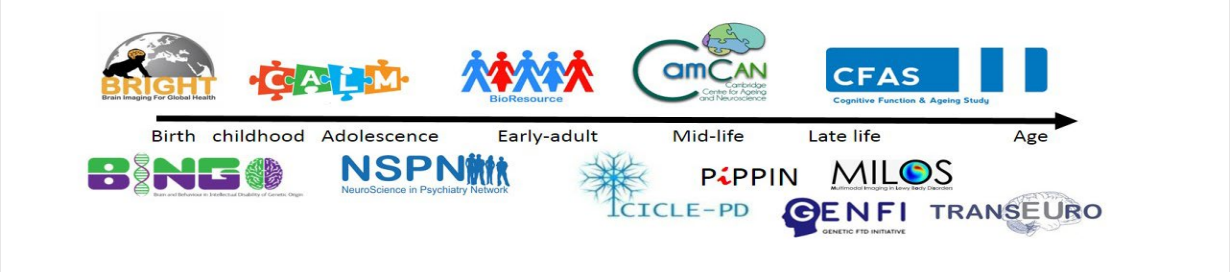
Our capacity is underpinned by the development of our infrastructure and facilities since REF2014.

3.2.1 Lifespan and Clinical Cohorts

We have invested heavily in developing cohorts of human participants spanning our three life-course themes (**Box 7**). Many of the cohorts are locally based in the East of England, facilitating our commitment to "level up" clinical research activity across the region. We also lead national and international cohorts in partnership with other organisations, including the unique NIHR Bioresource, where we have conducted cognitive phenotyping across 60,000 participants.

Box 7: Lifespan and clinical cohorts

The interdisciplinarity of UoA4 is exemplified by our integrated approach to clinical and lifespan cohorts. Investigators across Psychiatry, Psychology, Public Health, Neurology, Education, Engineering and the MRC-CBU, collaborate in "lifespan" studies from early childhood (BRIGHT), through adolescence (NSPN), mid-life and old age (CamCAN). This integrated framework mirrors the clinical cohorts for neurodevelopmental disorders (e.g. CALM), adolescent mental health (e.g. ROOTS), genetic (e.g. frontotemporal dementia, Down's syndrome, Alzheimer's) and lifestyle risks for dementia (e.g. CFAS, CC75), and manifest degenerative disease (e.g. PICNICS, ICICLE-PD, NIMROD, PiPPIN and QMINC). Leadership in national cohorts (e.g. NIHR BioResource, Dementias Platform UK Neuroimmunology and Synaptic Health Themes), and genetic neurodevelopmental cohorts spring from excellence in our Cambridge based population and clinical cohort research.



We are committed to maximal impact from our cohort studies. This comes from their direct links to clinical trials; from biomarker validation and trials optimisation; and a commitment to Open Data.

3.2.2 NIHR Cambridge Biomedical Research Centre

In 2016 we formed the Brain and Mind "Supertheme" linking the neuroscience, neurodegeneration and mental health translational research programmes of the BRC, renewed 2017 (GBP9m). This provides cross-disciplinary research infrastructure developing clinical cohorts, providing tissue biobanking, and a brain imaging platform for longitudinal and interventional studies. This underpins our commitment to develop unique deeply phenotyped disease cohorts in rare and common disorders to advance our understanding of disease mechanisms and develop and implement new therapies.

3.2.3 UK Dementia Research Institute – Cambridge hub

One of five DRI hubs, the Cambridge hub (GBP15m) has brought together chemists, biologists and clinicians under one roof focused on understanding molecular mechanisms of neurodegeneration to develop new treatments which are being evaluated in pre-clinical models and patients through linked clinical platforms. These are adjacent to the Alzheimer's Research UK – *ALBORADA Dementia Drug Discovery Institute* (GBP12m).

3.2.4 Brain imaging platforms

Competitive capital investment from the MRC and NIHR (GBP15m) with matched University funding revitalised human and animal brain imaging in Cambridge (**Box 8**), linked to high-performance computational infrastructure.

