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IS SCIENCE BUILT ON THE SHOULDERS OF WOMEN?

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ABSTRACT

Purpose: Women remain underrepresented in the production of scientific literature and relatively little is known regarding the labor roles played by women in the production of knowledge. This research examines these labor roles, using contributorship data from science and medical journals published by the Public Library of Science (PLOS). PLOS journals require each author to indicate their contribution to one or more of the following tasks: (1) Analyzed the data; (2) Conceived and designed the experiments; (3) Contributes reagents/materials/analysis tools; (4) Performed the experiments; and (5) Wrote the paper.

Method: We analyzed contribution data from more than 85,000 articles published between 2008 and 2013 in PLOS journals with respect to gender using both descriptive and regression analyses.

Results: Gender is a significant variable in determining the likelihood of performing a certain task associated with authorship. Women are significantly more likely to be associated with performing experiments and men are more likely to be associated with all other authorship roles. This holds true controlling for age: although experimentation is associated with academically younger scholars, the gap between male and female contribution to this task remains constant across academic age. Inequalities are observed in the distribution of scientific labor roles.

Conclusions: These disparities have implications for the production of science, the evaluation of scholars, and the ethical conduct of science. Adopting the practice of identifying contributorship rather than authorship in scientific journal will allow for greater transparency, accountability, and equitable allocation of resources in science.

Introduction

What constitutes women's work in science? The rhetoric of the "unique" and "special" talents of women relegated them to roles as amateurs and technical assistants in the production of knowledge in the early 20th century.[1] This secondary role was sustained by the relative underproduction and subsequent attrition of women in the labor market and the hierarchical nature of scientific inquiry promoted in the Big Science era. In contemporary science and medicine, women are matriculating at a greater rate than men, but still remain underrepresented in the production of science.[2] Furthermore, very little is known about the labor roles played by women and whether sex segregation in scientific production persists, despite claims for universalism in science.[3]

The inability to conduct large-scale analyses on this question has been largely a function of the idiosyncratic authorship practices of the 20th century, which provided authors on a byline (ordered in various ways, by disciplinary practice), without an acknowledgment of actual contributions.[4] These practices have led to several concerns—most notably the lack of public accountability of authors when issues of fraudulent research arise and the prevalence of ghost and honorific authorship. To counter this, medical journal editors have been proactive in arguing for greater specificity around authorship roles: for example, the International Committee on Medical Journals Editors (ICMJE) Recommendation includes explicit criteria for what constitutes authorship on a paper.[5]

However, practices of ghost and honorific authorship continue[6-7] as these standards fail to capture the precise roles played by each author on the paper—an issue that is further complicated by rising rates of hyperauthorship.[8] The notion of replacing authorship with contributorship was advanced in the late 1990s as a "radical change" in scholarly publishing[9] whereby authors would be listed by their roles, rather than in a ranked order. Fifteen years later, a few journals have begun to include contributor information, without abandoning the byline. Some have done this systematically (e.g., *JAMA*), but most collect data idiosyncratically—either in the form of acknowledgements or by providing an open field for specifying contributions (e.g., the *BMC Medical Education* journal). The lack of systematic data collection limits large-scale data mining.

The Public Library of Science (PLOS) is one early adopter of the practice of identifying author contributions. PLOS, a nonprofit open access publisher of seven high-impact journals, provides criteria for authorship and requests that the contribution of each author on the byline be identified in the following ways: (1) Analyzed the data; (2) Conceived and designed the experiments; (3) Contributes reagents/materials/analysis tools; (4) Performed the experiments; and (5) Wrote the paper. Each author can be assigned to one or more of these roles (other roles have been present historically; however, those enumerated represent the five main categories).

In this study, we analyze the contribution data found in 85,260 articles published between 2008 and 2013 in PLOS journals with respect to gender (controlling for variables such as discipline, authorship status, academic age, discipline, team composition, and country of author). Specifically, we seek to address whether there are gendered differences in scientific labor roles. This allows us to reveal, for the first time, a large-scale analysis of the differing roles played by the sexes in contemporary knowledge production.

