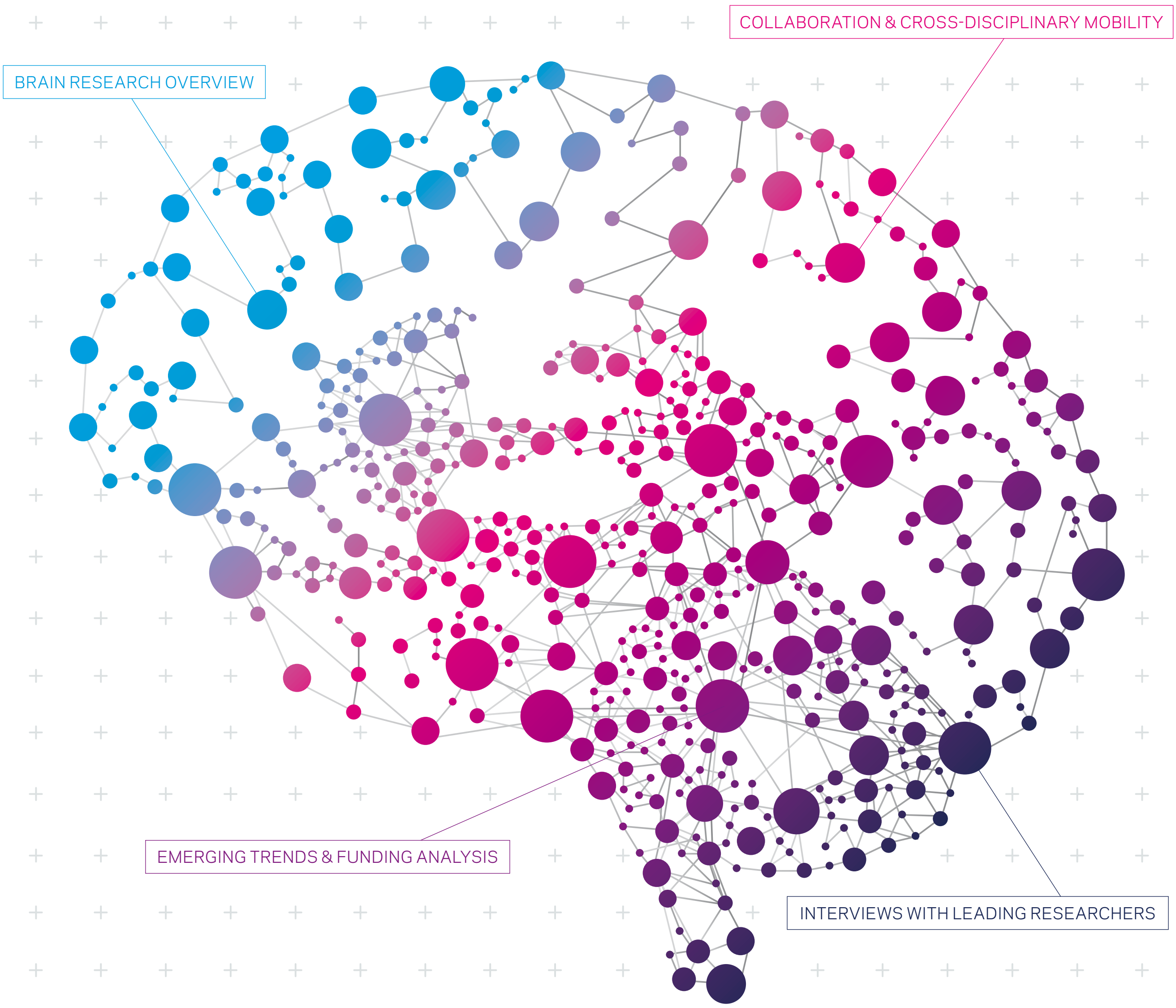
BRAIN SCIENCE

Mapping the Landscape of Brain and Neuroscience Research



ELSEVIER

A REPORT PREPARED BY ELSEVIER RESEARCH INTELLIGENCE ANALYTICAL SERVICES

Preface

The awarding of this year's Nobel Prize in Physiology or Medicine—to John O'Keefe, May-Britt Moser and Edvard Moser—not only recognizes the achievement of three excellent neuroscientists, but also stands as a tribute to the thriving field of brain research, a field that has seen impressive growth in the last decades. The proliferation of national and international funding initiatives has further strengthened the brain and neuroscience research effort and promises to accelerate our understanding of the human brain for the greater benefit of mankind.

Brain research is complex, encompassing the study of the organ itself, its cells, circuits, and structure (e.g., neuroscience), as well as how these structures and the processes they support contribute to brain functions like cognition and memory. The human brain is much more than the mechanics of neurons and circuitry; it is the core of our personalities, behaviors, and awareness. Consequently, the study of the brain is by nature a cross-disciplinary field of inquiry. It brings together biochemistry, cell biology, physiology, computer science, physics, engineering, medicine, and mathematics, as well as psychology, neurology, philosophy, and ethics. It is also conducted at multiple levels—molecular, cellular, circuits, cognitive, and behavioral—and across developmental and evolutionary time scales. Understanding how the human brain works is therefore not only an enormous undertaking, it is also one that will require a highly collaborative and collective research approach. It will require open data and resource sharing across disciplines, countries, and institutions, including private companies, research universities, research foundations, and philanthropies. Brain research will not only provide new insights into the fundamental biology of the brain, it also promises to help address the major societal challenges posed by mental illness and age-related brain disorders. This research holds the potential to deliver new treatments for serious degenerative disorders such as Alzheimer's disease and Parkinson's disease.

As a global provider of research information solutions, Elsevier is committed to making genuine contributions to help advance science and innovation. We strive to deliver world-class information through our role as traditional publisher while providing innovative tools and services that noticeably improve productivity and outcomes for those we serve. We have been proud to support brain research development through coverage in more than 150 neuroscience journals, including our flagship journal *Neuron*, launched in 1988 by Cell Press.

Elsevier has also prioritized its commitment to supporting neuroscience by developing domain-specific enhancements and search tools customized for neuroscientists within our products. We have interviewed hundreds of researchers to identify their most important challenges in search and discovery, and have started developing tools to solve them. Through this pilot program, we intend to transform scientific publishing to become smarter and more relevant, and bring our solutions closer to the real problems researchers face in their work every day.

Science is becoming increasingly data-centric, and brain research is no exception. The sheer volume of data generated in brain research and the expanding network of connections among brain researchers present great opportunities for collaboration, as well as formidable challenges to understanding and promoting progress within the field. We at Elsevier have sought new ways to contribute to the global effort on brain research by drawing from our own data from Scopus. As new interdisciplinary, collaborative, global brain research initiatives are starting worldwide, we felt it would be useful to apply Elsevier's SciVal solution to create a global overview of brain and neuroscience research activity using multiple indicators and presenting a multi-layered view of the current state of research. The findings offer new empirical knowledge and insights into the overall dynamics of this area of research and how that landscape has developed over time.

The analyses in this report offer the brain research and neuroscience community a new source of information for strategic assessment and the development of policy and funding strategies at the national and international levels. In addition to providing a static view of the field as it stands today, this report serves as an example of our effort to continuously develop and apply innovative analytical methodologies to answer new, more complex, and more dynamic questions of relevance to the community. One such question addressed in this report concerns the way researchers move in and out of brain research and other scientific areas over time. Another question is how to identify emerging trends within brain research. This report explores two promising methods based on a comparison of the scientific literature and awarded grant abstracts to tackle this question. Such methods will be of significant interest to those involved in science and technology strategy, as they provide intelligence for forward-looking exercises. Elsevier is following up with plans to add a new trends module to SciVal in February 2015.

This study was conducted by Elsevier with key contributors including Georgin Lau, Dr. Judith Kamalski, Dr. Holly J. Falk-Krzesinski, Dr. Stephane Berghmans, Dr. Anders Karlsson, Ludivine Allagnat, Jesse Mudrick, Jeroen Baas, Dr. Marius Doornenbal, and Dr. Katja Brose of Elsevier, and Dr. Stacey C. Tobin of The Tobin Touch, Inc (see Appendix A: Author Credits, Advisory Groups, and Acknowledgements for details). This report would not have been possible without invaluable inputs from the expert organizations. We would like to express our deepest gratitude and acknowledge the following individuals and organizations for their expertise, insight, and meaningful contributions toward the development of this report, including Professor Monica Di Luca, Professor Susumu Tonegawa, and Professor Richard Frackowiak who shared their views in our interviews with them:

- Monica Di Luca, President, Federation of European Neuroscience Societies (FENS) and Board Member, European Brain Council (EBC), European Union (EU)
- Marian Joels, Past President, FENS, EU
- Lars Kristiansen, Executive Director, FENS, EU
- Members of the FENS Executive Committee
- Medical Research and the Challenge of Ageing Unit, DG Research & Innovation, European Commission (EC), EU
- Flagships Unit, DG Connect, EC, EU
- Richard Frackowiak, Chair, Medical Sciences Scientific Committee, Science Europe and Co-Director, Human Brain Project (HBP), EU
- Kristen Cardinal, Director of Global Development, RIKEN Brain Science Institute (RIKEN BSI), Japan
- Charles Yokoyama, Director for Research Administration, RIKEN BSI, Japan
- Miyoung Chun, Executive Vice President of Science Programs, The Kavli Foundation, USA
- Christopher Martin, Science Program Officer, The Kavli Foundation, USA

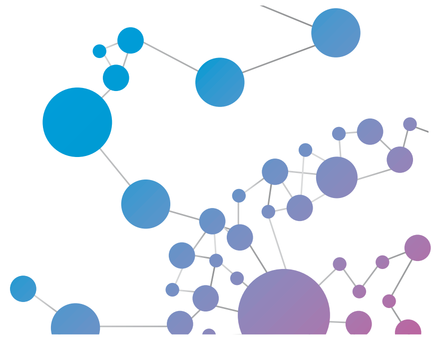
Along with its launch, the report will be discussed at the Society for Neuroscience Annual Meeting, Neuroscience 2014 in Washington, DC, amongst the thought leaders, innovators, and scientists working in brain and neuroscience research. We are honored with the opportunity to share the results of this analysis and hope that the findings in this report will prove valuable for the brain and neuroscience research community, including funders, scientists, and policymakers, in support of the continued development of national and international programs that support future advancement in brain and neuroscience research.

Ron Mobed
Chief Executive Officer, Elsevier

EXECUTIVE SUMMARY

BRAIN SCIENCE

Mapping the Landscape of Brain and Neuroscience Research



A report prepared by Elsevier Research Intelligence Analytical Services.
Available online at www.elsevier.com/research-intelligence/brain-science-report-2014.

The human brain—some consider it to be the greatest of life's mysteries, the scientific frontier for the 21st century. Certainly, it is the most complex organ in the body, one that constantly changes and adapts in response to its environment and is capable of directly influencing the outside world. Unlocking the secrets of the brain—how it works and what happens during disease or trauma—will potentially impact not only human health but also economies and societies worldwide. As the human lifespan increases, so will the incidence of age-related neurodegenerative diseases and the cost of care. Finding new ways to diagnose, treat, and even prevent diseases of the brain has become a global priority. Brain research also has profound implications for computational science and computing technologies—understanding the brain as an adaptive computer is informing the design of "neuromorphic computers" that mimic the physical architecture of neural networks to achieve the speed, agility, and interpretive ability of the human brain.[1]

Brain research is an enormous and complex enterprise, encompassing the study of brain anatomy, neuroscience, and cognitive science, as well as interrelated disciplines such as computer science, engineering, psychology, philosophy, and ethics. Integration of ideas and approaches across these disciplines can spur innovation and accelerate discoveries. Globally, countries have formed large collaborative research programs to tackle the complexity of the human brain, to discover how it works, and what happens during disease or trauma. The growing interest in new ways to treat or even prevent brain disorders, as well as the push toward interdisciplinary research and how the efforts of large initiatives will complement those of individual researchers, provides the context for this benchmarking report. What is the current state of brain and neuroscience research, where it is being done, who is doing it, and what areas are being emphasized by various stakeholders—researchers, funding agencies, governments, policymakers, and members of society?

Using the Scopus abstract and citation database of peer-reviewed literature, we applied a semantic fingerprinting approach, with additional input from internal and external brain research experts, to identify a comprehensive set of global publications in the area of brain and neuroscience research from the last five years. We then analyzed the resulting document set to determine global output by country, the types of collaborations across institutions, nations, and sectors, and how researchers publish across interrelated disciplines. We also examined emerging trends and evolving foci within brain and neuroscience research by comparing research publications with the abstracts of funded grants. The following summarizes the key points from our analyses, providing a snapshot of the current state of brain and neuroscience research that can help guide future research priorities, policy, and funding decisions.

Research Output

Our analysis identified approximately 1.79 million brain and neuroscience research articles in the Scopus database published between 2009 and 2013, representing approximately 16% of the world's total publication output. Researchers from European countries and the United States (US) together published more than 70% of the world's brain and neuroscience research in 2013, with the top five contributors in terms of publication volume being the US, the United Kingdom (UK), China, Germany, and Japan. China showed the highest average annual growth rate in brain and neuroscience research, while among top five nations, the US and Japan showed the lowest annual growth rates, at 2.9% and 1.5%, respectively. Among comparator countries, the Netherlands, Sweden, and the UK had the highest Activity Index (defined as a country's share of its total article output across a subject relative to the global share of articles in the same subject), and the Netherlands, Sweden, and Belgium had the highest number of brain and neuroscience research articles produced per researcher. The European Union (EU) countries and the US accounted for 91% of the world's citations, though China's citation share grew most rapidly at an average rate of 15.1% per year from 2009 to 2013. The EU and US dominated the share of the world's highly cited articles—defined as those in the top 1st or 10th percentiles worldwide in citation counts relative to all articles published in the same year and subject area.

[1] Greenemeier, L. (2013) "Integrating left brain and right, on a computer," Retrieved online from http://blogs.scientificamerican.com/observations/2013/08/08/integrating-left-brain-and-right-on-a-computer/.

Collaboration

Analyzing co-authorship patterns within the brain and neuroscience document set generated several surprising insights. Collaboration types (international collaboration, national collaboration, collaboration within a single institution, and single authorship) differed from country to country. International collaboration rates in brain and neuroscience research were quite high on average, with the highest 2013 rate belonging to Switzerland (65.5%). Consistent with previous studies, research articles produced through international collaborations were associated with higher citation impacts. In 2013, the field-weighted citation impact (FWCI; a research output indicator that normalizes for differences in citation activity by subject field, article type, and publication year) of Poland's internationally co-authored articles was almost five-fold higher than that of its articles authored by researcher teams from the same institution. As the leading Asian nations in brain and neuroscience research, China and Japan had international collaboration rates of 24.6% and 21.6% in 2013, falling into the lower quartile of comparator countries. Relative to the FWCI of single-institution collaborations for China and Japan, the corresponding FWCI for those countries' international collaborations was 2.6 times and 2.7 times higher. Network mapping further indicated a clear "core" of well-connected, typically highly productive countries that also produced highly cited international co-authored articles. The US was a collaborative partner to most countries and appeared to be the main broker between Asia and the EU. The network within the EU itself was strong and dense. In our cross-sector collaboration analysis, although academic-corporate collaborations accounted for a small percentage of each country's total output in brain and neuroscience research, they were associated with higher impact articles compared to other cross-sector collaboration types (academic-government and academic-medical).

Cross-disciplinary Mobility

We also tracked brain and neuroscience researcher mobility into and out of various disciplines based on journal classification. More than half (59.5%) of the 1.73 million active brain and neuroscience researchers were classified as Multidisciplinary (defined here as publishing in the area of brain and neuroscience research for fewer than two years at any given time) and only 5.8% did not publish outside of the area of brain and neuroscience throughout their research career. Researchers published most often in the areas of medicine, biochemistry, and genetics and molecular biology, but the fields of engineering and computer science were also included among the top 20 disciplines in which active brain and neuroscience researchers published. These findings reflect a state of flux in the area of brain and neuroscience research, where researchers continuously push across disciplinary boundaries to make innovative discoveries.

Emerging Trends and Funding Analysis

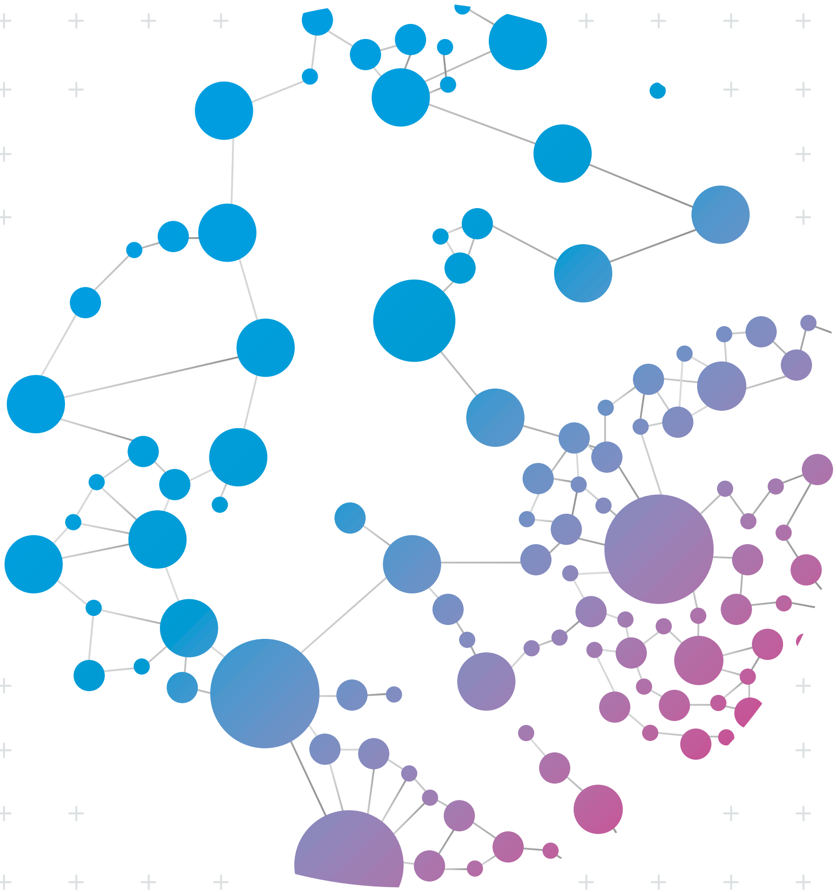
Analyzing the frequency of specific terms or concepts in the brain and neuroscience research document set, we identified and organized top concepts by overall theme (semantic group). The most highly recurring concepts in the theme of *disorders* were "Stroke," "Depression," "Neoplasms," and "Alzheimer Disease," while the most common concepts for *anatomy* were "Brain," "Eye," and "Neurons." We also compared the top concepts within the document set against those in abstracts from grant awards funded by the National Institutes of Health (NIH). As expected, broad concepts such as "Brain," "Neurons," "Seizures," and "Brain Neoplasms" appeared with similar frequency in the published articles and the NIH-funded grant abstracts. However, topics such as "Eye," "Pain," and "Stress, Psychological" were more highly represented in published articles than in NIH-funded abstracts, suggesting a divergence from funding to publication. Not surprisingly, NIH-funded abstracts more often contained disease-related concepts, consistent with the NIH's focus on areas of research with perceived high societal impact. When we compared concepts across published articles, NIH-funded grant abstracts, and European Commission (EC)-funded grant abstracts, the top shared concepts across all three document sets included "Alzheimer Disease," "Parkinson Disease," "Schizophrenia," "Dementia," "Mental Health," and "Neurodegenerative Diseases," confirming the shared international focus on the research of brain-related disorders.

Compared to the research funded by the EC, US research was focused on the concepts "Glioma," "Pervasive Child Development Disorders," and "Bipolar Disorder." Conversely, concepts such as "Memory Disorders," "Vision Disorders," "Myasthenia Gravis," "Hearing Loss," and "Alkalosis" appeared more frequently in the EC-funded research compared to the US, suggesting a different emphasis in research relating to disorders in brain and neuroscience. In the US, drugs related to substance abuse were highly researched, with the appearance of concepts such as "Methamphetamine," "Nicotine," and "Cannabis." In contrast, antipsychotic drugs that are mainly used to treat schizophrenia were high areas of focus in the EC-funded research.

With this report, we not only document traditional measures of the global brain and neuroscience research effort, such as publication output and citation or download frequency, but also analyze relative researcher activity, national and international patterns of co-authorship, researcher networks, and researcher mobility across traditional disciplinary boundaries. With our concept analyses, we also reveal areas of common effort and areas where research interests diverge. Taken together, this report provides a rich resource of data with which all stakeholders can evaluate changes in the global brain and neuroscience research effort, assess the effectiveness of collaborative research, and consider future research directions and funding priorities.

Contents

CHAPTER 1
BRAIN RESEARCH OVERVIEW



In this chapter, we look at the overall state of brain and neuroscience research by analyzing data on the volume, citation impact, growth, usage pattern of research in this area from key countries.

1.1 Introduction

1.1.1 The state of brain research

The sheer complexity of the human brain means that accelerating discovery in neuroscience will require global integration of effort, data, and analysis. As in other fields, the disciplinary silos that contribute to brain and neuroscience research are breaking down, with teams of investigators representing medicine, biology, engineering, computer science, and psychology working within large collaborative research initiatives of unprecedented scale and scope. These large collaborations are already uncovering common pathologies shared by various brain and spinal cord disorders, bringing into question some of the traditional classifications of "neurologic," "psychiatric," and "traumatic" brain disorders. It is anticipated that new treatments for brain disorders will be based on a more integrative understanding of neuropathophysiology, leading to hybrid approaches that change circuitry rather than the activity of individual neurotransmitters. Basic discoveries about the brain are happening in parallel with advances in technology, including the development of new imaging methods, computational analysis, and simulation software. New research tools and data sharing platforms are being developed and deployed to further support integrative analysis of research findings. Funding of brain and neuroscience research also reflects this diversity of effort. Large-scale initiatives funded by government entities are complementing foundation-supported, investigator-driven research, and private research institutes are partnering with publicly funded programs to drive discovery in brain and neuroscience research. Several of these initiatives are described in the next section.

1.1.2 Global initiatives in brain research

Large collaborative research programs to study the brain are underway in many countries, and partnerships between these initiatives are starting to form a truly global network of researchers that share the common goals of understanding how the brain works and how to better diagnose and treat diseases and disorders of the brain.

UNITED STATES

The BRAIN Initiative was launched as a Presidential Grand Challenge in April 2013 through the Office of Science and Technology Policy[2] with the goal of attaining a comprehensive understanding of the brain at multiple levels.[3] Approximately $100 million was invested in neuroscience research programs overseen by the National Institutes of Health (NIH), the National Science Foundation (NSF), the Defense Advanced Research Projects Agency (DARPA), and several private and philanthropic research partners. Evaluation of the ethical, legal, and social implications of the work of the BRAIN Initiative, its partners, and other neuroscience research programs is an equally important part of this initiative, making it a truly transdisciplinary endeavor.[4]

Research projects at DARPA[5] are focusing on understanding the dynamic functions of the brain and developing novel wireless devices to cure neurological disorders (SUBNETS)[6] and repair brain damage to restore memory loss (RAM).[7] BRAIN Initiative funding to the NSF[8] is supporting transdisciplinary research to develop theories of brain function; develop new imaging and treatment technologies; develop tools and standards for data collection, analysis, and integration; and build multi-scale models that relate changes in brain activity directly to cognition and behavior. The NIH has a strong track record of neuroscience research through the work of the National Institute of Mental Health (NIMH),[9] the National Institute of Neurological Disorders and Stroke (NINDS),[10] and the National Institute on Drug Abuse (NIDA),[11] as well as through the NIH Blueprint for Neuroscience Initiative, a cross-disciplinary collaboration across 15 NIH Institutes and Centers.[12] Under the BRAIN Initiative, NIH is focusing on developing new tools, training opportunities, and other resources in seven key priority areas (see Table 1.1).[13]

Table 1.1 —
BRAIN Initiative Support of Neuroscience at NIH

- → *Identify and provide experimental access to different brain cell types to determine their roles in health and disease*
- → *Generate circuit diagrams that vary in resolution from synapses to the whole brain*
- → *Produce a dynamic picture of the functioning brain with large-scale monitoring of neural activity*
- → *Link brain activity to behavior*
- → *Develop new theoretical and data analysis tools*
- → *Develop innovative technologies and integrated human brain research networks to understand the human brain and treat its disorders*
- → *Discover how dynamic patterns of neural activity are transformed into cognition, emotion, perception, and action in health and disease*

See page 15 and 16 for notes for section 1.1.

The BRAIN Initiative is also catalyzing efforts by several private and philanthropic research groups in order to merge their expertise, infrastructure, and resources with those of DARPA-, NIH-, and NSF-funded researchers. The Allen Institute for Brain Science is focusing on understanding how brain activity leads to perception, decision making, and action. Researchers are currently working on the BrainSpan Atlas of the Developing Human Brain,[14] which is a map of the entire human brain transcriptome, and they have already completed the Allen Mouse Brain Connectivity Atlas.[15] The Howard Hughes Medical Institute (HHMI) is developing new imaging technologies to understand how information is stored and processed within neural networks. The Kavli Foundation,[16] whose Brain Activity Map Project[17] directly informed the scientific thinking behind the BRAIN Initiative, continues to share knowledge with BRAIN Initiative researchers to address debilitating diseases and conditions of the brain. The Salk Institute for Biological Studies' Dynamic Brain initiative is combining its strengths in molecular neurobiology, neurophysiology, computational neuroscience, and behavioral neuroscience to map neuronal connections and their link to behavior and action in order to discover new treatments for brain disorders.[18] Other BRAIN Initiative partners include the New York Stem Cell Foundation, Microsoft Research, and Medtronic.

Another major brain research initiative in the United States is the NIH Human Connectome Project,[19] a 5-year project involving 36 investigators at 11 institutions who are working to map human brain connectivity and its variability in more than 1,200 normal adults. Preliminary imaging and behavioral data on the first 500 subjects was recently released and made available to the public. All data from the project will ultimately be integrated to produce network modeling tools that will be freely shared with the larger scientific community.

EUROPE

In Europe, the European Commission (EC) approved €1 billion in funding for the Human Brain Project (HBP),[20, 21] a collaboration across 24 countries and 112 institutions. The dual goals of the HBP are to develop and deploy new information and communication technology (ICT) platforms for collecting and integrating brain research data, and then use that data to create a computational model of the human brain. The ultimate vision of the HBP is to develop neuromorphic computers—physical models of human neural circuits on silicon using microelectronics with the ability to self-organize and adapt. To achieve this first requires development and sharing of ICT platforms with neuroscience, medicine, and computing communities worldwide to enable large-scale collaborative research across disciplinary and geographic boundaries. The goals and success of the HBP are firmly rooted in the concept of collaborative research, as it aims to bring large, disparate sets of neuroscience data together in order to understand and model the human brain at multiple levels. More than 100 partners across Europe have pooled resources to achieve the HBP's goals, and a partnership with the BRAIN Initiative in the United States was announced in March of 2014.[22]

The European Union (EU) also continues to support neuroscience research outside the HBP; from 2007 to 2012, the EU funded 1,268 projects and 4,312 investigators, with a yearly allocation of €300 million.[23] Researchers are investigating the integrative structure of brain, modeling neuronal processes, targeting brain diseases, developing new diagnostics and therapeutics, and improving patient management. Acknowledging the value of collaborative research, particularly in neuroscience, the EU also specifically funds initiatives that promote the formation of new research partnerships and provide supportive infrastructure.

The EU Joint Programme on Neurodegenerative Disease Research (JPND) was formed to coordinate neurodegenerative disease research between EU countries, focusing on the shared goals of identifying the causes of neurodegenerative disease, developing methods for earlier detection and treatment, and evaluating how best to support patients, their families, and their caregivers.[24] As part of EU Joint Programming, the JPND provides a supporting structure for collaborative neuroscience research between EU countries in order to better meet the enormous and complex medical, social, and economic challenges presented by neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, and motor neuron diseases, among others. The JPND helps identify research priority areas, opportunities for collaboration and resource sharing, and ways to disseminate technologies and tools to the wider scientific community. Recent activities include the establishment of Centres of Excellence in Neurodegeneration (COEN) to concentrate expertise and promote collaborative research.

There are also many national initiatives and funding programs in brain and neuroscience research across the EU. In Germany, neuroscience research funded by the German Research Foundation (DFG)[25] is conducted at universities designated as Clusters of Excellence and within cross-disciplinary Collaborative Research Centres, several of which involve multiple university partners working together to pool expertise and resources. In addition to basic and clinical research centers, there are also various priority programs composed of large, multi-institutional research teams focused on collaborative approaches to cutting-edge neuroscience research topics. Private and not-for-profit institutions also have programs dedicated to brain research, including The Max Planck Society for the Advancement of Science.[26]

The Netherlands also has a robust program of neuroscience research, supported by the National Initiative Brain & Cognition (NIHC) taskforce, formed in 2009 under the auspices of the Netherlands Organisation for Scientific Research (NWO).[27] With a budget of approximately €65 million over five years, the goal of the NIHC is to promote broad, cross-disciplinary research that integrates neuroscience and cognitive science, bringing together experts in neurology, biology, and psychiatry with linguists, communication technologists, and education researchers. The NIHC brings together research partners within and outside of The Netherlands as well as from several industry and social advocacy organizations.

OTHER GLOBAL INITIATIVES

The global network of neuroscience research also extends into Asia, with two Japanese institutions recently joining the HBP.[28] The Okinawa Institute of Science and Technology (OIST) is developing the Brain Simulation Platform, software that will link specific electrophysiological events and biochemical reactions in neurons in a spatial simulation. The RIKEN Brain Science Institute (BSI) was founded in 1997 to promote innovative, collaborative brain research that brings together the disciplines of medicine, biology, physics, computer science, and psychology. BSI is arranged around four core research areas: Mind and Intelligence, Neural Circuit Function, Disease Mechanisms, and Advanced Technology Development. Research at RIKEN BSI primarily focuses on the level of the neural circuit, which links molecular and cellular processes to neural networks, cognition, and behavior.[29] In addition to its internal research programs, RIKEN BSI has also established several productive national and international collaborations, including the RIKEN-MIT Center for Neural Circuit Genetics and the recently completed FIRST project.[30] As a partner institution within the HBP, RIKEN researchers are identifying the brain structures that determine specific mental capabilities and are involved in integrating information. In addition, Japan's ten-year brain project—Brain/MINDS (Brain Mapping by Integrated Neurotechnologies for Disease Studies—that was launched in May 2014, will develop the marmoset experimental model to accelerate the understanding of human mental disorders. Funded at ¥3 billion (US $27 million) for the first year, the program is divided into three groups focusing on structural and functional brain mapping, development of new technologies for brain analysis, and improving the analysis of clinical data such as human patients' brain scans for biomarkers of brain diseases.

In China, the Ministry of Science and Technology (MOST) funded the Brainnetome Project in 2010, one of more than 50 projects related to the research in brain and its disorders. Brainnetome[31] includes a partnership between the University of Queensland and The Institute of Automation at the Chinese Academy of Sciences—the Joint Sino-Australian Laboratory of Brainnetome was launched in 2013, with the goal of using advanced imaging techniques and computational analysis to map how normal and diseased neural networks function. In 2011, the National Natural Sciences Foundation of China (NSFC) launched the "Grand Research Plan for Neural Circuits of Emotion and Memory" with an allocated budget of 200 million RMB over eight years, which will focus on the research on emotion and memory and make use of cutting-edge technologies from medical science, life sciences, and information science.[32]

In North America, in recognition of the global acceleration of neuroscience research, Brain Canada[33] reorganized in 2010 to increase the scale and scope of funding specifically to Canadian brain researchers.

1.1.3 Analyzing the brain research efforts

It is clear that the landscape of brain and neuroscience research is starting to embrace its nature, forming large collaborative, cross-disciplinary initiatives and global networks of researchers that can tackle the complexity of the human brain. Yet this shift has not come without some challenges.

As with any new endeavor, the scale and scope of the HBP, and the shift of focus from individual investigator-driven neuroscience research to the work of a large collaborative initiative, has prompted concern among members of the global neuroscience community.[34] In response, the HBP funding agency, the EC, recognized the size and diverse needs of the neuroscience community, while also clearly outlining the risk-benefit proposition presented by the HBP: the challenges of efficiently executing a large, multi-institution research program must be weighed against the potentially far-reaching benefits resulting from the work.[35] The HBP Executive Committee acknowledged that the initiative represents not only a methodological paradigm shift, in that it seeks to combine all neuroscience data onto a single platform, but also a cultural paradigm shift: "to reconstruct and simulate a single synapse, neuron, brain region, whole brain or a disease, large teams of scientists, clinicians, and engineers need to work side-by-side on a single problem. It pushes all of us beyond what we are used to and are comfortable with. This is an essential state change that is needed to leverage everyone's data and synthesize all our knowledge."[36]

The concerns about the direction of human brain research, and its increasing push toward cross-disciplinary integration within large collaborative initiatives, underscore the need for a greater understanding of the state of brain and neuroscience research, how it is being done, who is doing it, and the level of quality and innovation being achieved. In this report, we present an analysis of the neuroscience research effort at a point in time when these large initiatives and partnerships, such as the BRAIN Initiative and HBP, are organizing and getting underway. Starting from this benchmark analysis, we can follow changes in the research effort over time as a way to evaluate the effectiveness of the collaborative approach to human brain research, define emerging and merging research areas, and guide future neuroscience funding priorities.

