Mapping Collaboration Networks in the World of Autism Research

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In the era of globalization and with the emergence of autism spectrum disorder as a global concern, the landscape of autism research has expanded to encompass much of the world. Here, we seek to provide an overview of the world of autism research, by documenting collaboration underlying the International Meeting for Autism Research (IMFAR), the pre-eminent annual scientific meeting devoted to the presentation of the latest autism research. We analyzed published abstracts presented at IMFAR meetings, between 2008 and 2013, to determine patterns of collaboration. We described collaboration networks on the individual, institutional, and international levels, and visually depicted these results on spatial network maps. Consistent with findings from other scientific disciplines, we found that collaboration is correlated with research productivity. Collaborative hotspots of autism research throughout the years were clustered on the East and West coasts of the U.S., Canada, and northern Europe. In years when conferences were held outside of North America, the proportion of abstracts from Europe and Asia increased. While IMFAR has traditionally been dominated by a large North American presence, greater global representation may be attained by shifting meeting locations to other regions of the world. ***Autism Res*** *2015, 8: 1–8.* © 2014 International Society for Autism Research, Wiley Periodicals, Inc.

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Introduction

Collaboration is an intrinsic component of scientific research. The specialization of expertise and limitations of time and resources results in the reality that the individual scientist cannot make large contributions outside of a niche area without collaboration [Hara, Solomon, Kim, & Sonnenwald, 2003]. The motivations for collaboration are varied. However, regardless of the intellectual, material, or social reasons for cooperative research, collaboration is strongly pragmatic and oriented toward promoting scientific productivity and progress in a mutually beneficial fashion [Melin, 2000]. Numerous studies support the high degree of correlation between collaboration and productivity: The most collaborative researchers tend to be the most productive, while the most prolific and prominent researchers tend to collaborate more [Lee & Bozeman, 2005].

Although collaboration is well studied in other fields such as mathematics (e.g. the Erdös Number, which quantifies for any researcher, the degrees of separation in collaboration networks from noted mathematician Paul Erdös [Hayes, 2000]), collaboration in autism research has not been investigated. In the era of globalization and with the emergence of autism spectrum disorders as a global concern, the landscape of autism research has expanded beyond its European and North American origins to encompass much of the world.

Here, we seek to provide a descriptive overview of the world of autism research, by documenting collaboration underlying the International Meeting for Autism Research (IMFAR), the pre-eminent annual scientific meeting devoted to the presentation of the latest autism research. We analyzed published abstracts presented at recent IMFAR meetings, between 2008 and 2013, inclusive. In the following sections, we describe notable collaboration-related phenomena at IMFAR, including the top collaborators both on an individual and institutional level, as well as the most prolific investigators. In addition, we map the spatial topology of collaboration networks to provide a visual perspective of the field of autism research in recent years.

Methods

Data

The basic unit of analysis was a published abstract presented at the IMFAR annual meetings from 2008 through

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2013, the years for which structured data on abstracts, including author and institutional affiliation information, were available in a readily analyzable format. Abstracts were obtained from a third-party conference and abstract management company. All data analysis was performed within the R environment [R Development Core Team, 2013].

Defining Collaboration

An existing body of literature in library and information sciences has described collaboration with a variety of definitions [Katz & Martin, 1997]. Here, we defined collaboration as occurring between two or more researchers if they co-authored a published IMFAR abstract [Newman, 2001]. This definition is relatively stringent and limited, since scientific collaboration can occur without publication, and IMFAR abstracts are only one of many possible products of collaboration. However, because publications and presentations, especially at IMFAR, are concrete and measurable manifestations of scientific knowledge, the context of IMFAR is a suitable arena for examining collaboration and productivity in the world of autism research.