Methods

Data

Two sources of data are used: Thomson Reuters' Web of Science (WoS) and all articles published by PLOS, available on the PLOS website in XML format. As of 2014, WoS covered more than 50 million articles published in almost 20,000 journals. PLOS has published 8 peer-reviewed scientific journals, largely in the biomedical area: *PLOS Biology* (founded in 2003), *PLOS Medicine* (2004), *PLOS Genetics (2005)*, *PLOS Computational Biology (2005)*, *PLOS Pathogens* (2005), *PLOS ONE* (2006), and *PLOS Neglected Tropical Diseases* (2007). *PLOS Clinical Trials* was published in 2006 and 2007 only. Nearly 95% of the articles used in this study were classed as biomedical (41.8%), clinical medicine (44.9%), or biology (7.9%).

The document object identifies (DOIs) for PLOS articles are provided in Article-Level Metrics, which was used to match each PLOS article with the corresponding record in WoS. (For a full description of this matching process, see the supplemental document.)

The dataset of PLOS articles, including authors' contributions as well as all WoS metadata, served as the sampling frame for the study. From this, any document types that were not standard articles and review articles were excluded. Furthermore, only articles published between 2008 and 2013 were included, as WoS only provided full first names from this time period. The journal *PLOS Clinical Trials* was excluded from the analysis, as it did not publish any articles during the period covered. Also excluded were articles lacking contributorship data (n=962) as well as those for which a match could not be established between PLOS and WoS (n=369). Four duplicates were also excluded. The final dataset included 85,260 articles published in seven PLOS journals between 2008 and 2013, for which we managed to establish a link between the PLOS and the WoS record.

Processing

The data underwent several rounds of processing before analysis. First, the contributions field had to be parsed to extract contribution type. There are several formats in which this could appear, so specialized code had to be developed for this. One of the unique features is that authors are listed by initials, rather than names, so the initial had to be matched back to author names (see online-only supplemental document). Academic age and gender were assigned to the authors, based on full name data. The gender of authors was given based on the gender assignation tables develop in Larivière et al.[2] This list uses given names and country combinations to assign gender to authors of articles. On the whole, this conversion list managed to assign a gender to 88.1% of authorships (i.e., author-paper combinations) of which 32.5% were female and 55.7% were male. Initials and unisex names accounted for 0.2% and 2.7% respectively, while the unknown rate was 8.9% (similar to what was found in Larivière et al.[2] for all WoS (i.e., 8.4%).

Academic age of authors was estimated using their year of first publication, as recorded in WoS. In order to obtain such age, authors found in the WoS were disambiguated automatically by the Center for Science and Technology Studies (CWTS, Leiden University) using the algorithm developed by Caron and van Eck.[10] Given that the majority of authors had less than 30 years of publication experience, the analyses for this paper focuses on those who have between zero (i.e., the first year in which a contributor was listed on a paper) to 30 years. It should be noted that, throughout the paper, when the term “academic age” is used, it refers to years since first publication.

Analysis

Descriptive analyses were run on the entire dataset. An analytic sample was constructed for the regression using those observations that contained all necessary variables (i.e., author position, academic age, number of authors, percent of female authors, country, and discipline): 270,103 observations were used of 589,906 possible observations. Differences between the regression and descriptive samples can be found in the supplemental materials. The most significant difference is the near total exclusion of 2013 data from the regression, given that age data was unavailable for this year. Given this, regressions should be interpreted as describing 2008-2012, whereas the descriptive figures (excluding those with age data), describe the 2008-2013 data. The regression analyses were conducted using SAS9.4.

Results

Hierarchy of science

Although not explicit, ranked authorship carries implicit assumptions of roles in certain disciplines. For example, in the biomedical sciences, the corresponding author is often the project investigator and senior researcher while the first author is the one who took a lead role in conducting the research. Figure 1 presents the proportion of men and women associated with certain labor roles, by the gender of the dominant author. When there is a female first or corresponding author, women are more likely to be associated with all tasks except contributing materials. In the case of male corresponding or first author, men are more likely to be associated with all tasks except experimentation. The largest gaps can be seen in terms of experimentation with female dominant authors—women are significantly more likely to be associated with experimentation in the case of dominant female authors.

Academic age roles

Women are, on average, academically younger than men in our sample and academic age has an effect on labor roles. Figure 2 presents the proportion of all authors of a given academic age and gender associated with a particular role. For example, nearly 80% of women and 60% of men in their first year of publishing are associated with performing experiments and that proportion decreases over time (i.e., more experienced researchers are less likely to perform experiments). However, there remains a clear gap in the contributions of experimentation, regardless of academic age, with women consistently doing proportionally more of this task.

