Scientometrics (2016) 109:121–141
DOI 10.1007/s11192-016-1919-0

Neurosciences in Brazil: a bibliometric study of main characteristics, collaboration and citations

Natascha Helena Franz Hoppen[1] · **Samile Andréa de Souza Vanz**[1]

Received: 6 December 2015 / Published online: 23 March 2016

Abstract Brazilian scientific output in the field of Neurosciences is analyzed based on articles indexed in Web of Science from 2006 to 2013 according to bibliometric indicators of production, collaboration, impact and keywords analysis. The growth rate of Brazilian scientific output is greater than global scientific production in the area, with a higher percentage of articles in English than other research areas in Brazil and Brazilian neuroscientists preferring to publish their work in foreign journals. However, Portuguese papers were also observed in domestic journals in connection mainly to one research focus—Psychiatry. Modes of production in the area are also transdisciplinary when analyzed within the scope of research topics, which branch into issues related to basic and experimental research as well as clinical research. In addition, the Brazilian Neurosciences output is highly concentrated to a small number of authors, regions, and particularly institutions, with most output coming from public universities in the southeastern and southern states. However, there is greater participation by the private sector than in other fields of knowledge (mainly private universities and hospitals). Interinstitutional collaboration occurs in 60.79 % and international collaboration in 29.40 %. Brazil's main partners in international collaboration are the USA, Colombia, Argentina and the UK. With regard to citations, journals that most cite Brazilian Neurosciences are US, English and English-language Dutch publications, but the citing authors are linked to institutions on all continents of the world. It concludes that global reach and accelerated productivity growth does not translate into excellent impact. Thus, it is suggested to conduct further studies to determine why research is scarce in the northern and northeastern states.

Keywords Brazil · Brazilian science · Scientific production · Neurosciences research · Research assessment · Collaboration analysis · Citation analysis

✉ Natascha Helena Franz Hoppen
na.hoppen@hotmail.com; natascha.hoppen@ufrgs.br

Samile Andréa de Souza Vanz
samilevanz@terra.com.br

[1] Universidade Federal do Rio Grande do Sul, Porto Alegre (Brazil), Av. Ramiro Barcelos, n. 2705, sala 214, Porto Alegre, RS CEP 90035007, Brazil

Mathematics Subject Classification 62-07 · 62Hxx

JEL Classification O32

Introduction

The field of Neurosciences has consolidated its importance from the late twentieth century to the present day. The 1990s were nicknamed the Decade of the Brain (Library of Congress 2000; Ventura 2010) due to major scientific discoveries about the brain and the nervous system, a phenomenon that was also evident into the large number of science publications disseminating the subject. In 2001, the World Health Organization issued a report highlighting a worldwide increase in mental and neurological diseases and the need to direct incentives at research and healthcare in fields pertaining to the brain and mind (World Health Organization [WHO] 2001). Neurosciences is, by definition, a field of knowledge encompassing different branches that study the nervous system and the brain (hence Neurosciences in the plural, since it refers to combination of several research areas).

Before the term Neurosciences came into use in Brazil, studies on the brain and its functioning were conducted in the Physiology Laboratories of brothers Alvaro and Miguel Ozório de Almeida, in the early nineteenth century, in the state of Rio de Janeiro (Timo-Iaria, n.d., Fundação Oswaldo Cruz, n.d.). In the middle of the century, followers of the Ozório de Almeida brothers took nervous system research to the state of São Paulo, and from there to the rest of the country. Nowadays, Neurosciences have gained importance in the country's science production for a number of reasons. Some of its most prominent researchers are neuroscientists such as Iván Izquierdo, identified as the most cited Brazilian researcher on Web of Science for almost twenty years (Myskiw and Yano 2012). Public and private sectors invest in setting up research centers in the field, such as Instituto do Cérebro (Institute of the Brain), affiliated with the Pontifícia Universidade Católica do Rio Grande do Sul and located in the South of the country, and Instituto Internacional de Neurociências de Natal Edmond e Lily Safra, located in the North. Additionally, Brazil is one of the fastest growing countries in terms of global Neurosciences productivity (Haustein et al. 2013).

Aware of the current importance of Neurosciences, researchers from other countries have conducted different bibliometric studies on the topic: China (Xu et al. 2003), Sweden (Glänzel et al. 2003), Cuba (Dorta-Contreras et al. 2008), India (Shahabudin 2013), Iran (Ashrafi et al. 2012) and Canada (Haustein et al. 2013). To date, Brazilian studies in the area show a qualitative bias and do not cover the entire national territory. This study aimed to identify and characterize Brazilian Neurosciences production through articles indexed on Web of Science from 2006 to 2013 in terms of journals and publishing language, and recurring themes and areas; establish where Brazilian Neurosciences research takes place (its authors, their institutional affiliation and in what regions of the country they are based); analyze national and international co-authorship; and finally, determine the impact of Neurosciences scientific output based on the number of citations received.

Methods

Due to the complexity of the area, special care was taken when defining the search strategy. A preliminary study was conducted to describe the search strategy that best encompassed this field in the country. To that end, strategies used in other bibliometric studies on Neurosciences were investigated in various databases (Xu et al. 2003; Glänzel et al. 2003; Dorta-Contreras et al. 2008; Shahabuddin 2013; Ashrafi et al. 2012;. Haustein et al. 2013). Next, the definition of the field according to Brazilian neuroscientists was analyzed, which shed light on the division adopted: in Brazil, research seems to be divided between "Basic Neurosciences" and "Clinical Neurosciences" (Bacheschi and Guerreiro 2004; Ventura 2004, 2010). An adaptation of the search strategy used by Dorta-Contreras et al. (2008) was adopted, which characterizes Neurosciences as the field of knowledge that studies the brain and diseases affecting it, thus narrowing the search for articles that include the subjects "Clinical Neurology", "Neuroimaging", "Neurosciences" and "Psychiatry" in the WC field (Web of Science Categories). In order to better characterize Neurosciences as it is understood by Brazilian researchers, the WC keywords "Psychology, Biological" were also included. This search strategy and its result were also validated with two experts (neuroscientists). All articles with at least one author affiliated with a Brazilian institution were retrieved.

The period studied (2006–2013) sought to cover the most recent years of scientific production. On July 26, 2014 we collected 9655 articles that constituted the main corpus of this survey. On August 26, 57,932 articles were collected, comprising the corpus of citing documents and on October 9, 2014, information was gathered on the number of Neurosciences articles from around the world and from each country that has collaborated with Brazil (according to the same search strategy).

We manually standardized the names of institutions, authors and states for the main corpus and institutions for the corpus of citing documents, using our research group's authorities list of authors and institutions. After cleaning the names, data were described, recorded, analyzed and presented using BibExcel, Philcarto, VOSviewer and Microsoft Excel. The software allowed for the calculation of absolute and relative bibliometric indicators and the production of maps and graphics that visually demonstrate different aspects of scientific production.

Results and discussion

Characteristics of Brazilian scientific output in neurosciences

Brazilian Neurosciences output grew on average 5.03 % per year over the survey period. A growth index was used (Haustein et al. 2013) to assess the performance of Brazil's productivity over the years and in relation to global Neurosciences productivity. This indicator is used to compare the increase in production of an entity (be it a country or an institution, for example), by dividing the total production in recent years by the total production in early years. The result is a number around 1 which identifies the growth or decline in what a research agent is producing compared with the recent performance of the agent itself. The index growth for Brazilian Neurosciences from 2006 to 2013 is 1.19, while the global index is 1.15. The rise in Brazilian Neurosciences output is also adjusted to linear growth