We classified collaborations as external or internal. For a given abstract, an external collaboration was defined as involving two or more authors from two or more institutions. Internal collaboration was defined as involving two or more authors from the same institution. From these definitions, it follows that an abstract with multiple co-authors is either the product of an internal collaboration, or an external collaboration, or both. We also examined paired collaboration, which is a measure of the number of abstracts on which two particular institutions collaborated. For example, if an abstract had authors affiliated with institutions A, B, and C, the paired collaborations defined were A-B, A-C, and B-C. Of note, authors were limited to a single institutional affiliation in 2008–2011 abstracts, but were allowed to have multiple affiliations in 2012–2013. For the years 2012–2013, 1,037 authors (15.0% of total) reported having multiple affiliations. In these instances, following the definitions above, an external collaboration was designated if there were two or more authors on the abstract.

For an individual researcher, the number of abstracts co-authored with others was used to rank the most collaborative researchers. Similarly, for a given institution, the number of internal and external collaborations was calculated to rank the most collaborative institutions.

Geocoding

All institutions were geocoded to a decimal latitude and longitude using the Google Places Application Programming Interface from within R using freely available code [Goldstein, Auchincloss, & Lee, 2014]. When geocoding could not resolve a latitude and longitude to the address level or otherwise failed, an attempt at manual geocoding was performed. All authors who could not be affiliated with a geocoded institution (e.g. due to missing institutional affiliation) were omitted from this analysis. In total, 98% of the authorship records were successfully geocoded to the address level; the remaining records were excluded from analysis.

We rounded the decimal values of latitude and longitude to three decimal places (corresponding to roughly 111 m distance at the equator). Because of the political complexity of organizational units (e.g. laboratories, schools, centers, institutes, and hospitals) within institutional structures that submitted abstracts to IMFAR, we defined distinct institutions based on geocoded coordinates. Institution A and Institution B were classified as distinct institutions if their latitude and longitude coordinates did not match to three decimal places. For example, Drexel University (latitude, longitude: 39.957, –75.190) and Boston University (42.351, –71.107) are distinct institutions. Therefore, abstracts co-authored by scientists at this pair of institutions would be deemed external collaborations. Geocoding was performed on a single day to account for possible variations to coordinates, such as a correction or addition of a geographic point.

Mapping

We used the R packages *maps* to draw the world map and *geosphere* to compute the spherical trigonometry coordinates and great circle distances between collaborating locations [Yau, 2011]. Curves (for paired collaborations) and points (for *n* of published abstracts) were plotted on maps, and visually weighted according to approximate tertiles: 1, 2, and ≥3 abstracts for paired collaborations, and 1, 2–9, and ≥10 abstracts for overall number abstracts published at IMFAR.

Results

For the years 2008–2013, there were 5,578 total published abstracts (Table 1). In total, institutions representing 66 countries published abstracts at IMFAR. Institutions in the U.S. authored 65.2% of all abstracts, the greatest by any individual country, followed by the United Kingdom (11.6%) and Canada (10.8%). Institutions in North America (76.4%) co-authored the majority of all abstracts, followed by Europe (26.2%), Asia (6.5%), Oceania (3.1%), South America (0.8%), and Africa (0.3%) (percentages do not sum to 100% because an abstract could be co-authored by institutions on different continents).

Table 1. Summary of Published IMFAR Abstracts by Year

	2008 London	2009 Chicago	2010 Philadelphia	2011 San Diego	2012 Toronto	2013 San Sebastian	Total 2008–2013
Abstracts	786	468	965	1,075	1,217	1,067	5,578
Authors							
Unique	2,316	1,566	2,758	2,920	3,503	3,418	10,418
Avg per abstract	4.6	5.2	4.7	4.7	4.9	5.0	4.8
Institutions							
Unique	614	373	595	729	849	914	1,956
Avg per abstract	2.1	2.2	2.1	2.5	2.3	2.5	2.3
Countries							
Unique	41	26	40	48	49	49	66
Avg per abstract	1.2	1.1	1.1	1.2	1.1	1.2	1.1
Continents							
N. America	508 (64.6%)	385 (82.3%)	815 (84.5%)	893 (83.1%)	983 (80.8%)	678 (63.5%)	4,262 (76.4%)
Europe	291 (37.0%)	104 (22.2%)	176 (18.2%)	216 (20.1%)	243 (20.0%)	430 (40.3%)	1,460 (26.2%)
Asia	65 (8.3%)	14 (3.0%)	49 (5.1%)	69 (6.4%)	82 (6.7%)	84 (7.9%)	363 (6.5%)
Oceania	22 (2.8%)	12 (2.6%)	13 (1.3%)	34 (3.2%)	38 (3.1%)	53 (5.0%)	172 (3.1%)
S. America	7 (0.9%)	4 (0.9%)	5 (0.5%)	6 (0.6%)	13 (1.1%)	7 (0.7%)	42 (0.8%)
Africa	1 (0.1%)	2 (0.2%)	1 (0.1%)	5 (0.5%)	3 (0.2%)	3 (0.3%)	15 (0.3%)