***Figure 1.1** — Key Events in Collaborative Brain Research*

SEPTEMBER 2011
Opportunities at the Interface of Neuroscience and Nanoscience Workshop

JANUARY 2012
Kavli Foundation publishes Brain Activity Map concept[37]

SUMMER 2012
Human Connectome Project begins imaging human brain connectivity in healthy adults[38]

JANUARY 2013
European Commission announces funding of the Human Brain Project[39]

APRIL 2013
President Barack Obama announces BRAIN Initiative[40]

WINTER 2013
Japanese research groups join Human Brain Project[41]

MARCH 2014
Allen Institute for Brain Science completes Mouse Brain Connectivity Atlas[42]

APRIL 2014
Sino-Australian Brainnetome project established[43]

APRIL 2014
Allen Institute publishes first results on the BrainSpan Atlas of the Developing Human Brain[44]

MAY 2014
Launch of Brain/MINDS in Japan

More than 250 scientists, from 135 research groups distributed across 81 research organizations in 22 countries, gathered in Lausanne, Switzerland for the Human Brain Project (HBP) kick-off meeting from 7 to 11 October 2013.

PHOTO: THE HUMAN BRAIN PROJECT

President Barack Obama and National Institutes of Health (NIH) Director Dr. Francis Collins announcing the BRAIN Initiative at the White House on April 2, 2013.

PHOTO: WHITE HOUSE

Prof. Perry Bartlett and Prof. Tianzi Jiang sign the agreement of the joint Sino-Australian Laboratory of Brainnetome at Institute of Automation in Beijing on March 21, 2013.

PHOTO: THE UNIVERSITY OF QUEENSLAND

1.1.4 **Methodology and data sources**

The majority of data presented in this report is derived from Scopus[45] (articles and citations) and ScienceDirect[46] (full-text article downloads). A number of other data sources have also been gathered to add to the breadth of knowledge exchange presented in this report. A detailed description of our subject definition methodology, an iterative approach to identifying articles related to brain and neuroscience research, is provided in Appendix B: Methodology and Data Sources. We provide an overview of the methodology here.

Defining Brain Research and Neuroscience

Before any quantitative analysis of research activity can begin, the first step is the appropriate and consistent definition of the subject of interest. The four-step approach deployed here to evaluate the state of brain and neuroscience research is shown in Table 1.2. First, we identified a set of neuroscience concepts and terms, defined as a semantic fingerprint, consisting of 21,029 concepts. After feedback from expert organizations and further evaluation, the semantic fingerprint was refined to 1,207 concepts[47] deemed relevant and specific to brain and neuroscience research. We then applied this semantic fingerprint to the full Scopus database, across all subject categories (not only Neuroscience), to identify all published articles related to brain and neuroscience research. The resulting set of articles was then analyzed to describe the state of brain and neuroscience research, in terms of research output, impact, collaboration, and quality, as well as the extent of cross-disciplinary research, emerging and highly active areas of research, and the state of research funding.

We defined brain and neuroscience research through the selection of relevant concepts derived from the semantic Elsevier Fingerprint Engine (see Figure 1.2 for an outline of the process of Fingerprinting),[48] with additional inputs from external neuroscience experts. Articles[49] in Scopus that contained the selected concepts were considered to be related to brain and neuroscience research, and were included in the document dataset for further analysis. Each document was given a field-weighted citation impact (FWCI), the calculation of which was based on a more granular scheme encompassing more than 300 subject subfields, consistent with the All Science Journal Classification (ASJC) codes. It is important to note that journal ranking was not a considered in the process of document selection, nor did it affect our subsequent analyses, as the calculation of FWCI is performed at the article level. The details of the calculation of FWCI can be found in Appendix C: Glossary of Terms.

Table 1.2 *— Four-step approach to evaluate the state of brain and neuroscience research.*

Step 1 *Identify key concepts and terms in publications classified under the Scopus subject of Neuroscience*
Step 2 *Select relevant and specific concepts to define the semantic fingerprint for brain science*
Step 3 *Identify all articles in Scopus that fit the brain science semantic fingerprint*
Step 4 *Analyze the resulting articles to evaluate the state of brain science research*

Figure 1.2 *— The Elsevier Fingerprint Engine creates fingerprints via a three-step process (see more at http://www.elsevier.com/online-tools/research-intelligence/products-and-services/elsevier-fingerprint-engine).*

1 MINE TEXT

The Elsevier Fingerprint Engine applies a variety of Natural Language Processing (NLP) techniques to mine the text of any scientific document, including publication abstracts, funding announcements and awards, project summaries, patents, proposals, applications, and other sources.

2 IDENTIFY CONCEPTS

Using thesauri spanning all the major science, technology, engineering, and mathematics (STEM) disciplines, the Elsevier Fingerprint Engine identifies key terms in the text pointing to concepts in the relevant thesaurus.

3 CREATE DOCUMENT FINGERPRINT

The Elsevier Fingerprint Engine creates an index of weighted semantic concepts that defines the text, known as a Fingerprint.

1.1.5 Resulting dataset for analysis

To select the publications used for our analysis of brain and neuroscience research activity, we utilized the Elsevier Fingerprint Engine to extract the fingerprint of key concepts represented most often in brain and neuroscience research. The result was a high-quality set of key concepts, with any duplicates and synonyms removed. Using this fingerprint, we identified approximately 1.79 million articles published between 2009 and 2013 (out of a total of 12.3 million articles published during this period), which comprised approximately 16% of the world's output, and contained a total of 164,404 concepts.

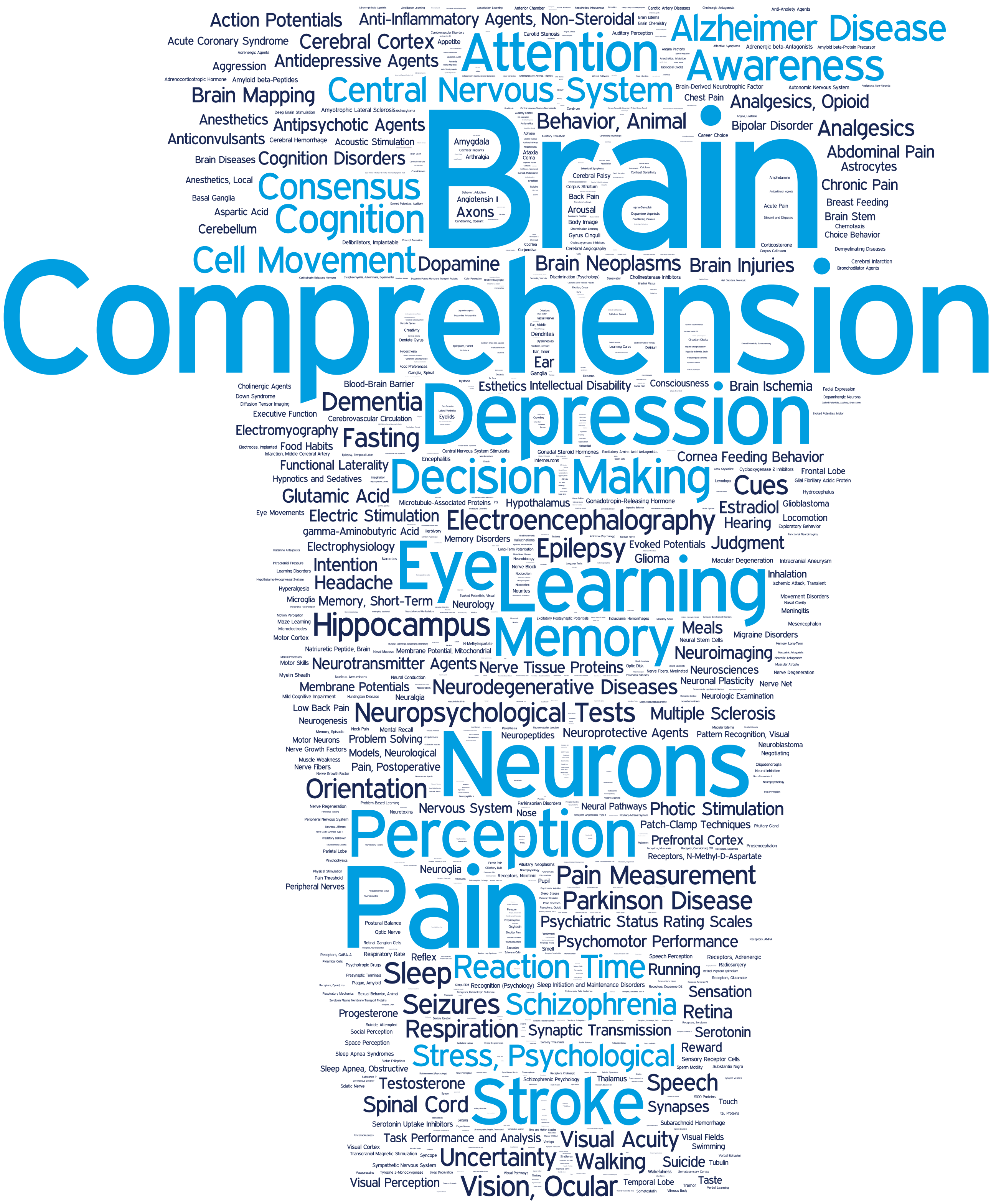
As a benchmark, publications belonging to journals classified in the Medicine category comprised 28.1% of all publications, while those in the Neuroscience journal category made up only 2.4% of world's output. This highlights the advantage of our semantic fingerprinting approach, where we were not limited to identifying only brain and neuroscience research articles that are traditionally classified as neuroscience in a journal-based classification system; rather, we were able to include articles in our analysis that are outside of the Neuroscience subject category but include a key concept and/or MeSH term that is considered specific and relevant to brain and neuroscience research. Our approach is multi-method and iterative, and relies on both automatic and manual input to select relevant articles for analysis. By combining three approaches—an initial journal-based classification system, semantic fingerprinting using the Elsevier Fingerprint Engine, and internal and external expert review and selection of key concepts—we were able to identify a broad set of articles that gives a more comprehensive representation of the entire field of brain and neuroscience research. Table 1.3 shows the distribution of journal categories to which the articles from the selected document set belong. Note that while 97.0% of the selected articles were in the Medicine journal category, they constituted 41.8% of all articles published in medicine; similarly, while only 20.8% of the selected articles were in the Neuroscience journal category, they made up 91.8% of all articles published in neuroscience.

While it is not possible to show the entire list of concepts, the methodology of using relevant concepts to define the area of brain and neuroscience research enabled us to select the set of documents that is most relevant to this field that should be included in the analysis. Figure 1.3 shows the word cloud of the concepts (weighted by the number of occurrences in the selected document dataset) that had a selection rate of 100%, meaning that no relevant documents that contained these concepts were excluded.

ASJC Subject Area	*% of Brain and Neuroscience Articles Tagged in the Journal Category*	*% of All Articles in the Journal Category*
Medicine	97.0%	41.8%
Biochemistry, Genetics and Molecular Biology	34.8%	31.9%
Neuroscience	20.8%	91.8%
Psychology	13.3%	64.0%
Pharmacology, Toxicology and Pharmaceutics	10.4%	34.9%
Agricultural and Biological Sciences	10.1%	14.8%
Social Sciences	6.5%	9.4%
Nursing	6.2%	45.6%
Immunology and Microbiology	5.7%	21.2%
Health Professions	5.3%	48.5%
Chemistry	4.0%	5.2%
Engineering	3.8%	2.0%
Environmental Science	3.1%	7.4%
Computer Science	3.1%	2.8%
Arts and Humanities	3.1%	9.3%
Veterinary	2.3%	27.3%
Chemical Engineering	1.7%	4.3%
Physics and Astronomy	1.7%	1.5%
Mathematics	1.6%	2.6%
Dentistry	1.5%	30.8%
Materials Science	1.3%	1.5%
Business, Management and Accounting	0.5%	2.5%
Economics, Econometrics and Finance	0.2%	1.6%
Earth and Planetary Sciences	0.2%	0.5%
Energy	0.1%	0.6%
Decision Sciences	0.1%	1.2%

***Table 1.3** — Distribution of journal categories to which the brain and neuroscience research articles in the selected document set belong, and the percentage of articles of each journal category that was included in the selected document set, 2009-2013. Each article can be tagged to multiple journal categories; thus, the percentages in the table will not add up to 100%. Source: Scopus.*

__Figure 1.3__ — Word cloud of concepts from the selected document set where the selection rate was 100%, meaning that no relevant documents that contained these concepts were excluded. Size of each concept is weighted by the number of occurrences in the selected document set. Please refer to the digital version of this report, which has zooming functionality, to see the concepts in smaller text. Source: Scopus.



[2] The White House, Office of Science and Technology Policy. (2013) "21st Century Grant Challenges," Retrieved online from http://www.whitehouse.gov/administration/eop/ostp/grand-challenges.

[3] The White House. (2013) "BRAIN Initiative," Retrieved online from http://www.whitehouse.gov/share/brain-initiative.

[4] Presidential Commission for the Study of Bioethical Issues. (2014) "Gray Matters: Integrative Approaches for Neuroscience, Ethics, and Society," Washington, DC. Retrieved online from http://www.bioethics.gov/sites/default/files/Gray%20Matters%20Vol%201.pdf.

[5] Defense Advanced Research Projects Agency. (2014) "Journey of discovery starts toward understanding and treating networks of the brain," Retrieved online from http://www.darpa.mil/NewsEvents/Releases/2014/05/27a.aspx.

[6] Defense Advanced Research Projects Agency. "Systems-based Neurotechnology for Emerging Therapies (SUBNETS)," Retrieved online from http://www.darpa.mil/Our_Work/BTO/Programs/Systems-Based_Neurotechnology_for_Emerging_Therapies_SUBNETS.aspx.

[7] Defense Advanced Research Projects Agency. "Restoring Active Memory (RAM)," Retrieved online from http://www.darpa.mil/Our_Work/BTO/Programs/Restoring_Active_Memory_RAM.aspx.

[8] National Science Foundation. "BRAIN: Brain Research through Advancing Innovative Neurotechnologies," Retrieved online from http://www.nsf.gov/news/special_reports/brain/initiative/.

[9] National Institutes of Health. "National Institutes of Mental Health," Retrieved online from http://www.nimh.nih.gov/index.shtml.

[10] National Institutes of Health. "National Institutes of Neurological Disorders and Stroke," Retrieved online from http://www.ninds.nih.gov/.

[11] National Institutes of Health. "National Institute on Drug Abuse," Retrieved online from http://www.drugabuse.gov/.

[12] National Institutes of Health. "NIH Blueprint for Neuroscience Research," Retrieved online from http://www.neuroscienceblueprint.nih.gov/index.htm.

[13] Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Working Group, Report to the Advisory Committee to the Director, and National Institutes of Health. (2014) "BRAIN 2025: A Scientific Vision," Retrieved online from http://www.nih.gov/science/brain/2025/BRAIN2025.pdf.

[14] Miller, J.A., Ding, S.L., and Sunkin, S.M., et al. (2014) "Transcriptional landscape of the prenatal human brain," Nature. 508(7495): 199-206 doi: 10.1038/nature13185.

[15] Oh, S.W., Harris, J.A., and Ng, L., et al. (2014) "A mesoscale connectome of the mouse brain," Nature. 508(7495): 207-214. doi: 10.1038/nature13186.

[16] The Kavli Foundation. (2014) "The BRAIN Initiative," Retrieved online from http://www.kavlifoundation.org/brain-initiative.

[17] Kavli Foundation. (2013) "The Brain Activity Map Project," Retrieved online from http://sas-origin.onstreammedia.com/origin/kavlifoundation/BAM/Timeline/TheBrainActivityMapProject.pdf.; Alivisatos, A.P., Chun, M., and Church, G.M., et al. (2013) "Neuroscience. The brain activity map," Science. 339(6125): 1284-1285. doi: 10.1126/science.1236939.

[18] Salk Institute for Biological Studies. "Scientific Initiatives: Dynamic Brain," Retrieved online from http://www.salk.edu/campaignforsalk/brain.html.

[19] National Institutes of Health. "NIH Blueprint: The Human Connectome Project," Retrieved online from http://humanconnectome.org/.

[20] Human Brain Project. (2013) Retrieved online from https://www.humanbrainproject.eu/.

[21] The Human Brain Project. (2012) "A Report to the European Commission," Retrieved online from https://www.humanbrainproject.eu/documents/10180/17648/TheHBPReport_LR.pdf/18e5747e-10af-4bec-9806-d03aead57655.

[22] Reardon S. (2014) "Brain-mapping projects to join forces," Retrieved online from http://www.nature.com/news/brain-mapping-projects-to-join-forces-1.14871.

[23] European Union. "European Brain Research. Achievements Under the EU Seventh Framework Programme for Research and Development (FP7) from 2007 till 2012," Retrieved online from http://ec.europa.eu/research/health/pdf/brain-research_en.pdf.

[24] EU Joint Programme. "Joint Programme Neurodegenerative Disease Research," Retrieved online from http://www.neurodegenerationresearch.eu/home/?no_cache=1.

[25] German Research Foundation. (2014) "Neurosciences Research in Germany," Bonn, Germany.

[26] Max-Planck-Gesellschaft. Retrieved online from http://www.mpg.de/en.

[27] Netherlands Organisation for Scientific Research. (2013) "National Initiative Brain & Cognition (NIHC)," Retrieved online from http://www.nwo.nl/en/about-nwo/organisation/nwo-divisions/nihc.

[28] Okinawa Institute of Science and Technology. "Japanese Research Organizations Contribute to Human Brain Project," Retrieved online from http://www.oist.jp/pressrelease/japanese-research-organizations-contribute-human-brain-project.

[29] RIKEN Brain Science Institute. Retrieved online from http://www.brain.riken.jp/en/.

[30] Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST). (2014) "Strategic Exploitation of Neuro-Genetics for Emergence of Mind," Retrieved online from http://www.brain.riken.jp/first-okano/en/index.html.

[31] Institute of Automation, Chinese Academy of Sciences. "Brainnetome," Retrieved online from http://www.brainnetome.org/en/brainnetomeproject.

[32] Zhu, Y-G., Cao, H-Q., and Dong, E-D. (2013) "Grand research plan for neural circuits of emotion and memory—current status of neural circuit studies in China," Neurosci Bull. 29(1): 121–124. doi:10.1007/s12264-013-1307-1.

[33] Brain Canada. Retrieved online from http://braincanada.ca/.

[34] "Open message to the European Commission concerning the Human Brain Project. July 7, 2014." Retrieved online from www.neurofuture.eu.

[35] Madelin, R. "No single roadmap for understanding the human brain. 18 July 2014," Retrieved online from http://ec.europa.eu/digital-agenda/en/blog/no-single-roadmap-understanding-human-brain.

[36] Human Brain Project Board of Directors and Executive Committee. "The vital role of neuroscience in the human brain project. 9 July 2014," Retrieved online from https://www.humanbrainproject.eu/documents/10180/17646/HBP-Statement.090614.pdf.

[37] Alivisatos, A. P., Chun, M., and Church, G. M., et al. (2012) "The brain activity map project and the challenge of functional connectomics," Neuron. 74(6): 970-974. doi:10.1016/j.neuron.2012.06.006.

[38] National Institutes of Health. "NIH Blueprint: The Human Connectome Project," Retrieved online from http://humanconnectome.org/.

[39] Human Brain Project. Retrieved online from https://www.humanbrainproject.eu/.

[40] The White House, Office of the Press Secretary. (2013) "Remarks by the President on the BRAIN Initiative and American Innovation," Retrieved online from http://www.whitehouse.gov/the-press-office/2013/04/02/remarks-president-brain-initiative-and-american-innovation.

[41] Okinawa Institute of Science and Technology. "Japanese Research Organizations Contribute to Human Brain Project," Retrieved online from http://www.oist.jp/pressrelease/japanese-research-organizations-contribute-human-brain-project.

[42] Oh, S. W., Harris, J. A., and Ng, L., et al. (2014) "A mesoscale connectome of the mouse brain," Nature. 508(7495): 207-214. doi: 10.1038/nature13186.

[43] Institute of Automation, and Chinese Academy of Sciences. "Brainnetome," Retrieved online from http://www.brainnetome.org/brainnetomeproject.

[44] Miller, J. A., Ding, S. L., and Sunkin, S. M., et al. (2014) "Transcriptional landscape of the prenatal human brain," Nature. 508(7495): 199-206. doi: 10.1038/nature13185.

[45] Scopus was developed by and is owned by Elsevier. It is the largest abstract and citation database of research literature in the world, with abstracts and citation information from more than 45 million scientific research articles in 18,000 peer-reviewed journals.

[46] ScienceDirect is a leading online resource for full-text scientific articles and books.

[47] These were medical subject headings (MeSH) terms, which, including descendants, expands to 2,428 concepts. MeSH is the National Library of Medicine's controlled vocabulary thesaurus. It consists of sets of terms naming descriptors in a hierarchical structure that permits searching at various levels of specificity. Refer to http://www.nlm.nih.gov/mesh/ for more details.

[48] The Elsevier Fingerprint Engine uses a variety of thesauri spanning all major subject areas, along with Natural Language Processing (NLP) techniques, to scan and analyze publication abstracts and to map terms and combination of terms to key concepts.

[49] This report uses the term "articles" to refer to the following types of peer-reviewed document types indexed in Scopus: articles, reviews, and conference proceedings. For a more detailed explanation, see Appendix C: Glossary of Terms.

1.2 Key Comparator Countries

Comparator countries were defined consistently across data sources: unless otherwise indicated, the United States, United Kingdom, China, Germany, Japan, Canada, Italy, France, Spain, Netherlands, Switzerland, Turkey, Sweden, Belgium, and Poland were used for charting. These are in fact the 15 countries that published the most articles in the area of brain and neuroscience research from 2009 to 2013.

For the purpose of this report, Europe was defined as consisting of the 41 countries (henceforth called 'EU41') with direct eligibility for FP7[50] funding, including all 28 current EU member states and 14 associated countries (i.e., those with science and technology cooperation agreements that involve contributing to the FP7 budget). Note that in this report, countries may be referred to by their ISO 3-character code (see Table 1.4); a full listing of these codes is included in Appendix D: Countries Included in Data Sources.

***Table 1.4** — Countries in this report and their ISO 3-character country codes.*

Country	*ISO 3-Character Code*
Belgium	**BEL**
Canada	**CAN**
China	**CHN**
France	**FRA**
Germany	**DEU**
Italy	**ITA**
Japan	**JPN**
Netherlands	**NLD**
Poland	**POL**
Spain	**ESP**
Sweden	**SWE**
Switzerland	**CHE**
Turkey	**TUR**
United Kingdom	GBR (**UK** used throughout the report)
United States	USA (**US** used throughout the report)

[50] The complete name of FP7 is 7th Framework Programme for Research and Technological Development (FP7), a seven-year initiative running from 2007 until 2013. The FP7 has a total budget of more than €50 billion. For details, see http://ec.europa.eu/research/fp7/understanding/fp7inbrief/what-is_en.html.

1.3 Key Findings

PUBLICATIONS, 2009-2013

1.79M

1.79 million articles published in 2009-2013 were considered to fall within the area of brain and neuroscience research, representing approximately 16% the world's output in this period.

PUBLICATION GROWTH, 2009-2013

3.9%

Publications in the area of brain and neuroscience research grew at an average rate of 3.9% annually, as compared to the average growth rate of 4.2% for publications across all subjects.

TOP CONTRIBUTORS

>70%

Researchers from the European countries and the US together published more than 70% of the world's brain and neuroscience research in 2013, with the top five contributors in terms of publication volume being the US, UK, China, Germany, and Japan.

PUBLICATION OUTPUT GROWTH AND ARTICLE SHARE

China

From 2009 to 2013, China showed both the largest growth in research output and world article share in brain and neuroscience research, at 11.6% and 7.5%, respectively.

FIELD-WEIGHTED CITATION IMPACT (FWCI)

1.14

Overall, in 2013, the FWCI of articles in brain and neuroscience research in the world was 1.14, meaning they were cited 14% more than the world average, across all subject areas. In contrast, EU41's output in 2013 achieved an FWCI of 1.32.

1.3.1 Research output is the highest in the US, while growth is fastest in China

Counting peer-reviewed publications is a common and easily understood measurement of research output. EU41 as a region produced the most articles in brain and neuroscience research, followed by the US. More notably, in Figure 1.4, we see that from 2009 to 2013, China significantly increased its research output in the area of brain and neuroscience research, reaching the same level of output as the UK in 2013. In 2013, China produced 34,413 articles compared to the UK's 34,518 articles. However, this may not reflect an increased focus of research in brain and neuroscience research in China, because China's overall research output has grown at a remarkable pace, as reported in a previous study.[51] Moreover, brain and neuroscience research output makes up only 8.1% of China's total research output in 2013, as compared to the UK where these articles made up 23.7% of the country's total output.

China's compound annual growth rate (CAGR)[52] for research output was also the highest at 11.6%, followed by Switzerland at 6.9%. As a group, EU41's research output grew at a rate of 3.6% from 2009 to 2013, which was faster than that of the US (2.9%) and Japan (1.5%).

1.3.2 World article share is highest for the US, and China's world article share is growing rapidly

As the total research output of the world has risen over the past decade, world article share[53] provides a normalized measure of each country's growth. As Figure 1.5 shows, most countries' article share did not show major changes over the past five years, with the exception of China. China's article share increased significantly between 2009 and 2013, reaching a level similar level to that of the UK in 2013, at 9.1% of the total number of articles produced in brain and neuroscience research.

Despite positive growth in research output for EU41, its article share declined slightly, by 0.2% per year. This indicates that the research output in brain and neuroscience research in this region is barely keeping pace with the high growth from China. Within EU41, the article share of Switzerland, Netherlands, Belgium, and Spain grew modestly, ranging between 1.6% and 2.9%. Outside of EU41, Japan and the US's article share declined, by 2.3% and 0.9% per year, respectively.

1.3.3 Focus on brain and neuroscience research is high within the Netherlands, Sweden, and the UK

Brain and neuroscience research articles accounted for approximately 16.3% of the world's total output from 2009 to 2013. In EU41, those articles made up approximately 19.0% of the region's total output during the same period. When we consider the country's research focus in this field in relation to the world, we can use the Activity Index,[54] which is defined as a country's share of its total article output across subject field(s) relative to the global share of articles in the same subject field(s). For example, from 2009 to 2013, the UK published 22.8% of its articles in brain and neuroscience research, while globally this subject field represents just 16.3% of all articles published. The Activity Index for the UK in brain and neuroscience research in this period is therefore 22.8% / 16.3% = 1.40. A value of 1.0 indicates that a country's research activity in a field corresponds exactly with the global activity in that field; an Activity Index higher than 1.0 implies a greater emphasis, while lower than 1.0 suggests a lesser focus.

As can be seen in Figure 1.6, amongst comparator countries, only France, Poland, and China's activity indices for publications in brain and neuroscience research were below that of the world, while the activity indices were the highest for the Netherlands (1.53), Sweden (1.41), and the UK (1.40).

[51] UK Department of Business Innovation and Skills. (2013) "International Comparative Performance of the UK Research Base – 2013," Retrieved online from https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2013.

[52] Compound Annual Growth Rate (CAGR) is the year-on-year constant growth rate over a specified period of time. Starting with the earliest value in any series and applying this rate for each time interval yields the amount in the final value of the series. The full formula for determining CAGR is provided in Appendix C: Glossary of Terms.

[53] World article share is the share of publications for a specific region expressed as a percentage of the total world output (see Appendix C: Glossary of Terms).

[54] Hu, X. J. and Rousseaub, R. (2009) "A comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries," Scientometrics. 81: 475-491. doi: 10.1007/s11192-008-2202-9.

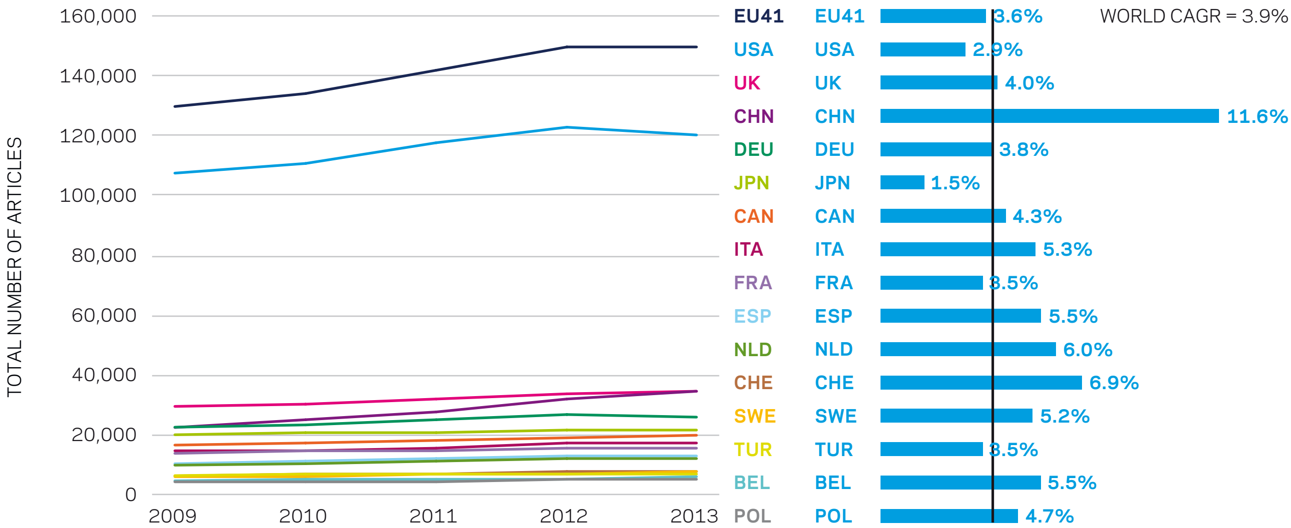


Figure 1.4 *— Overall number of articles and compound annual growth rate (CAGR) of articles for comparator countries, 2009–2013. Source: Scopus.*

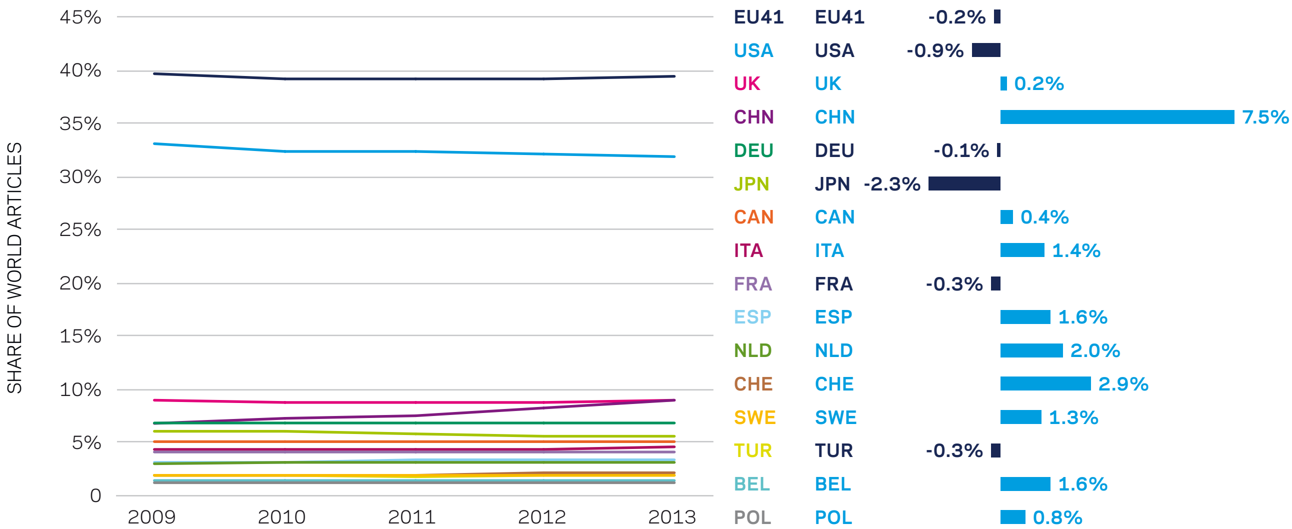


Figure 1.5 *— World article shares and compound annual growth rate (CAGR) of the article share for comparator countries, 2009–2013. Source: Scopus.*

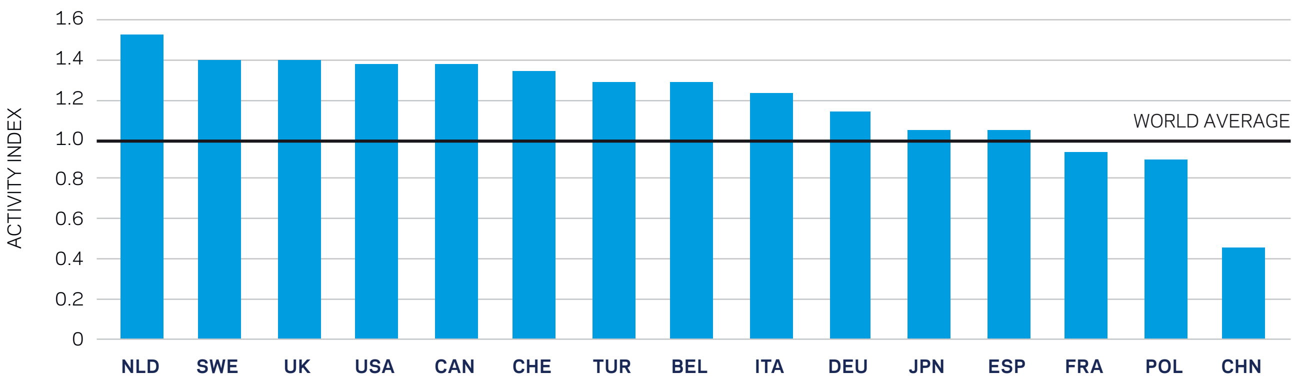


Figure 1.6 *— Activity index for comparator countries in brain and neuroscience research, 2009-2013. Source: Scopus.*

1.3.4 The Netherlands is the most productive in terms of articles produced per researcher

Research productivity at a national level refers to the capability of converting research inputs, such as R&D expenditures and human capital, into research outputs, such as articles and citations. Due to limitations in the availability of more precise data on research inputs specific to the area of brain and neuroscience research, this report utilizes the number of unique author profiles in the selected document set as a proxy for the research input, or the number of researchers in brain and neuroscience research in each comparator country.

