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Global neuroscience and mental health research: a bibliometrics case study

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Abstract This case study of the impact of publications in the area of Neurosciences and Mental Health was completed as part of an institutional analysis of health research activity at the University of Toronto. Our data show that selecting top researchers by total publication output favoured clinical research over all other research disciplines active in the subjects. The use of citation rate based measures broadened the research disciplines in the top group, to include researchers in Public Health (highest impact in the analysis), Commerce and Basic Sciences. In addition, focusing on impact rather than output increased the participation of women in the top group. The number of female scientists increased from 20 to 31 % in the University of Toronto cohort when citations to publications were compared. Social network analysis showed that the top 100 researchers in both cohorts were highly collaborative, with several researchers forming bridges between individual clusters. There were two areas of research, neurodegeneration/movement disorders and cerebrovascular disease, represented by strong clusters in each analysis. The University of Toronto analysis identified two areas neuro-oncology/neuro-development and mental health/schizophrenia that were not represented in the global researcher networks. Information about the areas and relative strength of researcher collaborative networks will inform future strategic planning.

Keywords Bibliometrics · Neurosciences · Mental health · Social network analysis · Research evaluation · Case study

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Introduction

The use of bibliometrics to evaluate the scope, size and impact of health research output has been part of the academic landscape for several decades and is considered one of the primary outputs in assessing the return on investment from health research funding (Frank and Nason 2009).

At an institutional level, bibliometrics is increasingly used for evidence-based decision making in strategic planning and as a key performance metric. New tools such as Google Scholar, Thomson Reuters' Incites and Elsevier's SciVal are expanding the scope of bibliometrics, however use of these tools without the appropriate contextual background can result in misleading conclusions (Hicks et al. 2015). The newly developed Leiden Manifesto has been created to provide a framework to guide institutional evaluations. Our study represents a case study of the use of bibliometric data linked to social network analysis to evaluate the current state of research in Neurosciences and Mental Health (NMH). The work was completed in consultation with leaders of the NMH community at the University of Toronto to ensure that contextual issues were identified and addressed.

The study used two commercially available bibliometrics data sources, Thomson Reuters' Web of Science (WoS) linked to the InCites analytical tool, and Elsevier's Scopus linked to the SciVal analytical tool. Google Scholar was not an appropriate tool due to limitations in data source coding, and lack of quality control in data inclusion (Kofia et al. 2015; Aguillo 2012). The global indicators were further analysed as part of the research strategic planning for the Faculty of Medicine at the University of Toronto (FoM, UofT) (O'Leary et al. 2015). The Faculty of Medicine is part of the Toronto Academic Health Sciences Network with nine fully affiliated academic hospitals. This network forms the largest health sciences research grouping in Canada and ranks 11th in the world (Times Higher Education 2015).

Methods

Bibliometrics data collection

Due to the prevalence of homonyms in the data sets obtained from InCites/WoS and Scopus sources, secondary data cleansing (disambiguation) was critical in ensuring that the records referred to a single individual. It was not feasible to compile a disambiguated data set for the full global neurosciences output (>200,000 documents), however the top 100 global researcher and the internal UofT datasets were disambiguated by manually checking each publication against the profile of the individual researcher, matching Institution, Department, research topic and where feasible the individual's curriculum vitae (UofT researchers only).

The evaluation focused on 5 years of publication output, 2008–2012. Previous bibliometric studies in the biosciences have shown peak citation rates occur in years 3–5 post-publication (Archambault and Lariviere 2010; Shahabuddin 2013), therefore new articles published between 2013 and 2014 were excluded from the study as there was insufficient time post-publication to assess peak citations. Citations to the articles published between 2008 and 2012 were collected from all publications in the InCites (UofT dataset) and Scopus (Global author dataset) between 2008 and 2014. The global output of neuroscience publications indexed in WoS was determined by aggregating the documents from the following subject-access fields from WoS: clinical neurology, neuroimaging, neurosciences, psychiatry, psychology—applied, psychology—biological, psychology—clinical, psychology—multidisciplinary, psychology—psychoanalysis, psychology, and substance abuse.

The InCites Institutional Comparisons module was utilized to identify the top 100 Institutions and the publication impact indicators: number of citations per publication and Impact Relative to Subject Area (IRSA) were collected for each publication. IRSA measures the impact of a publication by normalizing the citations received to the expected citation rate for all publications indexed in the area. In this case study the journals included in a subject area were defined by the InCites tool from Thomson-Reuters, an average performance would result in an IRSA of 1.0.

