Worldwide trends in brain research: A bibliometric analysis

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Over the last 80 years, brain research has gained a lot of traction, with recent advances such as the sequencing of the human genome, the development of tools for mapping neuronal connections, the improvement of neuroimaging technology, and the rise of nanoscience. This paper aims to determine how brain research has evolved over time in terms of papers and impact among countries, and how those various trends vary by areas of brain research. Our results show that over the past 30 years, the number of brain-related papers has grown at a faster pace than the number of papers from all disciplines combined with China being at the forefront of this growth. Different patterns of specializations among countries and funders have also emerged.

1. Introduction

Brain disorders exert a significant and increasing global burden with varying opportunities for prevention and intervention (Feigin et al., 2019; Rehm & Shield, 2019). Over the last 80 years, brain research has gained a lot of traction, culminating in the 1990s which was named “The Decade of the Brain” by President Bush to enhance the visibility of brain research and due to several major breakthroughs related to the brain and the nervous system (Library of Congress, 2020). In the 2000s, the World Health Organization (WHO) underlined the importance of brain and mental health research in the context of a worldwide increase in mental health and neurological conditions. More recently, the science academies of the G7 nations along with seven other scientific academies urged world leaders to develop global brain resources in order to understand, protect, and develop global brain resources (G-Science Academies, 2016). This attention on brain research has led to recent advances such as the sequencing of the human genome, the development of cutting-edge tools for mapping neuronal connections, the increase in resolution and quality of neuroimaging technology, and the rise of nanoscience which have created great opportunities to understand how the brain works in health and disease and integrate these various new methods across scientific fields (NIH, 2021). Brain research has advanced our understanding of the biological substrates of
human behavior and its perturbation across a variety of neurophysiological states and disorders. It comprises a diversity of research themes such as mental health, brain health, cognitive function, and basic brain function.

Bibliometrics have previously been used in several articles that attempted to study general brain research (Buchan et al., 2016; Yeung et al., 2017a; Yeung et al., 2017b), or specific brain research topics such as Alzheimer’s disease (Chen et al., 2014; Dong et al., 2019), neuroimaging (Yeung et al., 2019; Wu et al., 2020), brain-computer interfaces (Hu et al., 2016), epilepsy (Wang et al., 2019), microbiota-gut-brain (Zyoud et al., 2019), neuropharmacology (Yeung et al., 2018; Duan et al., 2020), deep brain stimulation (Hu et al., 2017), brain injuries (Li et al., 2018; Qi et al., 2020; Moigani et al., 2020), neuroethics (Leefmann et al., 2016), neuropathic pain (Chen & Wang, 2020), and music (Albusac-Jorge & Giménez-Rodriguez, 2015). The evolution of brain research in specific geographic areas such as South America, Brazil, and Saudi Arabia have also been covered (Hoppen & Vanz, 2016; Alhibshi et al., 2020; Forero et al., 2020). However, there currently is no recent comprehensive overview of the evolution of brain research and its various specialties over a long period of time. This paper aims to determine (1) how brain research has evolved over time in terms of papers, (2) country rankings in terms of papers and impact, (3) how those various trends vary by areas of brain research.

2. Methods
Data for this paper were drawn from Clarivate Analytics’ Web of Science (WoS) for a 30-year period (1991-2020). The lower bound (1991) of the period analyzed was selected as it is the year when papers’ keywords and abstracts began to be indexed in the WoS. We used a relatively broad definition of brain research, which includes papers published in 513 journals (Appendix 1) as well as those retrieved using a set of 247 keywords and expressions (Appendix 2) chosen by experts in the field and validated. The 513 core brain journals were manually selected based on their title and topic and included most journals indexed in the Neurology & Neurosurgery subfield from the classification developed by the Patent Board (Hamilton, 2003). Keywords were chosen following the method developed by Archambault et al. (2009). Finally, to reduce false positives, we limited the analysis to articles published in journals from fields of biomedical research, clinical medicine, health, and psychology, as well as the subfield of computer science. The final set of papers is based on all papers published in the 513 core journals, as well as the papers retrieved using the set of 247 keywords and published outside the core journals. It totals 2,467,708 papers, which represents 7% of all 33,608,813 papers indexed in the Web of Science over the 1991-2020 period.