When the number of articles produced by each country was normalized to the number of unique author profiles within the country, the data revealed Netherlands as the most productive country in terms of articles produced per researcher (see Figure 1.7). Sweden and Belgium were the next most productive countries by this definition, holding the second and third spots.

1.3.5 Research impact is evident from major European countries and the US where EU41 and the US brain and neuroscience research articles received 91% of the world citations

The number of times an article is cited by subsequently published articles is widely recognized as a proxy for the quality or importance of that article's research.[55] As Figure 1.8 shows, countries in the EU41 and the US accounted for 91% of the world's citations. Citations of brain and neuroscience research articles from the comparator countries comprised a relatively stable share of global citations, with China's citation share growing the fastest, at an average rate of 15.1% per year, reaching a citation share of 7.7%, just below that of Canada at 7.8%. Citation share of brain and neuroscience research articles from the US, however, declined at a rate of 1.7% per year since 2009, and fell below that of the EU41 region in 2013.

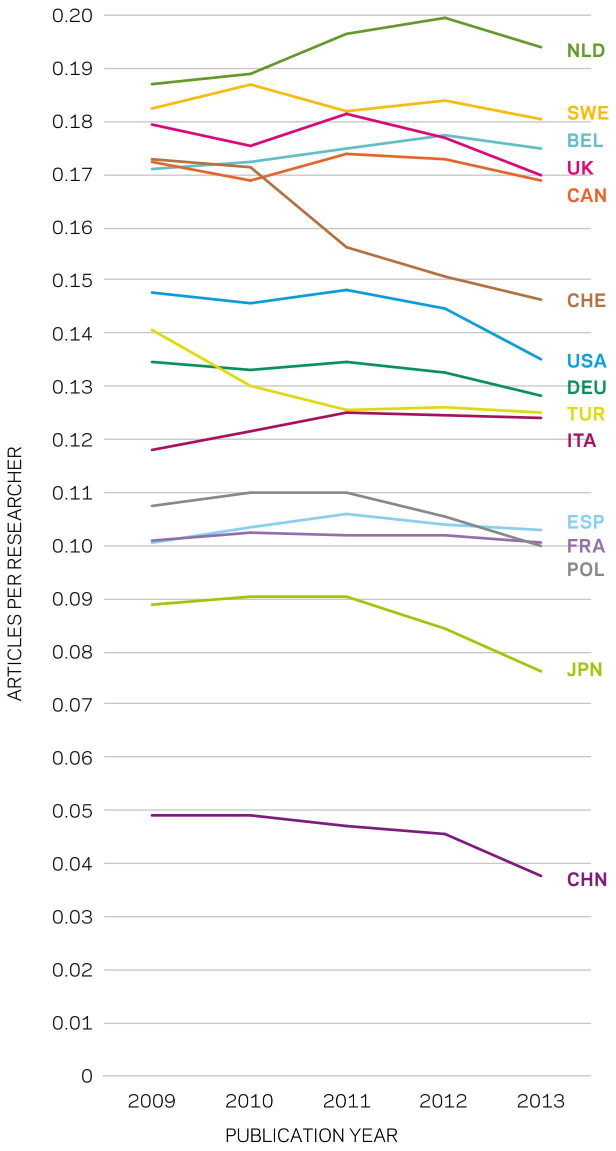


Figure 1.7 *— Articles per researcher for comparator countries, where the count of unique author profiles of articles in brain and neuroscience research serves as a proxy for the number of researchers, 2009–2013. Source: Scopus.*

[55] Davis, P. M. (2009) "Reward or persuasion? The battle to define the meaning of a citation," Learned Publishing. 22(1): 5–11. doi: 10.1087/095315108X378712.

Figure 1.8 *— World citation share across comparator countries, 2009–2013. Source: Scopus.*

1.3.6 Brain and neuroscience research articles are cited more than the global average and have a field-weighted citation impact (FWCI) greater than the global average

While citations provide an intuitive proxy for research impact, they are not comparable across different subject fields. For example, articles in the life sciences tend to be cited more often than those in mathematics. Secondly, different types of articles are cited with varying baseline frequencies; for example, review articles receive more citations than regular journal articles. A more sophisticated way of analyzing citation impact is to use field-weighted citation impact (FWCI). FWCI normalizes for differences in citation activity by subject field, article type, and publication year. This enables the comparison of citation impact across subject areas with different publication speeds and/or publication type norms. The world is indexed to an FWCI value of 1.00. An FWCI of more than 1.00 indicates that the entity's publications have been cited more often than would be expected based on the global average for similar publications.

As Table 1.5 reveals, the world FWCI of articles in brain and neuroscience research decreased slightly from 1.18 to 1.14 from 2009 to 2013, meaning that articles in brain and neuroscience research were cited 18% more than the global average in 2009, then dropped 4% to being cited 14% more often than the global average in 2013. Despite the decrease, the overall FWCI of articles in brain and neuroscience research remained higher than the world index of 1.00 for all subjects. The FWCI of EU41's articles in brain and neuroscience research increased in this period; by 2013, articles in brain and neuroscience research from EU41 were cited 32% (FWCI = 1.32) more often than the global average.

Table 1.5 *— Field-weighted citation impact (FWCI) of the EU41 region and the world for articles in brain and neuroscience research, 2009–2013. Source: Scopus.*

	2009	2010	2011	2012	2013
EU41	1.29	1.30	1.31	1.31	1.32
World	1.18	1.17	1.16	1.15	1.14

For ease of comparison, the FWCI of the comparator countries was rebased to the FWCI of the world in 2013 shown in Table 1.5, so that the FWCI of all brain and neuroscience research articles equaled 1.00. Figure 1.9 graphs the impact of brain and neuroscience research produced by the comparator countries against their respective world article share over time. Most comparator countries maintained their article share while increasing their FWCI over time. In the figure, we see that the Netherlands and Switzerland had the highest rebased FWCI in 2013 at 1.76 and 1.70, respectively. Except for the US and Turkey, all comparator countries' FWCI for brain and neuroscience research articles improved, with Poland's FWCI improving the most at an average of 5.9% per year from 2009 to 2013, reaching close to the average FWCI of brain and neuroscience research articles. The US showed a trend of decline in both article share and FWCI, but remained the country with the largest share of the world's articles in brain and neuroscience research. EU41's FWCI increased slightly from 2009 to 2013; however, its share of articles in brain and neuroscience research decreased by 0.4% during that time. In contrast, China's article share and FWCI both increased from 2009 to 2013.

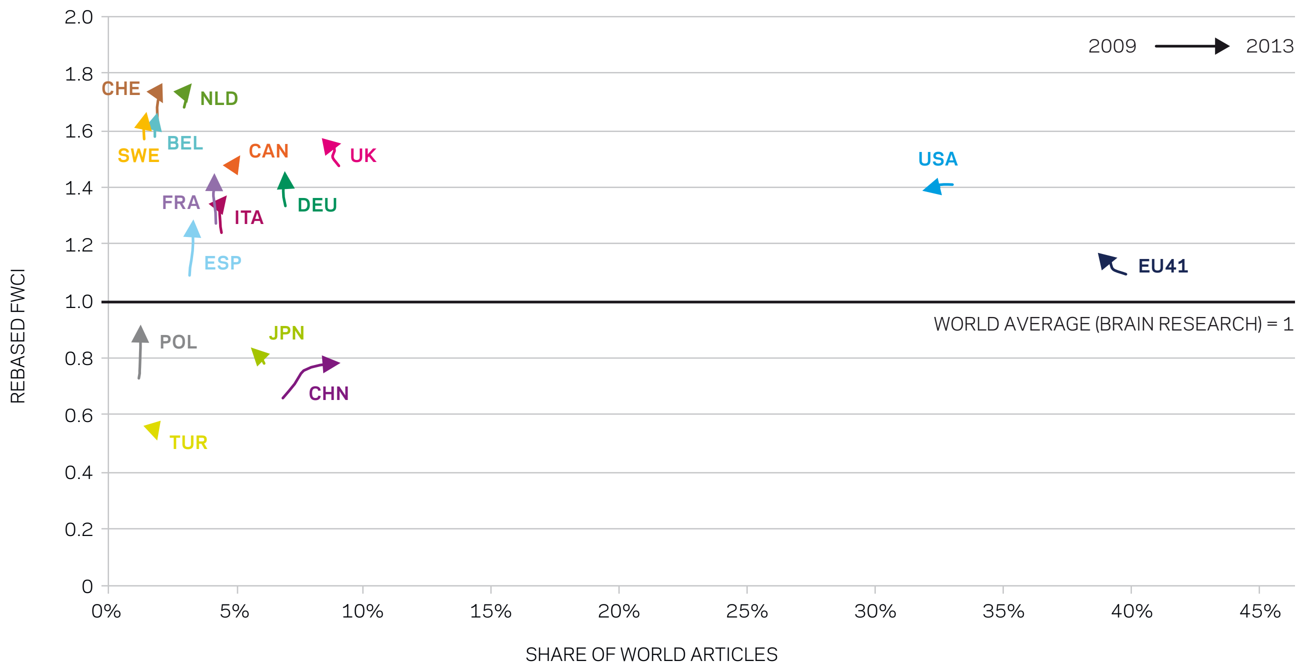


Figure 1.9 *— Rebased field-weighted citation impact (FWCI) versus world article share for brain and neuroscience research for comparator countries, 2009–2013. Source: Scopus.*

1.3.7 Approximately 1 out of 2 highly cited articles is (co-)authored by a US institution, but the proportion is dropping over time

Citations are known be unevenly distributed across articles and exhibit a strongly skewed distribution, with a small proportion of all published articles receiving the majority of the citations, a "long tail" of articles receiving the remainder, and a significant proportion of all articles never receiving a single citation.[56] Research suggests that not only is an examination of the small proportion of the most highly cited articles a robust approach to research assessment,[57] but it may also yield insights that are impossible to glean from aggregate measures alone. Similar to the methodology used to calculate FWCI, this report defines highly cited articles as those in the top 1st or 10th percentiles worldwide in citation counts relative to all articles published in the same year and subject area.

It is interesting to observe a similar skewed distribution of citations of brain and neuroscience research articles at the country level, as seen in Figure 1.10, which shows the US dominating in the percentage of the world's top 1st percentile highly cited articles and the remainder comparator countries distributed in the "long tail." For articles in brain and neuroscience research, highly cited publications from the US amounted to 63.1%[58] of the total highly cited articles in 2009 and dropped to 56.4% in 2013. Some evidence suggests that highly cited articles are mostly research articles, are typically multi-authored and often involve international collaboration, and may likely be interdisciplinary or relevant across different research fields.[59] These findings will be put into greater context once we examine the role of the US in the network of international collaboration in the next chapter.

We see a marked increase in China's share of highly cited brain and neuroscience research articles in the top 1st percentile, consistent with the increase in China's FWCI from 0.66 in 2009 to 0.78 in 2013 (see previous section). The relative output of highly cited articles in the top 1st percentile increased for most of the comparator countries, other than the US and Switzerland. Within the top 10th percentile, the distribution of highly cited articles was similar to that of the top 1st percentile, except for China occupying the top 4th position with the most highly cited articles (as compared to 8th position in Figure 1.10).

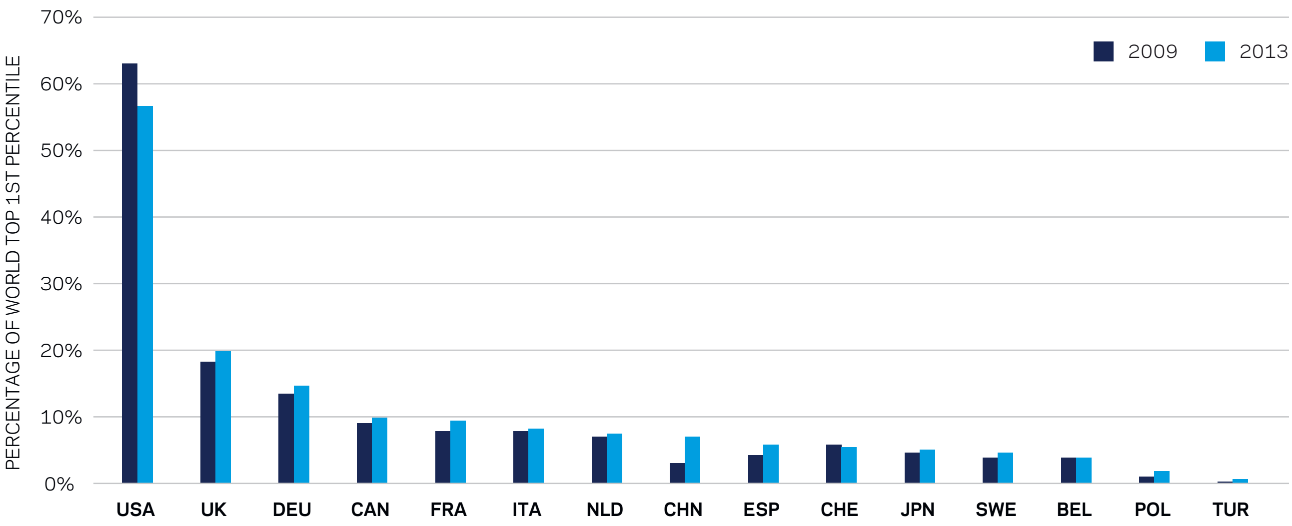


***Figure 1.10** — Percentage of total brain and neuroscience research articles with citation counts in the top 1st percentile worldwide for comparator countries, 2009 and 2013. Source: Scopus.*

[56] De Solla Price, D. J. (1965) "Networks of scientific papers," Science. 149: 510–515. doi: 10.1126/science.149.3683.510.

[57] Bornmann, L., Leydesdorff, L., and Walch-Solimena, C., et al. (2011) "Mapping excellence in the geography of science: an approach based on Scopus data," Journal of Informetrics. 5: 537–546. doi: 10.1016/j.joi.2011.05.005; Bornmann, L. and Marx, W. (2013) "How good is research really? Measuring the citation impact of publications with percentiles increases correct assessments and fair comparisons," EMBO Rep. 14: 226–230. doi: 10.1038/embor.2013.9.

[58] Note that publications fall into different collaboration types, and for international collaboration publications that have been cited, the cited publication was counted for each partner country (see Appendix B, section on article counting for more details). The next chapter will delve deeper into the analysis of research collaboration in brain and neuroscience research.

[59] Aksnes, D. W. (2003) "Characteristics of highly cited papers," Res Eval. 12: 159–170. doi: 10.3152/147154403781776645.

When the share of highly cited brain and neuroscience research articles and share of world articles were examined simultaneously, the US and EU41's dominance in both share of highly cited articles and world articles was clearly evident. The US's share of highly cited articles was larger than would be expected based on the US overall article share—the US (co-)authored 56.4% of the world's highly cited articles when its overall article share was just 31.8% in 2013. For EU41 as a region, it (co-)authored 51.5% of the world's highly cited articles when its overall article share was just 39.4% in 2013. In Figure 1.11, the US and EU41 have been excluded to show the remaining comparators more closely. Switzerland's ratio of highly cited article share to share of world articles was the highest in 2013 at 2.46, followed by Belgium at 2.44 and Sweden at 2.40. This suggests a higher degree of research excellence, as measured via citation impact, in this field for these countries and the others positioned above the line of parity in Figure 1.11.

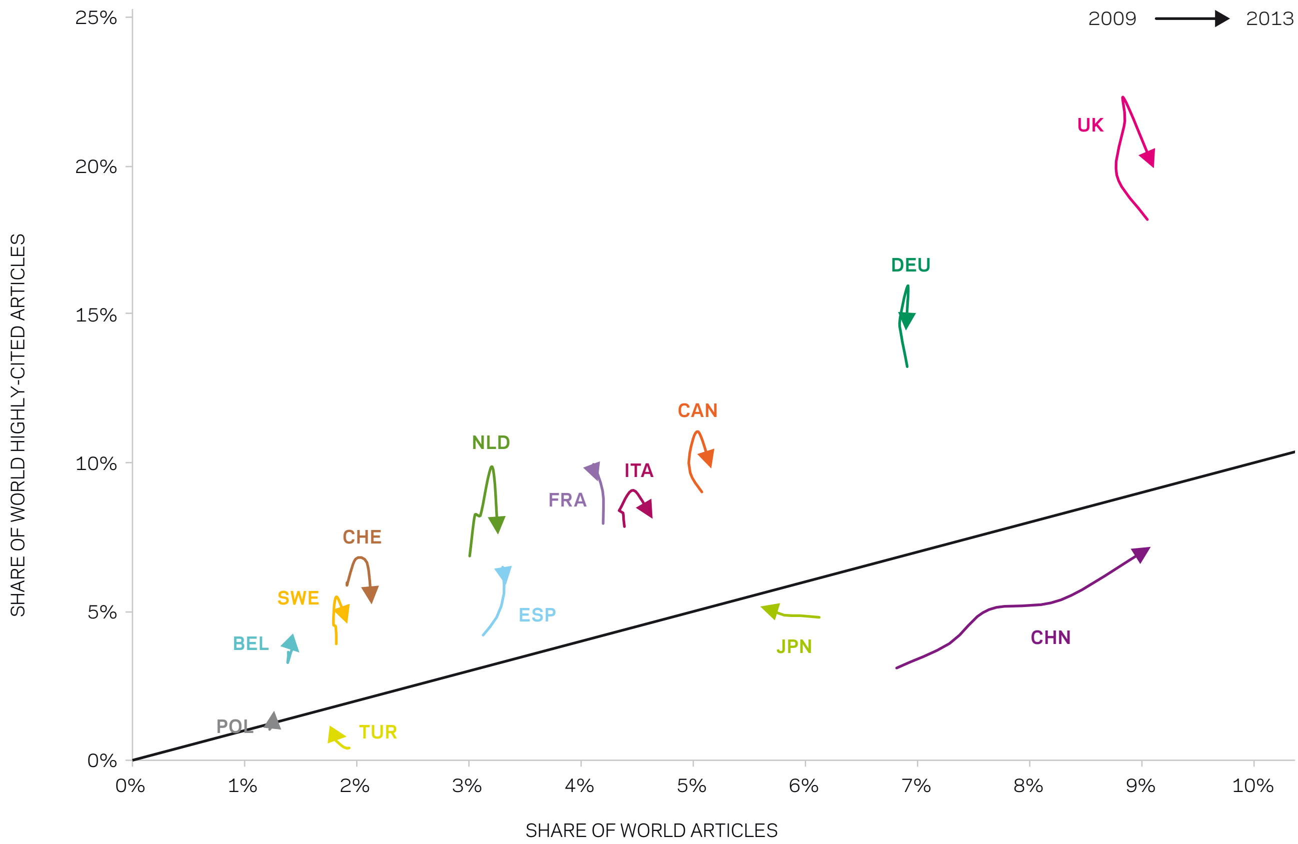


Figure 1.11 *— Share of the world's highly cited articles (top 1% of the most cited articles) versus share of world articles in brain and neuroscience research for comparator countries, 2009–2013. The beginning of the line indicates a country's share of highly cited and world articles in 2009, while the arrowhead shows its corresponding share of highly cited and world articles in 2013. For example, in 2009, China' s share of the world's highly cited articles in brain and neuroscience research was 3.1%, while it published 6.6% of the world's brain and neuroscience research articles; by 2013, China's share of the world's highly cited articles in brain and neuroscience grew to 7.2% and it published 9.1% of the world's brain and neuroscience articles. A country for which the share of global articles and the share of highly cited articles were equal would be placed on the line of parity. Source: Scopus.*

1.3.8 Article downloads as an alternative measure of impact

There is increasing interest in creating more and better indicators of the use and commercialization of research. Citations represent one pathway by which academic research utilization can be measured, but it is neither meant to nor does a good job of capturing the impact of academic research outside of academia. Moreover, measuring impact through citations is particularly difficult for recently published articles. Citation impact is by definition a lagging indicator, as the accumulation of citations takes time. After publication, articles need to first be discovered and read by relevant researchers, then those articles might influence the next wave of studies conducted and procedures implemented. For a subset of those studies, the results are written up, peer-reviewed, and published. Only then can a citation be counted toward that initial article. Moreover, citations do not necessarily capture the full extent to which an article is being used (by either the academic or corporate sectors) and may systematically understate the impact of certain types of research (clinical versus basic, for example).[60]

The number of article downloads from online platforms has emerged as an alternative metric that can be used as another proxy for research impact. When measuring downloads, one can start tracking usage immediately after the publication of an article, instead of waiting months or even years for citations to accrue. Research on publication download measurements and their implications is an emerging topic within the bibliometric community.[61]

Methodology

Since full-text journal articles reside on a variety of publisher and aggregator websites, there is no central database of download statistics available for comparative analysis. Despite this, downloads are nonetheless a useful indicator of early interest in, or the emerging importance of, research. This report used full-text article download data from Elsevier's ScienceDirect database, which provides more than 20% of the world's published journal articles in STM disciplines (the largest of any publisher), to offer an alternate perspective on how an institution's research is being used around the world. In this report, a download is defined as either downloading a PDF of an article on ScienceDirect or looking at the full-text article online on ScienceDirect, without downloading the actual PDF. Views of article abstracts are not counted. Multiple views or downloads of the same article in the same format during a user session are filtered out, in accordance with the COUNTER Code of Practice.[62] Field-weighted download impact (FWDI) is calculated from these data according to the same principles applied to the calculation of field-weighted citation impact (FWCI) (see Appendix C: Glossary of Terms for details of how FWDI is calculated).

[60] Van Eck, N. J., Waltman, L., and van Raan, A. F. J., et al. (2013) "Citation analysis may severely underestimate the impact of clinical research as compared to basic research," PLoS One. 8(4): e62395. doi:10.1371/journal.pone.0062395.

[61] Kurtz, M.J., and Bollen, J. (2012) "Usage bibliometrics," Ann Rev Information Sci Technol. 44(1) : 1-64. Retrieved online from: http://onlinelibrary.wiley.com/doi/10.1002/aris.2010.1440440108/pdf.; Moed, H. F. (2005) "Statistical relationships between downloads and citations at the level of individual documents within a single journal," J Am Soc Information Sci Technol. 56(10): 1088–1097. doi:10.1002/asi.20200.; Schloegl, C., and Gorraiz, J. (2010) "Comparison of citation and usage indicators: the case of oncology journals," Scientometrics. 82(3): 567–580. doi:10.1007/s11192-010-0172-1.; Schloegl, C., and Gorraiz, J. (2011) "Global usage versus global citation metrics: the case of pharmacology journals," J Am Soc Information Sci Technol. 62(1): 161–170. doi:10.1002/asi.21420.; Wang, X., Wang, Z., and Xu, S. (2012) "Tracing scientist's research trends realtimely," Scientometrics. 95(2): 717–729. doi:10.1007/s11192-012-0884-5.

[62] http://usagereports.elsevier.com/asp/main.aspx; http://www.projectcounter.org/code_practice.html

1.3.9 **Comparing FWCI and FWDI in 2013**

By juxtaposing FWCI and FWDI, we present two possible dimensions in which research impact may be measured. Similar to the FWCI of articles in brain and neuroscience research, the FWDI declined slightly between 2009 and 2013 for both the EU41 and the world. However, the world FWDI for brain and neuroscience research articles also fell below the world index of 1.00 in 2013, indicating that articles in brain and neuroscience research were downloaded 3% less than the global average. As Figure 1.12 shows, in 2013, most comparator countries had a higher FWCI than FWDI; the divergence among download and citation counts could be due to factors such as usage leak, citation leak, different reading and citing population, etc.[63] For China, Japan, Turkey, and Poland, however, the FWDI was higher than the FWCI, and incidentally, these four countries' rebased FWDI were also below the index of 1.00, meaning they were less downloaded on average. Possibly, articles from these countries might have been downloaded but were less likely to be cited further.

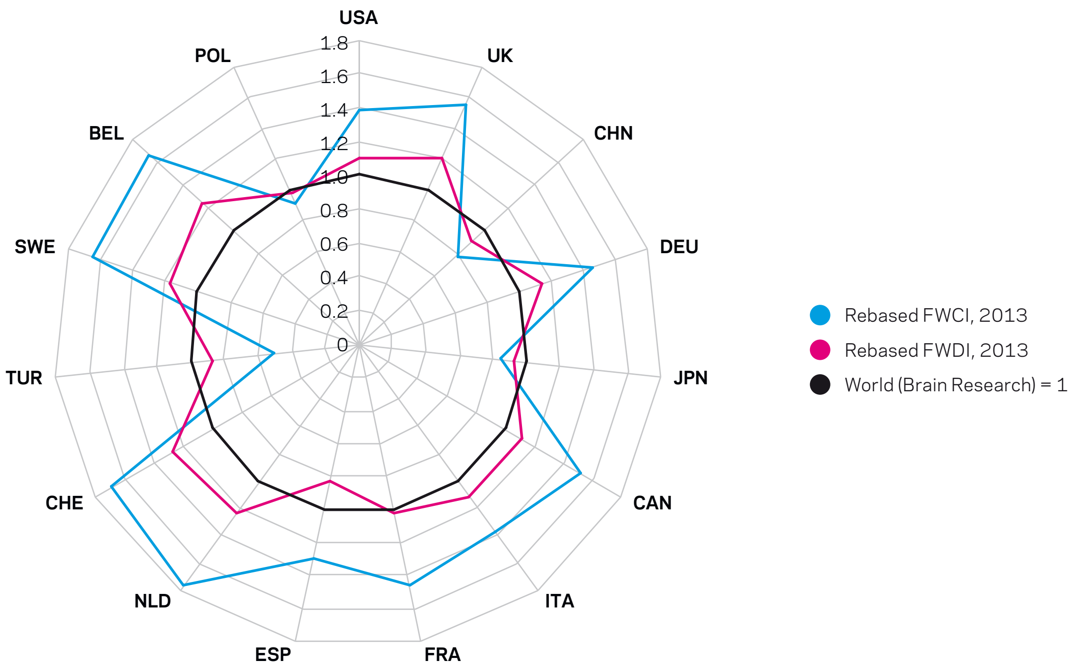


Figure 1.12 *— Rebased field-weighted citation Impact (FWCI) and field-weighted download impact (FWDI) of the comparator countries in 2013, where the FWCI and FWDI of all articles in brain and neuroscience research is indexed to 1. Source: Scopus and ScienceDirect.*

[63] Halevi, G. and Moed, H. (2014) "Usage patterns of scientific journals and their relationship with citations," In Proc. STI2014: 214–251. Retrieved online from: http://sti2014.cwts.nl/download/f-y2w2.pdf.

INTERVIEW
PROFESSOR MONICA DI LUCA

Monica Di Luca is President of the Federation of European Neuroscience Societies (FENS) and Board Member of the European Brain Council (EBC).

What do you consider to be the greatest opportunities and challenges in human brain research?

A study commissioned by the European Brain Council[64] states that Europe spends more on brain disorders than on cardiovascular diseases and cancer combined. The value cited by the study, including direct and indirect costs, equals €798 billion per year. The magnitude of these figures cannot be ignored and reflects an unquestionable level of emergency. The challenges presented by brain diseases, for which insight into basic functional mechanisms are still poorly understood, requires support for the full breadth of neuroscience research and represents the greatest opportunity and the major challenge of the coming 5 to 10 years. To face this societal emergency, we need to develop a strong network for both basic and clinical brain research. In addition, there is a need to encourage innovative and multidisciplinary approaches, and to foster and extend existing capabilities in basic, clinical, and translational research. Scientific discoveries often emerge from novel technologies, innovative sources, and novel thinking, thus making progress on all these aspects a priority. Hence, multidisciplinary networks including both fundamental research-oriented and disease-oriented scientists from different fields will need to be encouraged and recognized if new and effective therapies are to be developed in this area.

This vision can be exploited to illuminate key policy decisions, which include investment in research and development as the main instrument for increasing our understanding of the brain and for reducing the burden and cost of brain diseases. It is important for Europe not only to use existing resources in an efficient and equitable manner, but also to contribute to the development of new knowledge to improve the situation.

[64] Gustavsson, A., Svensson, M., and Jacobi, F., et al. (2011) "Cost of disorders of the brain in Europe 2010," Eur Neuropsychopharmacol. 21(10): 718–779. doi:10.1016/j.euroneuro.2011.08.008.; DiLuca, M., and Olesen, J. (2014) "The cost of brain diseases: a burden or a challenge?" Neuron. 82(6): 1205-1208. doi:10.1016/j.neuron.2014.05.044.

What do you consider to be the most important factors affecting how the field of brain research has developed in Europe in the recent past?

Brain research in Europe is a rapidly evolving field, and increasingly at the forefront of science. The complexity of understanding brain function and brain diseases brings responsibilities as well as opportunities for the neuroscience community: responsibility to develop novel tools and approaches in order to integrate and advance our understanding of the still unknown basic functions of the nervous system; opportunities to provide a better understanding of the underlying pathogenic mechanisms, and thus to generate novel therapeutic approaches for the benefit of society.

Despite these major challenges and all the efforts of the scientific community in Europe, we are still struggling with the discrepancy between the huge societal impact of brain diseases on the one hand, and the rather modest financial and time resources allocated to brain research, teaching, and the care of brain diseases on the other. Only a coordinated program to increase support for the research efforts in the field can achieve success in our ambitious endeavour, to relieve the burden of brain disorders through a better understanding of the brain. Given the targets of the Europe 2020 strategy (3% of GDP in research), both European and national funding are exceedingly important requirements for achieving this goal.

Indeed, in past years, the European Commission provided extensive support for brain research. Brain Research was considered a priority in the previous Framework Programme 7, to be endowed with the necessary, dedicated financial resources. More than €2 billion has been dedicated to brain-related research since 2007, with a yearly allocation of more than €300 million. This investment supported the foundation of a highly multidisciplinary scientific community dedicated to brain research, which reached a level of excellence and strongly requires continuity of support. It is of high value and importance, also under Horizon 2020 (H2020), to reinforce and continue this strong commitment to supporting brain research in Europe.

What do you see as the consequences of recent large-scale programs (e.g., BRAIN Initiative in the US, the Human Brain Project in Europe) on progress in neuroscience generally and how they are affecting research in individual labs, the culture of collaboration, and the questions being asked?

Generally speaking, funding of large-scale initiatives such as the Human Brain Project (HBP) may hopefully help further lift the field of neuroscience over the coming decade. However, they cannot replace the much-needed broader focus on neuroscience funding. In the European scenario, we at FENS are somewhat concerned that funding structures from the past Framework Programme have been discontinued with the start of the H2020 programme. This new approach will seriously dilute the resources available for brain research. To illustrate our concern: no dedicated financial resources for brain research have been indicated in the H2020 programme. This is a lost opportunity, considering that brain diseases will continue to represent a major and increasing societal challenge over the coming years. There is the hope that the start of influential programmes, such as the EU-FET Flagship Human Brain Project and complementary international programmes, such as the US BRAIN Initiative, will keep raising the attention of the general public and policymakers on brain research and will contribute to aligning national research agendas at national level across all European members states. This will certainly allow the intellectual capital on brain research that was seeded already in the last funding programme to flourish and move the field forward.

What are some examples of the implications of recent brain research discoveries for society?

Better understanding of aberrant behaviors that are associated with a variety of brain diseases provides direct benefits at multiple levels, both to society as well as to individuals suffering from brain diseases. These come in the form of improved insight into the circuitry and molecular alterations that influence different disease states and provide clues as to new treatment possibilities. Over the past decade, achievements at this level have been gained in particular in altered brain function related to the neurological domain in the form of much improved technologies and understanding of techniques such as deep brain stimulation, and psychiatric conditions and treatment are now benefitting from and improved understanding of complex brain functions. At the level of the patient, a better understanding of the disease state will importantly also lead to reduced stigma and improved adaptation to the often life-changing effects of brain disease.

As a federation, FENS recognizes the valuable benefits to society of brain research that directly impinge on the important disease focus. However, brain research also comes with direct societal benefits to an improved understanding of normal states of the brain. This comes in ways such as understanding the acquisition of new knowledge, e.g., how the normal brain learns reading and writing skills, as well as the brain's mechanisms to adapt to social interactions and coping with changes in life conditions that are linked to changes in society itself. Just think about the importance of improved understanding of how food intake is regulated or the regulation and importance of sleep. Brain research touches on all aspects of human life, from cradle to grave and through all life events.