Note. Percentages do not sum to 100% because abstracts could be authored by multiple authors from multiple countries and continents.

These numbers indicate that IMFAR has been fairly U.S.-centric. However, examining the data from 2008 to 2013 reveals a promising trend that IMFAR is attempting (and succeeding) at becoming more globally focused, with meetings held outside of North America. Conference location effects were evident in years where IMFAR was held in Europe (2008—London and 2013—San Sebastian). The proportion of abstracts with European authors approximately doubled in 2008 and 2013 (~40%), as compared with the other years (~20%). Similarly, there was a small increase in abstracts from Asia in 2008 and 2013. Accordingly, the proportion of abstracts with North American authors decreased in those years (from ~82% in 2009–2012 to ~64% in 2008 and 2013).

A high degree of collaboration on published abstracts was evident. On average, each abstract was written by 4.8 authors from 2.3 institutions representing 1.1 countries (Table 1), while over 90% of abstracts featured two or more authors (Table 2). For each year, we examined collaborations in terms of numbers and percentages of authors, institutions, and countries per abstract (Table 2). Summed across all years, four co-authors affiliated with a single institution was the most common breakdown of authorship for an abstract. As many as 44 authors, 20 institutions, and 8 countries collaborated on a single abstract. External collaborations became more frequent over the years, with 58.9% of abstracts in 2008 being authored by ≥2 institutions, increasing to 66.3% in 2013 (chi-squared test for trend in proportions $P < 0.0001$). There was no evidence of trends across the years in numbers of multiple-authored abstracts ($P = 0.36$) or for abstracts from more than one country ($P = 0.15$).

Table 3 lists rankings for the greatest numbers of abstracts in terms of authors, institutions, and collaborations, aggregated across all six years. Of the top 10 institutions producing the most abstracts, U.S. institutions held eight spots. The lists of the institutions with the most abstracts, internal collaborations, and external collaborations had significant overlap. The Spearman correlations of the number of external collaborations vs. the number of abstracts produced was 0.97, and 0.85 between internal collaboration and abstracts produced. Collaboration between Canadian institutions was prominent: with the exception of one U.S. pair (Children's Hospital of Philadelphia and the University of Pennsylvania, who are academically affiliated), Canadian institutions constituted 9 of the 10 most frequent pairs of collaborators.

Figure 1 and Supporting Information Figures S1–S5 display research network maps summarizing abstracts produced by institutions as well as paired collaborations for IMFAR 2013, and 2008–2012, respectively. A map aggregating all years can be found in Supporting Information Figure S6. The median and mean distances between unique pairs of collaborators were 671 km and 2,066 km. Of all collaborations (weighted by frequency), 25% occurred within 15 km, 33% within 75 km, 50% within 553 km, 67% within 1,418 km, and 75% within 2,557 km (Fig. 2). The maximum observed distance between a pair of collaborators was 18,700 km (between the University of Western Australia and Columbia University).