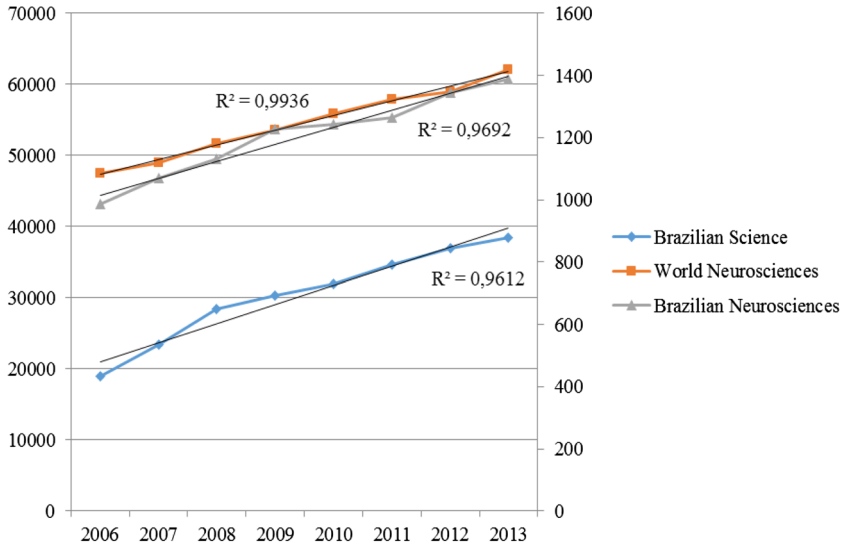


Fig. 1 Number of Brazilian Neurosciences articles per year on WoS from 2006 to 2013 compared with the growth of Brazilian science and world Neurosciences. *Source*: Survey data. Prepared with Microsoft Excel. *Note* Brazilian science and world Neurosciences lines are plotted by *right axis*. Brazilian Neurosciences line is plotted by the *left axis*

with $R^2 = 0.9692$ as can be seen in Fig. 1, which also shows world Neurosciences and Brazilian science on the same period for comparison proposes.

The constant growth in Brazilian scientific output observed in studies using the WoS database (Glänzel et al. 2006) occurs not only because of the increase in coverage of national journals in the database, but also due to a rise in scientific activity in Brazil and its productivity as a whole, as well as the increase in Brazil's contribution to total science production in Latin America and the world (Leta and Cruz 2003). In addition to the productivity growth of original articles (which make up the corpus of this research), Neurosciences is also identified as the third most productive area in review articles in Brazil, preceded only by Pharmacology and Chemistry, branches that interface with Neurosciences research (Almeida and Guimarães 2013).

In a recent study, Brazil was designated the seventh fastest growing country in Neurosciences production—behind only Iran (whose growth index is 2.43), China (1.78), South Korea (1.72), India (1.59), Ireland (1.56) and Portugal (1.44), in addition to being the 13th most active country in Neurosciences output in the world (Haustein et al. 2013). The leader in active production in this field is the United States of America (at least 37 % of everything published in Neurosciences is produced by an US author), followed by Germany and the United Kingdom.

The use of English in scientific publications is a requirement for those seeking to ensure visibility for their publications (Meadows 1999) and the Neurosciences area in Brazil seems to be trying to adapt to this reality: 96.02 % of papers were published in English, a higher percentage compared to the 80 % observed by Leta (2012) for Brazilian science published between 2001 and 2010 and indexed in Scopus and Web of Science databases. After English, the preferred languages for publishing among Brazilian researchers are

Portuguese (3.11 %) and Spanish (0.76 %). French, Italian and German languages were used in less than 0.1 % of articles.

The data show that the number of publications in Portuguese has gradually decreased, as has the variety of languages: recent years have seen a concentration of articles published in a single language, English. A Chi square test was performed in order to substantiate this finding. For the calculation, the Spanish, French, Italian and German languages (with values ranging from zero to five articles) were condensed into a single category: the so-called "Other languages" (see Table 1). Since the critical value of Chi square for 14 degrees of freedom and significance level of 5 % is equal to 23.685 and the value found is 273.53 (critical value $\chi^2 \geq \chi^2$ with p value <0.001, or more specifically, p value equal to 3.82E−50), the null hypothesis that the variables are independent is rejected. This means that the variables number of articles per language and years of research are not independent, that is, the variation in years has influenced the number of articles published in each language. There is a notable trend towards the predominance of English in publications and a decline in papers published in Portuguese.

The change in language settings for Brazilian Neurosciences publications can also be verified by analyzing the journals in which they were most published: the three Brazilian journals that previously accepted Portuguese-language articles recently announced they were changing their article submission requirements and would only accept English manuscripts (Revista Brasileira de Psiquiatria 2014; Revista de Psiquiatria Clínica 2014; Arquivos de Neuro-Psiquiatria n.d.). On the homepage of Revista Brasileira de Psiquiatria, for example, it is clear that the intention to publish in English is aimed at the journal's internationalization, since it asserts that its submission requirements are based on the Uniform Requirements for Manuscripts Submitted to Biomedical Journals: writing and editing for biomedical publications, edited by the International Committee of Medical Journal Editors (ICMJE).

The desired internationalization of Brazilian research, encouraged by recent national policies for higher education, seems to be present in Neurosciences publications: the only three journals that published in Portuguese—Arquivos de Neuro-Psiquiatria, Revista Brasileira de Psiquiatria and Revista de Psiquiatria Clínica—are also the only Brazilian journals located among the 471 that published Brazilian Neurosciences articles between 2006 and 2013. Of the journals that publish more Indian articles on Neurosciences, for

Table 1 Observed and estimated values for the number of articles in each language per year, using the Chi square test

Language	2006	2007	2008	2009	2010	2011	2012	2013	Total
English, observed and estimated	877	988	1092	1191	1197	1234	1319	1373	9271
	947	1028	1087	1178	1193	1214	1292	1332	–
Portuguese, observed and estimated	97	68	21	21	38	24	24	7	300
	31	33	35	38	39	39	42	43	–
Other languages, observed and estimated	12	15	19	15	7	6	3	7	84
	9	9	10	11	11	11	12	12	–
Total observed	986	1071	1132	1227	1242	1264	1346	1387	9655

Source: Survey data

Note: Values were rounded off in the table, but the calculation was performed with two decimal places for estimated values

Table 2 Comparison between publishing and citing journals for Brazilian Neurosciences articles published between 2006 and 2013, WoS

Journal title	Publishing ranking	No. of Brazilianpapers published	Citing ranking	No. of Brazilian papers cited	Country	Language	FI (2014)	Best Q
Arquivos de Neuro-Psiquiatria	1st	1338 (13.84 %)	5th	580 (1 %)	BRA	POR	0.843	Q3
Revista Brasileira de Psiquiatria	2nd	380 (3.93 %)	13th	340 (0.59 %)	BRA	MULT	1.765	Q3
Brain Research	3rd	294 (3.04 %)	7th	553 (0.95 %)	HOL	ENG	2.843	Q2
Neuroscience Letters	4th	286 (2.96 %)	8th	503 (0.87 %)	HOL	ENG	2.030	Q3
Behavioural Brain Research	5th	266 (2.75 %)	2nd	720 (1.24 %)	HOL	ENG	3.028	Q2
Neuroscience	6th	182 (1.88 %)	3rd	625 (1.08 %)	ENG	ENG	3.357	Q2
Neurochemical Research	7th	172 (1.78 %)	18th	245 (0.42 %)	USA	ENG	2.593	Q3
Pharmacology Biochem. & Behavior	8th	166 (1.72 %)	12th	342 (0.59 %)	ENG	ENG	2.781	Q2
Revista de Psiquiatria Clínica	9th	138 (1.43 %)	72th	126 (0.22 %)	BRA	POR	0.521	Q4
Epilepsy & Behavior	10th	118 (1.22 %)	9th	426 (0.74 %)	USA	ENG	2.257	Q2
Journal of Affective Disorders	11th	117 (1.21 %)	6th	554 (0.96 %)	HOL	ENG	3.383	Q2
Int. J. of Developmental Neuroscience	12th	113 (1.17 %)	57th	142 (0.25 %)	ENG	ENG	2.580	Q3
Brain Research Bulletin	13th	104 (1.08 %)	37th	183 (0.32 %)	USA	ENG	2.718	Q3
Physiology & Behavior	14th	101 (1.05 %)	28th	218 (0.38 %)	USA	MULT	2.976	Q2
Autonomic Neuroscience-Basic & Clinical	15th	91 (0.94 %)	107th	100 (0.17 %)	HOL	ENG	1.562	Q4
Metabolic Brain Disease	16th	89 (0.92 %)	116th	96 (0.17 %)	USA	ENG	2.638	Q3
Journal of Psychiatric Research	17th	82 (0.85 %)	19th	244 (0.42 %)	ENG	ENG	3.957	Q1
Neurochemistry International	18th	79 (0.82 %)	36th	187 (0.32 %)	ENG	ENG	3.092	Q2
Journal of Neuroscience Methods	19th	74 (0.77 %)	65th	135 (0.23 %)	HOL	ENG	2.025	Q3
Journal of Neuroscience	20th	73 (0.76 %)	4th	591 (1.02 %)	USA	ENG	6.344	Q1
Epilepsia	21th	72 (0.74 %)	15th	311 (0.54 %)	USA	ENG	4.571	Q1
Neurobiology of Learning and Memory	22th	67 (0.69 %)	44th	169 (0.29 %)	USA	ENG	3.652	Q1
Psychopharmacology	23th	67 (0.69 %)	14th	316 (0.55 %)	GER	ENG	3.875	Q1
Neurosurgery	24th	66 (0.68 %)	17th	250 (0.43 %)	USA	ENG	3.620	Q1
Neuropharmacology	25th	64 (0.65 %)	20th	243 (0.42 %)	ENG	ENG	5.106	Q1
Others	–	5056 (52.37 %)	–	47,292 (81.64 %)	–	–	–	–
Total	–	9665 (100 %)	–	57,932 (100 %)	–	–	–	–