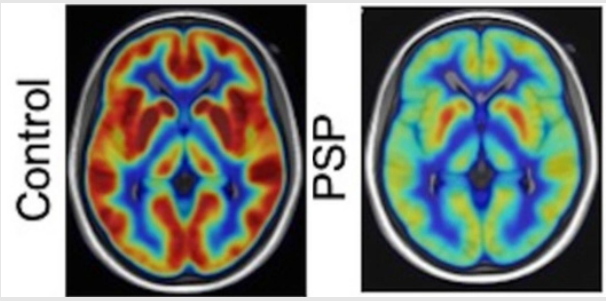
3.2.5 Clinical research facilities

Immediately adjacent to the acute hospital services, we have expanded multi-disciplinary clinical research facilities that incorporate psychology, mental health and neurodegeneration research, with the recent addition of hearing research under one roof. Additional clinical research facilities for higher risk or intensive studies include the recently expanded Cambridge Clinical Research Centre (GBP14.5m) enabling our first-in-man studies, Clinical Trials Unit and GSK Clinical Research Facility within Addenbrooke's Hospital, developed in partnership with Cambridge University Health Partners.

3.2.6 Cognitive and behavioural testing

Box 8: Neuroimaging in Cambridge: structure and function

Cambridge has the most comprehensive brain imaging infrastructure in Europe for translational clinical neuroscience and psychiatry. Our clinical research draws on high-field (3T) and ultra-high-field (7T) MRI; hyper-polarised ^{13}C-MRI supporting clinical trials; PET-CT and PET-MRI for positron emission tomography of pathology and chemistry, linked to an MHRA-accredited radiopharmaceutical unit for GMP production, and a preclinical ligand development laboratory; electroencephalography and magnetoencephalography facilities for neurophysiology and trials; magnetoceutical and electroceutical intervention programs. This is complemented by PET and ultra-high-field MRI (9.4T) animal scanning facilities for rodent and non-human primate models. Recent examples include the introduction of ^{11}C-UCBJ synaptic PET to quantify early pathophysiology in dementia and movement disorders (see figure), strategic investments in new PET ligand development for inflammation, protein synthesis and alpha-synuclein; mesoscale brain imaging at ~400-micron resolution; and high-throughput population imaging studies in psychiatric disorders, cognitive ageing, and dementia. These programs are backed by dedicated High Performance Computing facilities, and a culture of Open Data.



Neurodegenerative loss of synapses in the dementia-movement disorders complex of progressive supranuclear palsy (PSP) is revealed by in vivo [^{11}C]-UCBJ PET scanning. Red colours indicate high binding of [^{11}C]-UCBJ, a novel radiotracer of synaptic density, green/blue = low binding.

MRC-CBU and Psychology together provide world-class facilities for human behavioural and cognitive testing. This includes a GBP0.5m infant and toddler research suite with electroencephalography, near infra-red spectroscopy, eye tracking, brain stimulation, virtual reality and other facilities opened in 2018.

3.2.7 High performance computing

The computational infrastructure to support neuroscience has been underpinned by the MRC clinical research infrastructure award of GBP2m, enabling the development of the High-Performance Hub for Clinical Informatics, in partnership with University Information Services. Provision of this platform has driven economies of scale in delivery of specialist IT services and reduced fragmentation of projects, as well as enabling better access to processing power for ECRs. All neuroimaging data is curated and processed within this facility (over 450 users are registered on the platform, and it hosts over 2 Petabytes of data). In parallel, an ISO27001-accredited “safe haven” has been developed to host patient identifiable data within the University; this infrastructure makes it easier to curate research data with appropriate controls over information governance and direct access to high performance computing nodes.