The bottom of Figure 2 demonstrates the difference between female and male contributorships, by academic age. The gap between male and female contributions in conception, contributing materials, and writing the paper equalizes as the contributors age academically. Analyzing data, however, shifts from a male dominated activity in early years to a female dominated activity in later years.

Many hands make light work

The old adage might be expected to apply in scientific collaborations: as the number of authors increases, the proportion participating in any role should decrease. We see such a trend in most categories—with proportional contributions decreasing at nearly equal rates for men and women (Figure 3). Performing experiments, however, demonstrates a stable gap between men and women and very little change in proportional representation as the team size increases. A similar pattern can be observed in contributing material, with male dominance in this area. This demonstrates that an increase in team size does not lead to a more gender-balanced distribution of labor.

The relationship between the gender of the corresponding author and the gender of the contributors moderates the results. For example, when there is a male corresponding author, the proportion of women contributing to experimentation remains stable as the team size increases (Figure 4). However, for male authors (in the case of corresponding male authors), the proportion decreases as team size increases. Men are proportionally less likely to conduct experiments when there is a female corresponding author.

Irrespective of team size, women were more likely than men to be associated with one or two types of contribution per paper (and only slightly more likely to be associated with all five contribution types). Men were more likely than women to be associated with three or four contribution types per paper.

Gender roles

Given the differences observed in academic age, dominant author, and team size, a series of logistic regressions were conducted to control for these variables. The results of the logistic regressions demonstrate a significant ($p<0.0001$) relationship between gender and contributorship type, when controlling for all other variables. The odds of a female author being listed as performing the experiment were 1.52 times the odds of male author (Fig. 5). The odds for all other tasks were more likely to be a male author.

Regressions were conducted using the various types of contributorship (i.e., analysis, design, performing experiments) as the dependent variable and controlling for gender, authorship status, corresponding authorship status, academic age, number of authors, country, field, and publication year (Appendix A). In each case, gender remained a significant variable in determining likelihood of performing a specific role.

Limitations

This research has provided the first large-scale window into the gendered nature of contemporary science production. The results are limited, however, by the small range of time and the singular publisher from which data were gathered. The use of the first publication date as a proxy for academic age also introduces some imprecision into the age measurement (further complicated by the lack of 2013 data). Furthermore, given the newness of contribution statements, we require additional studies verifying the degree to which the stated contributions accurately reflect the work in the lab.

Discussion and Conclusions

There exists in the production of science inequalities in the distribution of scientific labor, with women more likely to be associated with the "physical" labor (i.e., performing experiments), whereas men are more likely to be associated with resource contributions and "conceptual" labor (i.e., conceiving and designing experiments and writing the paper). Gendered labor roles remain significant after controlling for academic age, discipline, country, authorship position, and proportion of male and female authors. These differences in labor roles may explain some of the disparities in the rates of scientific production between men and women[2], particularly in prestigious first and last author positions.[11]

It has been established that women are underrepresented among senior author positions generally[11] and in prominent medical journals specifically.[12] The present study extends previous research by demonstrating that the gender of the senior author is related to the roles played by other scientists on the team. Furthermore, the study has shown that the relationship between team size and proportional contribution to various tasks differs by gender of the corresponding author. The data suggests that, in the case of male corresponding authors, the proportion of authors contributing to a single task decreases as the team size increases. The same trend is not observed for female corresponding authors. The normative value of either model is arguable. On the one hand, there is evidence that specialization in scientific roles leads to higher quality science.[13-14] However, one could also argue that the growing rates of fraud (and the disproportionate representation of men in fraud cases)[15] suggests that the growing distance of authors from substantial aspects of authorship may have negative consequences.

Research on contributorship can reveal critical information on the mechanisms of science including, but not limited to, the role of gender and other variables in the effective functioning of the scientific workforce. However, this is dependent upon the collection of high quality contributorship data, a practice not widely employed by journals nor made available in machine-readable ways. In the field of medical education, there are very few journals that do this. The *BMC Medical Education* journal provides a designated section for author contributions. Other journals, such as *Medical Education*, *Medical Teacher*, and *Advances in Health Sciences Education* provide no indication regarding contributorship.

Future research depends on the availability of high quality data on contributorship, which will take a concerted effort on the part of journal editors, science policy makers, and scholars to advocate for and implement this reporting into the scholarly communication system. This is also an imperative for training—educating the next generation of scholars on equitable systems for distribution of labor and allocation of credit in scientific work. Replacing authorship with contributorship not only illuminates potential disparities in the scientific workforce, but may also mitigate scientific malpractice as scientists would be required to be more explicit about their roles, potentially lessening the opportunities for misappropriation of credit in scientific work. This is an important intervention point for those educating people in academic medicine. As authorship has changed, so too must our training, metrics, and documentation standards.