Source: Survey data and JCR 2014 issue (Journal Citation Reports 2015c)

example, 14 out of 18 are national, over 77 % (Shahabuddin 2013). This finding also indicates a unique characteristic for Neurosciences compared with the rest of Brazilian science, as observed by Leta et al. (2006) and Leta et al. (2013): according to the authors, Brazilian researchers prefer to publish their work in "domestic" journals (national or Latin American), which can compromise the visibility of their work. However, remnants of this characteristic are evident in that the three domestic journals with the lowest impact factors together account for nearly 20 % (19.21 %) of publications. Table 2 shows the journals that most published Brazilian Neurosciences studies from 2006 to 2013 and are indexed in WoS (alongside their position as the journals that most cited Brazilian Neurosciences studies, discussed in the following section).

It is noteworthy that three national journals are edited in the same Brazilian state: São Paulo. In addition to being the wealthiest and most industrialized state in Brazil, São Paulo also has the highest rate of participation in research owing to the papers published during the study period: 52.47 % of papers had at least one author affiliated with a São Paulo research institution.

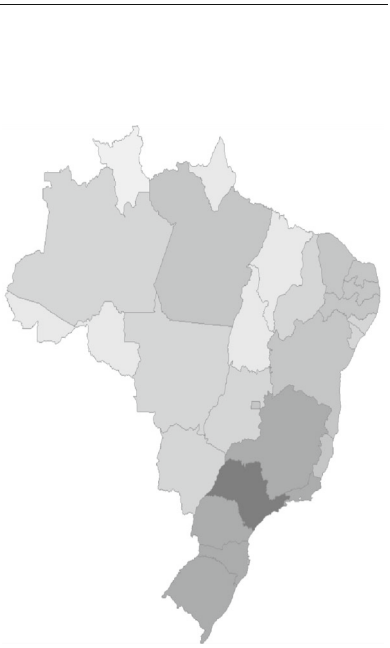
Table 3 and its corresponding figure show the scientific activity (number of publications) in Neurosciences in each Brazilian state and its uneven distribution across the national territory. It should be noted that, in the Northern region of the country, only one state produced an amount similar to that of Southern and Southeastern states: Pará (PA). The other states in the region are less productive, especially Amapá (AP), which produced only two articles, Acre (AC), which produced one, and Roraima (RR), which produced no papers.

The states of São Paulo (SP, 5066 articles), Rio Grande do Sul (RS, 1881 articles), Rio de Janeiro (RJ, 1189), Minas Gerais (MG, 855), Santa Catarina (SC, 718) and Paraná (PR, 485) are the most productive in the country in Neurosciences, all located close together in the South and Southeast. SP and RJ often appear on the domestic research ranking, which can be explained by their tradition in research and the amount of human resources devoted to it in these states, which pioneered Brain Physiology studies in Brazil (Timo-Iaria, n.d.). The already abundant productivity in the states of Rio Grande do Sul and Minas Gerais points to the stabilization of both in science, since they follow the same pattern of a 2003 study, when an increase was noted in the contribution of these states to national science (Leta and Cruz 2003).

The disparity in scientific productivity among nearby regions is a critical aspect, since such huge differences in scientific development between regions can be an obstacle to their development as a whole (Glänzel et al. 2006). Although some authors call for the allocation of research funds to groups, states or institutions that have shown good productivity or impact, it is assumed that the lack of research (or longtime incipiency) anywhere in the country undermines the development of neighboring regions and overburdens those already developed. When it comes to research in the field of health, this causes even more concern.

Over the 98 most productive institutions, the share of private institutions participating in Neurosciences research in Brazil is higher than in other fields at 43 %, most of which are private universities. This percentage is far higher than that recorded between 1991 and 2003, when only 5 % of private sector participation was observed for the whole production of science in Brazil (Leta et al. 2006). The 57 % corresponding to public institutions comprises 44 universities and 12 institutions of other types, such as public hospitals and research institutes.

Table 3 Brazilian states with number of Neurosciences articles published in WoS, 2006–2013, and their distribution across the Brazil

State	No. of articles	% in relation to collaborations	% in relation to total articles	Distribution across the Brazil
São Paulo	5066	42.96%	52.47%	
Rio Grande do Sul	1881	15.95%	19.48%	
Rio de Janeiro	1189	10.08%	12.31%	
Minas Gerais	855	7.25%	8.86%	
Santa Catarina	718	6.09%	7.44%	
Paraná	486	4.12%	5.03%	
Distrito Federal	398	3.38%	4.12%	
Pernambuco	227	1.93%	2.35%	
Bahia	183	1.55%	1.90%	
Ceará	179	1.52%	1.85%	
Rio Grande do Norte	160	1.36%	1.66%	
Pará	85	0.72%	0.88%	
Espírito Santo	71	0.60%	0.74%	
Paraíba	54	0.46%	0.56%	
Goiás	51	0.43%	0.53%	
Sergipe	45	0.38%	0.47%	
Piauí	41	0.35%	0.42%	
Mato Grosso	23	0.20%	0.24%	
Alagoas	21	0.18%	0.22%	
Mato Grosso do Sul	13	0.11%	0.13%	
Amazonas	13	0.11%	0.13%	
Maranhão	12	0.10%	0.12%	
Tocantins	11	0.09%	0.11%	
Rondônia	6	0.05%	0.06%	
Amapá	2	0.02%	0.02%	
Acre	1	0.01%	0.01%	
Roraima	0	0%	0%	

Source: Survey data. Map prepared with Philcarto

The top most productive institutions are public universities. Being a researcher in Brazil is strongly linked to teaching, which explains what was observed by Leta (2012): most of the country's researchers are employed in public universities, either state or federal. The private sector does not absorb the mass of researchers who graduate every year and those who are hired by the private sector are also linked to the teaching career. With this respect, Casani, Filippo, Garcia-Zorita and Sanz-Casado (2014) identify a global trend towards an increase in the number of private universities, many for-profit, due to the tendency to introduce market mechanisms into education. According to the authors, "University systems are in the midst of profound transformations and institutions are under growing competitive pressure to improve their performance.", which results in these private entities joining the sector (Casani et al. 2014, p. 48). However, the authors assert that these institutions, especially the for-profit ones, are much less involved in research than public institutions. Table 4 shows the top ten most productive Brazilian institutions.