Individual researcher output and impact

To reduce the time spent on manual record disambiguation the Scopus analytic tool (Elsevier) was utilized rather than InCites as publication coverage in core biomedical journals is identical in WoS and Scopus (Archambault et al. 2009; Leydesdorff et al. 2015). WoS aggregates records by last name and first initial, whereas Scopus uses last name and multiple initials, thus identifying individual researchers in datasets from Scopus requires less cleaning. The top 50 journals in Neurosciences were identified using the 5-year impact factor data in Journal Citation Reports (JCR, Thomson Reuters) representing 8 % of all Neuroscience journals indexed in JCR. Fifty percent of the journals were non-clinical (e.g. Science, Nature, Cell, Neuron, Molecular Cell) and fifty percent were clinical (e.g. New England Journal of Medicine, Lancet, Journal of the American Medical Association, British Medical Journal). The decision to select from the top 50 journals was based on Garfield's Law of Concentration that a small core of journals (10–20 %) account for 80–90 % of all citations in the relevant literature (Garfield 1977).

The International Standard Serial Numbers (ISSNs) of the 50 highest-impact journals were entered into the Scopus advanced search tool and the publication data collected on February 2nd 2014. A sub-group of 200 authors was identified by their high publication rates in the top 50 high–impact neuroscience journals between 2008 and 2012. Their full publication records (drawn from all journals, not limited to the top 50) were disambiguated to ensure each name represented a single individual. The total output of these researchers was analysed initially by total number of documents and then by impact, as defined by citation numbers, since the Scopus tool does not permit analysis of impact by IRSA.

Internal UofT analysis

The top UofT NMH researchers were identified using an institutional custom, disambiguated dataset in InCites that permits additional analyses not available in the global comparisons provided by either WoS or Scopus. The InCites Research Performance Profiles module was utilized to collect the publication data set on February 3 2015 covering the 2008–2012 period for publications and 2009–2015 for citations to these publications. The analysis of impact by Discipline/Department compared four metrics: total output, average citations, citations normalized to the category (the ratio of the actual citations to the expected citations for all journals indexed in the category, Category Actual: Category Expected, CA:CE), and citations normalized to the journal (ratio of actual citations received to the expected citation rate for all articles in the relevant journals, Journal Actual/ Journal Expected, JA:JE).

Social network analyses

Global analysis

The top 100 NMH researcher publication dataset derived from Scopus was utilized for the Social Network Analysis (SNA). The intent was to determine the level of collaboration of leading researchers and identify collaborative clusters by topic area. The analysis also examined whether there were specific researchers linking different clusters across the larger network, these individuals function as key information conduits.

The SNA data visualizations were created by loading the publication metadata into the Cytoscape network analysis program (PubMed:14597658) using the Social Network App (Kofia et al. 2015). Cytoscape was originally developed to examine intracellular signalling networks where nodes are genes or proteins and connections between them their interactions, but is designed to enable generic network analysis of any type. By adding the Social Network App we are able to create networks from publication data where nodes are researchers and the connections between them represent the publications that two researchers share. Both Cytoscape and the Social Network App are open source and freely available to download from http://cytoscape.org (a guide to using Cytoscape can be found at (http://tutorials.cytoscape.org).

The SNA visualizations utilized the global or UofT top 100 NMH researcher bibliometrics metadata reformatted to meet the needs of the Social Network App in Cytoscape program. Once the metadata was loaded, it was filtered to focus on only the 100 top researchers and exclude all other co-authors in the data set, this enabled clear visualization of clusters and identification of areas of research emphasis. For the SNA visualizations, the individual researchers are the nodes and co-authors are displayed as linking lines, or edges, and the thickness of the edge reflects the number of co-authorship links between a given set of researchers/nodes.

The top 100 data sets were grouped into clusters using the Cluster ONE Cytoscape application (Nepusz et al. 2012). Cluster ONE identifies densely connected regions (clusters) within a network by cohesiveness as defined by the level of interaction between individual nodes. The initiating node was identified by a high level of connectivity and subsequent nodes added by virtue of connectivity to the initiating node.

The Cluster ONE program provided an analysis of the clusters including the size (the number of nodes/cluster), the in-weight of the cluster (defined as the sum of edges or co-authorship links that lie completely in the cluster), the out-weight (defined as the sum of edges where one endpoint node is inside the cluster and the other lies outside), and quality (defined by the in-weight divided by the sum of the in-weight and out-weight such that a high quality cluster would have an in-weight > out-weight). The maximum quality value of a cluster would be 1.0 for a cluster unconnected to a larger network. The validity of a cluster was determined by statistical analysis of the in-weight and out-weight data using a one-sided Mann–Whitney U test. If a cluster had a $p < 0.01$, the in-weights were significantly greater than the out-weights, therefore the cluster was considered valid and not due to random effects (Newman 2001).

Once valid clusters were identified, additional analyses were completed using the Cytoscape Network Analyzer application. The network topology parameters, number of edges and betweenness centrality, were calculated to identify information transfer nodes across clusters. Betweenness centrality is calculated as the sum of the fraction of all shortest path connections that pass through a given node. The higher the fraction the more effective the node was as an information transfer conduit between sections of the network (Newman 2004; Yan and Ding 2009; Abbasi et al. 2014).