Can you comment on the technologic advances—in imaging, analysis software, computing—that are emerging in tandem with basic biomedical discoveries about the brain? What are the potential applications of these technologies for the field?

The emergence of new and more advanced technologies for brain research over the past decades have greatly impacted our insight into complex brain functions and influenced the manner in which brain research is now conducted. Big technological advancements, such as optogenetics and the combination of neuroscience with nanotechnologies, represent game-changing entries into the understanding of the brain. Further, the manner in which big data management is now helping research teams understand complex interactions at a different scale has transformed how neuroscience is conducted. Increasingly, new insight comes from multidisciplinary approaches consisting of collaboration between traditional and non-traditional (neuro)scientists with diverse and complementary skill sets.

What societal or ethical issues do you think will influence brain research priorities and applications in the future? What steps do you think the field should take to resolve these issues and effect greater engagement with the public?

Brain research, maybe more than other disciplines, has strong societal and ethical implications. This is not only related to the burden imposed by brain diseases on our society, but also because brain disorders are highly stigmatized so that citizens living with a brain disease are often challenged by the stereotypes and prejudice that result from misconceptions about these illnesses. There is compelling need for fundamental research for a better understanding of brain functioning in health and disease, and to transfer rapidly our biological understanding to the clinical setting and to better explain brain functioning to the general public and particularly to patients. Collaboration with patient organizations is very important for the development of the field; they should be properly informed on the results of research projects, and involved from the beginning in all aspects of research decisions and policies. Without knowing what the patients' real needs are, how can we develop our research to achieve the best results?

In addition, we need research into the ethical implications of emerging technologies: we need cross-disciplinary work that bridges experts of different disciplines. Lack of communication between neuroscientists and other fields such as economics, sociology, or genetics, too often increases the risk of slowing down the process of correctly translating our new knowledge.

We need a more brain-aware society to deal with the implications of scientific advances as well as an adequate regulatory and legal environment to promote collaborative, trans-national research.

In conclusion, we need to have a vision of our research, which should be a multilevel analysis of the brain, from molecular and cellular, to behavioral and even cultural levels.

Thinking about the future of brain research globally, where do you think we will be in 5 and 10 years' time?

The great challenge will be to solve the great complexity of the brain. The logic behind the assembly of millions of molecular, cellular, and structural components of the nervous system, their interactions at various scales, their dynamics, their plasticity, and their physiological properties, still needs to be fully understood. The major challenge of neuroscience is to analyze and integrate the complexity inherent to the organization of the nervous system, to understand the neuronal bases of cognitive functions and behavior. This challenge overcomes all fields of science because it aims not only to understand fundamental aspects common to any field of biology, but also the most sophisticated aspects specific to our brain and of the human being in its social dimension, including self-consciousness, emotion, thinking, language, and relationships with the environment and with others. The availability of advanced technologies, of merging different disciplines, and of large collaborative networks, will help us in this endeavor to move closer to understanding our brain and the cures for brain diseases.

Is there information in the present report that you think is particularly interesting, unusual, or likely to have an effect on the development of the field looking forward?

It is particularly interesting to observe how the outcomes of neuroscience research, i.e., number of publications, evolve in the different European countries. It is important to note however, that the national funding system in Europe is highly different from country to country. This profound discrepancy strongly affects in some cases the productivity and the development of a strong neuroscience community at national level. Thus, the possibility to demonstrate how a structured funding policy affected the field in a given European country could represent a useful example for further development.

Are there any aspects of the present report that you think should be further explored in relation to Europe?

It would be certainly interesting to have an analysis of topics related to the 7th Framework Programme (FP7)-funded grants. Neuroscience profited from dedicated funds in FP7, thus a systematic analysis of areas of neuroscience funded in the last 10 years would help in understanding the development of the field and how this has provided significant societal benefits

Thinking about the future of brain research, what additional piece of information do you think is needed to assess the current situation and consider future funding and/or policy decisions?

A piece of information that is lacking in the field of neuroscience is related to the return on investment. Making an attempt to analyze the possible cost/benefit ratio of increased investment in brain research would be particularly important to demonstrate that both public and private investments in neuroscience research are highly profitable investments for society.

CHAPTER 2
COLLABORATION & CROSS-DISCIPLINARY MOBILITY

In this chapter, we focus on understanding how research impact is affected by various types of collaboration. We examine the levels of international, national, institutional, and single-author articles, visualize the network collaboration of top collaborative partners in brain and neuroscience research, and view the amount of cross-sector collaboration in key countries. We also examine the cross-disciplinary mobility of researchers as they "move" between disciplines.

2.1 **Key Findings**

INTERNATIONAL COLLABORATION OUTPUT

65.5%

Amongst the comparator countries, Switzerland had the highest share of brain and neuroscience research articles by international collaborations. Switzerland's international collaborations grew from 61.8% of its total output in 2009 to 65.5% in 2013.

INTERNATIONAL COLLABORATION IMPACT

4.81

In 2013, the field-weighted citation impact (FWCI) of Poland's internationally co-authored articles was 4.81 times of its single institution co-authored articles. In contrast, the FWCI of the US's internationally co-authored articles was 1.56 times that of its single institution co-authored articles.

ACADEMIC-CORPORATE COLLABORATIONS

Switzerland

Switzerland collaborated the most (in terms of share of country's total output) with the corporate sector in 2013, where academic-corporate articles comprised 8.7% of its total output.

ACTIVE RESEARCHERS

1.73M

The assessment of cross-disciplinary researcher mobility was based on the movement of 1.73 million active researchers in the area of brain and neuroscience research since 1996.

CROSS-DISCIPLINARY RESEARCHER MOBILITY

59.5%

Multidisciplinary researchers comprised 59.5% of the total researcher base in the area of brain and neuroscience research.

2.2 International Collaboration

As technological advances facilitate long-distance communication and low-cost travel, researchers are increasingly collaborating with international partners.[65] Moreover, past research suggests that such collaborations are quite productive.[66] Internationally co-authored articles are associated with higher field-weighted citation impact (FWCI).[67] For this report, publications are classified as single-author or into one of three mutually exclusive types of geographic collaboration based on the nature of co-authorship:[68] international, national, and institutional (see Table 2.1 for definitions of each co-authorship type).

2.2.1 International collaboration is associated with higher field-weighted citation impact for all comparators

International collaboration has been a popular topic in past studies of research performance. Figure 2.1 presents international collaborations as the relative percentage of a region's total output in brain and neuroscience research. In 2013, the international collaboration rate within brain and neuroscience research was the highest for Switzerland (65.6%), Belgium (63.1%), and Sweden (57.3%). In fact, all comparator countries' rates of international collaboration grew between 2009 and 2013, with compound annual growth rate (CAGR) ranging from 1.5% (for Switzerland) to 5.5% (for Spain). Poland, Turkey, Japan, and China were relatively less engaged in international collaborations, falling into the lower quartile of comparator countries in terms of the percentage of internationally collaborative articles. Within each comparator country for the period 2009–2013, each collaboration type had the following averages:

- → Single-authorship articles accounted for the smallest average proportion, at 5.4% of total output;
- → Institutionally co-authored articles made up on average 26.0% of total output;
- → Nationally co-authored articles made up on average 28.5% of total output;
- → Internationally co-authored articles accounted for on average 39.6% of total output.

Table 2.1 *— Definitions of different geographic collaborations, based on co-authorship, used in this report.*

Type of Collaboration	*Definition*
International	*Multi-authored research outputs where authors are affiliated with institutions in at least two different countries*
National	*Multi-authored research outputs where authors are affiliated with institutions in more than one institution but within the same country*
Institutional	*Multi-authored research outputs where all authors are affiliated with the same institution*
Single Author	*Single-authored research outputs*

[65] Pan, R. K., Kaski, K., and Fortunato, S. (2012) "World citation and collaboration networks: uncovering the role of geography in science," Scientific Reports. 2: 902. Retrieved online from: http://www.nature.com/srep/2012/121129/srep00902/full/srep00902.html.

[66] Wuchty, S., Jones, B. F. and Uzzi, B. (2007) "The increasing dominance of teams in production of knowledge," Science. 316: 1036–1039. doi: 10.1126/science.1136099.

[67] Science Europe and Elsevier. (2013) "Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility," Retrieved online from: http://www.scienceeurope.org/uploads/Public documents and speeches/SE and Elsevier Report Final.pdf; The Royal Society. (2011) "Knowledge, Networks and Nations: Global Scientific Collaboration in the 21st Century," (J. Wilson, et al, Eds.) London: The Royal Society. p. 113. Retrieved online from: http://royalsociety.org/policy/projects/knowledge-networks-nations/report/.

[68] Melin, G., and Persson, O. (1996). "Studying research collaboration using co-authorships," Scientometrics. 36(3): 363–377. doi:10.1007/BF02129600; Glänzel, W., and Schubert, A. (2004) "Analyzing Scientific Networks through Co-authorship," In: H. F. Moed (Ed.), Handbook of Quantitative Science and Technology Research. Amsterdam: Kluwer Academic Publishers. pp. 257–276.

The proportion of single-authorship articles was the most consistent amongst the comparator countries, with a range[69] of only 7.2%, as compared to international co-authorship articles, which had a range of 52.3%. With the exception of single-authorship articles, the breakdown of collaboration types differs from country to country. Figure 2.2 shows the breakdown of share of articles by co-authorship type of four countries (China, Japan, Switzerland, and the US) with highly dissimilar breakdown of co-authorship types. The figures of all the comparator countries are available in Appendix E: Collaboration Types within Comparator Countries.

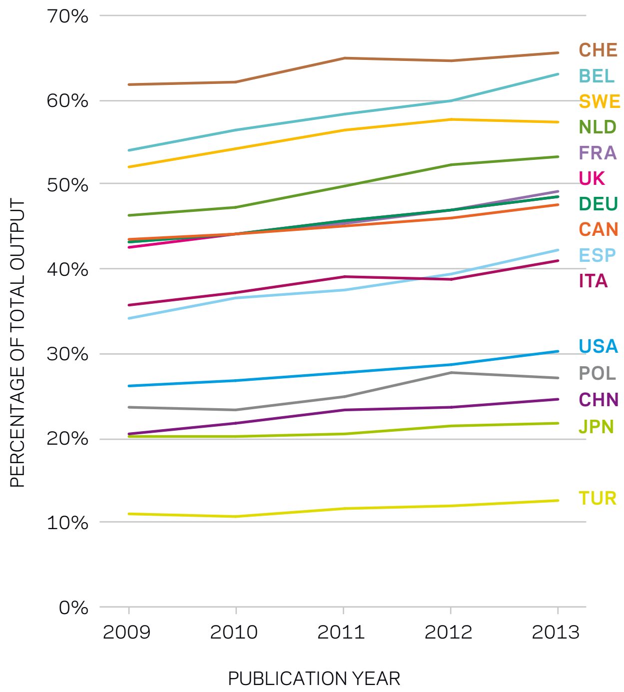
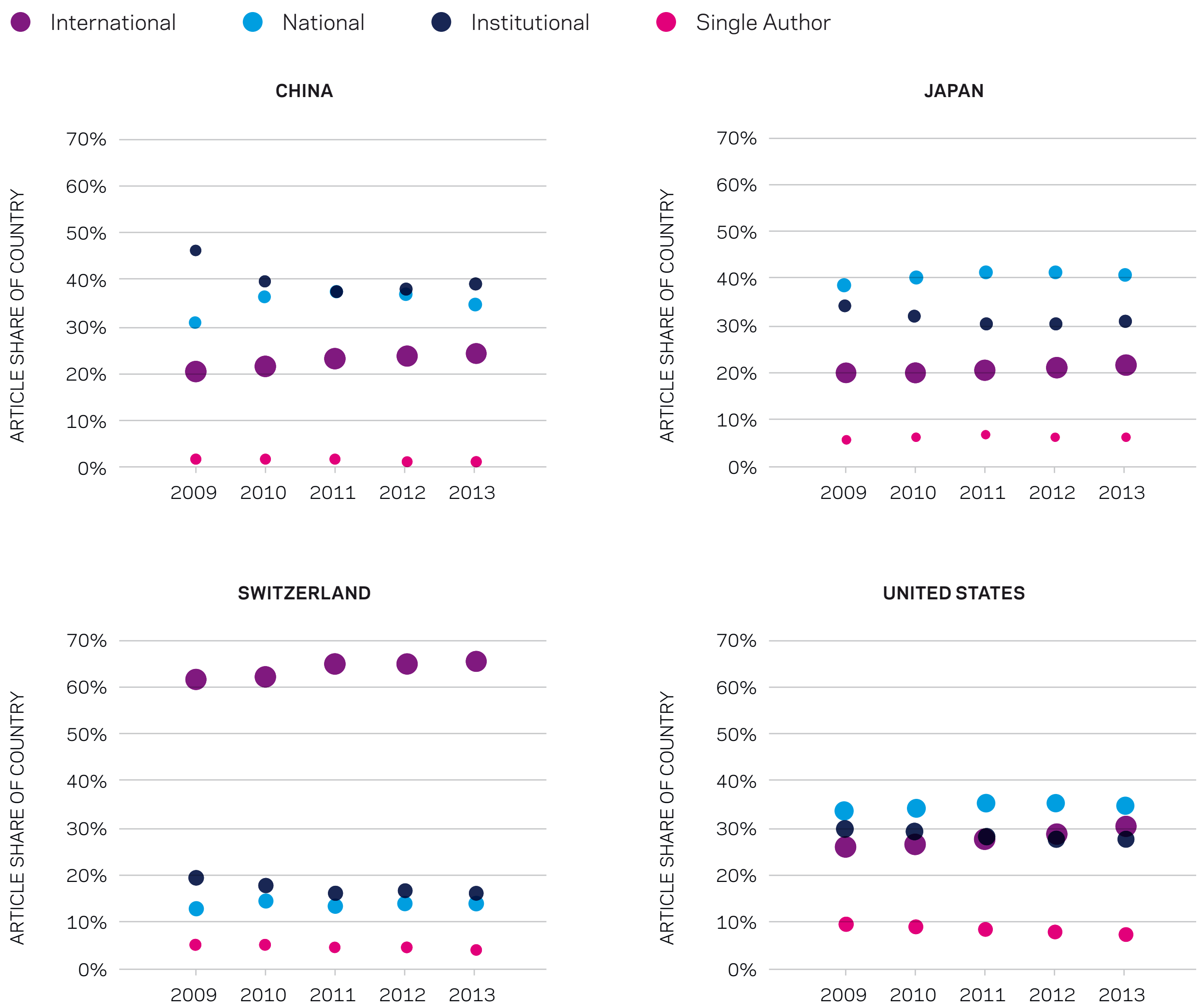


Figure 2.1 *— Level of international collaboration for comparator countries, in terms of percentage of internationally collaborated articles in brain and neuroscience research, 2009–2013. Source: Scopus.*

Figure 2.2 *— Share of brain and neuroscience research articles for the comparator countries by collaboration type, 2009–2013. Bubble size is proportional to field-weighted citation impact (FWCI). Source: Scopus.*



Not surprisingly, for the comparator countries, internationally co-authored articles were associated with high FWCI, over and above that of institutionally or nationally co-authored articles, an observation already well documented in previous reports.[70] Amongst the comparator countries in 2013, on average, internationally co-authored articles' FWCI was 2.6 times that of single-institution articles; nationally co-authored articles' FWCI was 1.1 times that of single-institution articles; and single-authorship articles' FWCI was 0.7 times that of single-institution articles. Across the comparator countries, there appears to be a relationship between the share of internationally co-authored articles and the FWCI of those articles (see Figure 2.3). However, the question of whether those countries engaging frequently in international collaboration are able to do so with typically high-impact results because they are selecting the best partners to work with, or whether countries that are likely to create high-impact research outputs are actively sought out for collaborative partnerships by other countries, cannot be answered on the basis of this observed relationship alone.

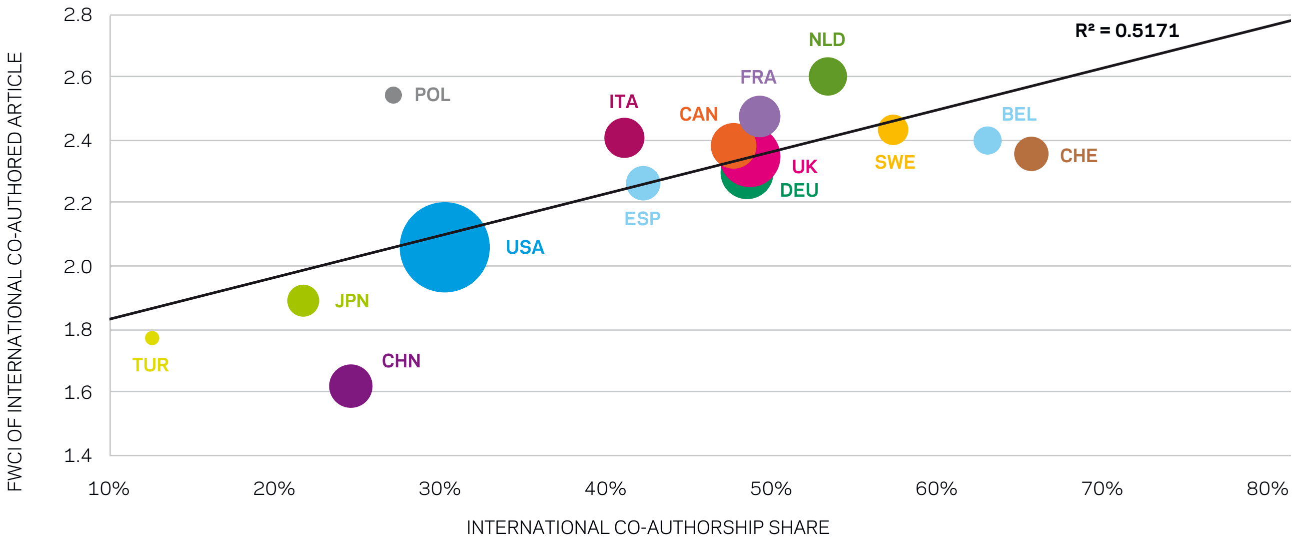


Figure 2.3 *— Correlation between international co-authorship share and FWCI of internationally co-authored articles in brain and neuroscience research for comparator countries, 2013. Size of circles is proportional to the number of international co-authored brain and neuroscience articles of the comparator country. The R^2 value (or coefficient of determination[71]) of linear regression is 0.5171, indicating that when we assume a simple linear model between international co-authorship share and the corresponding FWCI of international co-authored articles of a comparator country, the model accounts for 51.71% of the variance, suggesting a relationship between these two factors. Source: Scopus.*

2.2.2 Network of international collaboration in brain and neuroscience research

The national origin of partners in any research collaboration may have a profound effect on the outcomes of that research, from the degree of knowledge exchange of research methods and approaches, to the tangible contributions of access to research materials or equipment. The sheer volume of research outputs produced by the nations with the largest brain and neuroscience research means that international collaboration is more likely to occur between these countries, but collaborations involving less prolific nations may nevertheless be important. For example, for the US, the most frequent overall international collaborator since 2009 was China;[72] however, in the area of brain and neuroscience research, the most frequent international collaborators have been researchers from UK institutions (see Appendix F for the List of Collaboration Pairs). The US's place in the world of research is extensive, as seen by the fact that it made up 12 of the top 20 major co-authorship partners. It was the only country that had a significant amount of collaborative articles with China. However, not all collaborations were associated with a higher citation impact for both countries.

[69] Range is calculated by taking the difference between the countries with the highest and lowest proportion of that co-authorship type.

[70] UK Department of Business Innovation and Skills. (2013). "International Comparative Performance of the UK Research Base – 2013," Retrieved online from: https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2013.

[71] In statistics, the coefficient of determination indicates how well data fit a statistical model—sometimes simply as a line or curve. In this case, a simple linear model was assumed for the plot of FWCI of internationally collaborative articles in brain and neuroscience research versus the international co-authorship share of the country.

[72] UK Department of Business Innovation and Skills. (2013). "International Comparative Performance of the UK Research Base – 2013," Retrieved online from: https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2013.

As Figure 2.4 reveals, US collaborations with China and Taiwan were associated with higher citation impact for the partners (i.e., China and Taiwan), but not for the US (see Appendix F for more collaboration charts). To account for productivity within a country, we applied Salton's Index,[73] an indicator of the strength of collaborative ties between country pairs that normalizes by the volume of output of both partners (see Appendix F: List of Collaboration Pairs).

A holistic view of the top 20 collaborative pairings (in the period 2009-2013) of each comparator is represented by a network map of these connections, with each country (node) connected by lines (edges) weighted by Salton's Index and colored by the FWCI of the collaborative research outputs (see Figure 2.5). The network map shows the complex nature of research collaboration globally, with a clear "core" of well-connected countries which are typically highly-productive countries with high FWCI of their international co-authored articles. It is not surprising that most of the key comparator countries made up the core of the network and were surrounded by countries at the periphery of the network that had relatively weaker collaborative ties to their partners and typically lower FWCI for their overall international publications and also of their co-authored articles.

There were no clear sub-networks in brain and neuroscience research; however, the map revealed that the US is an important collaborative hub, and is a collaborative partner to most of the countries in the map. The US appeared to be the main broker between Asia (especially for smaller nations such as Thailand, Singapore and Korea) and the EU network. Within the EU, the network was strong and dense. A few interesting observations are further shown below:

- Russia had just three partners in the map: Finland, Lithuania, and Moldova.
- Spain was the only collaborative partner in the map for Argentina and Mexico.
- Ghana was the only African country in the map and was a partner of Albania.
- Saudi Arabia was the only Arab state in the map and was a partner of Liechtenstein.

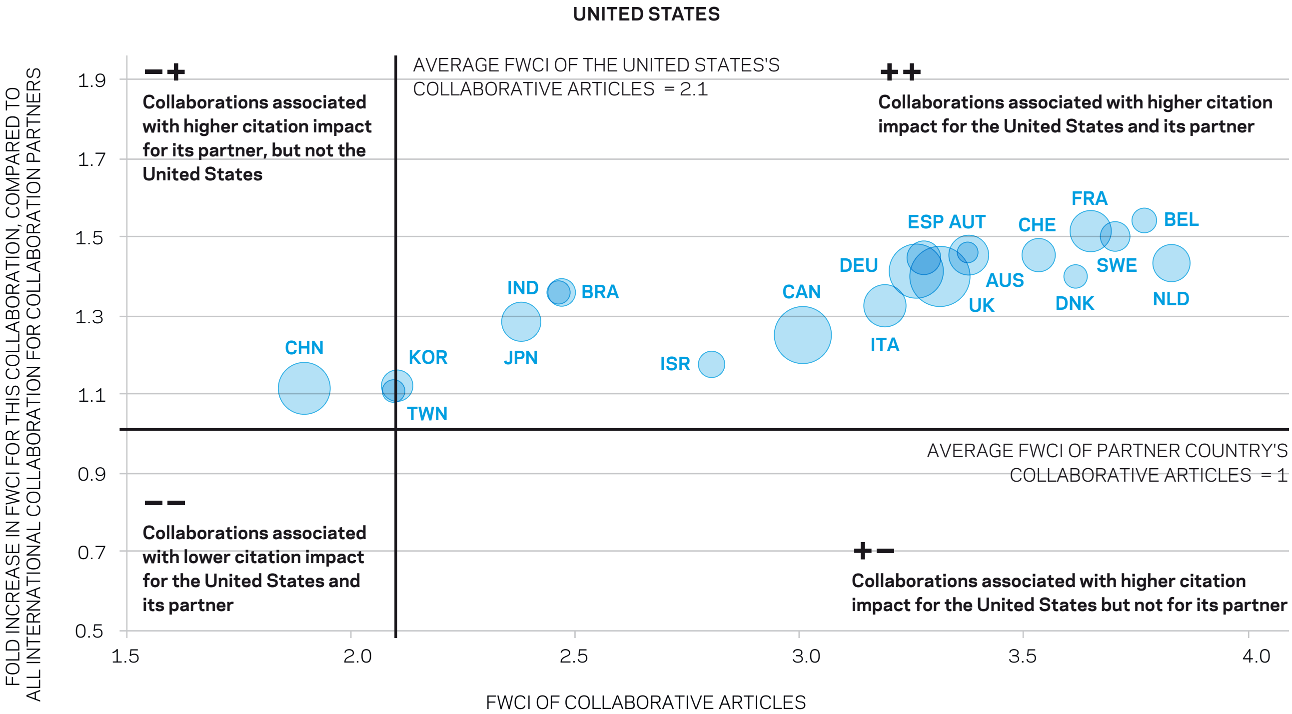


Figure 2.4 *— Citation impact of collaborative outputs in brain and neuroscience research between the US and the 20 largest collaborating countries, 2009–2013. Collaborations with China and Taiwan were associated with higher citation impact for the partners but not for the US. Source: Scopus.*

[73] Salton's Index is also known as Salton's cosine or Salton's measure for a country pair, and is calculated by dividing the number of co-authored articles by the geometric mean (square root of the product) of the total articles of the two partners—hence, it is a size-independent indicator of collaboration strength. Salton's Index is the most desirable indicator of collaboration strength when the results are to be used for visualization, as is the case here; Glänzel, W. (2001) "National characteristics in international scientific co-authorship relations," Scientometrics. 51: 69–115. doi: 10.1023/A:1010512628145.

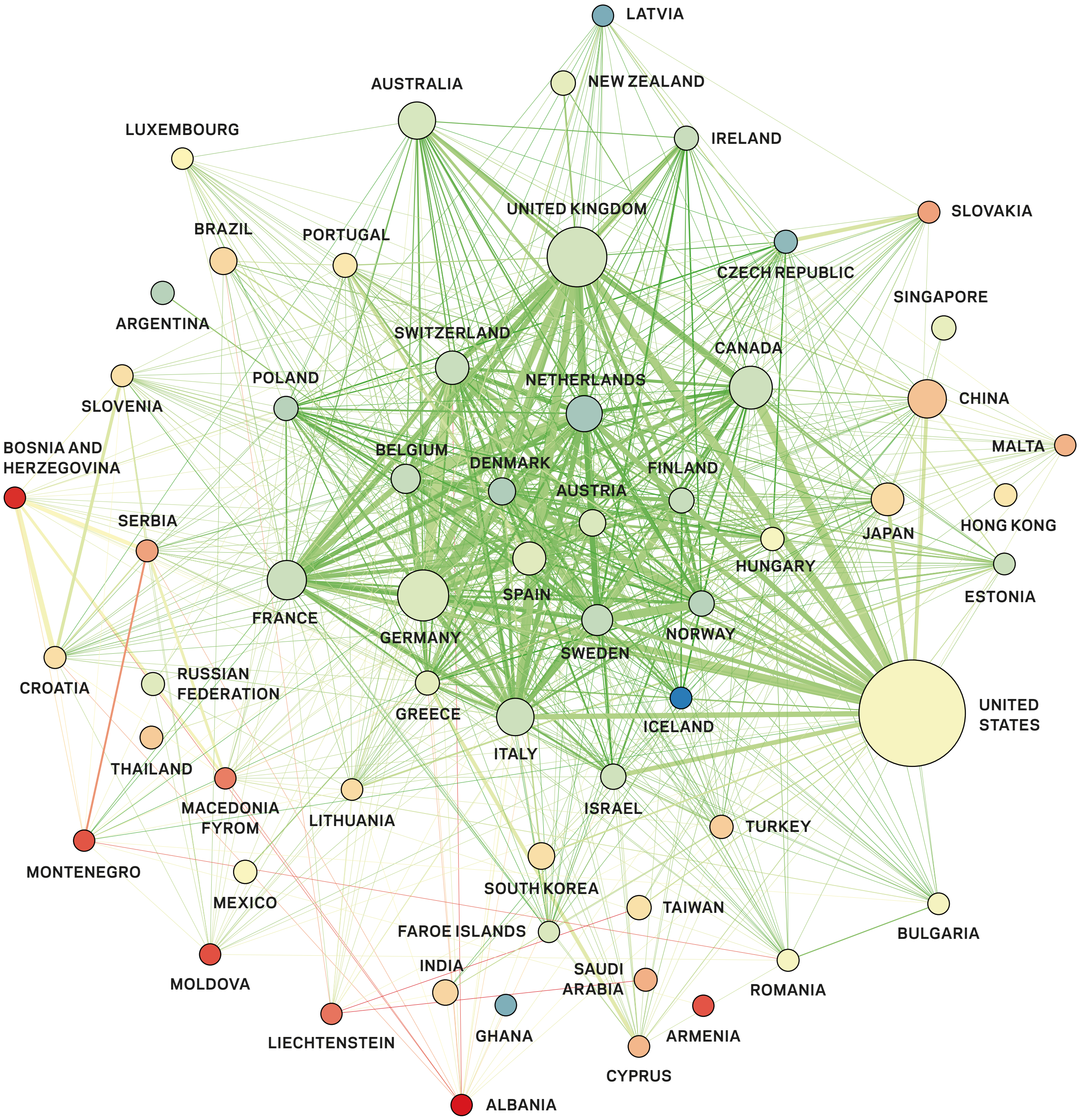


Figure 2.5 *— International collaboration network map in brain and neuroscience research, 2009–2013. Node size is proportional to overall international co-authored output for each country, with a fixed minimum size. Node color is the field-weighted citation impact (FWCI) of the overall international co-authored articles from the country (on a scale from red [minimum value amongst comparators] to yellow [average] to blue [highest amongst comparators]). Edges are weighted by Salton's Index (all edges used for layout, only country pairs with at least 1,000 co-authored articles are shown after filtering). Edge color is the FWCI of co-authored articles between each country pair (on a scale from red [below 1.0] to green [above 1.0], with amber equal to the world average [1.0]). Note that for certain countries with a high FWCI of overall international co-authored articles–such as Iceland, Latvia, and Ghana, their low volume of international co-authored output has to be taken into account when assessing their international research collaboration impact. Data were visualized with Gephi using ForceAtlas2 layout algorithm. For a full list of countries and their three letter codes, see Appendix D: Countries Included in Data Sources.*

2.3 Academic-Corporate Collaboration

Cross-sector collaboration provides another perspective of the way collaboration in brain and neuroscience research traverses the academic, corporate, government, and medical sectors. A great deal of research focuses on the benefits of complementarity between academic and commercially oriented research.[74] Measuring co-authored publications across sectors is one proxy for cross-sector collaboration. For this report, the affiliation of every co-author in an article was assigned to one of four sectors: academic (university, college, medical school, and research institute); corporate (corporate and law firm); government (government and military organization); or medical (hospital).[75] When an article was co-authored by authors with affiliations in different sectors, that article was added to the count of articles with cross-sector collaboration between those sectors. In this section, we report the rates at which authors collaborated across sectors amongst the comparator countries in brain and neuroscience research from 2009 to 2013.

Although academic-corporate collaborations accounted for, on average, the smallest proportion of each comparator country's total output in brain and neuroscience research, academic-corporate collaborations were associated with a higher FWCI as compared to other cross-sector collaboration types. In Figure 2.6, we can see that Switzerland had the highest proportion of its brain and neuroscience articles published with the corporate sector, while the US had the most brain and neuroscience academic-corporate articles published from 2009 to 2013 amongst the key countries.

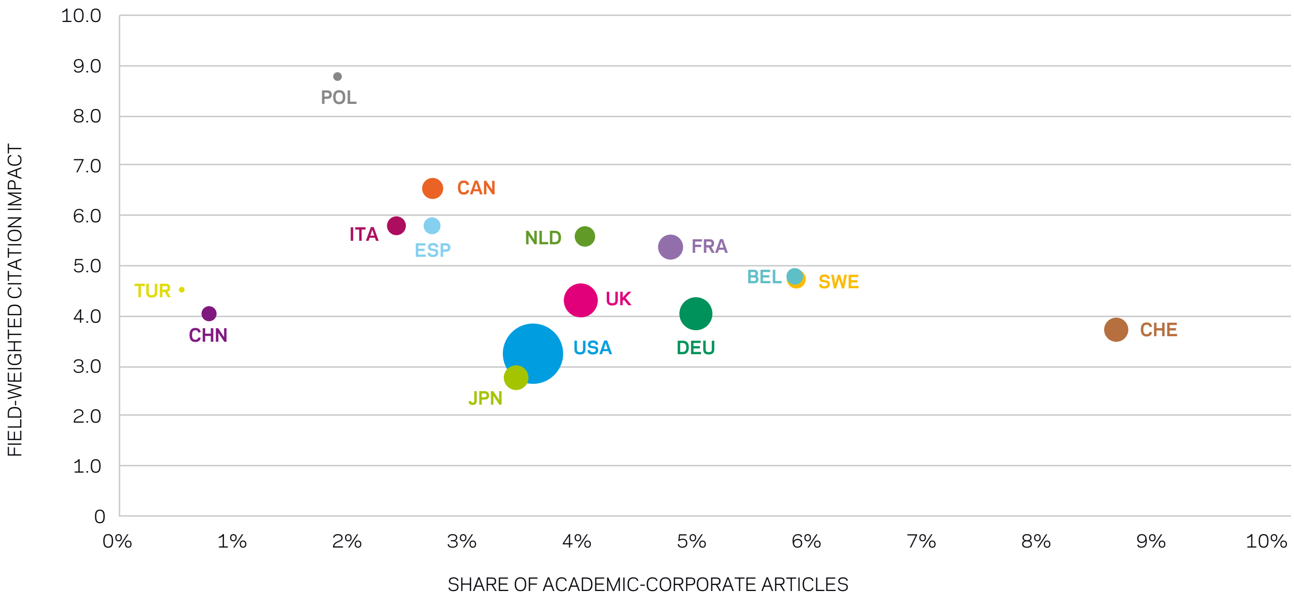


Figure 2.6 *— Field-weighted citation impact (FWCI) against the share of academic-corporate articles in brain and neuroscience research for comparator countries, 2013. Size of circles is proportional to the number of brain and neuroscience cross-sector articles of the comparator country. Source: Scopus.*

[74] Larsen, M. T. (2011) "The implications of academic enterprise for public science: an overview of the empirical evidence," Research Policy. 40(1): 6–19. doi: 10.1016/j.respol.2010.09.013.