3.2.8 Biological models

NIHR and University investment established the Cambridge Induced Pluripotent Stem Cell facility enabling human disease modelling. Recent investment in the Van Geest Centre for Brain Repair (Lakatos) has established human brain organoids. University mouse facilities have been centralised on the Biomedical Campus within the GBP60m Bellatrix building, incorporating platforms for behavioural analysis, MRI and PET imaging. We also host C. elegans, Zebra fish, rodent and Drosophila platforms allowing fundamental biology and translational research across complementary model systems. For regulatory reasons, our non-human primate and large animal

facilities are maintained on the West Cambridge site adjacent to the School of Veterinary Medicine (**Box 9).**

Box 9: UoA4 animal facilities in Cambridge

Eleven animal facilities support our research including rodents, non-human primates (rhesus macaques and marmosets), sheep, guinea pigs, naked mole rats, corvids, fish and *Drosophila*. All facilities have a core support infrastructure of qualified support staff including University vets, surgical assistants and animal technicians.

The **marmoset facility** houses up to 250 marmosets with 4 large behavioural testing suites, a surgery suite, infusion and perfusion rooms and offices for up to 14 research staff along with a small histology laboratory and fluorescent microscope room. This facility is internationally recognised as excellent, and hosts regular visits by academic delegations from around the world, particularly Japan, China and the USA. In addition to the **rhesus macaque facility** that houses up to 14 animals for focused neurophysiological studies, translational studies are performed on **large and farm animals** in a new facility providing surgical, procedural, behavioural testing and specialised cardiac and vascular biology laboratory space together with offices, barns, holding yards and grazing to provide a self-contained research station, unique worldwide. **Rodent behavioural neuroscience** includes animal holding and procedure rooms with reverse lighting capabilities and two aseptic surgical suites with dedicated surgery technicians and stereotaxic surgical equipment for delivery of substances (viruses and tracers) to the brains of rodents for in vivo optogenetic and GCaMP recording of neuronal activity, virtual reality equipment to record brain activity during spatial and visual recognition processes, behavioural and learning testing equipment including ~180 computerised operant behavioural testing chambers (18 of which are equipped for optogenetics, 12 for fibre photometry and 3 for in vivo freely moving in vivo electrophysiology), auditory isolation booths, and EEG recording. Additional established procedures include in-vivo microdialysis and biosensors. **Large outdoor aviaries hold a variety of bird species** and a dedicated **centralised facility for zebrafish** is also maintained by the University with an automated control and alarm system to ensure water temperature, salinity, pH and flow rate remain stable. UoA4 also benefits from 30 ***Drosophila*** research groups with at least ten working on the nervous system. Themes include development, circuits and behaviour and, recently, a focus on connectomics research.

3.3 National Research Infrastructure

Through interdisciplinary collaborative partnerships with the NHS, industry and other Universities/Institutes we support the following national infrastructure:

3.3.1 Dementias Platform UK

Initially a partner (Experimental Medicine, Imaging) we now co-lead (Rowe) the renewed MRC Dementias Platform UK (Rowe) driving clinical translational research in neurodegeneration across the UK (2020, GBP10m).

3.3.2 National Brain Imaging networks

Since 2014 our research infrastructure has achieved national and international reach, leveraging the major capital investments in the WBIC (Director, Bullmore) including leadership of the UK 7T MRI brain imaging network (Rowe) and PET/MRI network (Aigbirhio), co-leadership of Dementias Platform UK (Rowe) and the NIHR Translational Research Collaboration in dementia (Rowe, O'Brien).

3.3.3 NIHR BioResource for Translational Research in Common and Rare Diseases

UoA4 co-chairs the GBP37m NIHR BioResource (Chinnery) providing a national resource of over 120,000 healthy participants and patients with rare and common diseases, who have been genotyped and given consent for recall to experimental medicine and interventional studies.

4: Collaboration and contribution to the research base, economy and society

4.1 Networks and Partnerships

Underpinned by our vision to contribute to society through researching the brain and mind over the life course, our collaborations have been both wide-ranging and impactful. Examples include leadership of international research collaborations, two-way engagement with key external stakeholders, and evidence-based policy engagements across all three age-related themes.