Results

Global comparisons: national output

With almost 45 % of the publications in Neurosciences being authored or co-authored by American researchers, the United States of America (USA) is by far the top producer (Table 1). Canada ranked fourth in publication output, contributing 6 % of the world's

Table 1 Top National NMH Publication Output and Impact 2008–2012

Top countries (Output)	2008–2012 Documents	Impact relative to subject	Ranking by output	Ranking by impact
USA	233,604	1.17	1	8
UK	63,401	1.33	2	1
Germany	54,448	1.14	3	10
Canada	38,109	1.15	4	9
Australia	27,991	1.07	5	15
Japan	27,809	0.7	6	25
Italy	27,553	1.09	7	13
France	27,413	0.9	8	21
Netherlands	24,852	1.32	9	2
China	20,858	0.85	10	23
Spain	19,571	0.88	11	22
Switzerland	13,542	1.19	12	6
Brazil	12,255	0.73	13	24
Sweden	11,228	1.2	14	3
South Korea	11,097	0.69	15	32
Belgium	9297	1.2	16	4
Israel	7962	0.99	17	17
Turkey	7825	0.51	18	35
Denmark	6659	1.18	19	7
Taiwan	6562	0.73	20	30
Austria	6110	1.19	21	5
Norway	5975	1.11	22	12
India	5889	0.66	23	33
Finland	5666	1.14	24	11
New Zealand	4245	0.96	25	19
Ireland	3548	1.06	26	16
Hungary	3083	1.09	32	14
Portugal	2837	0.96	33	20
Argentina	2246	0.98	35	18

output in the period 2008–2012 and 9th in impact. When the USA output and impact were compared, the USA ranks #1 output and #8 in impact, the United Kingdom (UK) is ranked #2 in output and #1 in impact (Table 1). High publication output was not strongly correlated with impact, with 40 % of the countries in the top output group being below average (<1.0) in IRSA.

Global institutional output

The analysis of institutional output covered 384,528 documents over the 5-year period. As expected from the country-level data, the top 100 institutions by output were dominated by the USA with 39, Canada was represented by 5 for a North American total of 43; in Europe 11 countries were represented for a total of 41 institutions, with Germany ($n = 10$), the Netherlands ($n = 8$) and the UK ($n = 7$) being the major producers in the region. Of the top high output institutions 52 % were also in the top 25 by impact, and all institutions in the top group had an aggregate IRSA above average (IRSA >1.35). Of interest was the low output of the two highest impact institutions, Massachusetts Institute of Technology (MIT) and the Howard Hughes Medical Institute with 1810 and 1520 publications respectively, compared to Harvard with an output of 16,488 (Table 2).

Global researcher output

To complete the individual level analysis a disambiguated dataset derived from the Scopus data set was used. To determine if the switch from the InCites (used for the global and institutional analyses) to the Scopus bibliometric tool resulted in changes in the document coverage, the top 100 documents were compared in each analysis and there were no differences. However, it should be noted that Scopus covered 1223 journals in the topic area compared to 586 in WoS, thus, although the same publications and journals were present in the two top 100 datasets, the number of citations/document differed.

The dataset for the top 100 researchers covered 17,856 citable documents published over the 5-year period. The national distribution of top researchers closely mirrored the top institutions, however no single institution was associated with a significant number of top researchers (Table 3). When the disciplinary affiliations of the top 100 scientists were determined, 85 % held Doctor of Medicine degrees (MD) with 24 dual MD/Doctor of Philosophy (Ph.D.) degrees. Of the sub-disciplines in Medicine, the majority were appointed in Departments/Divisions of Neurology ($n = 56$). Of the 15 non-MD researchers, 9 were Ph.D. neuroscientists, 5 holding Ph.D. degrees in either Pharmacology or Pharmacy and 1 Doctor of Dental Surgery (DDS) in Public Health. Another striking finding was that of the top 100 researchers, only nine were women, of these six were MDs, 2 held Ph.D. degrees and one held a DDS degree.

Given the strong representation of Japanese researchers in the high output category and the predominance of English language journals in the Neurosciences evaluation, their publication rate in Japanese vs. English journals were determined. Of the 2200 publications associated with the Japanese researchers only 7 %, or 140 publications, were in Japanese language journals. To examine the question of language bias, the prevalence of publication in English–language journals by non-English native speaking countries was evaluated. In all cases the majority of publications irrespective of native language were in English-language journals, the average was 94 % with a high of 99 % and a low of 84 % (data not shown).