Table 4 Top ten Brazilian institutions that produced Neurosciences articles indexed in WoS and their percentage in total number of papers, 2006–2013

Institution	No. of articles	% in relation to 9655	State	Type
(1st) Univ São Paulo	2968	30.74	SP	UPU
(2nd) Univ Fed Rio Grande Sul	1327	13.74	RS	UPU
(3rd) Univ Fed São Paulo	1310	13.57	SP	UPU
(4th) Univ Fed Rio de Janeiro	836	8.66	RJ	UPU
(5th) Univ Fed Minas Gerais	630	6.53	MG	UPU
(6th) Univ Estadual Campinas	556	5.76	SP	UPU
(7th) Univ Fed Santa Catarina	466	4.83	SC	UPU
(8th) Pont Univ Cat Rio Grande Sul	348	3.60	RS	UPRI
(9th) Univ Est Paulista Júlio Mesquita Filho	326	3.38	SP	UPU
(10th) Univ Fed Paraná	290	3.00	PR	UPU

Source: Survey data

Note: *UPU* Public university, *UPRI* Private university

It is true that "[…] the concentration of scientific output in a few institutions is not a phenomenon unique to our country, but occurs in virtually all countries and with more intensity in developing nations." (Leta and Cruz 2003, p. 143). However, Brazil seems to exhibit a greater concentration compared to other developing countries that are also regarded as emerging nations. In China, concentration in a few institutions is less intense: 18 institutions fail to produce 50 % of the total (Xu et al. 2003). In Iran, the most productive institution in Neurosciences accounts for 24.96 % (Ashrafi et al. 2012.), while in Brazil the lead institution corresponds to 30.74 % of everything produced nationally—Universidade de São Paulo (USP).

USP is also one of the 100 most productive institutions in the field worldwide and has a higher growth index than the global average (1.5 and 1.17, respectively), ahead even of the leading Neurosciences producer, Harvard University (which has a growth index of 1.19) (Haustein et al. 2013). Universidade de São Paulo is therefore unique in the area and its productive and competitiveness power can be channeled to other national institutions through collaborative partnerships in research.

The most productive authors are also from southern and southeastern Brazil. Each individual produced on average 2.45 articles, with a variance of 26.1 articles per author. The most productive author published 182 articles in the period. The 25 authors who published the most were present in 24.39 % of papers, almost ¼ of the entire output. On the other hand, approximately 16,421 authors published only once, which amounts to nearly 53 % of the total scope of the study.

Collaboration characteristics

There is some level of collaboration (at least two authors) in 98.57 % of Brazilian Neurosciences articles published between 2006 and 2013. On an institutional scale, collaboration is present in 60.79 % of papers, averaging 2.39 institutions per article and a standard deviation of 0.02. International collaboration occurs in 29.4 % of publications, averaging 1.5 countries per article and a standard deviation of 0.01, which can be explained by the

high rate of articles with a single country signing. The maximum number of countries that collaborated in the same article was 25 and the number of institutions was 55.

Figure 2a, b shows the cooperation between domestic and foreign institutions. In addition to proximity by collaboration frequency, the figure also shows the weight of the institutions in the number of articles produced in collaboration. Thirteen different clusters appear in the figure. The ten most productive Brazilian institutions are in the center of the picture (the circle on the left side of USP and below UNIFESP is Universidade Federal de Minas Gerais, and circle on the left side of UFRGS and above UNIFESP is Universidade Federal do Paraná[1]). The map shows that these institutions work together; however, they have different patterns of collaboration with other institutions, placing them in different clusters. It can also be observed that there are separate clusters for some regions of the country, indicating that geographical proximity can be a major factor in collaboration.

Universidade de São Paulo once again emerges as the university that most produces and most collaborates with other institutions on the national scene, although its strongest connections are also with other state universities in São Paulo. However, among the 100 most productive institutions in Neurosciences in the world, USP exhibits low collaboration, similar to the University of Tel Aviv (Israel), Seoul National University (South Korea) and other Japanese and Spanish institutions (Haustein et al. 2013). All these institutions are in countries whose official language is not English, and since this is the dominant language of science, it is inferred that language is also a major factor in collaboration.

The Instituto Nacional de Neurociências Edmond e Lily Safra is closer to foreign entities than national ones. On the map, it is close to the cluster composed exclusively of foreign institutions (in the middle of the left side). All of these collaborate primarily with Universidade de São Paulo. Harvard University is at the center of another cluster consisting largely of institutions outside Brazil, on the far left of the map. On the international scenario, with the most productive institutions worldwide, Harvard is at the center of collaboration, separating networks of US and European institutions (Haustein et al. 2013).

Foreign institutions that conducted studies in conjunction with Brazilian researchers are from 85 different countries/territories. In absolute figures, Brazilian co-authorship occurs mainly with European and North American countries: the most frequent collaboration is with the USA, which occurred in 13.92 % of papers published in international collaboration, followed by the United Kingdom (4.85 %), Canada (3.15 %), Germany (3.08 %), Spain (2.65 %), France (2.23 %), Italy (2.19 %), Australia (1.93 %), the Netherlands (1.21 %), Argentina (1.15 %), and others with less than 1 % collaboration. However, Brazil conducts research in conjunction with countries from all regions of the globe, albeit to a lesser extent than with the aforementioned nations.

The use of absolute data produces a more immediate picture, such as research fronts and countries that are central to collaboration networks (Luukkonen et al. 1993; Glänzel 2003). Conversely, relative data are used for inferences that take into account the particularities of each scenario, for example, the total output number for a country to assess the weight of its collaboration with another. Glänzel et al. (2006) classify collaboration strength as strong when Salton's cosine is greater than or equal to 2.5; average between 1 and 2.5; and weak, when the value is less than 1. Table 5 shows the countries with strong or average collaboration strength with Brazil, according to these criteria.

[1] The names of these institutions do not appear in the screen cap of the map because they are too close to other institutions, but they can be identified when directly viewed using the software by placing the mouse over the circles.

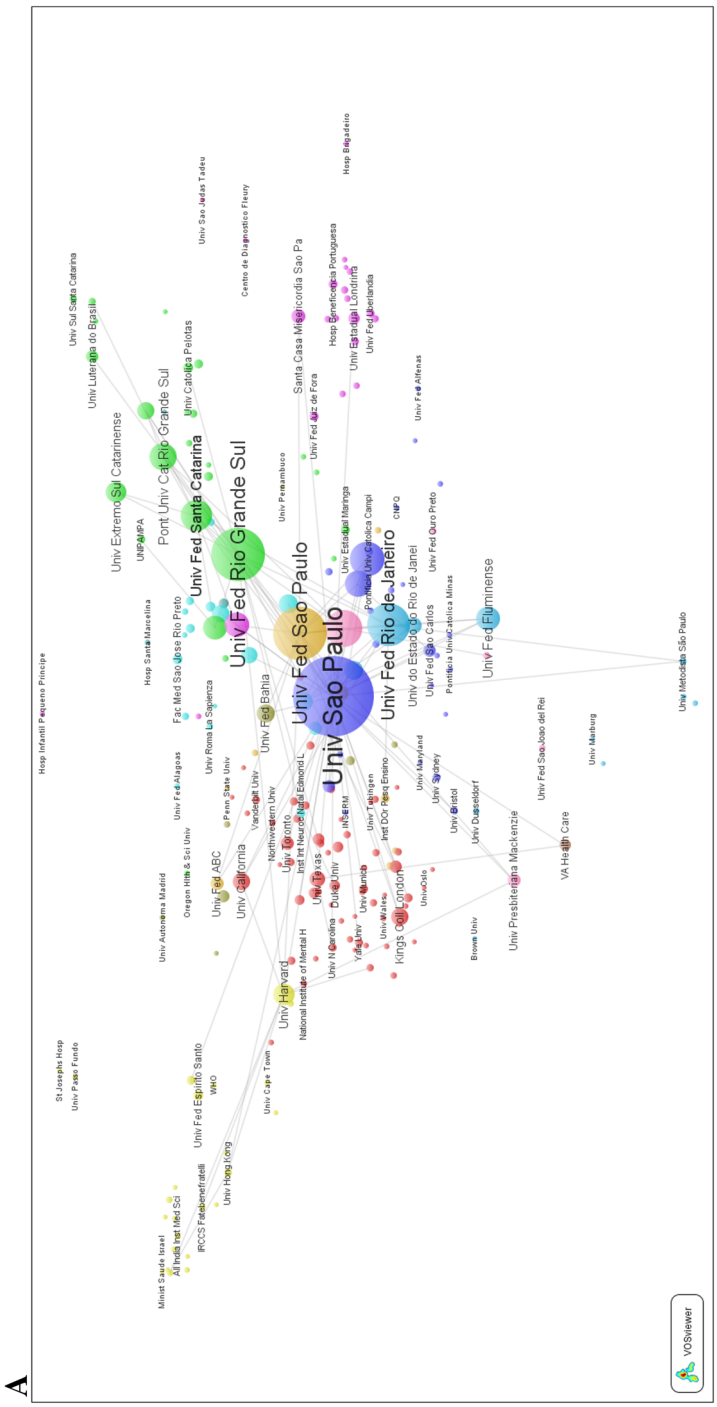


Fig. 2 **a** Collaboration between the most productive foreign and domestic institutions in Brazilian Neurosciences indexed in WoS, 2006–2013. *Source*: Survey data. Prepared with VOSviewer. **b** Collaboration between the most productive foreign and domestic institutions in Brazilian Neurosciences indexed in WoS, 2006–2013 showing clusters. *Source*: Survey data. Prepared with VOSviewer