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FIGURE LEGENDS

Figure 1. Proportion of male and female authors contributing to each labor role, by gender of corresponding author (top) and gender of first author (bottom)

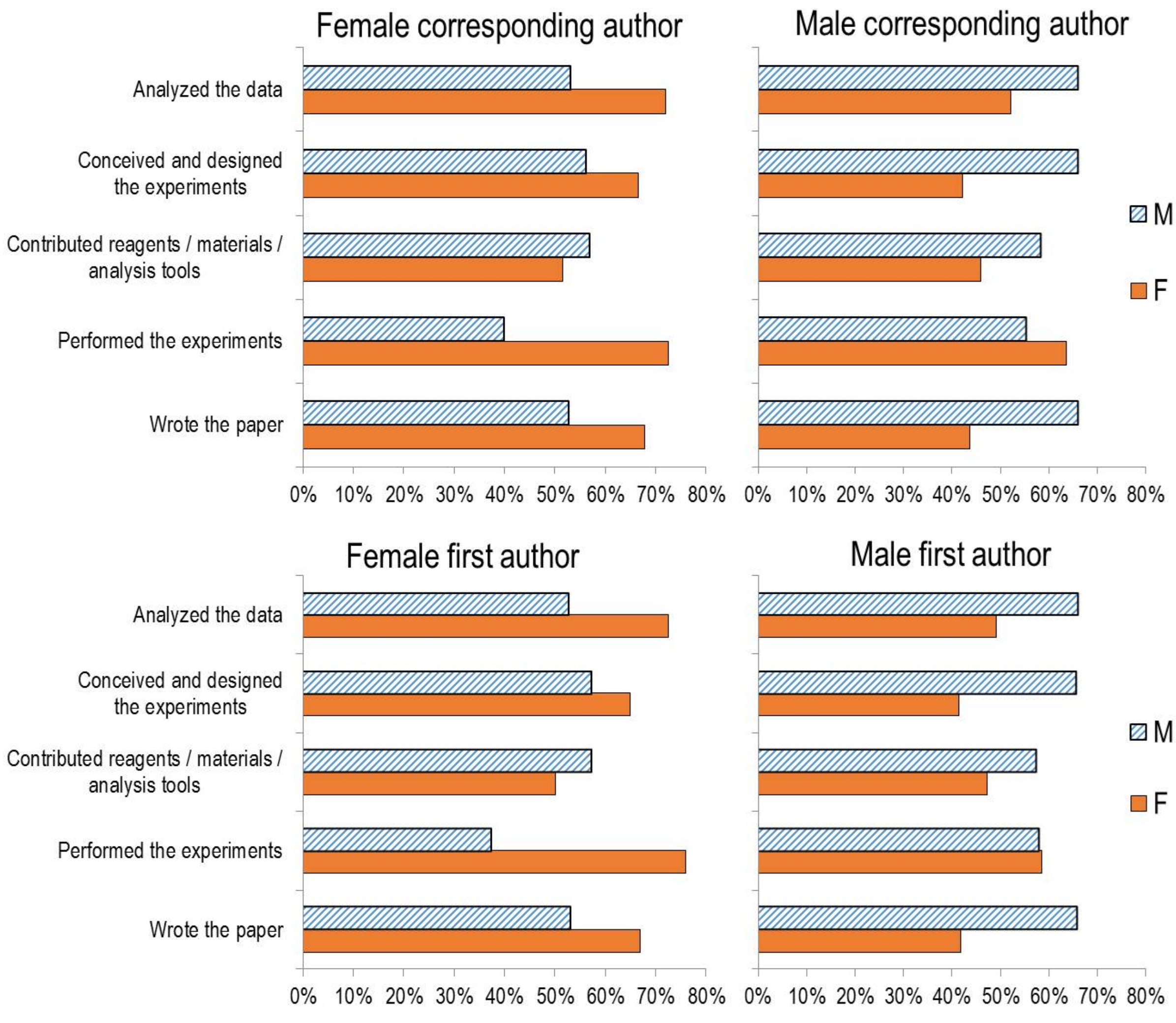


Figure 2. (Top) Proportion of male and female authorships (y-axis) associated with contributorship by career age (x-axis). (Bottom) Difference in female to male contributorship (y-axis) by career age (x-axis)