Visual examination of the maps suggests several notable features (Fig. 1 and Supplementary Figures). Collaborative hotspots of autism research throughout the years generally were clustered on the East and West coasts of the U.S., Canada, and northern Europe. Dots without connecting lines suggest potential opportunities

Table 2. Size of Collaborations on Published IMFAR Abstracts for Authors, Institutions, and Countries by Year

Author collaborations as number of abstracts per year[a] (% of total abstracts per year)

Size	2008	2009	2010	2011	2012	2013
Single author	69 (8.8)[b]	17 (3.6)	67 (6.9)	71 (6.6)	68 (5.6)	76 (7.1)
2	94 (12.0)	54 (11.5)	111 (11.5)	152 (14.1)	156 (12.8)	113 (10.6)
3	133 (16.9)	74 (15.8)	166 (17.2)	185 (17.2)	219 (18)	177 (16.6)
4	146 (18.6)	79 (16.9)	173 (17.9)	158 (14.7)	222 (18.3)	162 (15.2)
5	100 (12.7)	80 (17.1)	142 (14.7)	171 (15.9)	172 (14.1)	158 (14.8)
6	102 (13.0)	60 (12.8)	98 (10.2)	137 (12.7)	130 (10.7)	109 (10.2)
7	52 (6.6)	24 (5.1)	69 (7.2)	70 (6.5)	94 (7.7)	84 (7.9)
8	35 (4.5)	33 (7.1)	54 (5.6)	47 (4.4)	46 (3.8)	62 (5.8)
9	16 (2.0)	14 (3.0)	39 (4.0)	27 (2.5)	34 (2.8)	43 (4.0)
≥10	39 (5.0)	33 (7.1)	46 (4.8)	57 (5.3)	76 (6.2)	83 (7.8)

Institution collaborations as number of abstracts per year[a] (% of total abstracts per year)

Size	2008	2009	2010	2011	2012	2013
Single institution	323 (41.2)	190 (40.5)	432 (44.8)	403 (37.4)	463 (38.0)	360 (33.8)
2	253 (32.2)	140 (29.9)	270 (28.0)	325 (30.2)	369 (30.3)	316 (29.6)
3	133 (16.9)	78 (16.7)	150 (15.5)	187 (17.4)	214 (17.6)	200 (18.7)
4	41 (5.2)	36 (7.7)	69 (7.2)	89 (8.3)	87 (7.1)	94 (8.8)
5	20 (2.5)	10 (2.1)	21 (2.2)	32 (3.0)	32 (2.6)	45 (4.2)
6	9 (1.1)	4 (0.9)	11 (1.1)	15 (1.4)	17 (1.4)	28 (2.6)
7	1 (0.1)	5 (1.1)	6 (0.6)	7 (0.7)	14 (1.2)	12 (1.1)
8	3 (0.4)	0 (0)	2 (0.2)	3 (0.3)	2 (0.2)	6 (0.6)
9	1 (0.1)	1 (0.2)	3 (0.3)	6 (0.6)	8 (0.7)	3 (0.3)
≥10	2 (0.3)	4 (0.9)	1 (0.1)	8 (0.7)	11 (0.9)	3 (0.3)

Country collaborations as number of abstracts per year[a] (% of total abstracts per year)

Size	2008	2009	2010	2011	2012	2013
Single country	693 (88.1)	420 (89.7)	875 (90.7)	964 (89.6)	1,088 (89.4)	921 (86.3)
2	80 (10.2)	43 (9.2)	86 (8.9)	98 (9.1)	114 (9.3)	119 (11.2)
3	11 (1.4)	5 (1.1)	4 (0.4)	6 (0.6)	14 (1.2)	17 (1.6)
4	2 (0.3)	0 (0.0)	0 (0.0)	2 (0.2)	1 (0.1)	7 (0.7)
5	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	1 (0.1)
6	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.2)
7	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
≥8	0 (0.0)	0 (0.0)	0 (0.0)	4 (0.4)	0 (0.0)	0 (0.0)

[a]Total published abstracts per year: 2008: 786; 2009: 468; 2010: 965; 2011: 1,075; 2012: 1,217; 2013: 1,067.
[b]This can be interpreted as the *n* of abstracts for this size for this year (% of total); e.g. in 2008, 69 abstracts had a single author (8.8% of total).

for research collaborations, particularly in Asia, South America, and Africa. Noticeable conference location effects were observed. For example, from IMFAR 2008 (London) to 2009 (Chicago), there was a drop-off in collaboration networks involving countries outside North America. Similarly, for 2012 (Toronto) to 2013 (San Sebastian), collaboration networks involving European institutions grew in frequency.