Table 2 Top institutional NMH publication output and impact 2008–2012

Top 25 institutions (output)	2008–2012 Documents	Impact relative to subject	Top 25 institutions (impact)	2008–2012 Documents	Impact relative to subject
Harvard University (U)	16,488	1.55	MIT	1810	1.98
U Toronto	9531	1.23	Howard Hughes Medical Institute	1520	1.78
U College London	9475	1.67	U. Oxford	4779	1.7
Instutute National Sante Researche Medicale	8937	1.17	U. College London	9475	1.67
National Institutes Health (NIH)	8317	1.62	NIH	8317	1.62
U. California Los Angeles	7708	1.41	U. Pennsylvania	6880	1.61
Kings College London	7457	1.56	New York U.	4146	1.58
Columbia U.	7438	1.39	Kings College London	7457	1.56
Johns Hopkins U.	7298	1.19	Max Planck Society	4712	1.55
U. Pennsylvania	6880	1.61	Harvard U.	16,488	1.55
U. California San Diego	6575	1.51	U. California Berkeley	1872	1.51
Yale U.	6299	1.49	U. California San Diego	6575	1.51
U. Pittsburgh	6131	1.31	Washington U.	4135	1.5
U. California San Francisco	5996	1.37	Yale U.	6299	1.49
U. Michigan	5368	1.35	U. Cambridge	4090	1.47
U. Washington Seattle	5140	1.23	Stanford U.	5053	1.47
U. Melbourne	5082	1.28	Emory U.	3862	1.45
McGill U.	5066	1.27	U. California Los Angeles	7708	1.41
Stanford U.	5053	1.47	Imperial College London	2534	1.4
Duke U.	4782	1.35	U. Wisconsin Madison	2992	1.39
U. Oxford	4779	1.7	U. North Carolina Chapel Hill	3401	1.39
Max Planck Society	4712	1.55	Maastricht U.	3375	1.39
Vu U. Amersterdam	4706	1.38	U. California Irvine	2447	1.39
Karolinska Institute	4619	1.31	Columbia U.	7438	1.39
U. British Columbia	4490	1.38	U. British Columbia	4490	1.38

Data source Incites global comparisons

Table 3 Top 25 global NMH researchers by output and impact

Top 25 output	Institution	Output	Average cites	Top 25 impact	Institution	Output	Average cites
H. Diener	U. Essen	508	26	J. Trojanowski	U. Pennsylvania	228	70.8
R.S. Tubbs	Children's Hospital Alabama	416	4.1	R. Petersen	Mayo Clinic, Rochester	243	67.7
P.M. Thompson	U. California Los Angeles	409	25	D. Knopman	Mayo Clinic, Rochester	188	63.4
S. Tufik	U. Federal Sao Paulo	385	9.4	K. Tanaka	Tokyo Metropolitan	152	60
A. Toga	U.California Los Angeles	350	26	J. Hardy	U. College London	191	59.6
W. Maier	U. Bonn	308	28.8	B. Boeve	Mayo Clinic, Minnesota	171	57.8
K. Blennow	U. Gothenburg	265	35	L. Kappos	U. Basel	150	57
E. Vieta	U. Barcelona	265	28	R. Rademakers	Mayo Clinic, Florida	97	54.7
M. Fehlings	U. Toronto	250	15	D. Dickson	Mayo Clinic, Florida	220	53.3
M. Weiner	U.California San Francisco	244	49.5	M. Weiner	U.California San Francisco	244	49.5
R. Petersen	Mayo Clinic, Rochester	243	67.7	A. Bar-Or	McGill U.	83	48
G. Comi	U. Vita and Salute, Milan	241	30	B. Miller	U.California San Francisco	192	46.4
E.S. Connolly	Columbia U.	239	17.3	X. Montalban	Vall D'Hebron, Barcelona	159	41.5
P. Scheltens	Vrije U. Amsterdam	238	38.6	E. Masliah	U.California San Diego	219	40.5
M. Filippi	Hospital San Raffaele, Milan	238	32.6	P. Calabresi	Johns Hopkins	112	39
H. Zetterberg	U. Gothenburg	238	27	P. Scheltens	Vrije U. Amsterdam	238	38.5
C. Caltagirone	U. Roma Tor Vergata	236	17.3	M. Weller	U Zurich	188	37.4
R. Spetzler,	Barrow Neurological Institute Phoenix	236	6	W. Poewe	Medical U. Innsbruck	169	37.2
F. Barkhof	Vu Medical Centre, Amsterdam	233	36.5	M. Grossman	U. Pennsylvania	130	37
A. Teixeira	U. Federal Minas Gerais, Brazil	233	10	F. Barkhof	Vu Medical Centre Amsterdam	233	36.5
H-P. Hartung	U. Dusseldorf	229	26	A. Lees,	U. College London	191	35.5
J. Trojanowski	U. Pennsylvania	228	70.8	A. Lang	U. Toronto	157	35.2
G. Fink	U. Cologne	221	20	N. Giladi	Tel Aviv U.	83	35
D. Dickson	Mayo Clinic, Florida	220	53.3	K. Blennow	U. Gothenburg	265	35
E. Masliah	U.California San Diego	219	40.5	Z. Wszolek	Mayo Clinic Florida	157	34.6

Data source Elsevier Scopus

Internal UofT neurosciences output and impact

The InCites UofT dataset covered 9500 publications over the 5-year period with 654 authors including academic staff, students, post-doctoral fellows and highly skilled technical staff. To determine if publication output and/or impact measures created disciplinary bias, we completed four different analyses: total output, impact by average citations, impact normalized to citations expected for the journals (JA:JE) and impact normalized to citations expected for all journals in the subject category (CA:CE). To avoid confounding effects caused by authors publishing a small number of papers per year, only those authors publishing 10 or more papers in the 5 years of the study were included ($n = 299$).