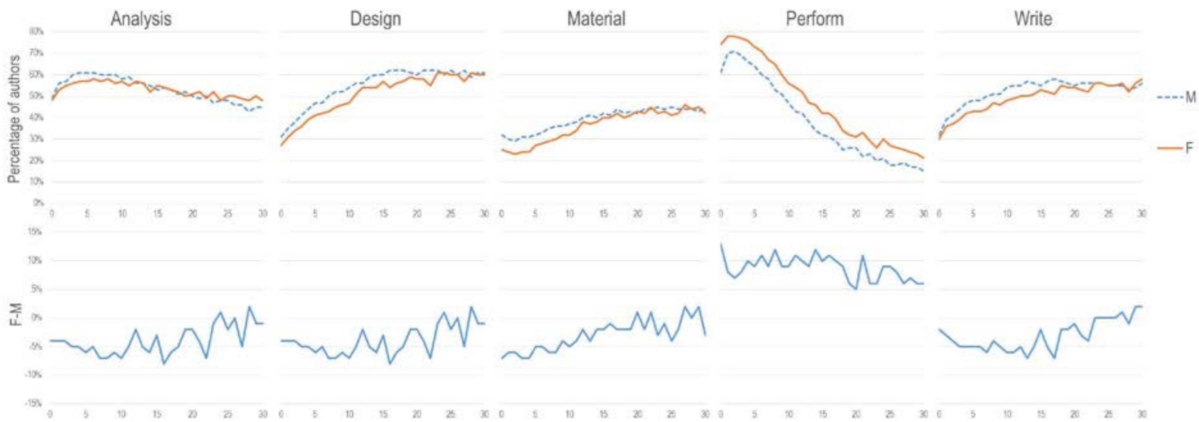


Figure 3. (Top) Proportional representation of female and male authors (y-axis) by number of authors on the paper (x-axis); (Bottom) Difference between female and male contributions (y-axis) by number of authors on the paper (x-axis)

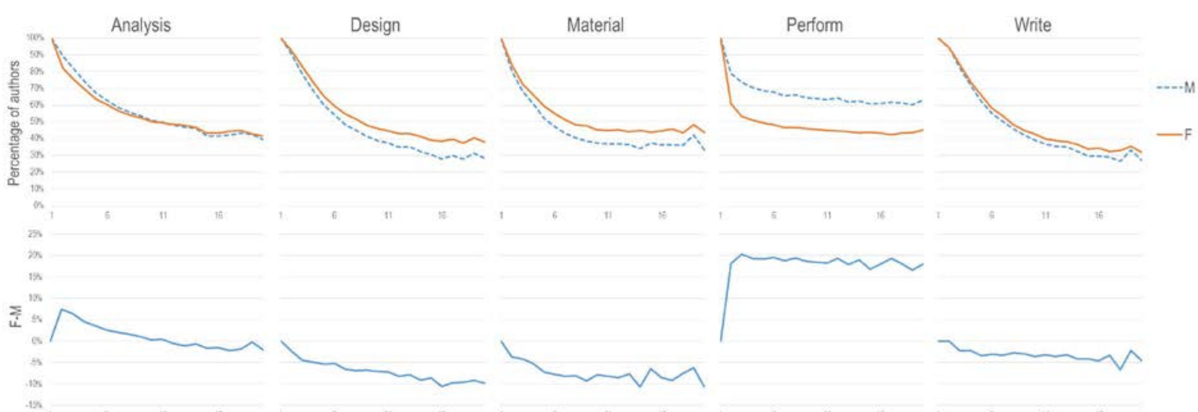


Fig. 4. Proportion of male and female contribution to authorship as a function of the total number of authors, by gender of corresponding author.