B

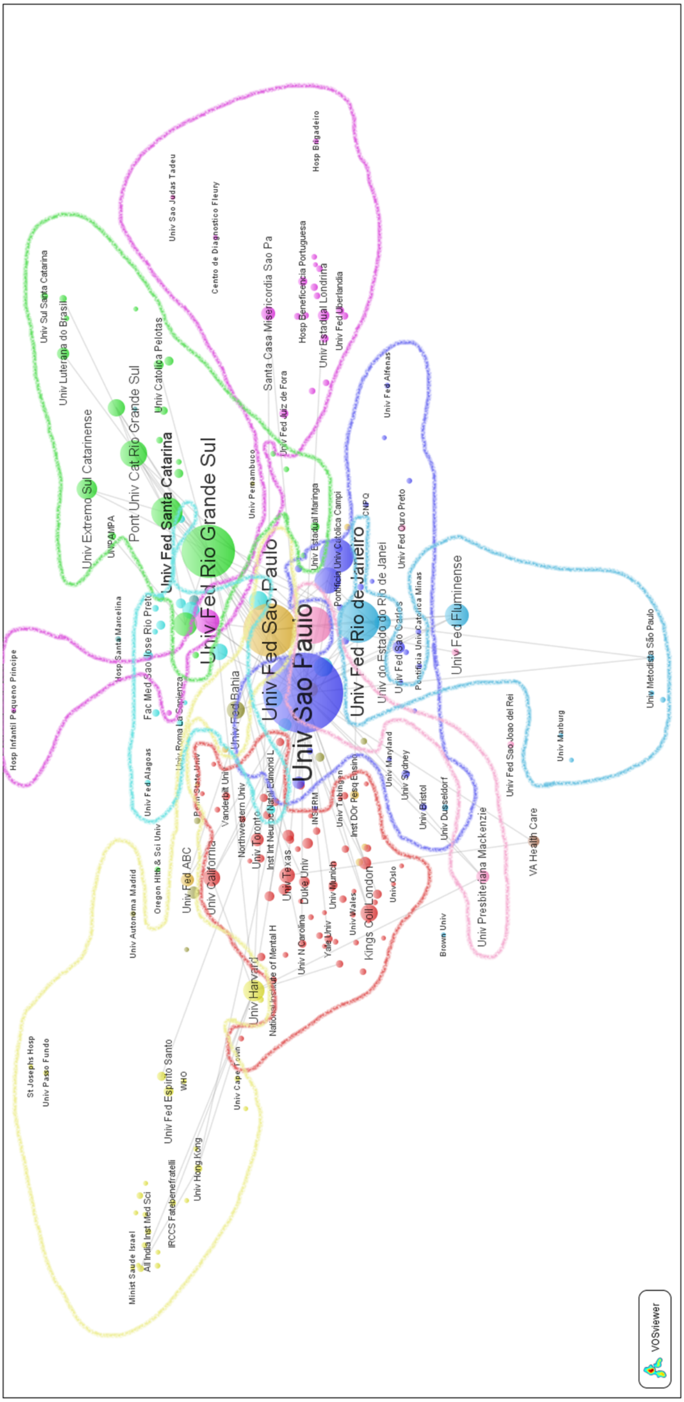


Fig. 2 continued

Table 5 Collaboration strength of Brazil with other countries measured by Salton's cosine for production indexed in WoS, 2006–2013

Collaborating country	Salton's Cosine	Number of articles	% in relation to total collaborative articles
USA	3.3	1344	13.92
Colombia	3.3	65	0.67
Argentina	2.7	111	1.15
United Kingdom	2.5	468	4.85
Portugal	2.2	96	0.99
Spain	2.2	256	2.65
Canada	1.9	304	3.15
Lebanon	1.8	30	0.31
Nigeria	1.6	31	0.32
France	1.5	215	2.23
Germany	1.5	297	3.08
Mexico	1.4	72	0.75
Italy	1.4	211	2.19
Australia	1.4	186	1.93
Peru	1.3	13	0.13
Romania	1.3	23	0.24
Bulgaria	1.3	24	0.25
Uruguay	1.2	16	0.17
Venezuela	1.1	14	0.15
Chile	1.0	30	0.31
Switzerland	1.0	96	0.99

Source: Survey data

Brazil collaborates in Neurosciences research with countries from all continents, as is shown in Table 5, especially countries in the Americas (mainly Latin America) and Western Europe. Collaboration strength follows this order: USA, Colombia, Argentina and the UK, followed by Portugal, Spain, Canada, Lebanon, Nigeria, France, Germany, Mexico, Italy, Australia, Peru, Romania, Bulgaria, Uruguay, Venezuela, Chile and Switzerland.

It is possible to reflect on Brazil's role in research partnerships according to the Neurosciences of each one. The USA and UK are central collaborators for Brazil, appearing in both absolute and relative data analysis. Furthermore, these countries have a significant impact factor for Neurosciences research and are highly specialized in the area (Haustein et al. 2013), aspects in which Brazil could perform better.

Argentina is on the ranking of the 35 most productive countries in Neurosciences (Haustein et al. 2013), although in a lower position than Brazil. In terms of Impact Factor and expertise in the area, Argentina outperforms Brazil, but the performance of both nations in these aspects is lower than the global average. Thus, Brazil could play a major role in research partnerships with Argentina, since its output is greater and it has a higher research growth rate, but both need to be aware of common factors that may be responsible for the low impact of their scientific production.

In the surveys conducted with Colombia, Brazil certainly plays a more central role, as Colombia is not a significant producer of Neurosciences research (there is no known

bibliometric study in which the country or any Colombian Neurosciences research institute appear, or even research on this field in the Colombian territory). Thus, this is a case in which it can play a leading role, which is said to be critical to the formation and maintenance of a sound scientific community in the country (Meneghini 1996).

Research topics

Keywords plus (KW +) are keywords taken from the titles cited by documents that demonstrate the topics researched and discussed in the articles (Garfield 1990; Garfield and Sher 1993). Figure 3 shows the most frequent topics in Brazilian Neurosciences research based on the highest incidence of KW + (at least 90 times), which are also represented by the links existing between them, i.e., keywords that co-occur the most are shown close together, indicating related survey foci. There are only four clusters of topics, depicted in the left of the figure, the cluster in the right side of the figure, the middle one (with only three keywords) and the middle-down one.

KW + demonstrate that Brazilian research is divided between Basic/Experimental Neurosciences and Clinical Neurosciences, as indicated by Bacheschi and Guerreiro (2004) and Ventura (2004, 2010). Even thematic areas of research can be identified through these keywords.

The cluster in the middle of the figure is the smaller, comprising only three keywords: memory, anxiety and behavior. It is the most centralized group, located in the middle of the other three clusters, prompting the assumption that memory, anxiety and behavior are research topics that, although different in co-occurrence (forming a separate group), are related to the topics in the other three groups. The middle-down cluster has the least strong links and is the second smallest in size. One can assume the existence of research groups investigating epilepsy within this cluster since contains the following keywords: model, system, damage, injury, lesions, epilepsy, temporal-lobe epilepsy, therapy, cortex, MRI, experience, seizures, surgery, abnormalities, management, and classification.