4.1.1 Collaboration across the University

We actively encourage interdisciplinary research endeavours between our research themes and the broader University.

Examples funded by the University include:

- ***Neuroscience IRC*:** As described in the REF2014 submission, much our work has been coordinated through Cambridge Neuroscience, under the leadership of Fletcher and Kourtzi. This facilitates interdisciplinary strategy across the broader community of over 600 researchers.
- ***Cambridge Centre for Data-Driven Discovery*:** This brings together researchers and expertise from across the academic departments and industry to drive research into the analysis, understanding and use of data science. The Centre facilitates the relationship between the University and the Alan Turing Institute under Kourtzi's leadership (4.1.3).
- ***The Wellcome – MRC Cambridge Stem Cell Institute (CSCI)*** is a world leading centre for stem cell research. The mission is to transform the prevention, diagnosis and treatment of disease and to promote healthy ageing through a deep understanding of the mechanisms regulating stem and progenitor cells, both normal and pathological. Four of the 27 research groups within the CSCI are neuroscientists returned in UoA4.
- ***Global Challenges Strategic Research Initiative*:** This supports the work of academic researchers and partners in civil society, NGOs, policy-makers, industry, and government who can, by working together, successfully deliver research projects that respond to the challenges faced by communities in developing countries. Several UoA4-led programmes have emerged through this activity, including the NIHR funded Global Trauma Consortium (Hutchinson and Menon, GBP1.7m).
- ***Language Sciences Interdisciplinary Research Centre*:** Established to promote dialogue between language scientists of all disciplines, to stimulate innovative thinking, and to catalyse the formation of new interdisciplinary partnerships for novel research and creative teaching. Kourtzi provides leadership in this domain through her role as a member of the Centre's Management Group.

4.1.2 Collaboration with local academic partners

We benefit from having a major footprint within the largest biomedical campus in Europe, one of six nationally recognised Life Science Opportunity Zones in the UK, and within the Cambridge Biotech Cluster. This critical mass of scientists facilitates collaboration with our major academic and NHS partners, and with industry. Capitalising on our location, our researchers show strong integration with several internationally-renowned research institutes all within a 10-mile radius.

Examples include:

- MRC Laboratory of Molecular Biology (Barker, Chinnery, Lakatos, Spillantini, Vértes).
- Wellcome Trust Sanger Institute (Chinnery, Jones, Sawcer).
- Babraham Institute (Coleman).
- European Bioinformatics Institute (Chinnery, Sawcer) on population, disease and single cell genomics.
- PHG Foundation (Chinnery).

4.1.3 Collaboration with national and international academic partners
Our national and international partners share the co-authorship of our 377 returned publications. We are partners through major national and international funding awards (3.1; 4.2). We also provide national and international leadership in research. Examples include:

***Childhood*:** We play key leadership roles in national and European consortia studying child development and infants at risk, including the BASIS network, EUROSIBS consortium and SAPIENS Network (Johnson). Horvath led the European Research Network (ERN) subgroup of Neuromuscular Diseases until the UK left the EU, and Chinnery leads for rare diseases within the NIHR BioResource (GBP37m).

Adolescence and adult life*:** We lead national and international networks studying the pathogenesis and treatment of acute brain injury, leading to global clinical trials which directly influence the management of patients (Impact case: TBI***) which is underpinned NIHR and the Global Challenges Research Fund (GBP1.7m).

We have established ourselves as leaders in mindfulness-based treatments ***(Impact: Mindfulness***), and we provide co-leadership of the MYRIAD Project (MY Resilience In Adolescence) (Ford and Dalgleish) which is an endeavour between the UK and the USA. Furthering links with mental health research across the globe include leadership of two MRC Global Health Awards in mental health, with sites in Africa and India. In a similar vein to our other impact case studies on ***(Impact: CSNAT***; ***Fake news vaccine***) we have collaborated with other UK HEIs to develop the Emotion Sense app as part of the UBhave: ubiquitous and social computing for positive behaviour change (Rentfrow).