Three indicators are used in the analysis: number of papers, specialization, and research impact. We focus on the number of papers published as an indicator of the brain research activity of countries. Each country’s percentage of all global papers is obtained by dividing their number of papers by the distinct number of papers published in brain research at the world level. Specialization in brain research is obtained by dividing the proportion of publications of each country in brain research by the proportion of the world’s publications in brain research. For example, if a country A has 14% of its papers in brain research, but the percentage of brain research at the global level is 7%, the country would have a specialization index (SI) of 2. An SI value above 1 indicates the country has a higher percentage of brain research than would be expected, while an index value below 1 indicates the opposite. Research impact of countries in brain research
is obtained through the compilation of the average of relative citations (ARC), which considers the fact that papers across different disciplines and specialities have different citation potential (Sugimoto & Larivière, 2018).

3. Results
Figure 1 presents the evolution of the number of papers at the global level for the 1991-2020 period, both for all disciplines combined and for brain-related papers, and the percentage that brain research represents across all fields. The overall number of papers has grown exponentially over the last 30 years, from about 600,000 papers in 1991 to more than 2 million papers in 2020. The number of brain-related papers has grown faster than the number of papers of all disciplines combined, particularly between 1991 and 2011. During this period, the relative importance of brain research—that is, the proportion of brain-related papers across papers published in all disciplines combined—increased from 5% to 8% and has been relatively stable since then.

Figure 1. Number of papers (all disciplines combined and brain-related research) and percentage of brain-related research across all disciplines, 1991-2020.

The research output in the field is, however, quite heterogenous across countries. Figure 2 shows the distribution of brain-related research around the world, demonstrating a concentration in North America, Western Europe, and Oceania. Among the countries with a sizeable scientific output. The country with the highest level of specialization in brain research is the Netherlands, with an SI of 1.62, indicating that they perform 62% more brain research than expected. This is followed by Israel (1.46), Canada (1.45), the United States (1.41), Sweden (1.37), United Kingdom (1.31),
and Switzerland (1.30). At the other end of the spectrum, India (0.44), Iran (0.54), and China (0.60) are considerably less active than expected in brain research.

Figure 2. Specialization in brain research by country. Blue indicates that the country is relatively more active in brain research; orange indicates that the country is relatively less active in the field; grey indicates that the country is performing brain research in the same percentage as expected values. 2011-2020.

The relative contribution of countries in the field has varied significantly over the last three decades (Figure 3). The decline of the United States—also observed across all domains combined—is quite striking. While the country accounted for more than 47% of all brain-related papers in 1991, this percentage is now at 34%. Complementary to this decline is the rise of China’s research activities in the field, which rose from less than 1% at the beginning of this millennium to 17% in 2020 (a growth of 2750%). Other countries whose contribution to brain research is declining includes Japan, whose share of global papers has decreased from 10% in the late 1990s to 5% in 2020; France, which decreased from 6% in 1991 to 4% in 2020; and Germany, which decreased from 9% in the early 2000s to 8% in 2020. Many nations, particularly in Europe, are now taking increasing space in the field: the Netherlands (170% increase in share of papers over the period), Spain (252% increase), Switzerland (162% increase), and Belgium (156% increase). In other parts of the world, notable increase includes the Republic of Korea (4626% increase), Turkey (1036% increase), Brazil (508%) and India (387%).