The right side group seems to be characterized by topics related to mental and neurologic disorders (mood disorders, disorders, schizophrenia, major depression, depression, deficits, impairment, dysfunction, dementia, age, risk, children and adults) and their diagnosis (diagnosis, association, rating-scale, scale, symptoms, validity, performance, prevalence, population and epidemiology). The left side cluster contains keywords that are likely associated with experimental research topics (due to the occurrence of keywords related to laboratory research, such as rats expression and mice) and/or the functional organization of the nervous system: central-nervous-system, neurons, cells receptors, modulation, activation, mechanisms, involvement, spinal-cord, multiple-sclerosis, blood-pressure, pain, responses, rats expression, mice, brain, hippocampus, stress, Alzheimer's-disease, Parkinson's-disease, dopamine, prefrontal cortex and bipolar disorder. Studies on Alzheimer's, Parkinson's and bipolar disorder therefore seem to be more frequent in experimental research. The most important organ in the nervous system, the brain, appears as the most frequent keyword in this cluster, and also carries the greatest weight among all keywords, if groupings are ignored.

Impact

Nearly 86 % (85.88 %) of the 9665 Brazilian articles in Neurosciences received citations, with a total of 88,346 citations and an average of 9.15 citations per article. The most cited article was mentioned 894 times. Therefore, there is great variability in the number of

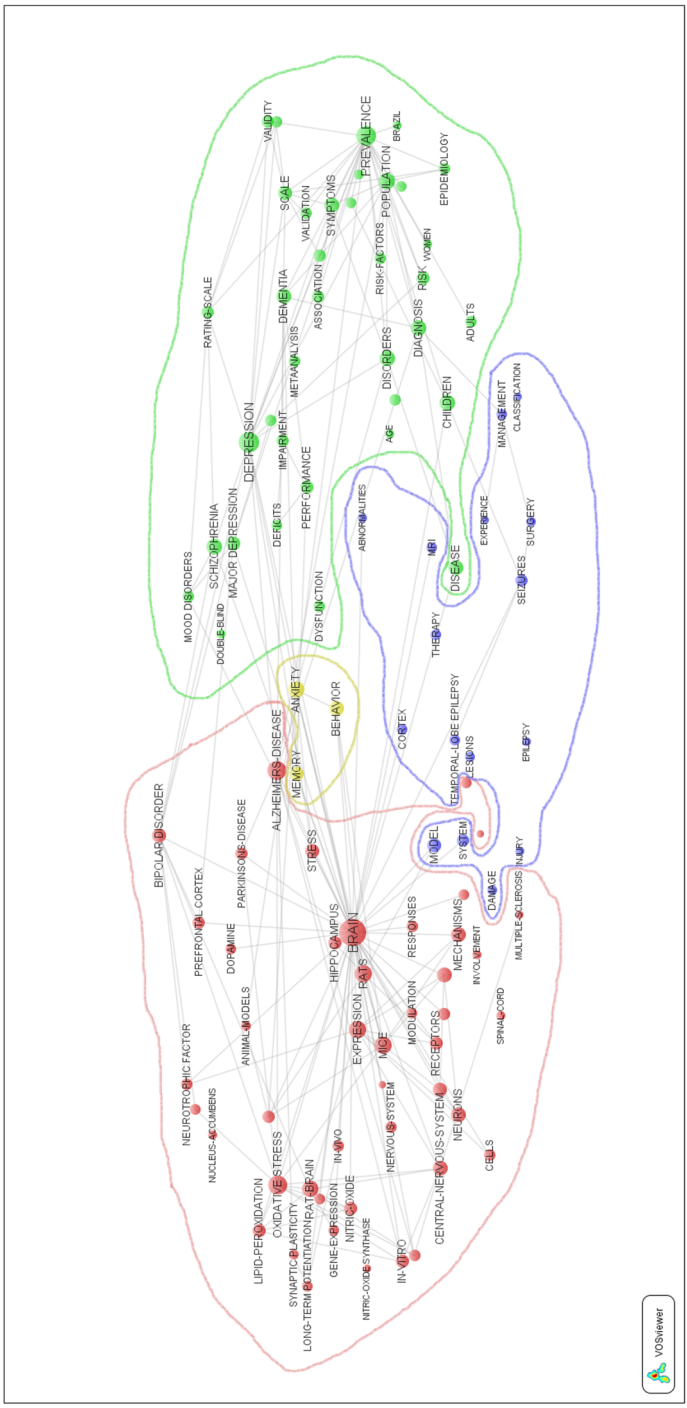


Fig. 3 Clusters with links for the most frequent topics in Brazilian Neurosciences research indexed in WoS, 2006–2013. *Source*: Survey data. Prepared with VOSviewer

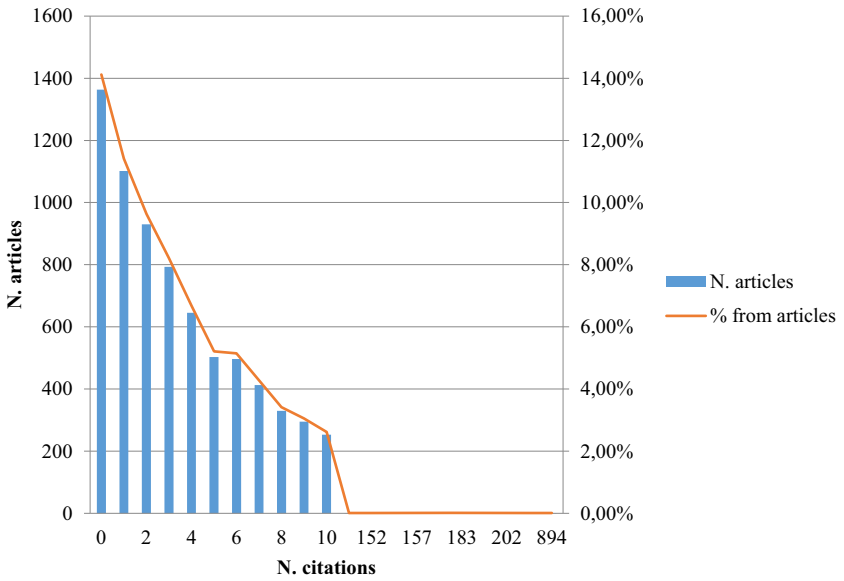


Fig. 4 Distribution of the number of articles with a certain number of citations from Brazilian Neurosciences output indexed in WoS, 2006–2013. *Source*: Survey data

times articles from Brazilian Neurosciences production are referenced, with a standard deviation of 17.19. The mode is zero citations per article and the median is four. If articles without citations are excluded, there is little change: there is less variability because the mean (10.65) and standard deviation (18.12) are slightly closer together, while the former was previously almost twice as high as the latter; however, the mean increases by no more than a digit and the median rises to six.

A total of 14.12 % of articles received no citations until data were collected for the study, and 35.93 % of articles received from one to four citations (Fig. 4). For example, more than 70 % of Indian Neurosciences papers indexed in WoS from 1992 to 2004 were never cited (Shahabuddin, 2013), placing Brazil at a good level of performance compared to that country, which is also considered an emerging nation. Shahabuddin (2013) states that the most cited Indian articles in the area are written in partnership with the USA and Brazil.

A number of factors influence citing behaviors (Meadows 1999; Vanz and Caregnato 2003; Bourdieu 2004) and the number of citations is not necessarily equivalent to good or bad performance in research. However, the repercussion and use of a study by peers are known measures of good results. Brazil performs better in the Neurosciences field compared to other emerging and developing nations, such as China (Xu et al. 2003) and Iran (Ashrafi et al. 2012), but is below average in relation to other countries which are also very productive in the area (Glänzel et al. 2003; Haustein et al. 2013). This result suggests that the contribution of national Neurosciences papers should be scrutinized, given the discrepancy between productivity and the impact of publications. One means of reverting this situation is to increase cooperation with the two countries that show the best impact in the area and are also highly specialized in Neurosciences: the Netherlands and Switzerland.