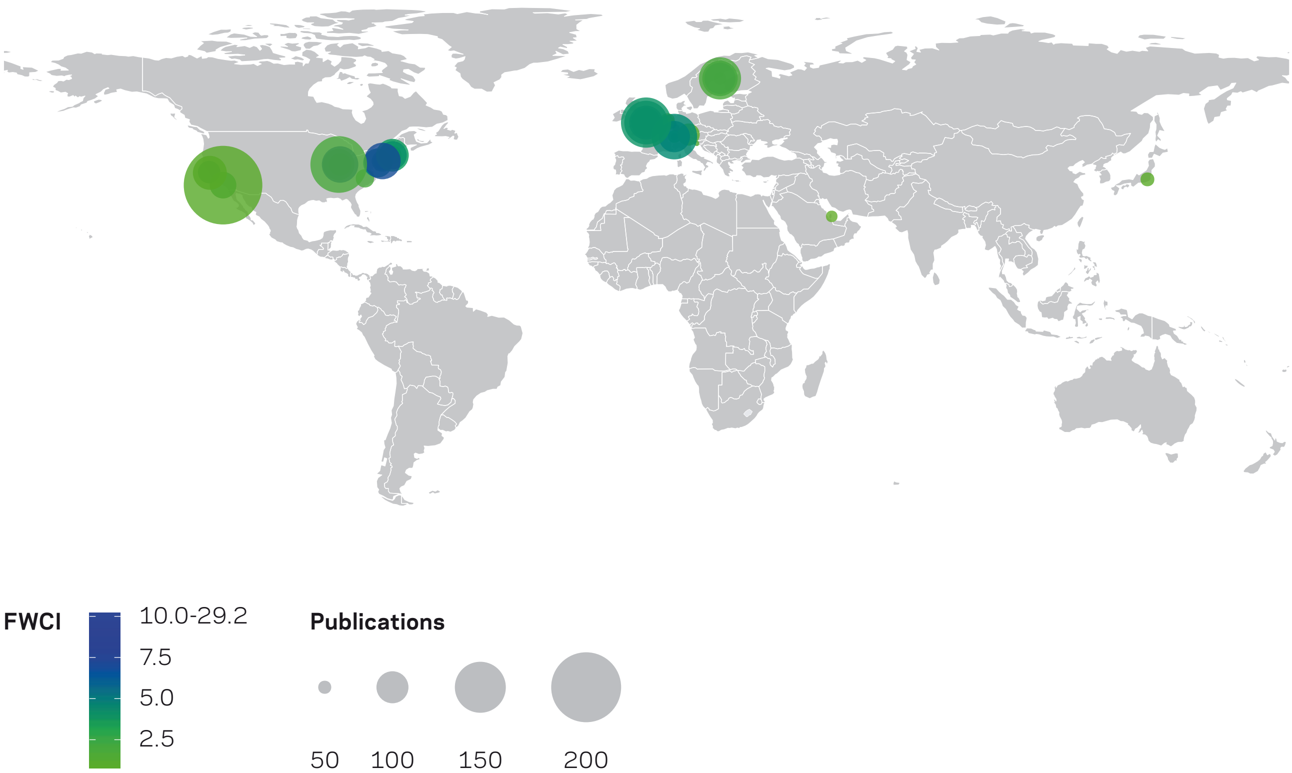
[75] Please see Appendix C: Glossary of Terms for more details on how institutions are specifically assigned to these sectors.

2.3.1 Top corporate institutions make up 48% of academic-corporate articles in brain and neuroscience research within comparator countries

To further investigate the trends in academic-corporate collaboration in brain and neuroscience research, we analyzed those corporate institutions with which the different comparator countries collaborated the most in the period 2009–2013 and the frequency and impact of those academic-corporate collaborations. Figure 2.7 displays a global view of those corporate institutions with which the comparator countries had at least 25 co-publications. The colors of the circles correspond to the field-weighted citation impact (FWCI) of the co-publications, on a scale of green (FWCI of greater than 1.0) to blue (maximum value of FWCI in academic-corporate collaborations). Certain institutions appear on the list of top collaborators for multiple countries and are represented by concentric circles of the respective collaboration type colors.

From the world map, it is clear that for brain and neuroscience research, corporate institutions with which comparator countries had collaborated the most were concentrated in a few hot spots, namely the US, the UK, and Switzerland. Unsurprisingly, these top corporate collaborators were large pharmaceutical firms such as GlaxoSmithKline, Pfizer, and Novartis. The top three corporate institutions made up 48% of all academic-corporate articles in the area of brain and neuroscience research amongst the comparator countries, highlighting the focus of knowledge production or knowledge exchange between academia and the industry in the brain and neuroscience research. In contrast, Japanese corporate institutions with which comparator countries collaborated the most were primarily technology-based companies, such as IBM Research Japan, Nippon Telegraph & Telephone, and Hitachi.

***Figure 2.7** — World map depicting top corporate institutions collaborating with the comparator countries, 2009-2013. Source: Scopus. Plotted using R/ggplot & rgal, and free vector and raster map data @ naturalearthdata.com.*



2.4 Cross-disciplinary Researcher Mobility

Discussions of researcher mobility have traditionally focused on the relative "brain drain" and "brain gain" that occurs as researchers move across geographical regions. Although these concepts are often viewed in terms of losers and winners, new research and theoretical frameworks suggest that talent mobility results in win-win situations where all parties accrue benefits, both in the short term and the long term.[76] In the context of geographical researcher mobility, many researchers may return with stronger skills and a new set of colleagues, thereby strengthening collaborative ties between the countries and institutions and improving the quality of their research. In this report, we did not examine mobility in a physical/geographical dimension, but rather from a disciplinary perspective, tracking *cross-disciplinary* (across different disciplines) researcher mobility, especially as brain and neuroscience research increasingly requires an interdisciplinary approach.[77]

While disciplinary and basic research may be cherished for its cultural merits and possible returns in the long term, most university managers and science policy makers are concerned about enhancing the direct contribution of science to the society or the economy.[78] The distinctive feature of interdisciplinary collaboration is that scientists contribute skills, techniques, or concepts originating from different disciplines in order to reach a shared goal of producing new knowledge, methodologies, or end products. Furthermore, it has been argued that interdisciplinary research has a positive impact on knowledge production and innovation, and that more comprehensive interdisciplinary knowledge transfer leads to radical innovations.[79]

The availability of comprehensive publication databases containing articles with complete author affiliation data, such as Scopus, has enabled the development of a systematic approach to analyzing researcher mobility, using the journal classification of researchers' published articles as a proxy for their discipline (see Appendix G: Subject Classification). The following section describes the individual components of our cross-disciplinary researcher mobility model, which draws on the methodology detailed in Moed et al.,[80] and is a relatively new approach to understanding the mobility of researchers across different disciplines in the area of brain and neuroscience research.

2.4.1 Measuring cross-disciplinary researcher mobility

For this report, we used Scopus author profile data to derive a history of active researchers affiliated with the respective disciplines in which the articles were published, and then assigned them to mobility classes defined by the type and duration of observed cross-disciplinary moves.

Illustrative Example of Characterizing Researcher Mobility Across Disciplines

Researchers were defined as all active researchers within the timeframe of 1996–present who had at least one article that included one or more of the concepts from the area of brain and neuroscience research (see Appendix B: Methodology and Data Sources, section on Subject Definition Methodology). In order to be considered an active researcher, a researcher must have either: a) at least one publication in the most recent five-year period (2009–2013) and more than 10 articles over the complete timeframe of the analysis (1996-present); or b) more than three articles in the last five years. Thus, even if an active researcher had not published any articles within the field of brain and neuroscience research in the last five years, if that researcher had done so earlier in his/her career, he/she would still be considered a brain and neuroscience

[76] Teferra, D. (2005) "Brain circulation: unparalleled opportunities, underlying challenges, and outmoded presumptions," J Studies Int Educ. 9(3): 229–250. doi:10.1177/1028315305277619; Tung, R. L. (2008) "Brain circulation, diaspora, and international competitiveness," Eur Manage J. 26(5): 298–304. doi:10.1016/j.emj.2008.03.005; Ciumasu, I. M. (2010) "Turning brain drain into brain networking," Science Public Policy. 37(2): 135–146.

[77] Wiesendanger, M. (2006) "Constantin von Monakow (1853-1930): a pioneer in interdisciplinary brain research and a humanist," Comptes Rendus Biologies. 329(5-6): 406–418. Retrieved online from: http://www.sciencedirect.com/science/article/pii/S1631069106000473.

[78] Etzkowitz, H., Webster, A., and Gebhardt, C., et al. (2000) "The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm," Res Policy. 29(2): 313–330. doi: 10.1016/S0048-7333(99)00069-4.

[79] Schmickl, C. and Kieser, A. (2008) "How much do specialists have to learn from each other when they jointly develop radical product innovations?" Res Policy. 37(3): 473–491. doi: 10.1016/j.respol.2007.12.001.

[80] Moed, H. F., Aisati, M., and Plume, A. (2013) "Studying scientific migration in Scopus," Scientometrics. 94(3): 929–942. doi:10.1007/s11192-012-0783-9.

researcher and included in this analysis. The model creates a proxy for researcher movement by examining changes in the researchers' associated disciplines over time. For example, consider the following publication history for Researcher A:

Year	*Publication Event*	*Discipline*
2008	*Published an article in the area of brain and neuroscience research (BNR)*	*Brain and Neuroscience Research (BNR)*
2010	*Published an article in the area of BNR*	*BNR*
2011	*Published an article in the Biochemistry, Genetics, and Molecular Biology journal category (and article does not contain any BNR concepts)*	*Biochemistry, Genetics, and Molecular Biology*
2012	*Published an article in the area of BNR*	*BNR*
2013	*Published an article in the area of medicine (and article does not contain any BNR concepts)*	*Medicine*

Researcher A published a brain and neuroscience (BNR) article in 2008, and another BNR article in 2010. However, in 2011, she published an article in the Biochemistry, Genetics, and Molecular Biology journal category, and this article did not contain any of the BNR concepts we defined in our semantic fingerprinting, hence this would count as a cross-disciplinary movement. The next article published by the researcher contained BNR concepts, and again would be counted as a cross-disciplinary movement. Finally, in 2013, the researcher published an article in the Medicine journal category but it did not contain any BNR concepts; therefore, a cross-disciplinary movement would again be registered.

Mobility Classes

For this report, the cross-disciplinary researcher mobility model grouped researchers into different categories based on common patterns of movement into and out of BNR. The model first identified single-discipline researchers—those who have published only within the area of brain and neuroscience research. Then, for the remaining set, the model mapped the movement of researchers who published in different disciplines and determined if that movement was short-term or long-term. For consistency, the model considered a researcher's "original discipline" to be the area associated with his or her first publication listed in the Scopus database. The model generated the following categories of cross-disciplinary researcher mobility.

SUBJECT DEFINITION METHODOLOGY

As described in section 1.1.4 Methodology and data sources above, a set of relevant and specific neuroscience concepts and terms, defined as a semantic fingerprint, was first extracted from articles classified under the Scopus subject area of neuroscience. This consisted 21,029 concepts that was subsequently refined to 1,207 concepts after feedback from external neuroscience experts and evaluation from analysts, forming the brain and neuroscience research semantic fingerprint. All 1.79 million articles in Scopus that fit this semantic fingerprint were extracted, and authors of these articles were identified as brain and neuroscience researchers. Subsequently, all publications of these authors, including non-brain and neuroscience articles, were analyzed to measure the cross-disciplinary researcher mobility. More details on the subject definition methodology can be found in Appendix B: Methodology and Data Sources.

Category	*Description*
Single-discipline (BNR only)	*Researchers who published only in the area of brain and neuroscience research (BNR)*
Inflow	*Researchers who came into the area of BNR*
Outflow	*Researchers who left the area of BNR*
Returnees (Inflow)	*Researchers who first published in the area of BNR, left and published outside the area of BNR for two or more years, and ultimately returned to the area of BNR*
Returnees (Outflow)	*Researchers who first published in other disciplines, came and published in the area of BNR for two or more years, and then left to publish in other disciplines*
Multidisciplinary	*Researchers who spent fewer than two years in the area of BNR at any given time; within this group, we separately analyzed those who published the majority of their work in the area of BNR (mainly BNR researchers) versus those who did not (mainly non-BNR researchers)*

Returning to the previous example, Researcher A would be classified as an outflow researcher because she originally published in the area of brain and neuroscience research and, as of 2013, last published outside of the area of brain and neuroscience research.

If Researcher A had not published in the area of medicine in 2013, she would have been classified as a Multidisciplinary researcher because she spent fewer than two years outside the area of brain and neuroscience research (2010-2011), publishing in the area and biochemistry, genetics, and molecular biology. Moreover, Researcher A would also have been classified as Multidisciplinary (mainly BNR) because three of five of her articles were in the area of brain and neuroscience research.

Indicators
For each of the mobility classes, the analysis included several indicators that characterized the publication profile of the sets of researchers:

Indicator	*Description*
Relative Productivity	*The number of papers published per year (PPY) since the first appearance of each researcher as an author in the database during the period 1996-present, relative to all researchers in that discipline for the same period. We calculated the relative productivity for an author's entire output of articles, not just those articles in that particular discipline.* *Relative productivity somewhat normalizes for career length, enabling comparisons of productivity across different mobility classes (e.g., those comprising mostly early-career researchers versus those comprising mostly senior academics). For instance, a mobility class that has a relative productivity of 1.28 produces 28% more PPY than that overall average PPY of that particular discipline.*
Relative Age	*The number of years since the first appearance of each researcher as an author in the database relative to all researchers in the discipline in the same period. We calculated relative age for the author's entire output in articles (e.g., not just those in the particular discipline).* *Since the dataset goes as far back as 1996, reporting on relative age is right-censored (e.g., the maximum "age" of a researcher in this dataset in terms of years since first publication is 17).*
FWCI	*The field-weighted citation impact (FWCI; see Appendix C: Glossary of Terms for full definition) of all articles associated with a researcher.*

2.4.2 More than half of active brain and neuroscience researchers are multidisciplinary

Based on our findings reported in Chapter 1, we know that the selected brain and neuroscience research articles from 2009 to 2013 accounted for approximately 16% of all articles published in the same period. Moreover, Table 1.3, which shows the journal categories to which the selected brain and neuroscience research articles belonged, illustrates how our definition of brain and neuroscience research encompasses a broad range of subject areas.

Figure 2.8 reveals that more than half (59.5%) of the 1.73 million active researchers were classified in the Multidisciplinary (mainly non-BNR) mobility class, and only 5.8% of the active brain and neuroscience researchers did not publish outside of the area of brain and neuroscience research in the period 1996-present (Single-discipline). A possible interpretation is that the core brain and neuroscience research is a field in constant flux, and/or that this field is highly innovative and cross-disciplinary research, including collaboration with specialists, is necessary to advance brain and neuroscience research. High mobility may also be a result of the availability of funding, since existing reward structures are often mentioned as the main barrier for inter- and transdisciplinary research.[81] However, given the limitations and uniqueness of our methodology, such a high percentage of Multidisciplinary researchers could be reflective of how researchers have been identified as brain and neuroscience researchers. For instance:

→ The breadth of disciplines resulting from our methodology may include areas where traditionally non-brain and neuroscience researchers, for instance computer scientists, naturally publish at times within brain and neuroscience research and at other times do not.

→ Identified researchers may in fact be specializing and publishing in their own discipline—for instance a materials engineer—but also publish in collaboration with brain and neuroscience researchers who require their expertise for specific research, such as in a neural engineering project.

Researchers belonging to the Multidisciplinary (mainly BNR) mobility class had the lowest relative age of 0.72 and the lowest FWCI of 1.44. At this point, we are unable to determine if this is because younger researchers tend to be more "mobile" or that Multidisciplinary researchers just tend to be younger. More broadly, sociological research on general categorization and typecasting suggest more complex relationships between how a researcher brands himself or herself early in a career (e.g., "I am definitely a neuroscientist versus someone who researches in neuroscience as well as biology").[82] Even though moving across disciplines in the short term did not result in a higher FWCI compared to other mobility classes, we expect that by combining insights from different disciplines, real progress can be made that might otherwise be inhibited if one were to stay within one discipline.

It is worth noting that the Returnee Inflow researchers (whose Scopus author data indicated that they first published in the area of BNR, subsequently published in a non-BNR area for at least two years and then published back in the area of BNR), had the highest FWCI (1.60) and were the most productive (relative productivity of 1.13) amongst all mobility classes. While the data do not prove that higher researcher mobility leads to articles with higher impact, it does demonstrate that in the area of brain and neuroscience research, interdisciplinary is indeed the most common approach.

2.4.3 Core brain and neuroscience researchers most often traverse the field of medicine

Looking deeper into the researcher mobility across disciplines, we considered active researchers in the Multidisciplinary mobility class. Figure 2.8 shows the 20 disciplines or sub-disciplines in which active brain and neuroscience researchers traversed the most (but only published for less than two years). It is not surprising that Figure 2.8 comprises mostly sub-disciplines from journal categories Medicine, Biochemistry, Genetics and Molecular Biology, Immunology, Pharmacology, and Chemistry. The interdisciplinary nature of the brain and neuroscience researcher becomes even more evident when scientific disciplines such as engineering, condensed matter physics, electrical and electronics engineering, and computer science applications appear in the top 20 disciplines as well.

[81] De Boer, Y., de Gier, A., and Verschuur, M., et al. (2006) "Building Bridges: Researchers on their Experiences with Interdisciplinary Research in the Netherlands," Retrieved online from: https://www.knaw.nl/en/actueel/publicaties/building-bridges/@@download/pdf_file/20071007.pdf.

[82] Ferguson, J.-P. and Hasan, S. (2013) "Specialization and career dynamics: evidence from the Indian Administrative Service," Admin Sci Q. 58: 233–256. doi: 10.1177/0001839213486759.; Zuckerman, E. W., Kim, T., and Ukanwa, K., et al. (2003) "Robust identities or nonentities? Typecasting in the feature-film labor market," Am J Sociol. 108(5): 1018–1074. doi: 10.1086/377518.; Dubois, P., Rochet, J. C. and Schlenker, J. M. (2014) "Productivity and mobility in academic research: evidence from mathematicians," Scientometrics. 98: 1669–1701. doi: 10.1007/s11192-013-1112-7.; Leahey, E. (2007) "Not by productivity alone: how visibility and specialization contribute to academic earnings," Am Soc Rev. 72(4): 533–561. doi: 10.1177/000312240707200403.

OUTFLOWS

18.5%

of the active brain and neuroscience researchers (about 319,000 researchers) moved from publishing in BNR to non-BNR for at least two years without returning.

FWCI of this group: 1.55
Relative Age: 1.26
Relative Productivity: 0.99

INFLOWS

16.3%

of the active brain and neuroscience researchers (about 281,000 researchers) moved from publishing in a non-BNR area to BNR for at least two years.

FWCI of this group: 1.59
Relative Age: 1.23
Relative Productivity: 1.03

SINGLE-DISCIPLINE

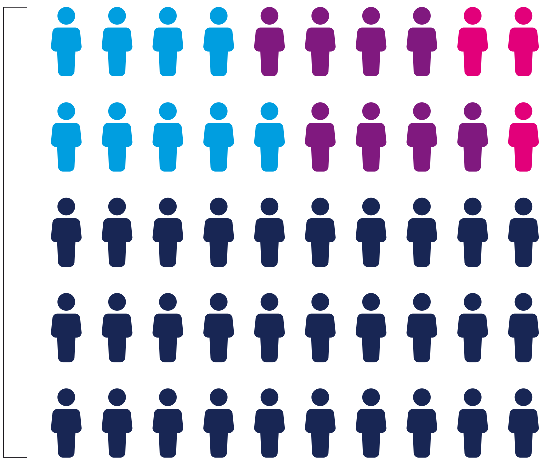
5.8%

of the active brain and neuroscience researchers (about 99,000 researchers) did not publish outside of brain and neuroscience research.

FWCI of this group: 1.55
Relative Age: 0.73
Relative Productivity: 0.60

1.73M

From 1996 onwards, there were 1.73 million active brain and neuroscience researchers.



MULTIDISCIPLINARY

59.5%

of the active brain and neuroscience researchers (about 1 million researchers) published publish across disciplines for less than two years at a time. Below are the top 20 disciplines in which they publish.

FWCI of this group: 1.48
Relative Age: 0.88
Relative Productivity: 1.02

TOP 20 DISCIPLINES

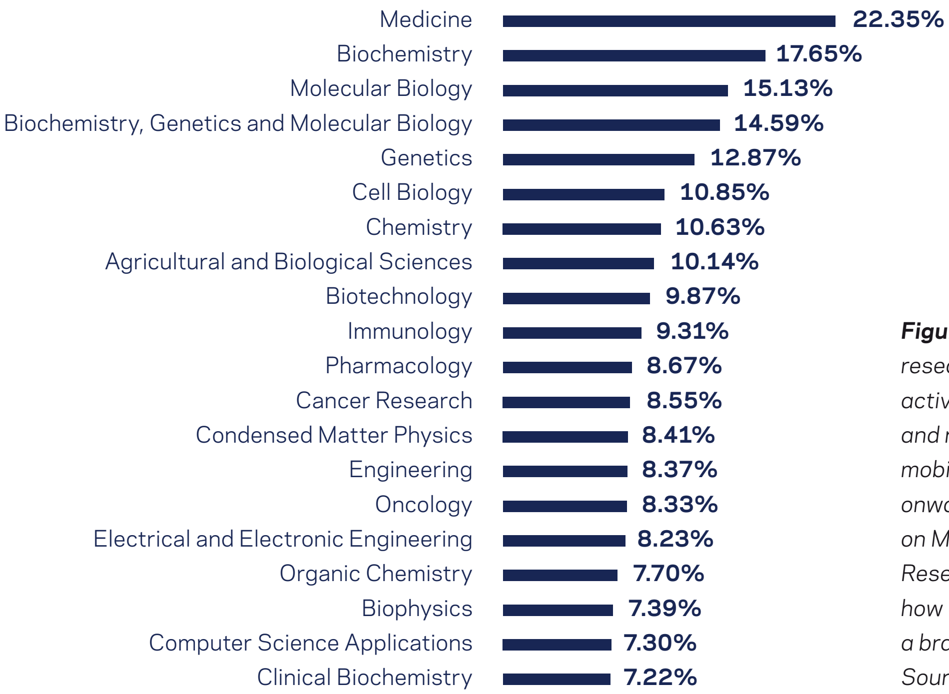


***Figure 2.8** — Cross-disciplinary researcher mobility for 1.73 million active researchers in the area of brain and neuroscience research (BNR), with mobility out of the area of BNR, 1996 onwards. Refer to Appendix B, section on Measuring Cross-disciplinary Researcher Mobility for details on how an author was determined to be a brain and neuroscience researcher. Source: Scopus.*

INTERVIEW
PROFESSOR SUSUMU TONEGAWA

Susumu Tonegawa is Director of the RIKEN Brain Science Institute (RIKEN BSI), Director of the RIKEN-MIT Center for Neural Circuit Genetics, and Picower Professor of Biology and Neuroscience, Massachusetts Institute of Technology. He was awarded the Nobel Prize in Physiology or Medicine in 1987.

What do you consider to be the greatest opportunities and challenges in human brain research?

The neuroscience field is still very young, and we understand very little about how the brain works, particularly the human brain. Right now, many of us are studying the brains of various animal models, with the hope that the basic principles we discover will also apply to the human brain—and most of them probably do. But if we want to know how the human brain works, we really need to understand the link between these basic processes and the resulting cognitive and behavioral functions that are, for the most part, unique to humans—things like consciousness, mathematics, creativity, and language. Until we understand the basis of these functions, we cannot say that we understand the human brain. This is our greatest challenge right now.

Can you comment on the technologic advances—in imaging, analysis software, computing—that are emerging in tandem with basic biomedical discoveries about the brain? What are the potential applications of these technologies for the field?

We are just starting to understand the function of specific circuits as part of the neural network in the brain. For the human brain, though, we must go beyond observing a particular neuron or circuit and what happens when it fires; we need to connect the molecular and cellular biology to the physiology: the emotion, cognition, and behavior. Currently available technology—primarily MRI—is being used at its limit of resolution as we begin linking the structures of neural circuits and pathways to brain function. I think we are due for a revolution in brain imaging technology, one that will allow us to directly measure the activity of individual neurons in the human brain and reveal the functional connections to cognition and behavior. These new technologies will not only help us answer new questions about the brain, but also revisit older questions in a more specific and rigorous way.

What do you see as the consequences of recent large-scale programs (e.g., BRAIN Initiative in the US, the Human Brain Project in Europe) on progress in neuroscience generally and how they are affecting research in individual labs, the culture of collaboration, and the questions being asked?

I am a big supporter of the BRAIN Initiative, which not only sets aside funding specifically for functional mapping of the human brain, but also gives scientists the freedom to decide what specific studies need to be done. Furthermore, from the beginning, the BRAIN Initiative actively engaged leaders in the field, set up workshops, and encouraged discussion about the key target areas for research, the available technologies and approaches, and overall project goals.

In Japan, there is tremendous political pressure to do science that is useful for society, for example, to develop a new drug for Alzheimer's disease. But I would argue that new drugs cannot be developed unless we first know how the human brain works under normal conditions, and then in the context of neurological disorders like Alzheimer's disease. As the Director of the RIKEN BSI, I continue to emphasize the importance of basic brain research, but we are not immune to outside pressure to do this kind of product-directed science. I do think that there will be significant advances in neurologic and psychiatric therapies, but not on the shortened time scale that is being proposed.

What societal or ethical issues do you think will influence brain research priorities and applications in the future? What steps do you think the field should take to resolve these issues and effect greater engagement with the public?

With every new technological advance comes the possibility that it will be misused. As scientists, we must be aware of the potential consequences of our work and try to engage with not only political leaders and policymakers, but also the lay public, to discuss the possible uses and misuses of new technology. There are many parties interested in the technologies that might emerge from human brain research: scientists want to use these technologies to understand how the brain works, whereas clinicians may be interested in using the same technologies to treat disease, and still other groups may want to know how the technologies could be applied to alter human cognition. Scientists must be sensitive to how their research might be used and make the ethical boundaries clear.

What are some examples of the implications of recent brain research discoveries for society?

There are two exciting new areas of research that may lead to more targeted treatments for neurologic or psychiatric disorders: stem cell-based tissue replacement therapy and deep brain stimulation. To achieve the latter, we must first map out in detail the brain areas and neural pathways involved in a particular disorder in animal models, then try and target the same area in human patients. Ideally, we should strive to discover treatments that are as non-invasive as possible; this will require cross-disciplinary collaboration between neuroscientists, engineers, and physicists. I would not be surprised to see non-invasive, targeted brain therapies being applied 20 to 30 years from now.

What do you consider the most important factors affecting how the field of brain research has developed in Japan in the recent past?

Japan is trying to internationalize the principal investigator (PI) workforce. For instance, RIKEN BSI has actively tried to recruit top scientists internationally. We have offered to provide internal funding so the PIs can engage in high-risk research in addition to the research supported by competitive grants, which we think is a powerful incentive in the current funding environment.

In the last five years we have also made improvements in collaborative research at RIKEN BSI. At universities, there are still significant departmental and disciplinary barriers which undermine multidisciplinary brain research. This will have to be changed if Japan is going to exert a stronger leadership role in international brain research.

Is there information in the present report that you think is particularly interesting, unusual, or likely to have an effect on the development of the field looking forward?

Information about productivity as researchers move geographically and across disciplines is going to be quite interesting. As Director of RIKEN BSI, one issue that I am particularly interested in is how to attract qualified PIs to Japan from abroad because I would like to see Japan play a larger role in international publication output. It has been changing over time, and I am curious to know what will happen in the next 10 to 20 years.

CHAPTER 3
EMERGING TRENDS & FUNDING ANALYSIS

In this chapter, we identify emerging trends in brain and neuroscience research and investigate the differences in research focus and concepts in brain and neuroscience research funding versus published brain and neuroscience research articles.

3.1 Emerging Trends

New research areas are emerging and evolving all the time. New discoveries may spur research, increase its importance, and cause a branching off into new research areas, while other research areas may lose importance over time and fade away. For example, human studies increased steadily and showed a sudden increase in prevalence, also called a burst, at the start of the Human Genome Project in 1998; this was strongly coupled by an increase in research on genes, DNA, RNA, and mouse and other animal models in the same time period.[83] Trends and correlations can give insights into how burst concepts[84] emerge from research outputs; however, the challenge remains to show trends that are obvious, real, and tangible while at the same time revealing correlations that are not so obvious and can be computed by building on big data and validated by experienced practitioners and scientists within the field.

Methodology

The burst detection algorithm from Kleinberg (2002) provides a model for the robust and efficient identification of word bursts, and allows the identification of rapid growth within categories or thesauri; it models time-dependent data using a self-operating mechanism to identify bursts in streams of words.[85] Our methodology combined the occurrence of brain and neuroscience research-related concepts through text mining and natural language processing (NLP) techniques inherent in the semantic Elsevier Fingerprint Engine (see Figure 1.2 for the overview of fingerprinting using the Elsevier Fingerprint Engine), and subsequent application of the burst method by computing the ratio of concept document share over two consecutive time periods defined by the analysts. Concept document share was defined as the share that a concept has in the overall concept annotations of a given document set. For

***Table 3.1** — Illustration of concept document share.*

Document	***Concept***
D1	C1
D1	C2
D1	C3
D2	C3
D2	C4
D2	C5
D3	C1
D3	C3
D3	C4

example, if a document set contains three documents (D1, D2, D3) having three concept annotations each, and there are a total of 9 concepts in the document set, the concept share for concept C1 is therefore 2/9 (Table 3.1).

Of the brain and neuroscience research document set that was selected for analysis (see section 1.1.5 resulting dataset for analysis), the frequency at which each concept occurred (document count) per year was computed. The relative document occurrence[86] of the concept per year was also computed, along with the relative concept occurrence[87] per year. Burst concepts were then calculated by:

- → Computing the concept document share CFt1 over a period of time t1, defined as a number of years.
- → Computing the concept document share CFt2 over a period of time t2, defined as a number of years, such that t2 starts right after t1.
- → Computing CFt2/ CFt1: the ratio between the share in the new period and the previous period. The larger the ratio, the more dramatically the concept's prominence has increased.

[83] Mane, K. K. and Börner, K. (2004) "Mapping topics and topic bursts in PNAS," Proc Natl Acad Sci USA. 101(suppl 1): 5287–5290. doi: 10.1073/pnas.0307626100.

[84] Concepts are the basic units that represent a meaning. In the Elsevier Fingerprinting process, a variety of Natural Language Processing (NLP) techniques are applied to mine the text of scientific documents such as publication abstracts, funding announcements and awards, project summaries, patents, proposals, applications or other sources. Key concepts that define the text are identified in thesauri spanning all the major disciplines. The Elsevier Fingerprint Engine creates an index of weighted terms that defines the text, known as a Fingerprint. See more at: http://www.elsevier.com/online-tools/research-intelligence/products-and-services/elsevier-fingerprint-engine.

[85] Kleinberg, J. (2002) "Bursty and hierarchical structure in streams," Proceedings of the Eighth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining - KDD '02. New York, New York, USA: ACM Press, p. 91. doi: 10.1145/775060.775061.; Small, H., Boyack, K. W., and Klavans, R. (2014) "Identifying emerging topics in science and technology," Res Policy. 43(8): 1450–1467. doi: 10.1016/j.respol.2014.02.005.

[86] Relative document occurrence per year was computed by dividing the frequency of a concept by the total number of documents in which the concept appeared in the selected document set.

[87] Relative concept occurrence per year was computed by dividing the frequency of a concept by the total number of concepts in the selected document set.

3.1.1 Emerging trends in brain and neuroscience research

When the method was applied to two five-year ranges, 2003–2008 and 2009–2013, the overall top 10 emerging trends that surfaced were:

→ High-Throughput Nucleotide Sequencing
→ Protein Multimerization
→ Molecular Targeted Therapy
→ Electrophysiological Phenomena
→ Molecular Docking Simulation
→ Sirtuin 1
→ Gene Knockdown Techniques
→ TOR Serine-Threonine Kinases
→ Genome-Wide Association Study
→ GPI-Linked Proteins

As shown in Table 3.2, we examined the top 10 emerging trends broken down by the frequency with which each burst concept occurred in 2009–2013, giving us bursts of varying magnitude. From the table, we can see that six of the top 10 overall burst concepts occurred between 1,001–5,000 times in 2009–2013. Burst concepts of smaller magnitudes included both broad and more specific brain and neuroscience terms (e.g., Purinergic P2X Receptor Antagonists, Anti-N-Methyl-D-Aspartate Receptor Encephalitis). Concepts identified as emerging that occurred more than 5,000 times are not indicated in the table, but tended to include more general terms such as "Genome-Wide Association Study," "Young Adult," "Nanoparticles," etc.