Figure 3. Percentage of world papers in brain research, by country, 1991-2020. Web of Science database. The top 20 countries with the highest number of papers are presented.
We then sought to assess the contribution of these countries to different subcategories of brain research. Figure 4 demonstrates the SI for each of the five areas of brain research: biomedical research, covering the biological or physiological aspects of research; clinical medicine, covering the clinical aspects; computer science, covering deep-learning-related research; public health; and psychology. Given that the majority of papers in the brain research field are published in clinical medicine, most countries are relatively close to the average (i.e., 1) in this domain. In biomedical research, China, Germany, Japan, France, and India are relatively more active, while the US, the UK, Canada, and Australia are relatively less active. Psychology and public health follow a similar pattern, with Western countries often being specialized in those areas, and Asian countries being relatively less active. In computer science, the relative strength of Asian countries (China, Korea, India, and Taiwan) and Spain is noteworthy.

Figure 4. Specialization in brain research, by area and country, 2011-2020. Specialization is obtained by dividing each country’s percentage of world papers for a given area by their percentage of world papers for all areas combined. Blue (>1) indicates the country is relatively...
more active in the area; orange (<1) indicates the country is relatively less active in the area; grey (≈1) indicates the country is performing brain research in the same percentage as expected values.

<table>
<thead>
<tr>
<th>Country</th>
<th>Biomedical Research</th>
<th>Clinical Medicine</th>
<th>Computer Science</th>
<th>Health</th>
<th>Psychology</th>
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</thead>
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<tr>
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<tr>
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<td>Republic of Korea</td>
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<td>1.3</td>
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<td>1.0</td>
<td>0.7</td>
<td>0.7</td>
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<td>0.6</td>
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<td>Turkey</td>
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<td>1.3</td>
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</table>

Next, we calculated the scholarly impact of brain research papers for the top 20 countries with the highest number of papers (Figure 5). For all domains of brain research, this demonstrated an overall high scholarly impact for countries such as Denmark, the United Kingdom, the Netherlands, Switzerland, Sweden, and Belgium. However, many other countries have a strong scholarly index in specific categories of brain research, such as the United States, China, Canada, and Australia in the field of computer science.

Figure 5: Scholarly impact, by country and area, 2011-2020. ARC is obtained by dividing each papers’ number of citations by the average citation rate of papers published in the same speciality and year. Blue (>1) indicates a higher scientific impact in the area; orange (<1) indicates a lower scientific impact in the area; grey (≈1) indicates a scientific impact on par with the world average.
4. Discussion and conclusions

Our results show that over the past 30 years, the number of brain-related papers has grown at a faster pace than the number of papers from all disciplines combined, with the Western world leading the charge in terms of specialization. There are likely multiple factors contributing to this growth in the proportion of brain-related research compared to all other disciplines combined: (1) the growth in funding and brain-related initiatives (Grillner et al., 2016), (2) a growth in the various neuroimaging technologies that allow for more precise studies of brain-related phenomena (NIH, 2021), (3) endogenous growth within the discipline (i.e. due to new discoveries and theories), and (4) exogenous growth related to increased awareness (i.e. on mental health) and demands from aging societies. Results have also shown the variation in the research contribution of countries over the past three decades, including the steady decline of the United States of America as a superpower in brain research and China’s rise as a major player with a growth of 2750% over the past 20 years.
While previous articles have used bibliometrics to study various topics of brain research, our study is the first to offer a comprehensive overview of the evolution of brain research and its various specialties through over a long period of time. One of the main limitations of this study is the use of WoS as a bibliometrics source of data which may lead to an underestimation of regional and non-English scientific literature (Glänzel, 1996; Hicks, 1999; Archambault et al., 2006), especially in countries such as China where publishing in Chinese is strongly encouraged by funders and stakeholders, even more so since the beginning of the Covid-19 pandemic (Larivière et al., 2020). However, the effect of these policies has yet to make a considerable difference in the Chinese research ecosystem (Shu et al., 2022). Furthermore, in interpreting the results of this study, it should be noted that increased research output does not linearly reflect research progress. For example, mental health researchers have lamented the slow progress in treatment of mental disorders despite large investments in basic research (Torrey et al., 2021). With these caveats in mind, our findings provide a large scope snapshot of the evolution of brain research and its funding which may be used as a baseline for future studies on these topics.