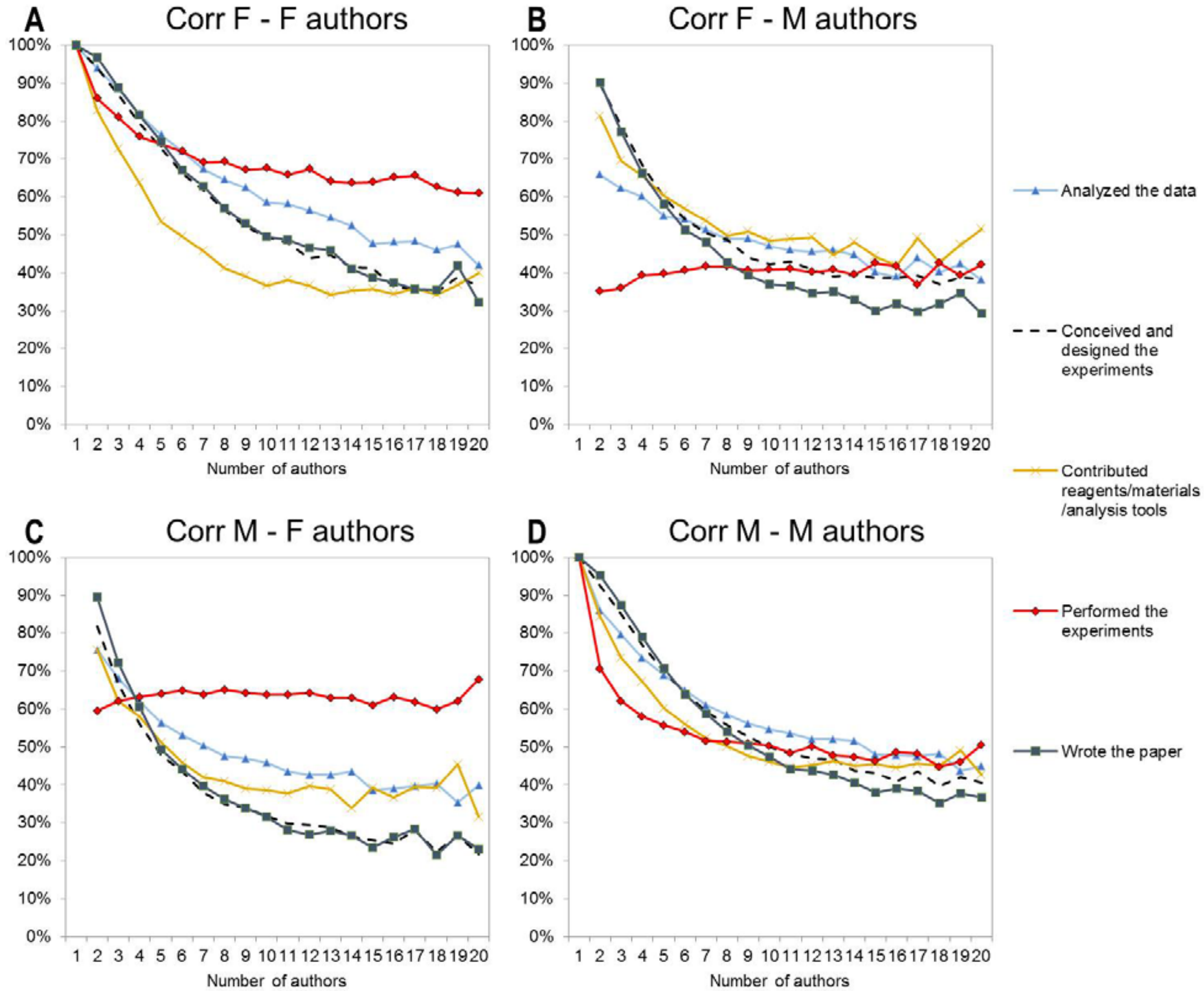
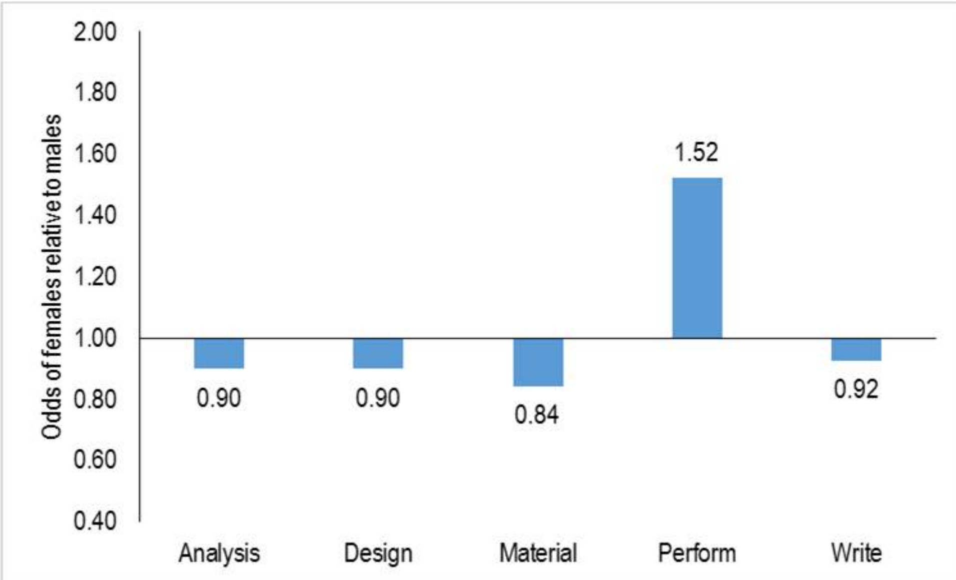