Discussion

Collaboration was a vital component of the research presented at IMFAR from 2008 to 2013. As the pre-eminent international meeting on autism research, IMFAR published abstracts from countries all over the world, with many collaborations occurring across national boundaries. IMFAR, to date, generally has been dominated by North American presenters, but promising data from meetings held in Europe indicate that a more globally inclusive IMFAR may be attained by shifting the meeting location to different countries. As expected, collaboration tended to occur more frequently when institutions were more geographically proximal. Both internal collaboration and external collaboration were closely linked with productivity as measured in terms of published abstracts. Compared with internal collaboration, external collaboration was more strongly correlated with productivity.

The findings are likely to be unsurprising to the knowledgeable reader. Results are consistent with previous work

Table 3. Top 10 Authors, Institutions and Collaborations by Number of Published IMFAR Abstracts, 2008–2013

Rank	By author	By institution	Internal collaboration[a]	External collaboration[b]	Pair[c]
1	Zwaigenbaum L (91)	University of North Carolina (169)	University of North Carolina (109)	University of North Carolina (131)	Dalhousie University & University of Alberta (55)
2	Roberts W (78)	University of California, Los Angeles (156)	University of Connecticut (97)	University of California, Los Angeles (130)	University of Toronto & University of Alberta (47)
3	(tie) Fein DA; Klin A (73)	Vanderbilt University (148)	University of California, Los Angeles (95)	Vanderbilt University (122)	Children's Hospital of Philadelphia & University of Pennsylvania (45)
4	–	(tie) Children's Hospital of Philadelphia; University of California, Davis (134)	Kennedy Krieger Institute (94)	(tie) University of California, Davis; Children's Hospital of Philadelphia (119)	(tie) McMaster University & University of Alberta; University of Toronto & Dalhousie University (39)
5	(tie) Bryson SE ; Szatmari P (66)	–	King's College Institute of Psychiatry (87)	–	–
6	–	Kennedy Krieger Institute (133)	(tie) Emory University; Vanderbilt University (84)	University of Alberta (104)	McMaster University & Dalhousie University (36)
7	Schultz RT (65)	King's College Institute of Psychiatry (131)	–	King's College Institute of Psychiatry (101)	Dalhousie University & University of Ottawa (34)
8	Baron-Cohen S (62)	University of Washington (127)	University of Washington (83)	University of Washington (97)	University of Ottawa & University of Alberta (33)
9	Mottron L (61)	University of Connecticut (118)	(tie) Yale University; Dalhousie University (73)	Kennedy Krieger Institute (92)	University of Toronto & University of Alberta (32)
10	Smith IM (60)	University of Alberta (115)	–	McGill University (91)	McMaster University & University of Toronto (29)

[a]Internal collaboration is calculated as the number of abstracts with ≥2 authors from the same institution.
[b]External collaboration is calculated as the number of abstracts with ≥2 authors from ≥2 institutions.
[c]Paired collaboration is calculated as the number of abstracts with authors from both institutions.

demonstrating the positive relationship between collaboration and productivity in other scientific disciplines, [Lee & Bozeman, 2005]. Moreover, the relationship between collaboration and conference abstracts published is also expected, given that the overall burden in production of an abstract can be divided among several authors.

There are several limitations to this analysis. Institutions were analyzed based on their geocoded locations. While 98% of institutions were successfully geocoded to street addresses, 2% of institutions could not be geocoded to this level and were thus excluded from analysis. Although a spot check indicated that the institutions that failed geocoding were generally infrequent contributors of abstracts and would therefore be unlikely to influence the overall findings, many were from non-U.S. countries, where representation was less common. In addition, the accuracy of self-report of institutional affiliation was a potential limitation, since different authors reported affiliations with varying degrees of precision, e.g. to the university level vs. to the institute level. We had no systematic way of verifying accuracy of reported affiliations or reconciling discrepancies. For more accurate identification of collaboration networks, future work may consider an institutional geocoding approach based on manual identification of parent and principal organizations, although such an approach would be laborious and likely error-prone because of the nuanced complexity of institutional hierarchies of different institutions.