Open science practices
Restrictions apply to the dataset used in this paper. The Web of Science data is owned by Clarivate Analytics. To obtain the bibliometric data in the same manner as authors (i.e. by purchasing them), readers can contact Clarivate Analytics at the following URL: https://clarivate.com/webofsciencegroup/solutions/web-of-science/contact-us/. Future versions of this paper may use open data sources or share and aggregated version of the dataset used.

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Author contributions
Conceptualization: MS, VL, CF, DK; Data curation: VL, DK, MS; Formal Analysis: VL, DK; Funding acquisition: VL, CF, MS; Investigation: MS; VL, CF; DK Methodology: VL, MS, CF, DK; Project administration: VL, CF; Resources: VL, CF; Supervision: VL, CF; Validation: MS, VL, CF, DK; Visualization: VL, MS; Writing – original draft: MS, JS, TS, VL; Writing – review & editing: MS, JS, TS, CF, VL, DK

Competing interests
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References


Appendix 1. Keywords used to retrieve papers outside the core journals

<table>
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<tr>
<th>BRAIN</th>
<th>NEUROGENESIS</th>
<th>HIPPOCAMPAL-APPLICATIONS</th>
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<td>WORKING-MEMORY</td>
<td>NEUROGENESIS</td>
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<td>PREFRONTAL CORTEX</td>
<td>STROKE</td>
<td>NEURONAL-ACTIVITY</td>
</tr>
<tr>
<td>CORTEX</td>
<td>MAJOR DEPRESSION</td>
<td>HUMAN CEREBRAL-CORTEX</td>
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<td>SUBVENTRICULAR ZONE</td>
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<td>POTENTIATION</td>
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<td>BASAL GANGLIA</td>
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Appendix 2. Core journals for which all papers are included in the analyses