We are also key partners in the MRC Addiction Initiative (MRC CBU, Robbins) and lead a CREATE Centre on Learning and Individualised Cognition (Kourtzi) in collaboration with NTU and funded by the National Research Foundation Singapore. We are a major partner in the Alan Turing Institute, promoting cross-theme collaboration with Kourtzi as the Turing University Lead.

***Old age*:** We lead national and international endeavours to understand and treat neurodegenerative diseases and dementia (3.2 & 3.3), and several natural history studies and clinical trials in Lewy-dementia (O'Brien) with the Universities of Exeter and Newcastle alongside UCL and King's. Barker plays a key role leading international efforts to develop cell therapies for Parkinson's disease and Huntington's disease (TRANSNEURO & STEMPD).

4.1.4 Collaboration with the NHS
Our researchers are embedded within two local NHS providers, who combined forces with the University to form Cambridge University Health Partners. **45%** of our returned staff hold honorary contracts with Cambridge University Hospitals NHS Trust (CUH) or Cambridgeshire and Peterborough NHS Foundation Trust (CPFT). CUH is the regional centre for neurology, neurosurgery and other acute medical and surgical specialities for the east of England. CPFT is the biggest provider of psychological therapies in the East of England, as well as being a partner in the East of England Applied Research Collaboration (ARC) and a partner in the first national consortium of leading mental health trusts providing secondary mental health services to serving Ministry of Defence and US Air Force staff. These partnerships form a platform for clinical research in the East of England and nationally, which underpin clinical cohorts, natural history and biomarker studies, and clinical trials.

4.1.5 Collaboration with industry
Our researchers have co-funded research programmes with Astra-Zeneca which opened its new global R&D centre (USD300m) on the Biomedical Campus in 2020 (Coleman, Kourtzi), and work closely with GSK through the embedded clinical research facility (Aigbirhio, Bullmore, Chinnery), and with GE in brain imaging (Aigbirhio, Rowe, OBrien). Additional industrial research links include those with Shionogi (Robbins, Roberts), Boehringer Ingelheim (Dalley), GSK (Dalley) and Sosei Heptares (Bullmore).

UoA4 researchers have established and sold several spin-out companies since 2014, including:

- ***Quethera***. Founded in Clinical Neurosciences and acquired by Astellas for GBP85m to develop gene therapy as a treatment for optic neuropathy.
- Cambridge Cognition arose from work in Psychology (***Impact: CANTAB***).
- **BitBio** from Clinical Neurosciences on stem cell technologies.
- **CITC Ltd** from Clinical Neurosciences on neural stem cells.

Our researchers have also interacted with media industry partners. For example, Fletcher collaborated with Cambridge-based games company, Ninja Theory in the production of Hellblade (***Impact: Hellblade***). Additionally, van der Linden has worked with Dutch company, DROG, to produce his vaccines against fake news games (***Impact: Fake news vaccine***).

4.2 Response to National and International Priorities

We take a coordinated strategic approach to emerging national and international priorities. This has required open and effective lines of communication across the community within Cambridge, to enable an optimally coherent and timely response.

Key examples since REF2014 include:

4.2.1 Dementia

We provide leadership in all key national initiatives integrating the UK dementia ecosystem from discovery science to improved patient care including:

- Alzheimers Research UK - *ALBORADA* Drug Discovery Institute (Rubinsztein, Lead Academic Scientist).
- UK Dementia Research Institute (Mallucci, Cambridge Centre Director).
- Dementias Platform UK (recently renewed 2021-26; Rowe Associate Director and Experimental Medicine Lead; O'Brien, Neuroimmunology Lead; Markus, Vascular Genetics Lead).
- NIHR Cambridge Biomedical Research Centre (Barker, Dementia theme Lead).