***Table 3.2** — Top 10 burst concepts obtained by contrasting two five-year ranges, 2003–2008 and 2009–2013, split by the frequency with which the concepts occurred in 2009–2013, sorted by decreasing prominence. Figures in parentheses are the frequency at which the concepts occurred in 2009–2013. In bold are the concepts that appeared in the overall top 10 emerging trends. Source: Scopus.*

Occurred fewer than 250 times in 2009–2013	***Occurred 251-500 times in 2009–2013***	***Occurred 501–750 times in 2009–2013***	***Occurred 751–1,000 times in 2009–2013***	***Occurred 1,001–5,000 times in 2009–2013***
Remote Sensing Technology (221)	Long Noncoding RNA (345)	**Molecular Docking Simulation (708)**	Psychology Biofeedback (844)	**High-throughput Nucleotide Sequencing (1,265)**
Prescription Drug Misuse (214)	Magnetite Nanoparticles (384)	**Sirtuin 1 (599)**	DNA Copy Number Variations (919)	**Protein Multimerization (3,055)**
Cell-derived Microparticles (209)	Mitochondrial Degradation (330)	**GPI-linked Proteins (588)**	Self-Assessment (936)	**Molecular Targeted Therapy (2,554)**
Purinergic P2X Receptor Antagonists (167)	Early Medical Intervention (307)	Monoclonal, Murine-derived Antibodies (707)	Psychological Resilience (899)	**Electrophysiological Phenomena (1,903)**
Anti-N-Methyl-D-Aspartate Receptor Encephalitis (238)	Corneal Wavefront Aberration (358)	Pharmaceutical Societies (651)	129 Strain Mice (859)	**Gene Knockdown Techniques (4,480)**
Chemical Precipitation (202)	CLOCK Proteins (432)	Adrenergic beta-2 Receptor Agonists (732)	Vertical Infectious Disease Transmission (834)	**TOR Serine-Threonine Kinases (1,656)**
Vascular Grafting (136)	Electrophysiological Processes (459)	Physicochemical Phenomena (535)	Social Media (823)	H1N1 Subtype Influenza A Virus (1,623)
Mucin 5AC (196)	Mechanical Phenomena (302)	Opiate Substitution Treatment (698)	Olfactory Perception (856)	Monoclonal, Humanized Antibodies (2,716)
Respiratory Physiological Processes (173)	Genotyping Techniques (327)	Gene Knock-In Techniques (687)	Small Untranslated RNA (797)	Biological Evolution (4,109)
Conductometry (199)	Optical Phenomena (310)	Adrenergic alpha-1 Receptor Antagonists (543)	X-Ray Microtomography (766)	Induced Pluripotent Stem Cells (1,572)

To identify the emerging trends in a particular year, the same method was applied to the five-year range 2003–2008 and each year within the 2009-2013 range (i.e., 2009, 2010, 2011, 2012, and 2013). Table 3.3 shows the concepts that became significantly more prominent in 2009, 2010, 2011, 2012, or 2013, when compared to the period 2003–2008.

Most of the concepts identified were broad and related to methods (e.g., High-throughput Nucleotide Sequencing, Molecular Targeted Therapy). Specific brain and neuroscience terms (e.g., Sirtuin1, TOR Serine-Threonine Kinases, NAV1.5 Voltage-Gated Sodium Channel, Connectome, Adrenergic beta-1 Receptor Antagonists) were also considered emerging trends, signaling a burst, or rapid growth, related to research in brain diseases and drug development. In particular, Molecular Docking Simulation is the only concept that consistently emerged as the most prominent concept in two consecutive years—2012 and 2013—showing a sustained interest in the computer simulation technique used to model interaction between two molecules.

Table 3.3 *— Emerging trends of a particular year, computed by contrasting the period 2003–2008 and the years 2009, 2010, 2011, 2012, and 2013, sorted by decreasing prominence. Figures in parentheses are the frequency at which the concepts occurred in the year stated in the corresponding column header. Source: Scopus.*

2009	2010	2011	2012	2013
Protein Multimerization (484)	H1N1 Subtype Influenza A Virus (408)	Molecular Targeted Therapy (777)	Molecular Docking Simulation (218)	Molecular Docking Simulation (415)
Electrophysiological Phenomena (232)	High-Throughput Nucleotide Sequencing (114)	Adrenergic beta-2 Receptor Agonists (247)	NAV1.5 Voltage-Gated Sodium Channel (63)	Animal Distribution (318)
Biocatalysis (180)	Nurse's Practice Patterns (49)	GPI-Linked Proteins (176)	Genotyping Techniques (155)	Long Noncoding RNA (166)
Mathematical Concepts (140)	Adrenergic beta-1 Receptor Antagonists (49)	Biological Evolution (1250)	Monoclonal, Humanized Antibodies (1,144)	Commerce (11,090)
Gene Knockdown Techniques (689)	Molecular Targeted Therapy (224)	Brain Waves (390)	LIM-Homeodomain Proteins (72)	Connectome (233)

3.1.2 Top concepts in different semantic groups

By categorizing the concepts into high-level semantic groups[88] (based on the semantic types that have been assigned to them under the Unified Medical Language System®[89] [UMLS]), we were able to discern more information about the focus of brain and neuroscience research in recent years. Here, each concept was ranked by the term frequency-inverse document frequency (tf-idf)[90] of the concept in each document it appeared, where the tf-idf value reflects the relevance and importance of the concept in the document. The top three concepts per document were selected and then the top concepts were obtained based on the sum of tf-idf of that concept in the entire document set.

Table 3.4 shows the top concepts by the semantic group that occurred in brain and neuroscience research articles from Scopus between 2008 and 2013. The top concepts were mostly in the "Disorders" semantic group, for instance, "Stroke," "Depression," "Neoplasms," and "Alzheimer Disease." In the "Activities & Behaviors" semantic group in brain and neuroscience research, the most prominent concepts were related to "Exercise," "Suicide," and "Motor Activity." Interestingly, within the "Anatomy" semantic group, the concept "Eye" was ranked higher than concepts such as "Neurons" and "Brain," although in terms of frequency, the concept "Brain" appeared more often than either "Eye" or "Neurons." Under the "Chemicals & Drugs" semantic group, research on "Cocaine" appeared as one of the top concepts. We will see in the next section that this is also an area of research focus from the funders' perspective.

***Table 3.4** — Top 10 concepts that occurred in brain and neuroscience research articles from Scopus between 2008 and 2013, based on the semantic groups to which they belong, sorted by the sum of term frequency-inverse document frequency (tf-idf) of the concepts in the document set. Figures in parentheses are the frequency with which the concepts occurred in the set of brain and neuroscience research articles from Scopus between 2008 and 2013. Source: Scopus.*

Activities & Behaviors	Anatomy	Chemicals & Drugs	Disorders	Genes & Molecular Sequences
Exercise (12,473)	Eye (14,836)	Proteins (12,255)	Stroke (21,404)	Single Nucleotide Polymorphism (4,007)
Suicide (6,106)	Neurons (14,388)	Glucose (7,423)	Depression (21,668)	Alleles (3,248)
Motor Activity (6,454)	Cells (15,167)	Food (8,477)	Neoplasms (25,047)	Genome (2,742)
Speech (8,055)	Muscles (10,758)	Alcohols (6,396)	Alzheimer Disease (14,522)	Quantitative Trait Loci (590)
Behavior (11,274)	Stem Cells (7,034)	Insulin (6,021)	Pain (16,719)	Major Histocompatibility Complex (450)
Smoking (4,667)	Brain (15,980)	MicroRNAs (4,180)	Schizophrenia (13,752)	Homeobox Genes (449)
Costs and Cost Analysis (6,437)	T-Lymphocytes (6,261)	Pharmaceutical Preparations (10,822)	Parkinson Disease (11,366)	Catalytic Domain (811)
Residence Characteristics (7,277)	Bone and Bones (7,257)	Peptides (6,718)	Wounds and Injuries (13,414)	Transcriptome (777)
Walking (5,517)	Spermatozoa (3,944)	Acids (5,225)	Syndrome (13,258)	Transgenes (513)
Work (7,139)	Face (5,974)	Cocaine (3,153)	Multiple Sclerosis (9,275)	Oncogenes (394)

[88] Semantic Groups - A small set of groups into which all semantic types are aggregated. Semantic groups provide a very broad view of Metathesaurus concepts through their assigned semantic types. Semantic groups are not included in the UMLS distribution but can be accessed through the Semantic Network Website [http://semanticnetwork.nlm.nih.gov/SemGroups/].

[89] The UMLS, or Unified Medical Language System, is a set of files and software that brings together many health and biomedical vocabularies and standards to enable interoperability between computer systems. Retrieved from http://www.nlm.nih.gov/research/umls/quickstart.html.

[90] The tf-idf value increases proportionally with the number of times a concept appears in the document, but is offset by the frequency of the concept in the document set, which helps to control for the fact that some concepts are generally more common than others. Adapted from Wikipedia http://en.wikipedia.org/wiki/Tf%E2%80%93idf.

3.2 Analysis of Funded Grant Awards

In this section, we turn our focus to a key driving force behind brain and neuroscience research—the funding. An overview of the state of brain and neuroscience research funding has been provided in section 1.1 of this report, where global initiatives and efforts in brain and neuroscience were summarized. In general, we expect that in an innovation system, the availability of funding will spur research, and that research programs and grants exist as important instruments to steer research direction at a national or even international level.[91] Here, we apply a similar methodology as in the previous section to detect emerging trends, this time to the funded grant awards for brain and neuroscience research by the US National Institutes of Health (NIH) and the EU European Commission (EC), where the most complete funded grant data are available and where the entirety of projects have a global reach through extensive research collaborations. We investigated the difference in the dominance of concepts in the research areas policy makers have incentivized and catalyzed (as described in funded projects' abstracts and titles), versus the research concepts evident in brain and neuroscience research articles from Scopus (abstracts, titles, and keywords). Are there any areas in which a great deal of research is conducted, but which may not be as well represented in research supported from grants? And alternatively, are there any areas of emphasis, as seen from awarded projects, which are not published in extensively?

Methodology

To analyze funding in brain and neuroscience research, first, the semantic fingerprint of each document set below was extracted using the Elsevier Fingerprint Engine (refer to Figure 1.2). Then, the resulting fingerprints were compared with one another, where:

Set A
2,084,648 brain and neuroscience research articles from Scopus (2008-2013)

Set B
59,637 publications produced by the recipients of funded grant awards related to brain and neuroscience research from the NIH Research Portfolio Online Reporting Tools (RePORTER) (2008 onwards)[92]

Set C
136 project abstracts that were available from the list of brain research projects supported by the European Commission (EC) (2007-2012)[93]

---

91 Foxon, T. J., Gross, R., and Chase, A., et al. (2005) "UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures," Energy Policy. 33(16): 2123–2137. doi: 10.1016/j.enpol.2004.04.011.; Canadian Association of University Teachers. (2013) "Science in the Public Interest: A New Direction for Science Policy in Canada," Retrieved online from: http://getscienceright.ca/wp-content/uploads/2013/11/Science-Policy-4.pdf.

92 NIH RePORTER website can be accessed from http://projectreporter.nih.gov/reporter_summary.cfm.

93 The project synopses of brain research supported by the European Union 2007-2012 can be accessed from http://ec.europa.eu/research/health/pdf/brain-research_en.pdf.

To perform the comparison, in each document set, each concept[94] was ranked by the normalized frequency and relevance of the concept. A logarithmic difference was then applied to the rank of the concept from the two contrasting document sets, and this value allowed us to identify the contrast in dominance of the concept in the two document sets. For example, in Table 3.5, the concept "Brain" had a ranking of 1 in both Set A and Set B, hence the logarithmic difference was 0, meaning that in Set A and Set B, there was no difference in the dominance of the concept "Brain" in both document sets. In addition, the high ranking of the concept "Brain" indicates, as expected, that it is a highly dominant concept in both document sets. Table 3.5 shows the top 20 concepts that had the least difference in terms of their ranking in both document sets. The presence and high ranking of concepts such as "Brain," "Neurons," and "Central Nervous System" in both document sets assured us that this new methodology would be effective as we further investigated the differences in dominating concepts between the research areas from funding programs and existing research outputs.

Due to the absence of a means to associate publications resulting from brain and neuroscience research projects supported by the EC, a similar contrast between EC-funded research projects and brain and neuroscience articles from Scopus was not possible. However, when we examined the most important (top 10%[95]) concepts in all three document sets, concepts such as "Alzheimer Disease," "Parkinson Disease," "Schizophrenia," "Dementia," "Mental Health," and "Neurodegenerative Diseases" appeared without exception, confirming the universal importance of research in brain and neuroscience-related disorders.

***Table 3.5** — Top 20 concepts that are ranked most similarly in both NIH grant descriptions related to brain and neuroscience and in brain and neuroscience research articles from Scopus, ranked by the least logarithmic difference in the ranking of the concept in each document set.*

Name	Rank in Set A Brain and neuroscience articles from Scopus	Rank in Set B Brain and neuroscience funded grant awards from NIH RePORTER
Brain	1	1
Neurons	2	2
Intellectual Disability	107	104
N-Methylaspartate	58	60
Pyramidal Cells	158	165
alpha-Amino-3-hydroxy-5-methyl-4-isoxazolepropionic Acid	187	196
Mesencephalon	156	164
Afferent Neurons	173	183
Axons	32	34
Eye Movements	170	184
Peripheral Nerves	159	145
Cholinergic Agents	128	141
Substantia Nigra	168	190
Brain Neoplasms	60	53
Opioid Analgesics	130	148
Central Nervous System	14	12
Neurites	116	96
Optic Nerve	235	194
Gyrus Cinguli	221	178
Seizures	50	40

[94] See footnote 84.

[95] The top concepts are found by generating the term frequency-inverse document frequency (tf-idf) of each concept in each document, from each document set. This method is also used for the Elsevier journal finder system. The top three concepts per document from Set A and Set B and the top 10 concepts per document from Set C are selected; the most important concepts are then generated by using the sum of tf-idf of the concept across all three document sets, and selecting the top 10% concepts that overlapped in all three document sets.

Table 3.6 shows concepts that occurred prominently in the document set of brain and neuroscience research articles from Scopus, but not in brain and neuroscience research grant awards from NIH RePORTER. Except for a few, many concepts identified were general concepts that defined brain and neuroscience, ranging from brain regions all the way to receptors with neurotransmitters and cell types. In this list were also concepts about methodologies, which might explain why these concepts were not a focus in grants. However, the presence of concepts such as "Eye," "Pain," and "Stress, Psychological" indicated that research in these areas could be a type of brain and neuroscience research not as emphasized in NIH grants.

Table 3.6 *— Top 20 concepts that are dominant in brain and neuroscience research articles from Scopus but not in NIH grant descriptions related to brain and neuroscience, with 1 being the highest ranking, i.e., concepts are ranked much higher in brain and neuroscience research articles from Scopus than in NIH grant descriptions related to brain and neuroscience. The concepts were ranked by the largest absolute logarithmic difference in the ranking of the concept in each document set.*

Name	***Rank in Set A*** *Brain and neuroscience articles from Scopus*	***Rank in Set B*** *Brain and neuroscience funded grant awards from NIH RePORTER*
Patch-Clamp Techniques	3	349
Reaction Time	7	356
Pain	4	146
Psychomotor Performance	18	599
Maze Learning	27	828
Animal Behavior	12	361
Eye	5	134
Pain Measurement	29	670
Animal Sexual Behavior	164	3,282
Functional Laterality	71	1,336
6-Cyano-7-nitroquinoxaline-2,3-dione	74	1,191
Intraventricular Injections	155	2,476
Membrane Potentials	28	444
Physical Stimulation	184	2,670
Feeding Behavior	61	752
Acoustic Stimulation	54	656
Cerebral Cortex	11	126
Photic Stimulation	24	267
Electric Stimulation	13	143
Psychological Stress	42	455

Table 3.7 shows the top 20 concepts that ranked much higher in the document set of brain and neuroscience grant descriptions from NIH RePORTER compared to the brain and neuroscience articles from Scopus. Some concepts were general and sometimes reflected the fact that scientists label brain regions differently (e.g., Prefrontal Cortex, Cerebrum). However, NIH grant descriptions related to brain and neuroscience contained more disease-related concepts (i.e., disorders) compared to brain and neuroscience research articles from Scopus (in Table 3.6). Prominence of concepts such as "Pervasive Child Development Disorders," "Cocaine-related Disorders," "AIDS Dementia Complex," and "Street Drugs" reflects an emphasis on translational research, and that these were areas of concern from the funder's perspective.

Of note, Table 3.5 and Table 3.6 contained (bio)chemical compounds (e.g., alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid, N-methylaspartate, 6-cyano-7-nitroquinoxaline-2,3-dione), whereas none of these concepts were included in Table 3.7; this might signal a primary research trend in the brain and neuroscience community that is not a funding priority, also reflecting the fact that authors publishing on their research will address fundamental and primary research topics that are perhaps not a priority of funding agencies.

Table 3.7 *— Top 20 concepts that are dominant in NIH grant descriptions related to brain and neuroscience but not in brain and neuroscience research articles from Scopus, with 1 being the highest ranking, i.e., concepts are ranked much higher in NIH grant descriptions related to brain and neuroscience than in brain and neuroscience research articles from Scopus. The concepts were ranked by the largest absolute logarithmic difference in the ranking of the concept in each document set.*

Name	Rank in Set A *Brain and neuroscience articles from Scopus*	Rank in Set B *Brain and neuroscience funded grant awards from NIH RePORTER*
Autistic Disorder	1,323	27
Nervous System Diseases	605	16
Pervasive Child Development Disorders	2,097	58
Self Administration	1,898	85
Corpus Striatum	86	4
Cerebrum	445	21
Cocaine	1,003	51
Diffusion Magnetic Resonance Imaging	1,526	80
Cocaine-Related Disorders	2,219	117
Amyloid	948	52
Synapses	53	3
Schizophrenia	82	5
Central Nervous System Diseases	894	63
Neuroimaging	146	11
Prefrontal Cortex	106	8
Neuroanatomy	1,160	88
Alzheimer Disease	75	6
Glutamates	174	14
AIDS Dementia Complex	1,431	120
Street Drugs	1,989	169

The presence of more recognizable concepts such as "Autistic Disorder," "Alzheimer Disease," and "Schizophrenia" prompted us to explore if their low rank in brain and neuroscience research articles from Scopus was due to the subject definition methodology that might have overlooked relevant articles. However, as seen in Table 3.8, with the exception of the concept "Autistic Disorder," documents related to autism, Alzheimer's disease, and schizophrenia were fully selected from the Scopus database.

Furthermore, in Table 3.9, which shows NIH's Categorical Spending for Research, Condition, and Disease Categories (RCDC) sorted by categories of highest growth, autism was ranked as the 4th highest growth category, confirming the increased focus in this research area by NIH. Hence, we can conclude objectively that the concepts in Table 3.7 likely represent gaps between active areas of research and research areas that NIH perceives as important for improving human health.

Table 3.8 *— Medical subject headings (MeSH) concepts from the brain and neuroscience articles selected from Scopus (2009–2013), showing the number of occurrences in the document set (Set A) and the selection rate of the concept. Selection rate refers to the percentage of all Scopus documents containing a particular concept that were selected for analysis. For example, 75.9% of all Scopus documents that contained the concept "Autistic Disorder" were selected for inclusion in the document set (Set A).*

Concept Name	***Occurrence in Set A*** *Brain and neuroscience articles from Scopus*	***Selection Rate***
Alzheimer Disease	52,256	100.0%
Alzheimer Vaccines	158	100.0%
Autistic Disorder	12,076	75.9%
Schizophrenia	43,430	100.0%
Schizophrenic Psychology	7,582	100.0%
Schizophrenia Paranoid	1,424	100.0%
Schizotypal Personality Disorder	862	100.0%
Childhood Schizophrenia	200	100.0%
Catatonic Schizophrenia	120	100.0%
Disorganized Schizophrenia	105	100.0%
Schizophrenic Language	100	100.0%

Table 3.9 *— National Institutes of Health (NIH) Categorical Spending for Research, Condition, and Disease Categories (RCDC), sorted by categories of highest growth. Source: http://report.nih.gov/categorical_spending.aspx.*

Research / Disease Areas With Highest Growth	***FY 2013 Actual*** *(in million US$ and rounded)*	***CAGR***[96] ***2009-2013***
Comparative Effectiveness Research	559	30.3%
Orphan Drug	764	14.7%
Conditions Affecting the Embryonic and Fetal Periods	151	12.3%
Autism	186	9.0%
Human Genome	2,473	8.6%
Infectious Diseases	4,887	7.7%
Malaria	147	7.5%
Ovarian Cancer	133	6.9%
Antimicrobial Resistance	325	6.7%
Stem Cell Research - Nonembryonic - Human	431	6.2%
Tuberculosis	240	6.2%
Neuropathy	151	6.1%
Lymphoma	233	6.1%
Prevention	6,686	5.8%
Nanotechnology	430	5.8%

3.2.1 Top concepts relating to "disorders" and "chemicals & drugs" semantic groups

With the appearance of several disorder-related concepts appearing in the top 10% concepts within each document set in the above analysis, it is clear that research of brain and neuroscience-related disorders is a major area of emphasis. Here, we performed a similar analysis to identify the top concepts in the "Disorders" semantic group for document sets A, B, and C, based on the same Unified Medical Language System® described in the previous section 3.1.2.

As shown in Table 3.10, half of the top 10 concepts (those highlighted in violet) appeared in all three document sets, indicating that "Stroke," "Alzheimer Disease," "Pain," "Schizophrenia," and "Parkinson Disease" are common areas of research across the world. Compared to EC-funded research, US research was also focused on the concepts "Glioma," "Pervasive Child Development Disorders," and "Bipolar Disorder." Conversely, concepts such as "Memory Disorders," "Vision Disorders," "Myasthenia Gravis," "Hearing Loss," and "Alkalosis" were more important in EC-funded research compared to the US, perhaps reflecting a different emphasis in research related to brain disorders.

***Table 3.10** — Top 10 concepts that occurred in brain and neuroscience research articles relating to disorders from document sets A, B, and C, based on the sum of term frequency-inverse document frequency (tf-idf) of the concept in the document set that it belonged to. Figures in parentheses are the frequency with which the concept occurred in the document set. Highlighted in violet are concepts that appeared in the top 10 disorder-related concepts in all three document sets, reflecting common areas of focus. Highlighted in magenta are concepts that only appeared in Set A and Set B. Concepts that are not highlighted were those unique to each document set, indicating different areas of focus in disorder-related concepts in brain and neuroscience research.*

TOP 10 CONCEPTS RELATING TO DISORDERS IN:

Set A *Brain and neuroscience articles from Scopus*	***Set B*** *Brain and neuroscience funded grant awards from NIH RePORTER*	***Set C*** *Brain research project synopses supported by the European Commission*
Stroke (21,404)	**Alzheimer Disease (1,366)**	**Stroke (6)**
Depression (21,668)	**Stroke (1,044)**	**Parkinson Disease (7)**
Neoplasms (25,047)	**Schizophrenia (1,219)**	**Schizophrenia (5)**
Alzheimer Disease (14,522)	**Pain (817)**	Memory Disorders (3)
Pain (16,719)	**Parkinson Disease (869)**	Vision Disorders (2)
Schizophrenia (13,752)	**Depression (910)**	**Alzheimer Disease (4)**
Parkinson Disease (11,366)	**Neoplasms (829)**	Myasthenia Gravis (1)
Wounds and Injuries (13,414)	Glioma (526)	Hearing Loss (3)
Syndrome (13,258)	Pervasive Child Development Disorders (626)	Alkalosis (1)
Multiple Sclerosis (9,275)	Bipolar Disorder (499)	**Pain (1)**

[96] Compound Annual Growth Rate (CAGR) is the year-on-year constant growth rate over a specified period of time. Starting with the earliest value in any series and applying this rate for each time interval yields the amount in the final value of the series. The full formula for determining CAGR is provided in Appendix C: Glossary of Terms.

Table 3.11 shows the top 10 concepts for the three document sets in the "Chemical & Drugs" semantic group. The different focus areas relating to chemicals & drugs in brain and neuroscience research was more pronounced, and there were no common top related concepts across all three document sets. In the US, drugs related to substance abuse were highly researched, with the appearance of concepts such as "Methamphetamine," "Nicotine," and "Cannabis." In contrast, antipsychotic drugs ("Risperidone" and "Clozapine") that are mainly used to treat schizophrenia were high areas of focus in EC-funded research.

Table 3.11 *— Top 10 concepts that occurred in brain and neuroscience research articles relating to chemicals & drugs from document sets A, B, and C, based on the sum of term frequency-inverse document frequency (tf-idf) of the concept in the document set that it belonged to. Figures in parentheses are the frequency with which the concept occurred in the document set. Highlighted in violet are concepts that only appeared in Set A and Set B. Highlighted in magenta are concepts that only appeared in Set A and Set C. Concepts that are not highlighted were those unique to each document set, indicating different areas of focus in chemicals & drugs-related concepts in brain and neuroscience research.*

TOP 10 CONCEPTS RELATING TO CHEMICAL & DRUGS IN:

Set A *Brain and neuroscience articles from Scopus*	***Set B*** *Brain and neuroscience funded grant awards from NIH RePORTER*	***Set C*** *Brain research project synopses supported by the European Commission*
Proteins (12,255)	**Alcohols (1,209)**	Enzymes (2)
Glucose (7,423)	**Cocaine (807)**	NADPH Oxidase (1)
Food (8,477)	Ethanol (563)	Inflammation Mediators (1)
Alcohols (6,396)	Methamphetamine (391)	Anticonvulsants (2)
Insulin (6,021)	Analgesics, Opioid (499)	Quantum Dots (1)
MicroRNAs (4,180)	Nicotine (496)	Iron (1)
Pharmaceutical Preparations (10,822)	**MicroRNAs (374)**	**Peptides (1)**
Peptides (6,718)	Dopamine (650)	Risperidone (1)
Acids (5,225)	Cannabis (253)	Clozapine (1)
Cocaine (3,153)	Prions (213)	Phosphotransferases (2)

INTERVIEW
PROFESSOR RICHARD FRACKOWIAK

Richard Frackowiak is Director of the Department of Clinical Neuroscience, Centre Hospitalier Universitaire Vaudois in Lausanne, Switzerland, Chair, Medical Sciences Scientific Committee, Science Europe, and co-director of the Human Brain Project (HBP).

What do you consider to be the greatest opportunities and challenges in human brain research?

I think that neuroscience has really captured the public's imagination for a number of reasons. Brain diseases affect people of all ages, so the public is very aware of the practical need for research in terms of improving human health. But the brain has also supplanted the heart as the organ that defines our humanity. The more people learn about the brain, the more they appreciate their own lives and experiences; this is reflected in the growth of funding for neuroscience. After 40 years of neuroscience research, we have made many profound basic science discoveries, but the challenge now is figuring out how these separate discoveries made at various levels of organization relate to each other—starting with genes and going to individual nerve cells and their supporting cells, through to networks and systems, and finally to complex brain functions such as cognition and emotion. The second big challenge is in medicine—we understand very little about diagnosing and treating psychiatric diseases. We have some very powerful behavior-modifying drugs, but no treatments that directly target pathophysiology. These two challenges interact in the sense that understanding pathologic mechanisms and identifying new targets for treatments is severely limited by the fact that we don't really have a blueprint of how the normal brain is organized and how it functions. This is where we really need to work hard, and where we need to change the ways we do research in order to bring about fundamental advances.

What do you consider the most important factors affecting how the field of brain research has developed in Europe in the recent past?

A number of fundamental discoveries in brain research were made in Europe, and so there is an established research culture. In more recent years, brain research in Europe took a technologic leap forward with brain imaging with MRI, which let us look inside the normal human brain. Most recently, the fields of physics and mathematics brought new methodological approaches into brain research, such as ultrahigh resolution microscopy and informatics.

As these various disciplines started coming together, it initiated a synthesis of vision throughout the European Union and development of policy and funding programs to promote collaboration. The culture started shifting from individual scientists to collaborative networks of scientists working on common projects within various framework programs. Subsequent changes in funding policies have had a major effect on brain research by bringing scientists together into a new environment of collaborative, non-competitive work across disciplines.

Now we are dealing with data that need to be integrated from researchers from many countries, and we are encountering all sorts of legal issues about moving and sharing data, and how to handle patient data.

What do you see as the consequences of recent large-scale programs (e.g., BRAIN Initiative in the US, the Human Brain Project in Europe) on progress in neuroscience generally and how they are affecting research in individual labs, the culture of collaboration, and the questions being asked?

Large-scale initiatives are the natural progression of brain research based on the recognition that there has been major progress as researchers started collaborating across disciplines. Europe has taken the lead to try and formalize cross-disciplinary collaboration with initiatives like the Human Brain Project (HBP), which is taking an informatics approach to understanding how the human brain is structured through a completely new method of simulation modeling. I think that the large-scale initiatives represent an extraordinary moment in research policy and funding. It is very important to remember that the HBP is part of an existing portfolio—it adds to it, but it certainly doesn't supplant it. Many of us involved in the HBP have our standard research portfolios. But part of our research effort is contributing to the HBP, which has its own road map and aims and in which research is done in a completely different way.

The BRAIN Initiative is slightly different in the sense that it was created as a way to expand neuroscience research to recover from the detrimental effects of the 2008 recession on research funding. The BRAIN Initiative is more focused on technology development, and it will be extremely exciting to see how those efforts interact with the European-focused big data approach, and how new collaborations will be formed.

How these initiatives may affect credit given for research discoveries is a particularly important issue for young people who are just starting their research careers. In the past, if you were making discoveries and publishing them as the first or last author, you got the credit and you got more funding. This first-and-last author system does not reflect the work being done by groups, and does not encourage researchers to engage in the sort of interactive, collaborative work that we need to be doing.

What are some examples of the implications of recent brain research discoveries for society?

Brain imaging is probably recognized as the biggest advance with direct implications for society. On a practical level, patients once had to endure invasive and painful procedures and all of these have disappeared because of imaging. Imaging of the brain, and human diagnostic imaging in general, has really spawned data visualization as a science unto itself, from molecular imaging all the way up to crowdsourcing the spread of influenza. As they say, "A picture is worth a thousand words," and brain imaging is an iconic transmission of very complex information. There are also great success stories in the area of rehabilitation after brain trauma or stroke, with therapies based on our basic discoveries of what happens when the brain reorganizes itself.

On the other hand, you have areas of brain research where society expects major advances, but they have been slow to materialize. One example is the lack of new treatments for dementia and psychiatric diseases. Many pharmaceutical companies are pulling out of drug development because of the limited understanding of brain pathophysiology. We first need to determine how the brain is organized, then we can understand pathophysiology and identify new therapeutic targets. The good news is that pharma companies are seeking out partnerships with academia.

Can you comment on the technologic advances—in imaging, analysis software, computing—that are emerging in tandem with basic biomedical discoveries about the brain? What are the potential applications of these technologies for the field?

The integration of technology and brain research is remarkable. The combination of informatics, microtechnology, and nanotechnology with the life sciences and medicine has led to some remarkable advances with brain-machine interfaces and the development of endoprostheses and exoprostheses, in which signals from the brain are captured and processed into stimuli for controlling switches. Right now these technologies are working at a very primitive level, but you can just imagine what might happen in 10 to 20 years' time.

Thinking about the future of brain research globally, where do you think we will be in 5 and 10 years' time?

The research culture will continue to change, with a considerable component based around collaborative interdisciplinary work rather than competitive uni-disciplinary work. I also predict that the impact of computer science will increase massively, both in medical science and in basic neuroscience. How we diagnose brain disorders is also going to radically change, relying more on objective criteria as opposed to the classical criteria that have served us so well for the last 150 years.

What societal or ethical issues do you think will influence brain research priorities and applications in the future? What steps do you think the field should take to resolve these issues and effect greater engagement with the public?

I see there being a much bigger influence of society on medical research in the sense that the impact of research on society is becoming a more and more important aspect of resource allocation. The world's resources are limited, and we are working within fixed budgets that are not growing. Areas of the world that were once in extreme poverty are beginning to rise up and there is increasing demand for better health and the need to rein in disease. We need to be careful about the way we interact with the people who represent societal interests and make policy decisions. We need to make sure that the research being supported with taxpayers' money is well designed and conducted, but at the same time ensure that innovation and novelty are not lost to societal or political pressure.

Scientists need to have a strong voice and we need scientists who can communicate about research and research priorities to interact with those who make legal and policy decisions, and we need to engage with decision-makers in a much more coordinated way across Europe.

The ethics of neuroscience research is a very interesting issue. As we move from the heart to the brain, from emotion to the integration of emotional cognition, we need to grasp the concept that just as ethics influences the direction of neuroscience research, new discoveries in neuroscience will drive the development of new ethical frameworks and constructs that will guide our life in the future.

Is there information in the present report that you think is particularly interesting, unusual, or likely to have an effect on the development of the field looking forward?