Although the main corpus of this study consisted of articles (since they present original research), various other types of documents cited them. Of the citing documents, 77.5 % are other original articles, 17.74 % review articles, 2.17 % editorials, 1.63 % event papers, 1.6 % letters, and less than 1 % was book chapters, corrections, and news, among others. These works were mostly published in English (96.66 %), less than 1 % in Portuguese and Spanish (0.87 and 0.81 %, respectively) and an even smaller share in other 19 languages, such as German, French, Turkish, Russian, Polish, Czech, Italian, etc.

The years of publication of these documents ranged from 2006 to 2014 (including citations as of August 2014, the date of data collection), with a clear concentration in the later years. It is likely that documents published in 2013 have not yet had enough time to be incorporated by the scientific community and referenced in further studies. The 57,932 citing documents were published in 4641 different sources, including journals, books and proceedings (particularly journals, since more than 95 % of the documents are original articles or reviews). The citing documents are widely distributed across different sources, since the source that published the highest number of documents amounted to only 2.69 % of the total (1558 documents), and the four following sources published only up to 1 % of documents. In total, 1502 journals published only one citing document, 685 only two, 482 published three documents, and so on.

The citing authors are linked to 22,688 institutions from 150 different territories (or 143 countries, since some nations have extra-continental territories, see note in Fig. 5). Figure 5 shows the global reach of Brazilian Neurosciences output. The institutions on which articles had greater repercussion (in number of citations) are linked to countries such as Brazil itself, in addition to nations in North America (USA and Canada), Europe (Germany, Italy and UK) and Asia (China). Since the visibility of a research group is linked to the number of times its work is cited (Rousseau 1998) and increased collaboration is a mean to increasing the visibility of research, particularly international collaboration (Leta and Chaimovich 2002), it is demonstrated that Brazilian scientific output in Neurosciences enjoys good visibility because it is cited by countries on all continents around the world. Furthermore, the forms of publishing indicate the internationalization of research. However, reach across all continents, collaboration and internationalization still do not occur concomitantly with better impact of Brazilian Neurosciences research.

Main conclusions

Brazilian scientific output in Neurosciences grows every year, along with the percentage of articles published in English and in foreign journals. The papers published in Portuguese and in domestic publications are more related to the field of Psychiatry, indicating somehow a particular form of producing and publishing in this branch that differentiates it from others that make up the country's Neurosciences. Another characteristic related to areas and themes in Brazilian Neurosciences seems to be the division into two forms of research: basic/experimental and clinical. KW + confirmed this hypothesis as well as some research specialties linked to them.

Brazilian Neurosciences research is highly concentrated among a small number of institutions, authors and regions. Although this is a recurrent finding in developing countries, Brazil demonstrates a more intense concentration compared to China and Iran, for example. The top 25 most productive authors totaled almost 1/4 of everything published in the area in the period, and the ten most productive institutions penned more

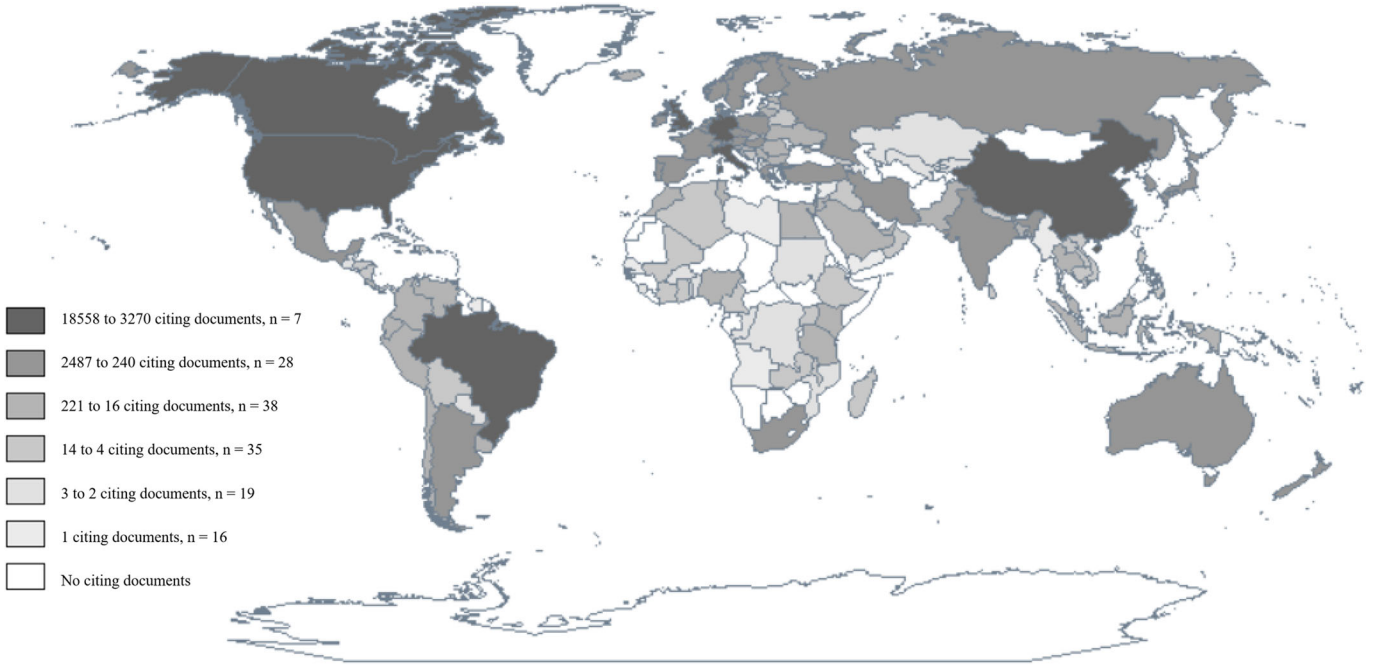


Fig. 5 Dispersion of institutions to which authors are linked that cite the Brazilian Neurosciences output indexed in WoS, 2006–2013. *Source*: Survey data. Prepared with Philcarto. *Note* Due to limitations of the map database, papers from countries known as territories of other nations were assigned to the countries used by the United Nations Statistics Division (UNITED NATIONS, 2013) and Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics) (2014c). Papers by authors linked to institutions in Taiwan were attributed to China; those from Martinique, Reunion, French Guiana and Guadeloupe (French overseas territories) were attributed to France; from Greenland, to Denmark, and from the Netherlands Antilles, to the Netherlands. Zaire was identified as the Democratic Republic of the Congo

than nine out of ten articles. These institutions and authors are concentrated in a few states (the wealthiest) in the southeastern and southern regions of the country (especially São Paulo, which participates in 52 % of studies).

The concentration of research in the southeastern and southern regions of the country is a characteristic of general domestic scientific production (all areas), as found in previous bibliometric studies. It is assumed that in the case of Neurosciences, concentration in the states of RJ and SP can be explained by the history of this field in Brazil, which started with researchers from these states, among other factors. São Paulo is also the country's wealthiest state and the most developed in terms of science and the scientific community, which is evidently no different for the area of Neurosciences, since the three publishing national journals are issued in this state.

The same studies that found a concentration of science in the South and Southeast also indicate that national science is almost exclusively carried out in public universities, with less participation by other public research institutions and negligible private sector contribution. This is a point in which Neurosciences differs, since it shows a higher rate of private sector participation (though still small), mainly from universities and hospitals. There is a private university is among the ten most productive in the field (PUC-RS), which is home to Instituto do Cérebro (Institute of the Brain). However, some public universities among the most productive institutions also follow the national pattern: public universities. USP, UFRGS, UNIFESP, UFRJ, UFMG, UNICAMP, UFSC, PUC-RS, UNESP and UFPR account for over 90 % of everything produced in Neurosciences in Brazil.

These ten national institutions collaborate substantially, but also partner with other institutions outside the group. Proximity seems to be a major factor in collaboration within the country. USP is the institution that most collaborates with foreign entities and PUC-RS is the most "closed" in terms of collaboration with other regions, a characteristic it shares with other institutions in the states of Rio Grande do Sul and Santa Catarina, states located in the southernmost region of the country.