Our work has provided definitive evidence for UK incidence and prevalence of dementia on which DoH policy is based, and identified strategies for risk reduction and the influence of multimorbidity. We have developed NHS guidance (O'Brien, NICE Guideline Group Member and NIHR National Specialty Lead for Dementia). We have strong industrial partnerships embedded within the Biomedical Campus (e.g. Astra-Zeneca) and we are closely allied with key dementia charities (Rowe, Chief Scientific Advisor Alzheimer's Research UK; O'Brien Co-chair, Alzheimer's Society National Research Advisory Committee).

4.2.2 Genomics in healthcare

Our researchers played a key role shaping NHS diagnostic services and the adoption of whole genome sequencing in the NHS. The NIHR BioResource (Co-chair Chinnery) led the pilot study for the 100,000 genomes project, showing increased diagnostic yield (~22%) and a shorter diagnostic odyssey for patients with rare diseases, including neurological disorders with new treatments (*Nature*, 2020).

4.2.3 Global health – head injury

The NIHR Global Health Research Group on Neurotrauma (NIHR GHRGN) group is led from Cambridge and includes neurotrauma experts and young researchers based in 12 different countries (Ethiopia, Tanzania, Zambia, South Africa, Nigeria, Indonesia, Malaysia, Myanmar, India, Pakistan, Brazil, Colombia) supporting >30 clinical research fellows to conduct locally relevant research with the overriding principle to promote neurotrauma care and drive change in prevention and treatment. This has generated over 60 peer-reviewed articles, 40 national and international presentations, and a set of international consensus guidelines. NIHR GHRGN has

recruited >1,500 patients from > 50 countries and we are trialling a worldwide neurotrauma registry to be implemented by the World Federation of Neurosurgical Societies.

4.2.4 COVID-19

Our researchers vigorously engaged with the challenges presented by COVID-19, contributing to the national effort. Much of this work remains in progress at the time of submission.

National leadership in COVID-19 research:

- Leadership of the NIHR/UKRI national programme CNS-COVID (GBP2.3m, Bullmore as MRI lead, Menon as biomarker lead, and Chinnery as Co-chair of the Scientific Advisory Board) studying the neurological and psychiatric complications of acute and post-COVID-19 infection across the UK. UoA4 researchers (Sawcer, Menon) made early clinical and imaging observations describing the neurological manifestations of COVID-19.
- Leadership of the COVID-19 under-50s bioresource (Chinnery) in partnership with Genomics England and the GenOMICC study to identify genetic factors predisposing individuals to severe COVID-19 infection and death (GBP3m).
- Chinnery was appointed National Core Lead for COVID-19 therapeutics by the Government Chief Scientific Adviser to ensure coherent and efficient clinical trial delivery for prophylaxis, community and hospital studies; and to establish and chair the national group selecting treatments for trials in COVID-19 including RECOVERY and PRINCIPLE.

We have initiated over 30 COVID-19 specific studies. Selected examples:

- Hughes is working with the Centre for Family Research to understand family disruption, with potentially long-lasting behavioural and psychological effects during the UK lockdown.
- Van Der Linden has developed: a free online COVID-19 educational game that “vaccinates” players against misinformation; and a browser tool that informs policy-makers about public opinion on COVID-19 around the world.
- Blakemore is conducting a large-scale longitudinal study to examine how social isolation in the COVID-19 crisis is affecting young people’s well-being, loneliness and mental health.
- Rentfrow is examining the extent to which personality and culture contribute to geographical differences in reactions to, and the spread of, COVID-19.
- Cheke has initiated a study on the impact of COVID-19 on memory and cognition.