The report takes a broad view of the entire neuroscience field across several countries over 15 years—what I found most interesting were the outliers, and I think these outliers may be of major interest to policymakers. For example, why is the US so dominant, with 7 million researchers producing such highly innovative work? Is it related to the way the universities are organized? Is it the mixture of state funding and small private foundation funding? As I went through the report, I noticed several of these kinds of outliers that deserve to be examined in much greater depth.

Are there any aspects of the present report that you think should be further explored in relation to Europe?

I hope that the methodology will be developed further, particularly to examine the research effort at the regional, local, or institutional level. What types of institutions are doing the research and how are they funded? And how does this affect research output and quality?

I was intrigued by the methodology used to assess neuroscience research, involving the determination of a taxonomy for the various areas and the various types of activities, which then relate to the ontology for the various aspects of neuroscience. The taxonomies appear to be replicating themselves. As the very broad categories become more and more particular, molecular, and defined, there is a great heterogeneity in the way things are named. I think schematics will help, and machine learning or actual language processing could bring some order to the process.

Thinking about the future of brain research, what additional piece of information do you think is needed to assess the current situation and consider future funding and/or policy decisions?

Selecting the relevant concepts is going to be very important. The influence on policy and funding decisions is going to depend on how the results fit into the much broader concept of how a nation apportions its resources on its population. That is a very complex problem and demands not only knowledge about the individual area of research but also knowledge of context and knowledge of time-related changes. It is as complex as trying to understand how the human brain is organized!

What the report does in relation to the data that exist and the methods that can be used is to show that we can present much finer details about the research effort to policy makers. I think that scientists themselves will need to present these kinds of data, but we will need to partner with publishers who have the ability to mine their massive data and publishing databases to provide us with information.

I think we are seeing something evolving in society and its relationship to informatics, which is going to have an enormous impact on our ability to understand and use all the knowledge we are generating. This is going to become the great challenge of the future.

CHAPTER 4
CONCLUSION

4.1 Conclusion

This report represents a pioneering effort to capture the state of global brain research. It provides various stakeholders in brain research—funders, governments, universities, research institutions, and policy groups—with a resource that can help inform decisions about future research strategies and funding priorities, guide international coordination and collaboration, and steer policy and advocacy efforts.

Our analyses reveal the breadth and complexity of brain and neuroscience research efforts around the globe. Research collaboration is strong, with a consistently increasing proportion of inter-institutional and/or international collaboration. Like the brain itself, it is clear that the field of brain research is malleable and ever changing, with researchers from various fields creating novel links between subjects, methods, and approaches, and traversing disciplinary borders to form new collaborations—essentially rewiring the field to reach new conclusions and make new discoveries.

In order to capture the dynamics of brain and neuroscience research, rather than using a preset taxonomy system or journal category-based approach for the analyses, we employed an expert-reviewed semantic fingerprinting methodology to generate an article-level document set that most accurately reflects the broad, dynamic, and cross-disciplinary nature of brain and neuroscience research. This report includes both traditional bibliometrics assessments of brain and neuroscience research output and impact, as well as many new measures of the global research effort, including types of collaboration and disciplinary mobility, to more comprehensively describe the current state of brain research. We also developed novel methods to identify and compare emerging trends in the brain and neuroscience research literature and funded research; this approach has potentially wide applications for assessing research priorities and gaps in various settings.

Differences between high-frequency "top concepts" and "burst concepts"—those with a rapid rise in frequency—reveal variances between consistently prominent research interests and fast-growing areas of interest. These findings may be particularly valuable for national and foundation funding bodies as they assess their current research portfolios and consider future research priorities. The methodology itself—comparing trends and key concepts in published brain research and funded grant abstracts—is also an important and promising first step toward developing evidence-based predictive and prescriptive recommendations for future research directions.

This report offers the research community a comprehensive assessment of the state of global brain research at a time when several large, collaborative initiatives in brain research are getting underway across the globe. It serves as an initial benchmark from which the changing landscape of brain research can be tracked and the achievements of these large national and international initiatives, as well as those of universities and research institutions, can be assessed over time. Future reports can help researchers navigate the interdependency of basic, translational, and clinical research activities and the progress made as different disciplines converge and sub-disciplines emerge within the larger brain and neuroscience research field.

The strength of this report rests not only on the quality of the data sources and the robust and novel methodologies employed, but also on the invaluable input from external neuroscience leaders. We would again like to thank the various contributors for their insights and guidance.

APPENDICES

APPENDIX A
AUTHOR CREDITS, ADVISORY GROUPS, AND ACKNOWLEDGEMENTS

This study is a pro-bono report by Elsevier with inputs from expert organizations. It was conducted and written by Georgin Lau, Dr. Judith Kamalski, Dr. Holly J. Falk-Krzesinski, Dr. Stephane Berghmans, Dr. Anders Karlsson, Ludivine Allagnat, Jesse Mudrick, Jeroen Baas, and Dr. Marius Doornenbal of Elsevier, and Dr. Stacey C. Tobin of The Tobin Touch, Inc.

Special thanks to George Lan, Sarah Huggett, Dr. Ning Kang, Dr. Katja Brose, Dr. Rick Misra, Dr. Felisa van Hasselt, Dr. Judson Dunham, Dr. Andrew Plume, and Mathew Richardson of Elsevier for providing helpful information and/or valuable reviews of and feedback on drafts of this report.

Preliminary findings from this report were presented at the 9th FENS Forum on Neuroscience Global Advocacy Event. We thank the participants at this event for their helpful insights and feedback.

This report was designed for online and print by CLEVER°FRANKE, www.cleverfranke.com

The report is available online at www.elsevier.com/research-intelligence/brain-science-report-2014

APPENDIX B
METHODOLOGY AND DATA SOURCES

Subject Definition Methodology

We took an iterative four-step approach to evaluate the state of brain and neuroscience research (Table B.1). In summary, first, we identified a set of relevant and specific neuroscience concepts and terms, defined as a *semantic fingerprint* (refer to "What is Semantic Fingerprinting?" box below). We then applied this semantic fingerprint to the Scopus database to identify all published articles related to brain and neuroscience research. The resulting set of articles was then analyzed to describe the state of brain and neuroscience research, in terms of research output, impact, collaboration, and quality, as well as the extent of cross-disciplinary research, emerging and highly active areas of research, and the state of research funding.

Table B.1 *— Four-step, iterative methodology to evaluate the state of brain and neuroscience research.*

Step 1 *Identify key concepts and terms in publications classified under the Scopus subject of Neuroscience*
Step 2 *Select relevant and specific concepts to define the semantic fingerprint for brain and neuroscience research*
Step 3 *Identify all articles in Scopus that fit the brain and neuroscience research semantic fingerprint*
Step 4 *Analyze the resulting articles to evaluate the state of brain and neuroscience research*

Step 1: Identify key concepts and terms in publications classified under the Scopus subject of Neuroscience

Using the semantic Elsevier Fingerprint Engine (see box), we extracted a set of key concepts from publications classified under the Scopus subject area of Neuroscience.

Step 2: Select relevant and specific concepts to define the semantic fingerprint for brain and neuroscience research

From the initial list of key concepts identified by the Elsevier Fingerprint Engine (from articles classified under the Scopus subject area of Neuroscience), only those considered relevant and specific to the area of brain and neuroscience research were selected to define the *brain and neuroscience research semantic fingerprint*. The initial set of key concepts was evaluated by internal subject matter experts and representatives from the following expert organizations: the European Commission (EC), Federation of European Neuroscience Societies (FENS), Human Brain Project (HBP), National Institute of Mental Health (NIMH) at the National Institutes of Health (NIH), Kavli Foundation, and RIKEN Brain Science Institute (BSI). The subject matter experts collectively recommended an additional 256 terms, which were consolidated to a list of 187 non-duplicate concepts. Of these, 77 (including 10 medical subject headings [MeSH]), were deemed relevant and specific to brain and neuroscience research and were used as the selection criteria for articles related to brain and neuroscience research. Concepts that were not selected were considered to be too general, for example, "visualization," "anxiety,"[97] and "emotion."[98] By including only relevant and specific concepts, the final semantic fingerprint is expected to more accurately identify articles related to brain and neuroscience research. For example, by including the concept "brain" in the semantic fingerprint but excluding the more general concept "anxiety," all publications about the brain that also mention anxiety would be included in our analysis, but publications about anxiety alone would not. It is also important to note that the MeSH system is a hierarchy, and if a parent term is included, all sub-terms are automatically included. Therefore, while not all sub-terms may appear on the list of 77 relevant terms, they are included if their parent term is on the list and are used to select the relevant brain and neuroscience research document set for analysis.

[97] Even though this concept was not included at this stage, it was eventually included to identify the document set as it is relevant to the area of brain and neuroscience research. Of the documents selected for analysis, 62,020 documents contained the concept "anxiety" and the concept had a document selection rate of 87.5% (i.e., 22.5% of Scopus documents that contained the concept "anxiety" were not selected for inclusion in our document set for analysis).

[98] Refer to footnote above. The selection rate for the concept "emotion" was 87.5%.

What is Semantic Fingerprinting?

A semantic fingerprint consists of all the key concepts derived from a piece of text, weighted to reflect their relative importance.

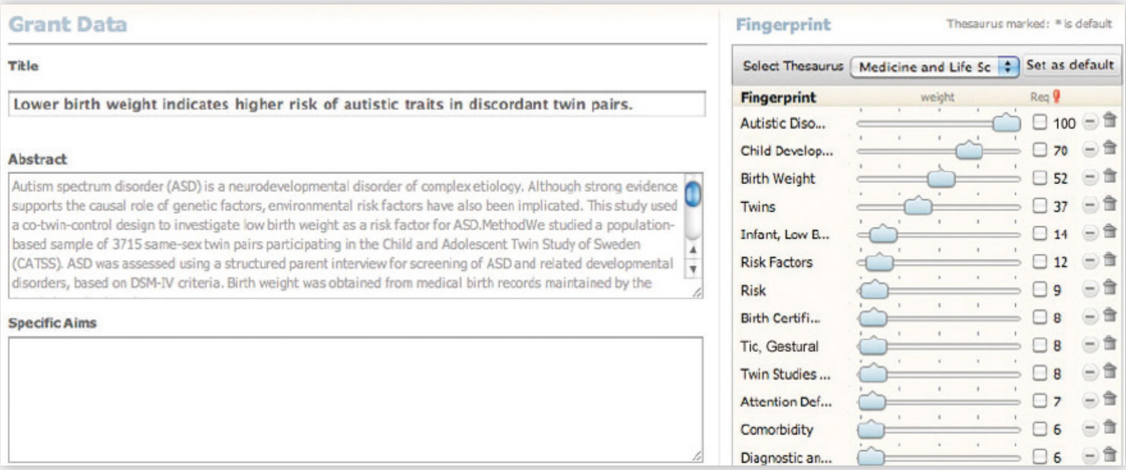
The Elsevier Fingerprint Engine can be used to determine the semantic fingerprint of any text, from grant applications to publications. A number of thesauri spanning all major disciplines, along with Natural Language Processing (NLP) techniques, are applied to scan and analyze text; in this study, publications from the Scopus database were scanned to identify and weight key concepts and terms related to brain and neuroscience research. The Elsevier Fingerprint Engine assigns to each document a collection of key representative concepts—its semantic fingerprint.

The advantage of using key concepts based on semantic fingerprint technology is that the resulting terms are of higher quality and are more representative than standard sets of keywords, which often contain duplicates, synonyms, and inclusion of irrelevant terms. With the Elsevier Fingerprint Engine, various NLP modules are applied to a text source, enabling the computer to recognize and interpret complex text, including idioms, hyphenations, and abbreviations. The concept-finding algorithm is sensitive to spelling variations such as case sensitivity, stop words, normalization, and word ordering, but ignores insignificant differences wherever these variations have no meaning. Concept finding can be constrained by part-of-speech requirements on terms (e.g., “lead” identified as a noun or a verb) and also by immediate negated context (e.g., “non-Hodgkin Lymphoma” must not be found as “Hodgkin Lymphoma”).

Figure B.1 shows an example of a semantic fingerprint based on a published abstract. The Elsevier Fingerprint Engine generates a graphical representation of the concepts and terms included in the abstract, weighted by importance.

Semantic fingerprints can be used for describing themes and identifying all articles in Scopus worldwide that are related to a theme. Fingerprints are ideal for describing groups of articles and identifying articles that are related to one another in terms of subject area, such as brain and neuroscience research. Fingerprints can be aggregated at the department, institute, and country level to examine research output, emerging research trends, who is doing the research, and where it is being done.

Figure B.1 *— Semantic fingerprint of a scientific abstract after processing by the Elsevier Fingerprint Engine.*



Step 3: Identify all articles in Scopus that fit the brain and neuroscience research semantic fingerprint

Using the brain and neuroscience research semantic fingerprint—the combined relevant and specific key concepts selected in Step 2—as the selection criteria, we selected articles published between 2009 and 2013 from the entire Scopus database, across all 27 subject areas (not only the Neuroscience journal category) that fit the *brain and neuroscience research semantic fingerprint*. The resulting set had 1.79 million articles (approximately 16% of the world's output in that period), representing the collective publication output in the broad field of brain and neuroscience research, which was then used in various analyses to characterize the state of global brain and neuroscience research in Step 4.

Multi-level approach

The advantage of using a semantic fingerprinting approach is that we are not limited to identifying only brain and neuroscience research articles that are traditionally classified as neuroscience in a journal-based classification system; rather, we are able to include articles in our analysis that are outside of the Neuroscience subject category but include a key concept and/or MeSH term that is considered specific and relevant to brain and neuroscience research. Our approach is multi-method and iterative, and relies on both automatic and manual input to select relevant articles for analysis. By combining three approaches—an initial journal-based classification system, semantic fingerprinting using the Elsevier Fingerprint Engine, and internal and external expert review and selection of key concepts—we were able to identify a broad set of articles that best represent the entire field of brain and neuroscience research.

To get a better sense of the characteristics of the documents being analyzed, Table B.2 shows the top 100 concepts based on the number of times the concept appeared in the selected document set, and where the selection rate[99] was more than 75%.

Table B.2 *— Top 100 concepts from the selected document set, based on the number of times the concept appeared in the selection collection, and where the selection rate is more than 75%.*

Brain	Ocular Vision	Dopamine	Testosterone
Comprehension	Electroencephalography	Headache	Sensation
Pain	Seizures	Retina	Synaptic Transmission
Neurons	Orientation	Action Potentials	Ear
Depression	Epilepsy	Glutamic Acid	Synapses
Learning	Neuropsychological Tests	Opioid Analgesics	Hearing
Eye	Fasting	Intention	Anticonvulsants
Perception	Cues	Cognition Disorders	Chronic Pain
Stroke	Pain Measurement	Photic Stimulation	Suicide
Memory	Dementia	Judgment	Feeding Behavior
Attention	Parkinson Disease	Antidepressive Agents	Anesthetics
Decision Making	Uncertainty	Multiple Sclerosis	Axons
Awareness	Respiration	Neuroimaging	Serotonin
Anxiety	Speech	Antipsychotic Agents	Electromyography
Cognition	Affect	Estradiol	Brain Ischemia
Cell Movement	Visual Acuity	Abdominal Pain	Depressive Disorder
Consensus	Spinal Cord	Meals	Cerebrospinal Fluid
Alzheimer Disease	Analgesics	Electric Stimulation	Cornea
Emotions	Walking	Non-Steroidal Anti-Inflammatory Agents	Activities of Daily Living
Central Nervous System	Animal Behavior	Psychological Adaptation	Nervous System
Reaction Time	Brain Mapping	Psychomotor Performance	Functional Laterality
Hippocampus	Brain Neoplasms	Neurotransmitter Agents	Short-Term Memory
Psychological Stress	Neurodegenerative Diseases	Running	Esthetics
Schizophrenia	Cerebral Cortex	Psychiatric Status Rating Scales	Reward
Sleep	Brain Injuries	Nerve Tissue Proteins	Prefrontal Cortex

[99] Selection rate is the percentage of Scopus documents containing a particular concept that was selected for analysis. For example, in the selected document set, 62,020 documents contained the concept "anxiety" and the concept had a selection rate of 87.5% (i.e., 22.5% of Scopus documents that contained the concept "anxiety" were not selected for inclusion in our document set).

In contrast, Table B.3 shows the 30 top occurring concepts in the selected document set, which have a much lower selection rate, illustrating the lower relevancy of these concepts to the area of brain and neuroscience research.

Table B.3 *— Top 30 concepts based on the number of occurrences in the selected document set. Source: Scopus.*

Name	***Selection Rate***
Humans	42.4%
Male	50.4%
Female	47.9%
Patients	45.9%
Methods	40.4%
Therapeutics	44.7%
Animals	44.9%
Adult	49.8%
Middle Aged	46.4%
Time	42.3%
Aged	45.8%
Cells	36.5%
Disease	42.0%
Brain	100.0%
Risk	42.3%
Child	48.5%
Adolescent	50.6%
Research	46.4%
Population	40.6%
Comprehension	100.0%
Proteins	32.5%
Diagnosis	44.7%
Mice	44.4%
Neoplasms	31.5%
Rats	60.7%
Young Adult	54.2%
Evaluation Studies as Topic	41.6%
Tissues	39.1%
Treatment Outcome	45.9%
Women	46.7%

Step 4: Analyze the resulting articles to evaluate the state of brain and neuroscience research

The analyses of the resulting articles are presented in the main body of the report.

Research Output Analysis Methodology

Our methodology is based on the theoretical principles and best practices developed in the field of quantitative science and technology studies, particularly in science and technology (S&T) indicators research. *The Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems* (Moed, Glänzel and Schmoch, 2004)[100] gives a good overview of this field and is based on the pioneering work of Derek de Solla Price (1978),[101] Eugene Garfield (1979),[102] and Francis Narin (1976)[103] in the USA; Christopher Freeman, Ben Martin, and John Irvine in the UK (1981, 1987);[104] and several European institutions including the Centre for Science and Technology Studies at Leiden University, the Netherlands, and the Library of the Academy of Sciences in Budapest, Hungary.

The analyses of research output data in this report are based on recognized advanced indicators (e.g., the concept of relative citation impact rates). Our base assumption is that such indicators are useful and valid, though imperfect and partial measures, in the sense that their numerical values are determined by research performance and related concepts, but also by other influencing factors that may cause systematic biases. In the past decade, the field of indicators research has developed best practices that state how indicator results should be interpreted and which influencing factors should be taken into account. Our methodology builds on these practices.

Article Types

For all research output analyses, only the following peer-reviewed document types were considered:

→ Article
→ Review
→ Conference Proceeding

Article Counting and Deduplication

All analyses made use of whole counting rather than fractional counting. For example, if a paper was co-authored by one author from the US and one author from the UK, then that paper counted towards both the publication count of the US as well as the publication count of the UK. Total counts for each country represent the unique counts of publications.

The same publication may have been part of multiple smaller component entities, such as in the calculation of counts of publications in subject areas. However, this report deduplicated all within an aggregate entity, so that a publication

[100] Moed H., Glänzel W., and Schmoch U. (2004) Handbook of Quantitative Science and Technology Research, Kluwer: Dordrecht.

[101] de Solla Price, D.J. (1977–1978) "Foreword," In: Essays of an Information Scientist, Vol. 3, v–ix.

[102] Garfield, E. (1979) "Is citation analysis a legitimate evaluation tool?" Scientometrics. 1(4): 359–375.

[103] Pinski, G., and Narin, F. (1976) "Citation influence for journal aggregates of scientific publications: theory with application to literature," Inf Process Manag. 12(5): 297–312.

[104] Irvine, J., Martin, B. R., and Abraham, J. et al. (1987) "Assessing basic research: reappraisal and update of an evaluation of four radio astronomy observatories," Res Policy. 16(2-4): 213-227.

was counted only once even if it was included by several component entities. For example, a UK and Italy publication on advances in functional and structural brain imaging analysis would have been counted once each toward the totals of that country's research output in Neuroscience and Engineering. However, this publication would have counted only once toward the aggregate entity of all publications from the UK and Italy.

Citation Counting and Self-Citations

Self-citations are those in which an entity refers to its previous work in new publications. Self-citing is normal and expected academic behavior, and it is an author's responsibility to make sure their readers are aware of related, relevant work. For this report, self-citations were included in citation counts and the calculation of field-weighted citation impact (FWCI).

Measuring Cross-disciplinary Researcher Mobility

The approach presented here used Scopus author profile data to derive a history of active author affiliations recorded in their published articles and to assign them to mobility classes defined by the type and duration of observed moves.

How are individual researchers unambiguously identified in Scopus?

Scopus uses a sophisticated author-matching algorithm to precisely identify articles by the same author. The Scopus Author Identifier gives each author a unique ID and groups together all the documents published by that author, matching alternate spellings and variations of the author's last name and distinguishing between authors with the same surname by differentiating on data elements associated with the article (such as affiliation, subject area, co-authors, and so on).

The Scopus algorithm favors accuracy and only groups together publications when the confidence level that they belong together—the precision of matching—is at least 99% (that is, in a group of 100 papers, 99 will be correctly assigned). This level of accuracy results in a recall of 95% across the database: if an author has published 100 papers, on average, 95 of them will be grouped together by Scopus. These precision and recall figures are accurate across the entire Scopus database. There are situations where the concentration of similar names increases the fragmentation of publications between Author Profiles, such as in the well-known example of Chinese authors. In addition, there are instances where a high level of distinction in author names results in a lower level of fragmentation, such as in Western countries.

The Scopus matching algorithm can never be 100% correct because the data it is using to make the assignments are not 100% complete or consistent. The algorithm is therefore enriched with manual, author-supplied feedback, both directly through Scopus and also via Scopus' direct links with ORCID (Open Researcher & Contributor ID 21).

What determines whether an author is a "brain and neuroscience researcher"?

To define the initial population for study, brain and neuroscience researchers were identified as those authors who had one or more publications (articles, reviews, and conference papers) extracted in the process of brain and neuroscience research subject definition.

What is an 'active researcher'?

The authors of the publication set selected for analysis in the report include a large proportion with relatively few articles over the entire period of analysis. As such, it was assumed that they were not likely to represent career researchers, but individuals who have left the research system. A productivity filter was therefore implemented to restrict the analysis to those authors with at least one article published in the most recent five-year period (2009–2013) and at least 10 articles in the entire period 1996-present, or, for those with fewer than 10 articles in the 1996-present period, at least four articles in 2009–2013.

How are mobility classes defined?

The measurement of cross-disciplinary researcher mobility by co-authorship in the published literature is complicated by the difficulties involved in teasing out long-term mobility from short-term mobility. In this study, the publishing of articles in a different discipline of two years or more was considered long-term movement across disciplines (inflow or outflow) and authors were further subdivided into those where the researcher remained in other disciplines or where s/he subsequently returned (i.e., returnees) to the area of brain and neuroscience research.

Those who published articles in a different discipline for less than two years were deemed multidisciplinary, and were also further subdivided into those who mostly published under brain and neuroscience research (mainly BNR) or those who mostly published in other disciplines (mainly non-BNR). Authors were assumed to be from the discipline where they first published (for inflow or outflow researchers) or from the discipline where they published the majority of their articles (for multidisciplinary researchers). In individual cases, these criteria may have resulted in authors being assigned cross-disciplinary mobility patterns that may not accurately reflect the real situation, but such errors may be assumed to be evenly distributed across the groups and so the overall pattern remains valid. Researchers without any apparent mobility based on their publications were considered as single-discipline researchers (BNR only).

Long-term

- *Outflow:* active BNR researchers whose Scopus author data for the period 1996-present indicates that they moved from publishing in BNR to non-BNR for at least two years without returning to BNR.
- *Returnees Outflow:* active BNR researchers whose Scopus author profile data for the period 1996-present indicates that they first published outside of BNR, and published in BNR for at least two years, and then left to publish in a non-BNR area.
- *Total Outflow:* the sum of Outflow and Returnee Outflow groups.
- *Inflow:* active BNR researchers whose Scopus author data for the period 1996-present indicate that they moved from publishing in a non-BNR area to BNR for at least two years.
- *Returnees Inflow:* active BNR researchers whose Scopus author data for the period 1996-present indicates that they first published in BNR, subsequently published in a non-BNR area for at least two years, and subsequently moved back to publishing articles in BNR.
- *Total Inflow:* the sum of Inflow and Returnee Inflow groups.

Multidisciplinary

- *Multidisciplinary (mainly non-BNR):* active BNR researchers whose Scopus author data for the period 1996-present indicates that they published in BNR for less than two years at a time and predominantly published in non-BNR areas.
- *Multidisciplinary (mainly BNR):* active BNR researchers whose Scopus author data for the period 1996-present indicates that they published outside of BNR for less than two years at a time and predominantly published in BNR.
- *Total Multidisciplinary:* the sum of Multidisciplinary (mainly non-BNR) and Multidisciplinary (mainly BNR) groups.

Single-discipline (BNR only)

- *Single-discipline (BNR only):* active BNR researchers whose Scopus author data for the period 1996-present indicates that they did not published outside BNR.

What indicators are used to characterize each mobility class?

To better understand the composition of each group defined on the mobility map, three aggregate indicators were calculated for each to represent the productivity and seniority of the researchers they contain, and the field-weighted citation impact (FWCI) of their articles.

Relative productivity represents a measure of the articles per year since the first appearance of each researcher as an author during the period 1996-present, relative to all BNR researchers in the same period. Relative seniority represents years since the first appearance of each researcher as an author during the period 1996-present, relative to all BNR researchers in the same period. FWCI was calculated for all articles in each mobility class. All three indicators were calculated for each author's entire output in the period.

Measuring Article Downloads

Citation impact is by definition a lagging indicator: newly published articles need to be read, after which they might influence studies that will be carried out, which are then written up in manuscript form, peer-reviewed, published, and finally included in a citation index such as Scopus. Only after these steps are completed can citations to the earlier article be systematically counted. For this reason, investigating downloads has become an appealing alternative, since it is possible to start counting downloads of full-text articles immediately upon online publication and to derive robust indicators over windows of months rather than years.

While there is a considerable body of literature on the meaning of citations and indicators derived from them,[105] the relatively recent advent of download-derived indicators means that there is no clear consensus on the nature of the phenomenon that is measured by download counts.[106] However, a small body of research has concluded that download counts may be a weak predictor of subsequent citation counts at the article level.[107]

In this report, a download was defined as the event where a user views the full-text HTML of an article or downloads the full-text PDF of an article from ScienceDirect, Elsevier's full-text journal article platform; views of an article abstract alone, and multiple full-text HTML views or PDF downloads of the same article during the same user session, are not included in accordance with the COUNTER Code of Practice.[108] ScienceDirect provides download data for

105 Cronin, B. (2005) "A hundred million acts of whimsy?" Curr Sci. 89(9): 1505–1509; Bornmann, L., and Daniel, H. (2008) "What do citation counts measure? A review of studies on citing behavior," J Document. 64(1): 45–80.

106 Kurtz, M.J., and Bollen, J. (2010) "Usage bibliometrics," Ann Rev Information Sci Technol. 44(1): 3–64.

107 Moed, H.F. (2005) "Statistical relationships between downloads and citations at the level of individual documents within a single journal," J Am Soc Information Sci Technol. 56(10): 1088–1097; Schloegl, C. and Gorraiz, J. (2010) "Comparison of citation and usage indicators: the case of oncology journals," Scientometrics. 82(3): 567–580; Schloegl, C. and Gorraiz, J. (2011) "Global usage versus global citation metrics: the case of pharmacology journals," J Am Soc Information Sci Technol. 62(1): 161–170.

approximately 16% of the articles indexed in Scopus; it is assumed that user downloading behavior across countries does not systematically differ between online platforms. Field-weighted download impact (FWDI) was calculated from these data according to the same principles applied to the calculation of field-weighted citation impact (FWCI).

Data Sources

ScienceDirect is Elsevier's full-text journal articles platform. With an invaluable and incomparable customer base, the use of scientific research on Science-Direct.com provides a different look at performance measurement. ScienceDirect.com is a leading journal articles platform, used by more than 12,000 institutes worldwide, with more than 11 million active users and over 700 million full-text article downloads in 2012. The average click through to full-text per month is nearly 60 million. More info can be found on http://www.elsevier.com/online-tools/sciencedirect.

Scopus is Elsevier's abstract and citation database of peer-reviewed literature; covering over 50 million documents published in more than 21,000 journals, book series, and conference proceedings by some 5,000 publishers. Reference lists are captured for 29 million records published from 1996 onwards, and the additional 21 million pre-1996 records reach as far back as the publication year 1823.

Scopus coverage is multi-lingual and global: approximately 21% of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa, and the Asia Pacific region. Scopus also comprises more than 400 titles from publishers based in the Middle East and Africa.

Scopus coverage is also inclusive across all major research fields, with 6,900 titles in the Physical Sciences, 6,400 in the Health Sciences, 4,150 in the Life Sciences, and 6,800 in the Social Sciences (the latter including some 4,000 Arts & Humanities-related titles). Covered titles are predominantly serial publications (journals, trade journals, book series, and conference material), but considerable numbers of conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in the computer sciences). Acknowledging that a great deal of important literature in all fields (but especially in the Social Sciences and Arts & Humanities) is published in books, Scopus has begun to increase book coverage in 2013, aiming to cover some 75,000 books by 2015.

For this report, a static version of the Scopus database covering the period 1996-present inclusive was aggregated by country. In addition to the custom subject area defined for brain science, typically, subjects were defined by ASJC subject areas (see Appendix G: Subject Classification for more details). When aggregating article and citation counts, an integer counting method was employed where, for example, a paper with two authors from a US address and one from a UK address would be counted as one article for each country. This method was favored over fractional counting to maintain consistency with other reports (both public and private) we have conducted on the topic.

A body of literature is available on the limitations and caveats in the use of such "bibliometric" data, such as the accumulation of citations over time, the skewed distribution of citations across articles, and differences in publication and citation practices between fields of research, different languages, and applicability to social sciences and humanities research.

[108] http://usagereports.elsevier.com/asp/main.aspx; http://www.projectcounter.org/code_practice.html

APPENDIX C
GLOSSARY OF TERMS

Article (unless otherwise indicated) denotes the main types of peer-reviewed documents published in journals: articles, reviews, and conference papers.

Article output for an institution or region is the count of articles with at least one author from that institution (according to the affiliation listed in the authorship byline). All analyses make use of "whole" rather than "fractional" counting: an article representing international collaboration (with at least two different countries listed in the authorship byline) was counted once each for every country or institution listed.

Article share (world) is the share of publications for a specific region expressed as a percentage of the total world output. Using article share in addition to absolute numbers of articles provides insight by normalizing for increases in overall growth of the world's research enterprise.

Compound Annual Growth Rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$\text{CAGR}\,(t_0, t_n) = (V(t_n) / V(t_0))^{\frac{1}{t_n - t_0}} - 1$$

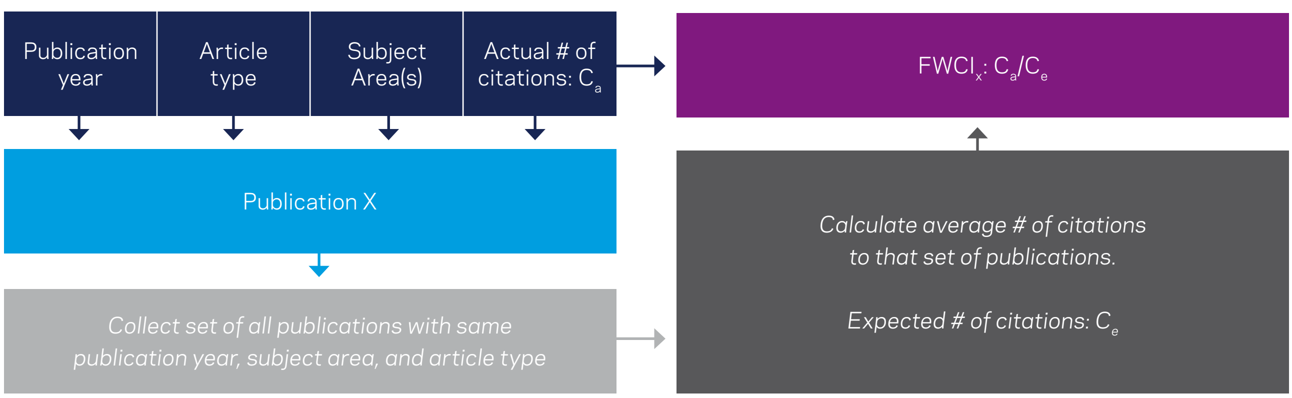
$V(t_0)$: start value
$V(t_n)$: finish value
$t_n - t_0$: number of years

Citation is a formal reference to earlier work made in an article or patent, frequently to other journal articles. A citation is used to credit the originator of an idea or finding and is usually used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by an article from subsequently published articles is a proxy of the quality or importance of the reported research.

Downloads are defined as either downloading a PDF of an article on ScienceDirect, Elsevier's full-text platform, or looking at the full-text online on ScienceDirect without downloading the actual PDF. Views of abstracts were not included in this definition. Multiple views or downloads of the same article in the same format during a user session were filtered out, in accordance with the COUNTER Code of Practice Release 4.[109] ScienceDirect provides download data for approximately 16% of the articles indexed in Scopus. It was assumed that user downloading behavior across countries does not systematically differ between online platforms. Field-weighted download impact (FWDI) was calculated from these data according to the same principles applied to the calculation of field-weighted citation impact (FWCI).