The top 100 researchers at UofT included four researchers (M Fehlings, A. Lang, A. Lozano and S. Black) who were included in the top 100 global NMH researchers. At the UofT the majority of researchers were appointed in the FoM with representation from the

Table 4 Academic discipline of the top 100 NMH researchers at UofT by output and impact

UofT Academic Unit	Output	Av. cites	JA:JE	CA:CE
Faculty of Medicine Departments	83	80	78	80
Basic sciences				
Molecular Genetics	1	1	1	1
Physiology	2	8	4	5
Medical Biophysics	0	3	0	3
Total	3	12	5	9
Clinical sciences				
Anaesthesia	6	5	11	10
Family and Community Medicine	2	0	1	1
Lab Medicine and Pathobiology	1	4	2	3
Medical Imaging	9	0	6	1
Medicine	15	21	16	20
Paediatrics	6	2	2	2
Psychiatry	27	28	23	26
Surgery	14	8	11	8
Total	80	68	72	71
Rehabilitation Sciences				
Speech Language Pathology	0	0	1	0
Faculties of Medicine and Engineering and Applied Sciences				
BioMaterials and BioEngineering	1	0	0	0
Faculty of Arts and Science				
Department of Psychology	10	8	10	9
Faculty of Dentistry	1	1	1	0
Faculty of Nursing	0	2	1	1
Faculty of Pharmacy	0	0	1	1
Dalla Lana School of Public Health	5	7	8	8
Rotman School of Management	0	2	1	1
% Women	20	31	28	31

Faculties of Public Health; Arts and Science; Nursing; Dentistry; Pharmacy and the Rotman School of Management (Table 4). The use of total output as the metric for identifying the top 100 favoured the Clinical Disciplines (80 %), while the impact measures increased the representation of the non-clinical disciplines. In the analysis by citation measures clinical research remained predominant with 70 % of the researchers engaged in this area irrespective of the impact metric. Of interest was the finding that changing the base metric from total output to impact favoured women researchers, with 20 % in the top output group and 28–31 % in the impact categories (Table 4).

Social network analysis: global NMH research

With few exceptions, the 100 most productive international researchers collaborate extensively with one another. Of the 17,856 documents in the dataset the collaborative networks involved 17,784 or 99.5 %. Only 3 researchers showed no evidence of collaboration with other members of the top 100 (Fig. 1). Within the clusters formed by the co-publication networks there were seven co-authorship dyads/triads that co-published >100 highly cited papers. With one exception these dyads/triads involved investigators at the same institution (e.g. Petersen, Knopman and Boeve at the Mayo Clinic; Toga and Thompson at UCLA; and Blennow and Zetterberg at University of Gothenburg).