Collaboration recorded through article co-authorship between at least two authors (lower level) occurs in almost all Neurosciences articles, 6 out of 10 of the output are produced between two or more institutions and almost 30 % have international collaboration. The absolute frequency of international collaboration shows that Brazil more often partners with the USA, UK, Canada and Germany, having collaborated with a total of 85 different territories/countries between 2006 and 2013. However, given the productivity of each country, Brazil's key collaborators are the USA, Colombia, Argentina and the United Kingdom. Among these countries, the United Kingdom accounts for the highest Impact Factor and the USA is the most specialized in Neurosciences. These are collaborators on which Brazil can rely to improve its research performance. On the other hand, while Argentina and Colombia have experience in the field, their expertise and impact are poorer than those of Brazil, meaning the latter could play a leading role in Neurosciences research when collaborating with these nations. Brazil has established research partnerships in Neurosciences on every continent, but has a higher number of collaborators in South America and Western Europe.

Although Brazilian studies are cited in English publications from the USA or Europe, the authors citing Brazilian work are linked to institutions from all continents. In other words, Brazilian Neurosciences reflects on, to a greater or lesser degree, all over the world. This visibility, however, does not translate into a singificant impact (as citations), since Brazil has underperformed in relation to other highly productive nations in Neurosciences. The impact of Brazilian Neurosciences research has not kept pace with its growth.

It is suggested that further studies be conducted in order to broaden understanding of issues raised by this survey, such as the scarcity of research in the Northern and Northeastern states of Brazil, the use of data to analyze national collaboration and the development of analyses with research front or thematic association indicators based on references and co-citations.

Acknowledgments The authors would like to thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for funding the survey.

References

Almeida, E. C. E., & Guimarães, J. A. (2013). Brazil's growing production of scientific articles—How are we doing with review articles and other qualitative indicators? *Scientometrics, 97*(2), 287–315.

Arquivos de Neuro-Psiquiatria. (n.d.). *Sobre nós*. São Paulo: Associação Arquivos de Neuro-Psiquiatria. Retrieved from: http://www.scielo.br/revistas/anp/paboutj.htm.

Ashrafi, F., Mohammadhassanzadeh, H., Shokraneh, F., Valinejadi, A., Johari, K., Saemi, N., et al. (2012). Iranian's contribution to world literature on neuroscience. *Health Information and Libraries Journal, 29*, 323–332.

Bacheschi, L. A., & Guerreiro, C. A. M. (2004). Situação das neurociências no Brasil: Neurociências clínicas. *Ciência e Cultura, 56*(1), 25.

Bourdieu, P. (2004). *Os usos sociais da ciência: por uma sociologia clínica do campo científico*. São Paulo: UNESP.

Casani, F., Filippo, D., García-Zorita, C., & Sanz-Casado, E. (2014). Public versus private universities: Assessment of research performance; case study of the Spanish university system. *Research Evaluation, 23*(1), 48–61.

Dorta-Contreras, A. J., Arencibia-Jorge, R., Martí-Lahera, Y., & Araujo-Ruiz, J. A. (2008). Productividad y visibililidad de lós neurocientíficos cubanos. *Revista de Neurología, 47*(7), 355–360.

Fundação Oswaldo Cruz. (n.d.). *Dicionário Histórico-Biográfico das Ciências da Saúde no Brasil (1832–1930)*. Retrieved from: http://www.dichistoriasaude.coc.fiocruz.br/iah/pt/index.php.

Garfield, E. (1990). KeyWords Plus: ISI's breakthrough retrieval method. Part I. Expanding your searching power on Current Contents on Diskette. *Current Contents, 32*, 5–9.

Garfield, E., & Sher, I. (1993). KeyWords Plus: Algorithmic derivative indexing. *Journal of the American Society for Information Science, 44*(5), 298–299.

Glänzel, W. (2003). *Bibliometrics as a research field: A course on theory and application of bibliometric indicators*. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.97.5311&rep=rep1&type=pdf.

Glänzel, W., Dannel, R., & Persson, O. (2003). The decline of Swedish neuroscience: Decomposing a bibliometric national science indicator. *Scientometrics, 57*(2), 197–213.

Glänzel, W., Leta, J., & Thijs, B. (2006). Science in Brazil. Part 1: A macro-level comparative study. *Scientometrics, 67*(1), 67–86.

Haustein, S., Côté, G., & Beaudet, A. (2013). *State of knowledge production in Neuroscience in Alberta: A bibliometric assessment*. Montréal: Science-Metrix.

Instituto Brasileiro de Geografia e Estatística. (2014c). *Tabela de códigos de áreas.* Retrieved from: http://concla.ibge.gov.br/classificacoes/por-tema/codigo-de-areas/codigo-de-areas.

Journal Citation Reports. (2015c). *2014 JCR Science Edition*. New York: Thomson Reuters.

Leta, J. (2012). Brazilian growth in the mainstream science: The role of human resources and national journals. *Journal of Scientometric Research, 1*(1), 44–52.

Leta, J., & Chaimovich, H. (2002). Recognition and international collaboration: The Brazilian case. *Scientometrics, 53*(3), 325–335.

Leta, J., & Cruz, C. H. B. (2003). A produção científica brasileira. In E. B. Viotti & M. M. Macedo (Eds.), *Indicadores de ciência, tecnologia e inovação no Brasil* (pp. 123–168). Campinas: Unicamp.

Leta, J., Glänzel, W., & Thijs, B. (2006). Science in Brazil. Part 2: Sectorial and institutional research profiles. *Scientometrics, 67*(1), 87–105.

Leta, J., Thijs, B., & Glänzel, W. (2013). A macro-level study of science in Brazil: Seven years later. *Encontros Bibli, 18*(36), 51–66.

Library of Congress. (2000). *The decade of the brain*. Washington: LOC. Retrieved from: http://www.loc.gov/loc/brain/.
Luukkonen, T., Tijssen, R., Persson, O., & Sivertsen, G. (1993). The measurement of international scientific collaboration. *Scientometrics, 28*(1), 15–69.
Meadows, A. J. (1999). *A comunicação científica*. Brasília: Briquet de Lemos.
Meneghini, R. (1996). The key role of collaborative work in the growth of Brazilian science in the last ten years. *Scientometrics, 35*(3), 367–373.
Myskiw, J., & Yano, C. (2012). Memórias de um brasileiro de Buenos Aires. *Ciência Hoje, 50*(297), 64–71.
Revista Brasileira de Psiquiatria. (2014). *Instructions to authors*. São Paulo: Associação Brasileira de Psiquiatria. Retrieved from: http://www.scielo.br/revistas/rbp/iinstruc.htm.
Revista de Psiquiatria Clínica. (2014). *Announcements*. São Paulo: USP. Retrieved from: http://www.scielo.br/revistas/rbp/iinstruc.htm.
Rousseau, R. (1998). Indicadores bibliométricos e econométricos para a avaliação de instituições científicas. *Ciência da Informação, 27*(2), 149–158.
Shahabudin, S. M. (2013). Mapping neuroscience research in India: A bibliometric approach. *Current Science, 104*(12), 1619–1626.
Timo-Iaria, C. (n.d.). *História da neurofisiologia no Brasil*. Retrieved from: http://www.sbnec.org.br/site/texto.php?id_texto=3.
United Nations. (2013). *Countries or areas, codes and abbreviations.* Genova: United Nations. Retrieved from: http://unstats.un.org/unsd/methods/m49/m49alpha.htm.
Vanz, S. A. S., & Caregnato, S. E. (2003). Estudos de citação: uma ferramenta para entender a comunicação científica. *Em Questão, 9*(2), 295–307.
Ventura, D. F. (2004). Situação das neurociências no Brasil: disciplinas básicas. *Ciência e Cultura, 56*(1), 25–26.
Ventura, D. F. (2010). Um retrato da área de Neurociência e Comportamento no Brasil. *Psicologia: teoria e pesquisa, 26*, 123–129.
World Health Organization. (2001). *The world health report. Mental health, new understanding, new hope*. Geneva: WHO. Retrieved from: http://www.who.int/whr/2001/en/.
Xu, W., Chen, Y., & Shen, Z. (2003). Neuroscience output of China: A medline-based bibliometric study. *Scientometrics, 57*(3), 399–409.