4.3 Developing and Engaging Diverse Communities

UoA4 researchers recognise their responsibility to communicate their science to the general public, and embrace the opportunity to involve the broader community in priority setting for our research whenever possible. Several of our research themes actively connect with hard-to-reach communities including individuals affected by addiction and drug misuse, ethnic minorities with rare inherited diseases, and mental health disorders associated with stigma. The NIHR East-of-England ARC has a particular focus on developing research activity in disadvantaged “populations in focus” in Peterborough and Fenland, Great Yarmouth and Waveney, Stevenage and Thurrock. In all of these contexts, open engagement has improved the impact of our research, placing engagement at the heart of what we do.

At an organisational level, we facilitate patients and public involvement by providing facilities and infrastructure, such as the Patient Led Research Hub (PLRH, **Box 10)**, but we provide training and engagement awards to PhD students and postgraduate researchers.

Box 10: Cambridge Patient Led Research Hub

Established in 2015 as a partnership between the Cambridge Clinical Trials Unit and our partner organisation CUH, the hub is founded on the principle that patients have important ideas about what research would be most beneficial to their lives. However, due to the complexity and cost involved in running clinical trials, the majority of research originates with the pharmaceutical industry or academic researchers. Therefore, the hub supports patient led research, working in partnership with patient groups to deliver clinical studies based on their own research questions. Current examples include members of the Alzheimer's Society who shaped the priorities and protocol of the NIHR BioResource – Genes and Cognition Study, which includes a downloadable platform for cognitive testing. The patients and family members helped produce the 'Frequently asked questions' document and assisted with web site design.

Our engagement and involvement falls into two overlapping categories:

- ***Inspiring public understanding of science*:** We embrace digital and broadcast media, as well as face-to-face events, particularly in schools through our outreach programme, and through patient advocacy groups in the UK and abroad. Our researchers actively engage the public through written and broadcast media and have authored several influential science books for the lay reader since 2014 (**Box 11**). In addition to our annual participation in the Cambridge Science Festival, we hosted ***BrainFest*** (2017) which brought together neuroscientists to present ground-breaking research through interactive exhibits, film, art, neuro-theatre and Q&A with Cambridge experts at *Café Scientifique,* directly engaging >3,000 visitors and > 1,200 school students.

- ***Directly involving the public in our research*:** Healthy participants and patients across the lifespan actively contribute to our research through their continued engagement in our study cohorts (**Box 8**), shaping the research priorities and advising on the logistics of research delivery.

Box 11: Contributing to public discourse and understanding: books and broadcasting

2016 Sahakian and Gottwald published ***Sex, Lies, and Brain Scans*** (Oxford University Press). which won the British Psychological Society Book Award for Popular Science.

2018 The Inflamed Mind (Bullmore, Short Books), an introduction to neuro-immunology and its implications for depression and mental health. A *Sunday Times* bestseller published in 14 other countries selling >100,000 copies.

2018 Inventing Ourselves (Blakemore, Black Swan, UK) won the Royal Society Science Book Prize (2018) and the British Psychological Society Popular Science Prize (2020).

2020 The Pattern Seekers by Baron-Cohen "sheds light on one of humanity's most distinctive traits, celebrates human cognitive diversity, and is rich with empathy and psychological insight" (*Steven Pinker)*.

Other researchers have collaborated with popular authors to further contribute to public understanding of depression and memory in aging: Khandaker featured in Alastair Campbell's 2019 BBC documentary *Depression and Me*, and his book, *Living Better: How I Learned to Survive Depression*; and Simons advised Jane Gordon, author of *How Not to Get Old,* on techniques to maintain memory in old age.

Key activities include:

Childhood**:** Supervised by Ford, PhD student Soneson has developed innovative public health approaches to identifying and responding to mental health difficulties in children, including the creation of a school staff advisory group, blog posts and public presentations, and discussions with NHS practitioners and Home Office policymakers.

Adolescence and adulthood**:** Jadva and Zadeh hosted a series of workshops in secondary school centred around a short play called 'I'm an IVF Baby', which increased the understanding of teenage audiences and provided fresh perspectives on the topic to the research team.