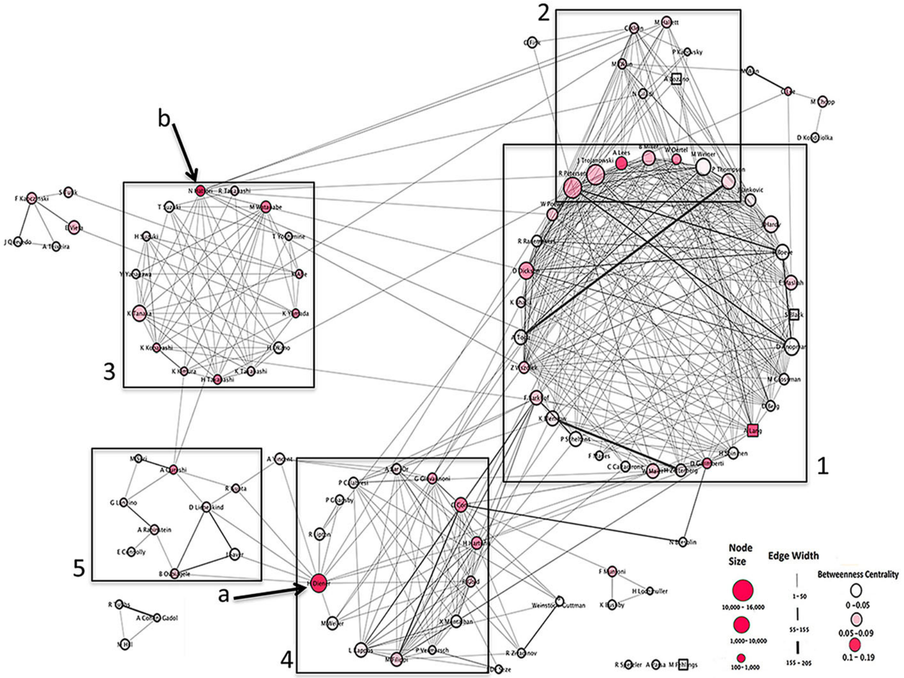

Fig. 1 Global social network analysis. *Open square box* Faculty of Medicine. *Open circle* Global Researcher. *Boxed* areas indicate the network clusters, details are provided in Table 6. *Arrows* identify two individuals with high betweenness centrality and link together two or more clusters. The node size represents the number of citations received to the papers authored by individual researchers. The edge width represents the number of co-authored publications between two nodes. The betweenness centrality identifies individuals with high connectivity in the network

When the SNA data was analysed by cohesiveness (strength of links between researchers), 13 clusters were initially identified, of these five were statistically valid (Table 5). The clusters were comprised of researchers who either share a particular research focus within NMH or share a common non-English language, Japanese. The largest of the clusters with 31 researchers/nodes focused on the study of neurodegenerative disease, particularly Alzheimer's and Parkinson's. The neurodegeneration cluster was effectively linked to three smaller clusters; movement disorders, Japanese language and neuroinflammation and multiple sclerosis (Fig. 1; Table 5). The links between the movement disorders and neurodegenerative disease clusters were sufficiently strong that several members of the latter were linked into the movement disorders cluster (e.g. Petersen, Trojanowski, Oertel and Thompson).

The exception to the subject area focused clusters involved researchers sharing the Japanese language. This was one of the most insular with only 15 of the 54 edges connecting to nodes external to the cluster (Fig. 1, Cluster 3). When the Betweeness centrality for the network was calculated for the Japanese nodes, Dr. Hattori, was identified as a key information conduit to the main network (Table 6). Interestingly in the period covered by this study Dr. Hattori published a total of 169 documents only 12 of which were represented in the Japanese cluster. When the size of the individual Japanese nodes (reflecting the number of citations to their publications) was compared to the nodes in the other clusters it appears that their citations/document were similar, however the citation data reflects all publications from the individuals and was not limited to the Japanese language publications. When the citations to the Japanese-language publications was compared to English language publications there was an order of magnitude difference with an average of 19 citations per publication in English language journals and 0.6 citations per publication in the Japanese journals. The German-language researchers were similar; an example is Professor Diener, from the Universitatsklinikum Essen who published 508 documents in the 5 years period with an average citation rate of 26.0. Of these 266 were published in German journals with an average citation rate of 0.76, and the remaining 242 in English-language journals with an average citation rate of 53.5.

The SNA analysis of betweeness centrality identified a number of key individuals who linked together the different clusters in the overall network representing information conduits (Table 6). The two most effective connectors were H. Hattori of Juntendo University a member of the Japanese cluster and H. Diener of Essen University a member of the neuroinflammation and multiple sclerosis cluster. Both these individuals linked their respective clusters to the large neurodegenerative diseases cluster and to a second cluster.

Table 5 Top 100 Global NMH researchers: SNA Cluster Analysis

Cluster	Size	Density	In-weight	Out-weight	Quality	Items	*P* value	Subject
1	31	0.47	218	71	0.75	5887	<0.001	Neurodegenerative disease
2	28	0.51	193	76	0.72	5199	<0.001	Movement disorders
3	15	0.51	54	15	0.78	142	<0.001	Japanese language
4	15	0.51	54	47	0.54	2962	<0.001	Neuroinflammation and multiple sclerosis
5	7	0.52	11	12	0.48	1254	<0.05	Cerebrovascular

Table 6 Top 100 Global NMH researchers: SNA betweenness centrality

Name	Institution	Items	Degree	Betweenness centrality
N. Hattori	Jutendo U.	169	15	0.15
H. Diener	U. Essen	506	13	0.14
A. Lees	U. College London	192	22	0.09
AE Lang	U. Toronto	160	18	0.08
M. Watanabe	Hokkaido U.	209	11	0.07
G. Comi	U. Vita and Salute	316	11	0.07

Eight additional researchers showed strong connectivity between their cluster and one other cluster.

University of Toronto research networks

The NMH researchers at UofT collaborated extensively, only three were not linked to other members of the cohort (Fig. 2). When the SNA data was analysed by cohesiveness, four clusters were statistically valid (Table 7). Two of the clusters were associated with research areas not identified in the global SNA, the largest, with 16 members, was focused in the area of paediatric neuro-oncology and neuro-development, the second, involving 15 researchers, was focused on mental health and schizophrenia. The other two clusters were in movement disorders/neurodegeneration and cerebrovascular disease (Fig. 2, Table 7). One investigator formed a strong linkage between the movement disorders/neurodegeneration and mental health clusters (Dr. Houle).