Field-Weighted Citation Impact (FWCI) is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review, or conference proceeding paper), publication year, and subject field. Where the article is classified in two or more subject fields, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.00 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (reviews typically attract more citations than research articles, for example) as well as subject-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

Field-Weighted Citation Impact (FWCI)



When FWCI is used as a snapshot, an unweighted variable window is applied. The FWCI value for “2008,” for example, is comprised of articles published in 2008 and their FWCI in the period 2008-2012, while for “2012,” it is comprised of articles published in 2012 and their FWCI in 2012 alone. When FWCI is used in trend analysis, a weighted moving window is applied. The FWCI value for “2010,” for example, is comprised of the weighted average of the unweighted variable FWCI values for 2008 and 2012 (weighted 13.3% each), 2009 and 2011 (weighted 20% each), and 2010 (weighted 33.3%). The weighting applies in the same ratios for previous years also. However, for 2011 and 2012, it is not possible to extend the weighted average by two years on either side, so weightings are readjusted across the remaining available values.

Field-Weighted Download Impact (FWDI) is an indicator of mean usage, and compares the actual number of downloads of an article with the expected number of downloads for articles of the same document type (article, review, or conference proceeding paper), publication year, and subject field. Where the article is classified in two or more subject fields, the harmonic mean of the actual and expected download rates is used. The indicator is therefore always defined with reference to a global baseline of 1.00 and intrinsically accounts for differences in download accrual over time, differences in download rates for different document types, as well as subject-specific differences in download frequencies overall and over time and document types. The principles applied to the calculation of FWDI are the same as that for calculating field-weighted citation impact (FWCI) detailed above.

Highly cited articles (unless otherwise indicated) are those in the top-cited X% of all articles published and cited in a given period. We report on highly cited articles in the top 1%, and top 10%.

International Collaboration (i.e., research collaboration) in this report is indicated by articles with at least two different countries listed in the authorship byline. Publications are assigned to different collaboration types using the following cascading decision tree:

Multiple authors? ↓ *Yes*	*No* →	Single authorship
Multiple countries? ↓ *No*	*Yes* →	International collaboration
Multiple institutions? ↓ *No*	*Yes* →	National collaboration
Institutional collaboration		

Journal is a peer-reviewed periodical in which scholarship relating to a particular research field is published, and is the primary mode of dissemination of knowledge in many fields. Research findings may also be published in conference proceedings, reports, monographs, and books, and the significance of these as an output channel varies between fields.

Research and Development (R&D) is any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture, and society, and the use of this knowledge to devise new applications. R&D includes fundamental research, applied research in such fields as agriculture, medicine, industrial chemistry, and experimental development work leading to new devices, products, or processes.

Sectors in this report refer to the different organization types used to categorize institutional affiliations. The main sectors are:

Academic	universities, colleges, medical schools, and research institutes
Corporate	corporate and law firms
Government	government and military organizations
Medical	hospitals
Other	non-governmental organizations, other non-profit organizations, foundations

[109] http://www.projectcounter.org/r4/COPR4.pdf

APPENDIX D
COUNTRIES INCLUDED IN DATA SOURCES

Countries and their ISO 3-character codes.

Country	ISO 3-Character Code	Comparator group	EU28	EU41
Albania	ALB			●
Austria	AUT		●	●
Australia	AUS			
Austria	AUT			
Belgium	BEL	●	●	●
Bosnia and Herzegovina	BIH			●
Brazil	BRA			
Bulgaria	BGR		●	●
Canada	CAN	●		
China	CHN	●		
Croatia	HRV		●	●
Cyprus	CYP		●	●
Czech republic	CZE		●	●
Denmark	DNK		●	●
Estonia	EST		●	●
Faroe Islands	FRO			●
Finland	FIN		●	●
France	FRA	●	●	●
Germany	DEU	●	●	●
Ghana	GHA			
Greece	GRC		●	●
Hong Kong	HKG			
Hungary	HUN		●	●
Iceland	ISL			●
India	IND			
Ireland	IRL		●	●
Israel	ISR			●
Italy	ITA	●	●	●
Japan	JPN	●		
Latvia	LVA		●	●
Liechtenstein	LIE			●
Lithuania	LTU		●	●
Luxembourg	LUX		●	●
Macedonia, the former Yugoslav Republic of	MKD			●
Malta	MLT		●	●
Mexico	MEX			
Moldova, Republic of	MDA			●
Montenegro	MNE			●
Netherlands	NLD	●	●	●

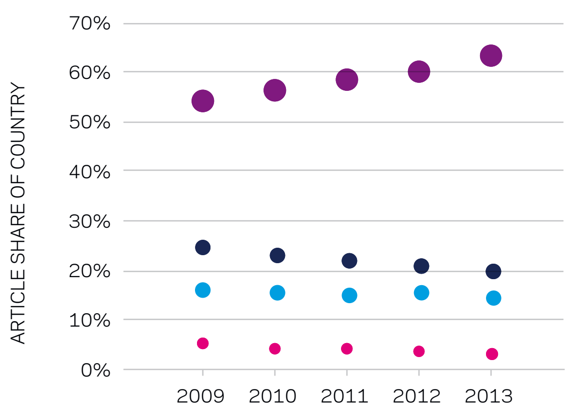
Country	ISO 3-Character Code	Comparator group	EU28	EU41
New Zealand	NZL			
Norway	NOR			●
Poland	POL	●	●	●
Portugal	PRT		●	●
Romania	ROU		●	●
Russian Federation	RUS			
Saudi Arabia	SAU			
Serbia	SRB			●
Singapore	SGP			
Slovakia (Slovak Republic)	SVK		●	●
Slovenia	SVN		●	●
South Korea	KOR			
Spain	ESP	●	●	●
Sweden	SWE	●	●	●
Switzerland	CHE	●		●
Taiwan	TWN			
Thailand	THA			
Turkey	TUR	●		●
United Kingdom	UK	●	●	●
United States	USA	●		

APPENDIX E
COLLABORATION TYPES WITHIN COMPARATOR COUNTRIES

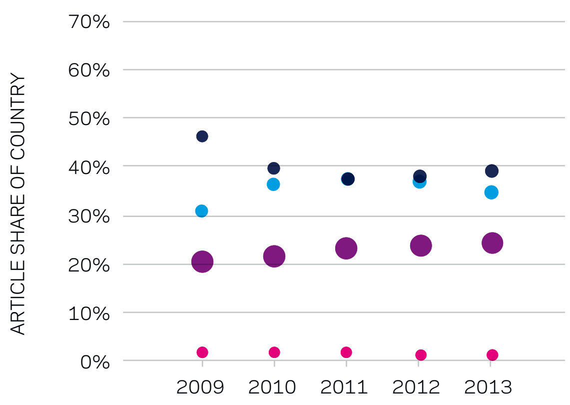
Figures below show the share of articles for brain and neuroscience the key countries by co-authorship type, 2009-2013. Bubble size is proportional to field-weighted citation impact (FWCI).

International National Institutional Single Author

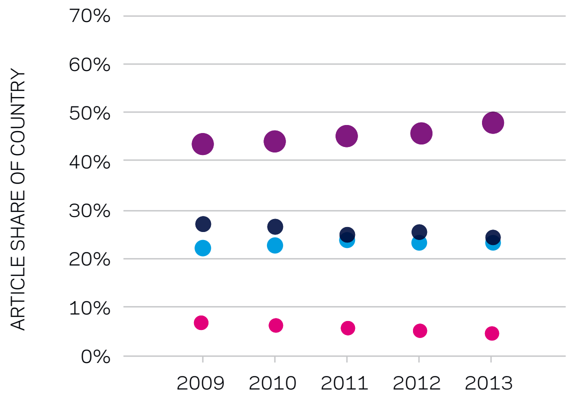
BELGIUM



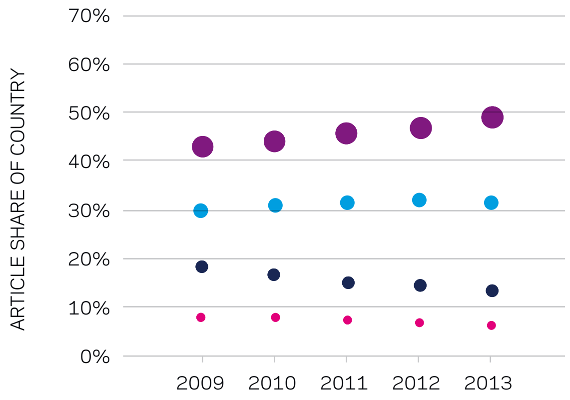
CHINA

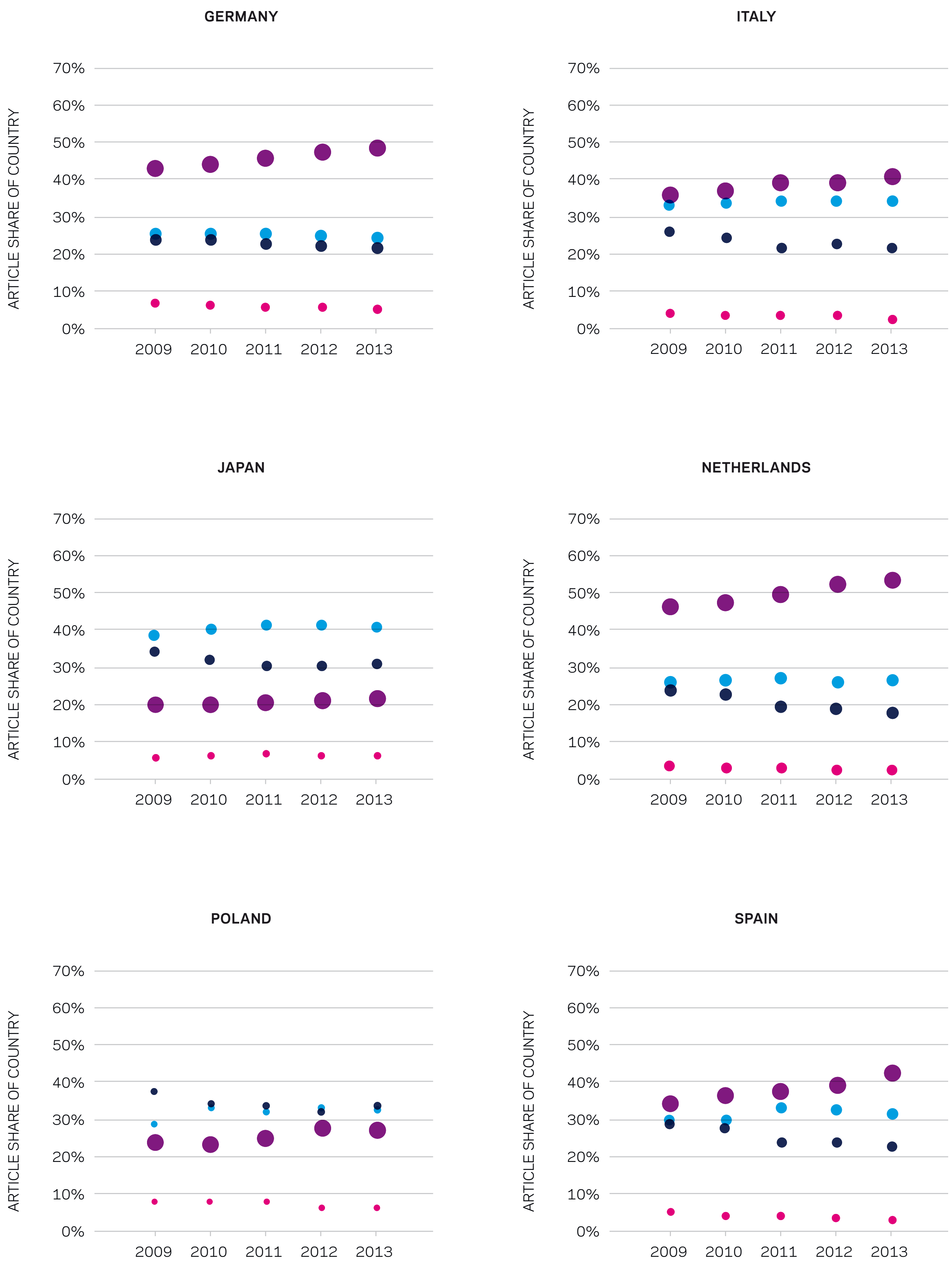


CANADA



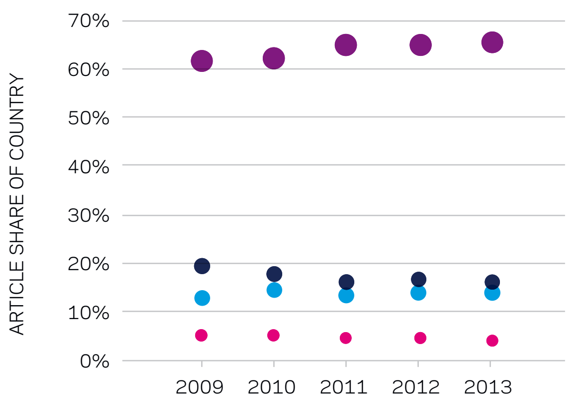
FRANCE



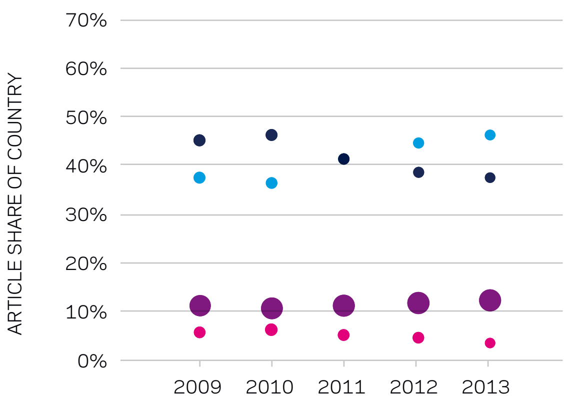

GERMANY
ITALY
JAPAN
NETHERLANDS
POLAND
SPAIN
ARTICLE SHARE OF COUNTRY
70%
60%
50%
40%
30%
20%
10%
0%
2009
2010
2011
2012
2013

SWEDEN

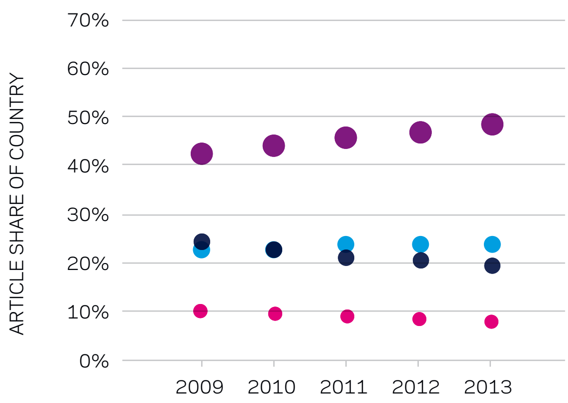
SWITZERLAND



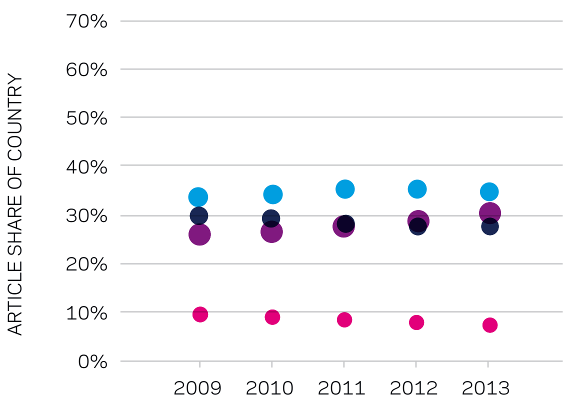
TURKEY



UNITED KINGDOM



UNITED STATES



APPENDIX F
LIST OF COLLABORATION PAIRS

Major country partnerships in brain and neuroscience research, 2009-2013

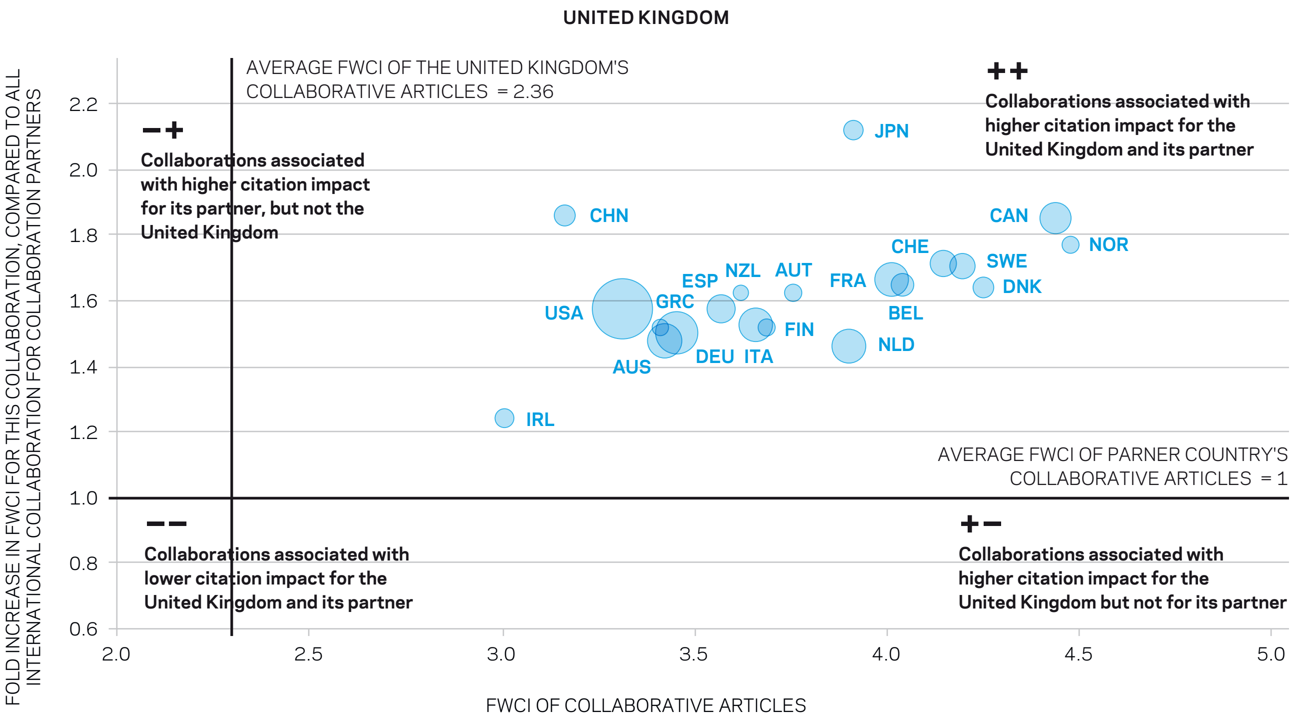
Top 20 pairings sorted by (a) count of co-authored articles (left table), and (b) Salton's Index (right table).

Partner A	Partner B	Co-authored articles	FWCI of co-authored articles	Salton's Index
UK	USA	24,695	3.31	0.0184
CAN	USA	22,186	3.01	0.0219
DEU	USA	19,981	3.26	0.0153
CHN	USA	18,351	1.90	0.0083
DEU	UK	12,158	3.46	0.0178
ITA	USA	12,149	3.19	0.0121
FRA	USA	11,573	3.65	0.0104
USA	AUS	10,804	3.38	0.0121
JPN	USA	10,441	2.38	0.0083
NLD	USA	9,443	3.83	0.0124
UK	AUS	8,041	3.43	0.0173
UK	NLD	7,810	3.90	0.0197
ESP	USA	7,718	3.27	0.0082
FRA	UK	7,715	4.01	0.0133
CHE	DEU	7,668	2.86	0.0231
UK	ITA	7,660	3.66	0.0146
CHE	USA	7,565	3.53	0.0116
USA	KOR	6,723	2.10	0.0075
DEU	NLD	6,637	4.03	0.0172
CAN	UK	6,601	4.44	0.0125

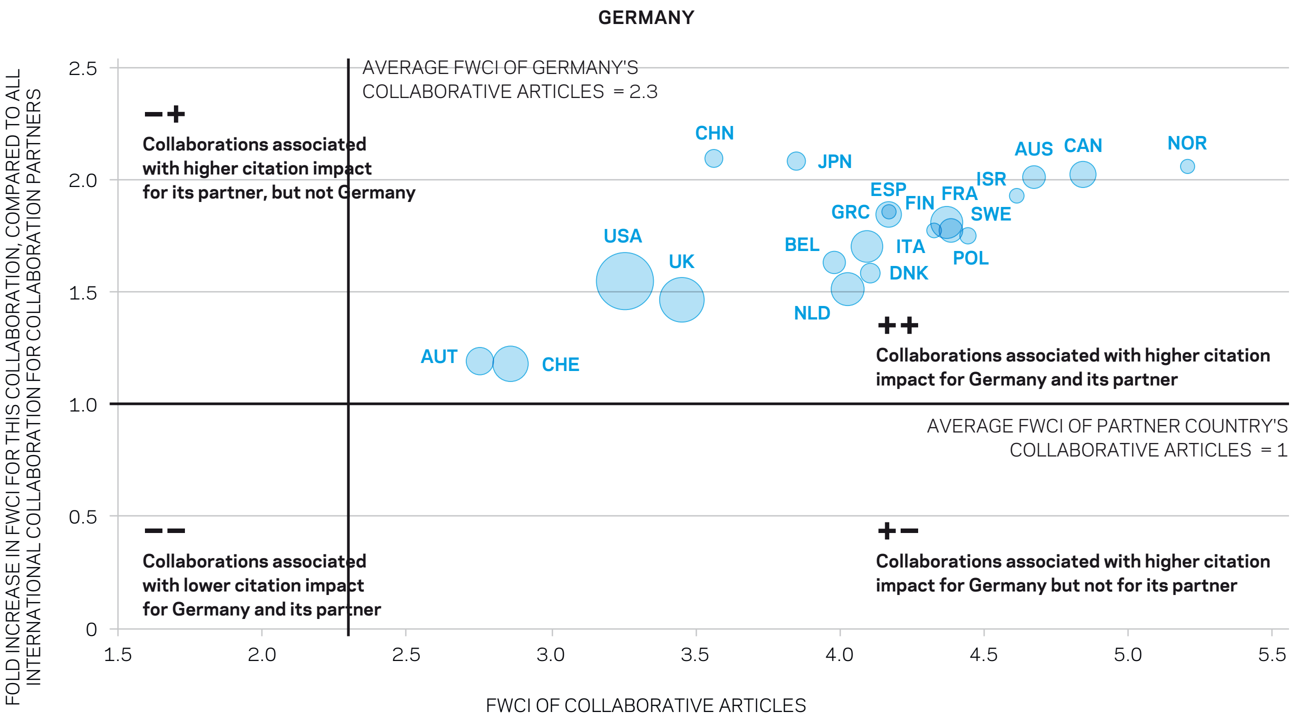
Partner A	Partner B	Co-authored articles	Salton's Index
CHE	DEU	7,668	0.0231
CAN	USA	22,186	0.0219
UK	NLD	7,810	0.0197
AUT	DEU	4,578	0.0188
UK	USA	24,695	0.0184
DEU	UK	12,158	0.0178
UK	AUS	8,041	0.0173
DEU	NLD	6,637	0.0172
DEU	USA	19,981	0.0153
UK	ITA	7,660	0.0146
UK	SWE	4,364	0.0138
CHE	UK	4,691	0.0138
FRA	UK	7,715	0.0133
CAN	UK	6,601	0.0125
NLD	USA	9,443	0.0124
USA	AUS	10,804	0.0121
ITA	USA	12,149	0.0121
DEU	ITA	6,130	0.0120
CHE	USA	7,565	0.0116
FRA	ITA	4,985	0.0114

The table above presents a more nuanced view of international collaboration in brain and neuroscience research on the basis of Salton's Index. While some of the same collaborations are still represented as being of a significant relative magnitude (such as Canada with the US and UK with the US), some much smaller but very close collaborative ties are brought to the fore, such as those between Switzerland and Germany, or between UK and the Netherlands. Collaborations between Canada and the UK appear to have the highest impact, with the highest field-weighted citation impact (FWCI) in both tables above.

Collaboration quadrants for the UK and Germany



The above chart shows the citation impact of collaborative outputs in brain and neuroscience research between the UK and the 20 largest collaborating countries, 2009–2013. Collaborations with all the top 20 partners were beneficial in terms of citation impact for both the UK and its partners. Source: Scopus.



The above chart shows the citation impact of collaborative outputs in brain and neuroscience research between Germany and the 20 largest collaborating countries, 2009–2013. Collaborations with all the top 20 partners were beneficial in terms of citation impact for both Germany and its partners. Source: Scopus.

APPENDIX G
SUBJECT CLASSIFICATION

All Science Journal Classification (ASJC)

27 main subject areas, including Neuroscience, and more than 330 sub-disciplines.

General

Agricultural and Biological Sciences (all)

Agricultural and Biological Sciences (miscellaneous)
Agronomy and Crop Science
Animal Science and Zoology
Aquatic Science
Ecology, Evolution, Behavior and Systematics
Food Science
Forestry
Horticulture
Insect Science
Plant Science
Soil Science

Arts and Humanities (all)

Arts and Humanities (miscellaneous)
History
Language and Linguistics
Archaeology
Classics
Conservation
History and Philosophy of Science
Literature and Literary Theory
Museology
Music
Philosophy
Religious studies
Visual Arts and Performing Arts

Biochemistry, Genetics and Molecular Biology (all)

Biochemistry, Genetics and Molecular Biology (miscellaneous)
Ageing
Biochemistry
Biophysics
Biotechnology
Cancer Research
Cell Biology
Clinical Biochemistry
Developmental Biology
Endocrinology
Genetics
Molecular Biology
Molecular Medicine
Physiology
Structural Biology

Business, Management and Accounting (all)

Business, Management and Accounting (miscellaneous)
Accounting
Business and International Management
Management Information Systems
Management of Technology and Innovation
Marketing
Organizational Behavior and Human Resource Management
Strategy and Management
Tourism, Leisure and Hospitality Management
Industrial relations

Chemical Engineering (all)

Chemical Engineering (miscellaneous)
Bioengineering
Catalysis
Chemical Health and Safety
Colloid and Surface Chemistry
Filtration and Separation
Fluid Flow and Transfer Processes
Process Chemistry and Technology

Chemistry (all)

Chemistry (miscellaneous)
Analytical Chemistry
Electrochemistry
Inorganic Chemistry
Organic Chemistry
Physical and Theoretical Chemistry
Spectroscopy

Computer Science (all)

Computer Science (miscellaneous)
Artificial Intelligence
Computational Theory and Mathematics
Computer Graphics and Computer-Aided Design
Computer Networks and Communications
Computer Science Applications
Computer Vision and Pattern Recognition
Hardware and Architecture
Human-Computer Interaction
Information Systems
Signal Processing
Software

Decision Sciences (all)

Decision Sciences (miscellaneous)
Information Systems and Management
Management Science and Operations Research
Statistics, Probability and Uncertainty

Earth and Planetary Sciences (all)

Earth and Planetary Sciences (miscellaneous)
Atmospheric Science
Computers in Earth Sciences
Earth-Surface Processes
Economic Geology
Geochemistry and Petrology
Geology
Geophysics
Geotechnical Engineering and Engineering Geology
Oceanography
Paleontology
Space and Planetary Science
Stratigraphy

Economics, Econometrics and Finance (all)
Economics, Econometrics and Finance (miscellaneous)
Economics and Econometrics
Finance

Energy (all)
Energy (miscellaneous)
Energy Engineering and Power Technology
Fuel Technology
Nuclear Energy and Engineering
Renewable Energy, Sustainability and the Environment

Engineering (all)
Engineering (miscellaneous)
Aerospace Engineering
Automotive Engineering
Biomedical Engineering
Civil and Structural Engineering
Computational Mechanics
Control and Systems Engineering
Electrical and Electronic Engineering
Industrial and Manufacturing Engineering
Mechanical Engineering
Mechanics of Materials
Ocean Engineering
Safety, Risk, Reliability and Quality
Media Technology
Building and Construction
Architecture

Environmental Science (all)
Environmental Science (miscellaneous)
Ecological Modelling
Ecology
Environmental Chemistry
Environmental Engineering
Global and Planetary Change
Health, Toxicology and Mutagenesis
Management, Monitoring, Policy and Law
Nature and Landscape Conservation
Pollution
Waste Management and Disposal
Water Science and Technology

Immunology and Microbiology (all)
Immunology and Microbiology (miscellaneous)
Applied Microbiology and Biotechnology
Immunology
Microbiology
Parasitology
Virology

Materials Science (all)
Materials Science (miscellaneous)
Biomaterials
Ceramics and Composites
Electronic, Optical and Magnetic Materials
Materials Chemistry
Metals and Alloys
Polymers and Plastics
Surfaces, Coatings and Films

Mathematics (all)
Mathematics (miscellaneous)
Algebra and Number Theory
Analysis
Applied Mathematics
Computational Mathematics
Control and Optimization
Discrete Mathematics and Combinatorics
Geometry and Topology
Logic
Mathematical Physics
Modelling and Simulation
Numerical Analysis
Statistics and Probability
Theoretical Computer Science

Medicine (all)
Medicine (miscellaneous)
Anatomy
Anesthesiology and Pain Medicine
Biochemistry, medical
Cardiology and Cardiovascular Medicine
Critical Care and Intensive Care Medicine
Complementary and alternative medicine
Dermatology
Drug guides
Embryology
Emergency Medicine
Endocrinology, Diabetes and Metabolism
Epidemiology
Family Practice
Gastroenterology
Genetics (clinical)
Geriatrics and Gerontology
Health Informatics
Health Policy
Hematology
Hepatology
Histology
Immunology and Allergy
Internal Medicine
Infectious Diseases
Microbiology (medical)
Nephrology
Clinical Neurology
Obstetrics and Gynecology
Oncology
Ophthalmology
Orthopedics and Sports Medicine
Otorhinolaryngology
Pathology and Forensic Medicine
Pediatrics, Perinatology and Child Health
Pharmacology (medical)
Physiology (medical)
Psychiatry and Mental health
Public Health, Environmental and Occupational Health
Pulmonary and Respiratory Medicine
Radiology Nuclear Medicine and imaging
Rehabilitation
Reproductive Medicine
Reviews and References, Medical
Rheumatology
Surgery
Transplantation
Urology

Neuroscience (all)
Neuroscience (miscellaneous)
Behavioral Neuroscience
Biological Psychiatry
Cellular and Molecular Neuroscience
Cognitive Neuroscience
Developmental Neuroscience
Endocrine and Autonomic Systems
Neurology
Sensory Systems

Nursing (all)
Nursing (miscellaneous)
Advanced and Specialized Nursing
Assessment and Diagnosis
Care Planning
Community and Home Care
Critical Care
Emergency

Fundamentals and Skills
Gerontology
Issues, Ethics and Legal Aspects
Leadership and Management
LPN and LVN
Maternity and Midwifery
Medical-Surgical
Nurse Assisting
Nutrition and Dietetics
Oncology (nursing)
Pathophysiology
Pediatrics
Pharmacology (nursing)
Psychiatric Mental Health
Research and Theory
Review and Exam Preparation

Pharmacology, Toxicology and Pharmaceutics (all)

Pharmacology, Toxicology and Pharmaceutics (miscellaneous)
Drug Discovery
Pharmaceutical Science
Pharmacology
Toxicology

Physics and Astronomy (all)

Physics and Astronomy (miscellaneous)
Acoustics and Ultrasonics
Astronomy and Astrophysics
Condensed Matter Physics
Instrumentation
Nuclear and High Energy Physics
Atomic and Molecular Physics and Optics
Radiation
Statistical and Nonlinear Physics
Surfaces and Interfaces

Psychology (all)

Psychology (miscellaneous)
Applied Psychology
Clinical Psychology
Developmental and Educational Psychology
Experimental and Cognitive Psychology
Neuropsychology and Physiological Psychology
Social Psychology

Social Sciences (all)

Social Sciences (miscellaneous)
Archaeology
Development
Education
Geography, Planning and Development
Health (social science)
Human Factors and Ergonomics
Law
Library and Information Sciences
Linguistics and Language
Safety Research
Sociology and Political Science
Transportation
Anthropology
Communication
Cultural Studies
Demography
Gender Studies
Life-span and Life-course Studies
Political Science and International Relations
Public Administration
Urban Studies

Veterinary (all)

Veterinary (miscellaneous)
Equine
Food Animals
Small Animals
Dentistry (all)
Dentistry (miscellaneous)
Dental Assisting
Dental Hygiene
Oral Surgery
Orthodontics
Periodontics

Health Professions (all)

Health Professions (miscellaneous)
Chiropractics
Complementary and Manual Therapy
Emergency Medical Services
Health Information Management
Medical Assisting and Transcription
Medical Laboratory Technology
Medical Terminology
Occupational Therapy
Optometry
Pharmacy
Physical Therapy, Sports Therapy and Rehabilitation
Podiatry
Radiological and Ultrasound Technology
Respiratory Care
Speech and Hearing

About

This report was prepared and published by Elsevier's Analytical Services, part of the Elsevier Research Intelligence portfolio of products and services, which serve research institutions, government agencies, and funders. Whether your institution is conducting research or funding it, Elsevier Research Intelligence provides the objective and analytical insight needed to improve your ability to establish, execute, and evaluate national and institutional research strategy.

For more information about Elsevier Research Intelligence, please visit: elsevier.com/research-intelligence.

Notes

ELSEVIER