Because the present analysis was focused on providing descriptive baseline data, we note that there are many areas for future comprehensive assessments. We were not able to provide in this analysis an assessment of subject content of the abstracts. This would be useful in order to detect hot topics and trends in research, and is an important consideration, especially for fields where specific research topics are more likely to involve large-scale collaborations (e.g. genetic consortia) or smaller scale collaborations (e.g. experimental studies). Semantic analysis that would be needed to accomplish this is challenging in the face of large numbers of text items, although automated approaches ranging from extraction of MeSH keywords [Hughes, Peeler, Hogenesch, & Trojanowski, 2014] to latent semantic analysis [Hu, Huang, & Hu, 2012] are possible tools to be used for this endeavor.

One important consideration for future work is that the autism research world extends beyond IMFAR, and other forums for scientific presentation would be useful to examine. Collaborative research is not that well represented by conference abstracts, since factors such as available funding and travel distance mean that conference attendance is self-selected. Productivity is only crudely

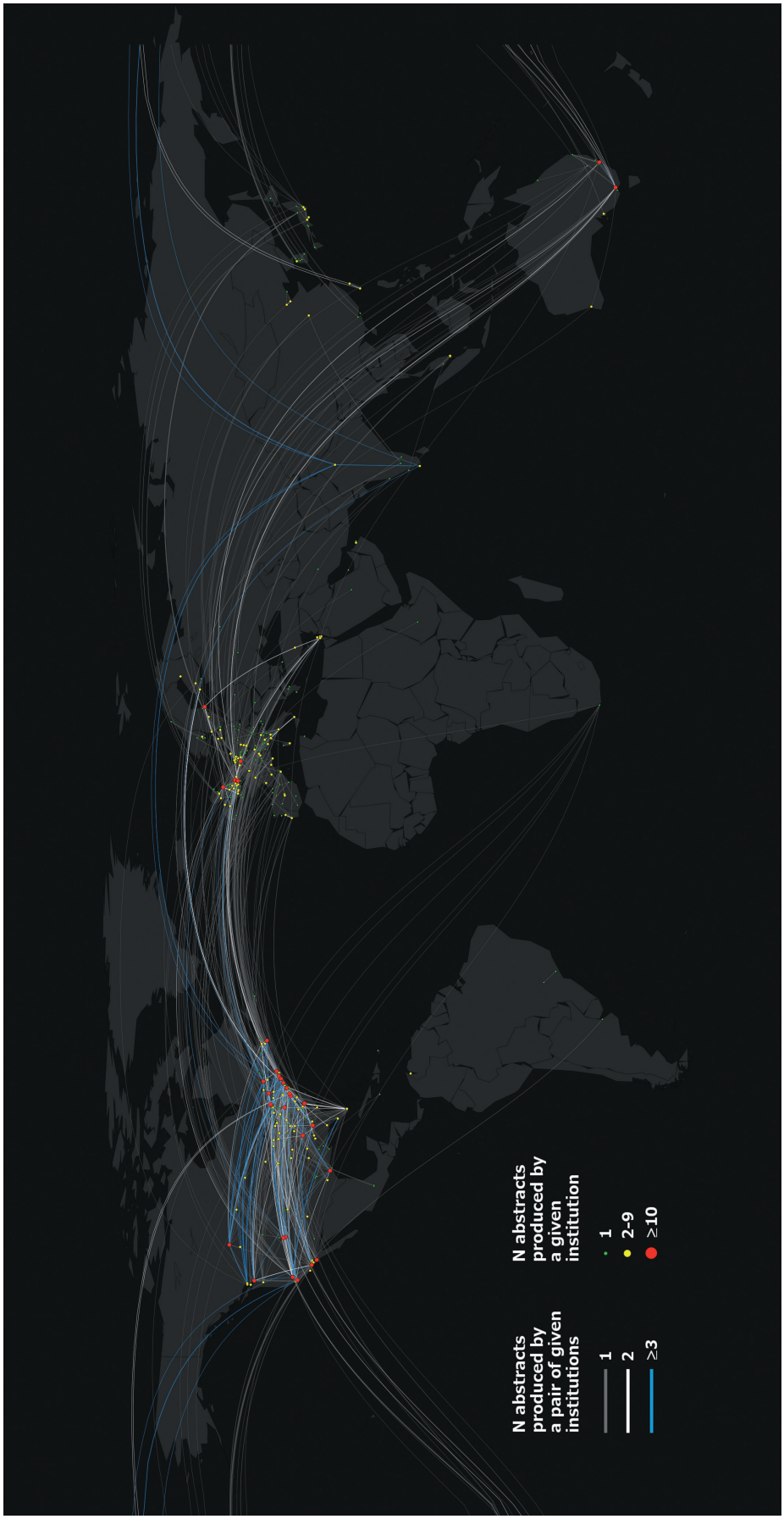

Figure 1. Collaboration map: IMFAR 2013, San Sebastian.

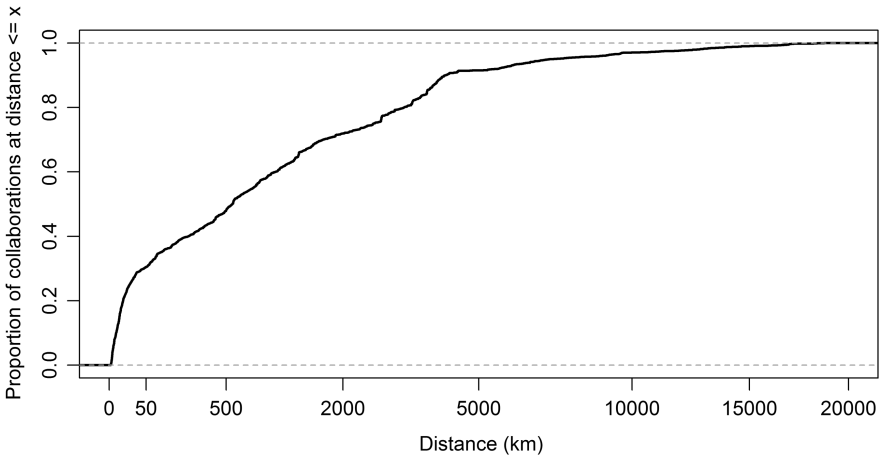

Figure 2. The empirical cumulative distribution function of the distance between pairs of collaborating institutions, IMFAR 2008–2013. Distances are plotted on the square root transform scale.

captured by published abstracts, and other bibliometric indicators such as publications in peer-reviewed journals can answer the question of whether abstracts that are published at IMFAR lead to publication in a peer-reviewed journal. Another consideration is that sociodemographic indicators