The SNA analysis of betweeness centrality identified a number of key individuals who linked together the different clusters in the overall network representing information conduits (Table 8). The two most effective connectors were Dr. S. Black in the Department of Medicine (Fig. 2a) and Dr. S. Houle of the Department of Psychiatry (Fig. 2b). Dr. Black was an effective bridge between researchers in the Department of Psychology in the Faculty of Arts and Science (FAS) and researchers in the UofT FoM.

Discussion

While bibliometrics plays a central role in institutional evaluations, there are inherent biases to the methodology. It is well known that the English scientific literature predominates the discourse irrespective of the quality of the work published in non-English publications (Meneghini and Packer 2007). A secondary challenge is the prevalence of homonyms such that the error rate in aggregated datasets can be as high as 30 % of records (Tang and Walsh 2010). While evaluations at the global level are minimally affected by the error rate (Leydesdorff et al. 2015) when the unit of comparison is at the mid (institutional) or low level (departmental) level the use of disambiguated data sets should be required. Although, the coverage of core high impact English-language journals is identical in WoS and Scopus, Scopus has a broader overall coverage of lower impact and non-English language journals (Mongeon and Paul-Hus 2014). Combining both tools to evaluate the global NMH output permitted an analysis across multiple language sets.

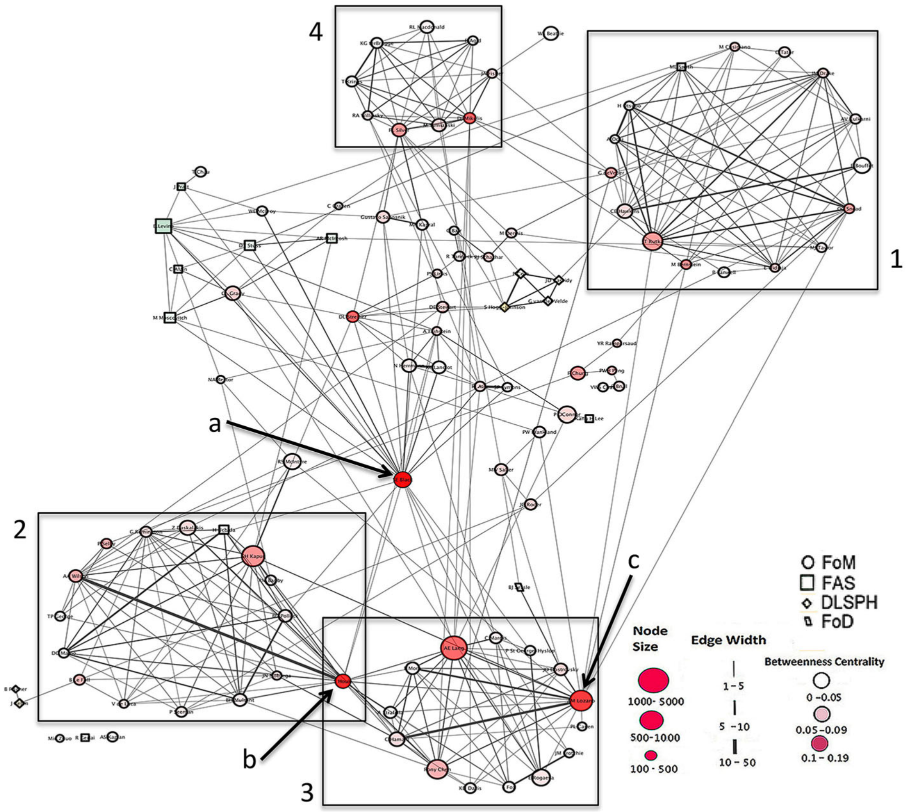

Fig. 2 UofT social network analysis. *FoM* Faculty of Medicine, *FAS* Faculty of Arts and Sciences, *DLSPH* Dalla Lana School of Public Health, *FoD* Faculty of Dentistry. *Boxes* indicate the topic clusters, details are provided in Table 8. *Arrows* identify three individuals with high betweenness centrality and link two or more clusters. The node size represents the number of citations received to the papers authored by individual researchers. The edge width represents the number of co-authored publications between two nodes. The betweenness centrality identifies individuals with high connectivity in the network

Table 7 Top 100 UofT NMH researchers: SNA cluster analysis

Cluster	Size	Density	In-weight	Out-weight	Quality	Items	*P* value	Subject
1	16	0.48	57	17	0.77	425	<0.001	Paediatric neuro- oncology and neuro-development
2	15	0.52	55	30	0.65	348	<0.001	Mental Health and Schizophrenia
3	15	0.47	49	40	0.55	344	<0.001	Movement disorders and neurodegeneration
4	10	0.71	32	17	0.65	212	<0.001	Cerebrovascular disease