The Autism Research Centre has worked with advisory groups of autistic adults to develop the Vulnerability Experiences Quotient (VEQ), a measure used to define the negative life experiences of autistic people.

Old age**:** Kotter and Davies founded the first advocacy group for patients with myelopathy, formally launched at the House of Lords (**Box 12**).

Box 12: Working with patients to enhance research impact

Kotter and Davies founded Myleopathy.org in 2015 as an information and support platform for patients. Iwan Sadler, a cervical spondylotic myelopathy (DCM) patient frustrated by the lack of support, had founded his own Facebook Support group. Given their common goals, Iwan joined Myelopathy.org to set up and lead a support community for patients by patients.

The community is made up of over 2,000 members from all over the globe and is the first worldwide charity for cervical myelopathy. Patients have been instructive in the design and instrumental in delivery and steering of Clinical Trials. Kotter has established Research Objective and Common Data Elements for DCM (AO Spine RECODE-DCM) as an international, multi-stakeholder initiative to create a research toolkit that helps accelerate knowledge discovery and improve outcomes in DCM.

4.4 Contribution to the National and International Research Base

Our **157** returned staff have made a major contribution to the national and international research base through participation in peer review, including funding panels and journal editorships. International recognition includes invitations to give endowed lectures, election to learned societies, personal research fellowships, prizes and awards, and national honours.

Selected examples 2014-20 include:

4.4.1 National leadership roles

- Chinnery was appointed MRC Clinical Director (2018) overseeing UKRI clinical translational activity, and COVID-19 therapeutics National Core Study lead (2020) by the UK Government Chief Scientist.
- Bullmore was elected to the Council of the Academy of Medical Sciences (2018) and then as Treasurer (2019).

4.4.2 New elections to learned societies

- Nine Fellows of the Academy of Medical Sciences (Barker, Baron-Cohen, Franklin, Hutchinson, Markus, Mallucci, O'Brien, Roberts and Dalgleish). 16 in total.
- Three Fellows of the Association for Psychological Science (Blakemore, Rentfrow and Simons). 10 in total.
- Five Fellows of the British Academy (Blakemore, Gathercole, Golombok, Lambon-Ralph and Sahakian). Eight in total.
- One Fellow of the Royal Society (Spillantini). 7 in total.
- One Fellow of the American Academy of Arts and Science (Johnson).
- Nine NIHR Senior Investigators (Barker, Bullmore, Chinnery, Czosnyka, Hutchinson, Jones, Markus, O'Brien, Rowe).

4.4.3 Senior Fellowships

Our returned staff were awarded ***16*** senior research fellowships since REF2014.

4.4.4 National honours

- Knighthood (Baron-Cohen).
- CBE (Robbins, Compston, Ford, Goswami).
- OBE (Gathercole).
- Order of Canada (St George-Hyslop).
- Order of the Star of Italy (Spillantini).

4.4.5 Major prizes and awards

Our returned staff were awarded ***42*** national and international awards including **Box 13**.

Box 13: Trevor Robbins, Wolfram Schultz and Angela Roberts

2014 Robbins won the Lundbeck Foundation Brain Prize for translating basic neuroscience findings to illuminate human disorders including drug addiction and obsessive-compulsive disorder.

2017 Schultz won the Brain Prize for discovering the role of dopamine neurons in reward learning processes and economic decision-making.

2020 Roberts won the Brain & Behavior Research Foundation Goldman-Rakic Prize for outstanding achievement in cognitive neuroscience.

4.5.6 Funding committees
Our returned staff hold ***58*** positions on national and international funding committees

4.5.7 Journal editorship
Our returned staff hold **56** journal editorial positions.

4.5.8 Highly cited researchers (Clarivate Analytics, 2020)
Psychology/Psychiatry or Neuroscience/Behaviour: Baron-Cohen, Jones, Robbins, Bullmore.