are useful as key signals as to the direction of a research field; indicators to examine include representation of authors by training level, age, gender, and underrepresented minorities. In particular, it would be of great interest to track the trajectories of students and trainees as they progress toward independent research careers.

Finally, future efforts to describe the world of autism research should also discuss the funding environment. Given the worldwide economic turmoil of recent times, autism research has undoubtedly been influenced, and the repercussions remain to be seen. As all autism researchers would likely agree, we have an uphill battle ahead of us in terms of accomplishing impactful research with ever-shrinking budgets. Providing a quantitative assessment of the financial context (i.e. grants, operating budgets) underlying autism research and the relationship with subsequent research product would be an important area for future analysis.

In summary, we have provided a broad overview of the state of collaboration in the world of autism research as indirectly reflected by IMFAR-published abstracts from 2008 to 2013. The data presented here are not meant to be exhaustive, but rather serve as a baseline for more comprehensive efforts in the future, and to stimulate a dialogue regarding the evolving world of autism research. Although the findings may be unsurprising, self-assessment of our field over the last several years will be useful as we scientific researchers look to shape the future of autism research.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Figure S1. Collaboration map: IMFAR 2008, London.
Figure S2. Collaboration map: IMFAR 2009, Chicago.
Figure S3. Collaboration map: IMFAR 2010, Philadelphia.
Figure S4. Collaboration map: IMFAR 2011, San Diego.
Figure S5. Collaboration map: IMFAR 2012, Toronto.
Figure S6. Collaboration map: IMFAR 2008-2013.