A N A E Approche Neuropsychologique Des Apprentissages Chez L Enfant
Acs Chemical Neuroscience
Acta Neurobiologiae Experimentalis
Acta Neurochirurgica
Acta Neurologica Belgica
Acta Neurologica Scandinavica
Acta Neuropathologica
Acta Neuropathologica Communications
Acta Neuropsychiatrica
Acta Psychiatrica Scandinavica
Actas Luso-Espanolas De Neurologia Psiquiatria Y Ciencias Afines
Advances In Neuroimmunology
Advances In Neurology
Aging & Mental Health
Aging And Cognition
Aging Neuropsychology And Cognition
Aging Neuropsychology And Cognition
Aktuelle Neurologie
Alzheimer Disease & Associated Disorders
Alzheimers & Dementia
Alzheimers Research & Therapy
American Journal Of Electroneurodiagnostic Technology
American Journal Of Medical Genetics Part B-Neuropsychiatric Genetics
American Journal Of Neuroradiology
American Journal Of Psychiatry
Amyotrophic Lateral Sclerosis And Frontotemporal Degeneration
Amyotrophic Lateral Sclerosis And Other Motor Neuron Disorders
Annals Of Clinical And Translational Neurology
Annals Of Indian Academy Of Neurology
Annals Of Neurology
Annals Of Neurology
Annual Review Of Neuroscience
Applied Neuropsychology
Applied Neuropsychology-Adult
Applied Neuropsychology-Child
Aquivos De Neuro-Psiquiatria
Archives Of Clinical Neuropsychology
Archives Of Neurology
Asn Neuro
Audiology And Neuro-Otology
Auditory Neuroscience
Autism
Autonomic Neuroscience-Basic & Clinical
Baillieres Clinical Neurology
Behavioral And Brain Functions
Behavioral And Brain Sciences
Behavioral Neuroscience
Behavioural Brain Research
Behavioural Neurology
Biological Psychiatry
Biological Psychiatry-Cognitive Neuroscience And Neuroimaging
Biological Psychology
Bipolar Disorders
Bmc Neurology
Bmc Neurology
Bmc Neuroscience
Bmc Psychiatry
Brain
Brain & Development
Brain And Behavior
Brain And Cognition
Brain And Language
Brain Behavior And Evolution
Brain Behavior And Immunity
Brain Cell Biology
Brain Connectivity
Brain Imaging And Behavior
Brain Impairment
Brain Injury
Brain Pathology
Brain Research
Brain Research Bulletin
Brain Research Protocols
Brain Research Reviews
Brain Sciences
Brain Stimulation
Brain Structure & Function
Brain Structure & Function
Brain Topography
Brain Tumor Pathology
British Journal Of Neurosurgery
British Journal Of Psychiatry
Canadian Journal Of Neurological Sciences
Canadian Journal Of Neurological Sciences
Canadian Journal Of Psychiatry-Revue Canadienne De Psychiatrie
Cellular And Molecular Neurobiology
Cellular And Molecular Neurobiology
Central European Neurosurgery
Cerebellum
Cerebral Cortex
Cerebrovascular And Brain Metabolism Reviews
Ceska A Slovenska Neurologie A Neurochirurgie
Child Neuropsychology
Clinical EEG And Neuroscience
Clinical Neurology And Neurosurgery
Clinical Neuropathology
Clinical Neuropharmacology
Journal Of Parkinsons Disease
Journal Of Pineal Research
Journal Of Psychiatry & Neuroscience
Journal Of Psychiatry & Neuroscience
Journal Of Psychopharmacology
Journal Of Spinal Cord Medicine
Journal Of The American Academy Of Child And Adolescent Psychiatry
Journal Of The International Neuropsychological Society
Journal Of The International Neuropsychological Society
Journal Of The Neurological Sciences
Journal Of The Neurological Sciences
Journal Of The Neurological Sciences
Journl Of Neuroscience Psychology And Economics
Klinische Neurophysiologie
Lancet Neurology
Lancet Neurology
Language Cognition And Neuroscience
Learning & Memory
Metabolic Brain Disease
Mind Brain And Education
Minimally Invasive Neurosurgery
Molecular And Cellular Neuroscience
Molecular And Chemical Neuropathology
Molecular Autism
Molecular Brain
Molecular Brain Research
Molecular Neurobiology
Molecular Neurobiology
Molecular Neurodegeneration
Molecular Neurodegeneration
Molecular Psychiatry
Multiple Sclerosis And Related Disorders
Nature Clinical Practice Neurology
Nature Neuroscience
Nature Neuroscience
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Pediatric Neurology
Pediatric Neurology
Pediatric Neurosurgery
Perception
Perspectives On Developmental Neurobiology
Pharmacopsychiatry
Progress In Brain Research
Progress In Neurobiology
Progress In Neuro-Psychopharmacology & Biological Psychiatry
Progress In Veterinary Neurology
Psn-Psychiatrie Sciences Humaines Neurosciences
Psychiatry And Clinical Neurosciences
Psychiatry Research-Neuroimaging
Psychiatry Research-Neuroimaging
Psychological Medicine
Psychologie & Neuropsychiatrie Du Vieillissement
Psychology And Aging
Psychoneuroendocrinology
Psychoneuroendocrinology
Psychopharmacology
Respiratory Physiology & Neurobiology
Restorative Neurology And Neuroscience
Reviews In The Neurosciences
Revista De Neurologia
Revista Ecuatoriana De Neurologia
Revue De Neuropsychologie
Revue Neurologique
Rivista Di Neuroradiologia
Saggi-Neuropsicologia Infantile Psicopedagogia Riabilitazione
Schizophrenia Bulletin
Schizophrenia Research
Seminars In Neurology
Seminars In Neuroscience
Seminars In Pediatric Neurology
Social Cognitive And Affective Neuroscience
Social Neuroscience
Stereotactic And Functional Neurosurgery
Stroke
Stroke And Vascular Neurology
Surgical Neurology
Techniques In Neurosurgery