Table 8 Top UofT NMH researchers: SNA betweenness centrality

Name	Department	Items	Degree	Betweenness centrality
S. Black	Medicine, FoM	96	21	0.16
S. Houle	Psychiatry, FoM	70	22	0.14
A. Lozano	Surgery, FoM	121	17	0.12
DJ Mikulis	Medical Imaging, FoM	57	14	0.10
DL Streiner	Psychiatry, FoM	63	11	0.10
AE Lang	Medicine, FoM	111	16	0.09

Researchers from many different countries were represented in the top 100 high output dataset with 48 of the 100 from non-English language countries. However, the majority of their publications were in English language journals. This was case with the Japanese language cluster identified by SNA, with over 97 % of the citations to their papers coming from English-language journals. Thus, while there is an identifiable Japanese publishing network, the reach/impact of these publications is limited and the authors have overcome this by publishing in English-language journals. A similar situation was identified during a bibliometric study of Indian Neurosciences research (Shahabuddin 2013), indicating that while vibrant ethnic research cultures exist in non-English language countries the impact of this research will be under-represented by conventional bibliometric analyses.

The debate concerning appropriate impact measurements to use for bibliometrics continues with the search for a normalization method that recognises asymmetric distribution of citations (90 % of citations are obtained by 10 % of publications) and the fact that citation rates vary widely across disciplines and research fields in the clinical and biomedical sciences (Bornmann and Mutz 2011; Opthof 2011). In addition to the inherent flaw created by using comparisons valid for symmetric data for asymmetric samples, is the challenge created by the use of non-disambiguated publication records. In all cases the commercially available tools for bibliometric analyses use publication records that are not disambiguated by author, this produces an overall systemic error that is most extreme in comparisons at the institutional and individual level (D'Angelo et al. 2011). The current study addressed the issue of data accuracy at the institutional and individual level however has not addressed the issue of statistical validity.

Disciplinary analysis

In both the global and the internal UofT datasets the highest output researchers were in the clinical disciplines with few basic, social sciences/behavioural or population sciences researchers represented. However, it should be noted that the majority of the clinicians in the top groups held M.D./Ph.D. degrees with advanced research training. These findings support earlier work comparing citation patterns for clinical and basic sciences in cardiovascular research (Opthof 2011). In the analysis of the UofT cohort, changing from total output to one of the three impact measures available from the InCites tool increased the representation of non-clinical researchers by 10 %. The use of impact data also increased the representation of women from 20 to 31 %. These results support the move away from using publication output alone as a metric to assess individual careers, and imply that institutions need to move beyond the "publish or perish" reward system that simply counts number of publications. The availability of normalized citation data, although limited to individual researcher publication data at moment, provides additional context to the bibliometric impact measures. When using bibliometrics to compare across disciplines, as in the current study, the most appropriate impact measure was considered to be the normalized journal citations (JA:JE).

SNA analysis

The SNA analysis was completed to determine the extent to which the top global and local NMH researchers work together in collaborative networks and to identify the research areas of the collaborative clusters. In the global SNA, collaborations spanned multiple countries united by disease focus and in the local network the collaborators spanned multiple Faculties at the UofT. Two areas, neurodegeneration and cerebrovascular disease, were represented in both SNA with researchers in common (A. Lozano, A.E. Lang, S. Black). The finding of two unique clusters in the UofT FoM SNA, informs strategic planning, indicating that paediatric neuro-oncology/neuro-development and mental health/schizophrenia are areas of institutional strength reaching across the UofT and Toronto Academic Health Sciences Network research institutes.

A hallmark of individuals with high betweenness centrality is the ability to undertake interdisciplinary research (Yan and Ding 2009). Researchers capable of working across disciplinary boundaries are in high demand to lead and motivate members of the large program grants common in the health sciences (Anderson and Steneck 2011). In the global SNA, two clusters; neurodegenerative diseases and movement disorders were linked by multiple researchers, whereas, in the UofT SNA these two research areas were represented by a single strong cluster. In both cases the high level of connectedness reflects the underlying neurological deficits associated with the diseases.

The ability of researchers to effectively collaborate both within their institutions and internationally results in higher impact publications and increased productivity (He et al. 2009; Lee and Bozman 2005). The increased emphasis on publication impact rather than volume by the two major annual university ranking systems (Times Higher Education and Quacquarelli Symonds) is leading institutions to examine the feasibility of strategies encouraging researchers to focus on high impact journals (Altbach 2010; Bornmann and Leydesdorff 2014). The use of SNA to supplement bibliometrics analyses enables institutions to identify and support effective research collaborative networks, which in turn should result in an increased number of high impact publications. SNA analysis can also identify those key researchers whose retirement or move to a different institution would uncouple collaborative networks. In this situation institutional hiring strategies could be focused on identifying an individual(s) capable of increasing the strength of network ties in the affected research area (van Rijnsoever and Hessels 2011).

In conclusion, the increased use of citation counts as an impact measure, while continuing to bias the literature towards the English-language publications and high profile journals, should at the same time increase visibility of women researchers and non-clinical research disciplines in the health sciences.

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