Figure 5. Odds of females identified as contributor for each type of contribution relative to males



Appendix A. Regression results.

Dependent variable: Analysis

	B	Se	p	odds
intercept	0.4069	0.6275	0.5167	
female	-0.1072	0.0104	<.0001	0.898346
Unknown gender	-0.0924	0.0143	<.0001	0.91174
first author	2.3825	0.0555	<.0001	10.83195
last author	0.7962	0.0125	<.0001	2.2171
corresponding author	0.3042	0.3042	<.0001	1.35554
academic age	-0.0121	0.000452	<.0001	0.987973
number of authors	-0.0302	0.000694	<.0001	0.970251
percent authors	0.1262	0.0222	<.0001	1.134509

female				
Country			<.0001	
Field			<.0001	
publication year			<.0001	

Cox & Snell's pseudo- R^2: 0.1640

Dependent variable: Design

	B	se	p	odds
intercept	2.0272	0.8175	0.0131	
female	-0.1729	0.0113	<.0001	0.841222
unknown	-0.1737	0.0154	<.0001	0.840549
first author	1.683	0.0535	<.0001	5.381677
last author	2.3855	0.0171	<.0001	10.86449
corresponding author	0.7458	0.7458	<.0001	2.108127
academic age	0.0431	0.000489	<.0001	1.044042
number of authors	-0.0393	0.000811	<.0001	0.961462
percent authors female	0.0699	0.0241	0.0037	1.072401
country			<.0001	
field			<.0001	
publication year			<.0001	

Cox & Snell's pseudo- R^2: 0.2688

Dependent variable: Materials

	B	Se	p	odds
intercept	-1.4909	0.7699	0.0528	
female	-0.1728	0.0102	<.0001	0.841306
unknown	-0.0895	0.0138	<.0001	0.914388
first author	-0.1049	0.0451	<.0001	0.900415
last author	-0.1649	0.0124	<.0001	0.847978
corresponding author	0.0858	0.0858	0.0551	1.089588
academic age	0.0291	0.000445	<.0001	1.029528
number of authors	-0.00174	0.000558	0.0018	0.998262
percent authors female	-0.1381	0.0214	0.0037	0.871012
country			<.0001	
field			<.0001	
publication year			<.0001	

Cox & Snell's pseudo- R^2: 0.0269

Dependent variable: perform experiment

	B	se	p	odds
intercept	-0.7563	0.6072	0.2129	

female	0.4205	0.0108	<.0001	1.522723
unknown	0.212	0.0148	<.0001	1.236148
first author	2.0301	0.0605	<.0001	7.614848
last author	-0.6188	0.0143	<.0001	0.53859
corresponding author	-0.3874	0.0598	<.0001	0.67882
academic age	-0.0825	0.000525	<.0001	0.920811
number of authors	-0.0127	0.000629	<.0001	0.98738
percent authors female	0.0826	0.0234	0.0004	1.086107
country			<.0001	
field			<.0001	
publication year			<.0001	

Cox & Snell’s pseudo- R^2: 0.2359

Dependent variable: write

	B	se	p	odds
intercept	2.8428	1.0728	0.0081	
female	-0.078	0.0117	<.0001	0.924964
unknown	-0.1794	0.0161	<.0001	0.835772
first author	2.5613	0.0593	<.0001	12.95264
last author	2.3059	0.016	<.0001	10.0332
corresponding	0.706	0.0594	<.0001	2.025872

author				
academic age	0.0321	0.000496	<.0001	1.032621
number of authors	-0.044	0.00087	<.0001	0.956954
percent authors female	-0.2813	0.0249	<.0001	0.754802
country			<.0001	
field			<.0001	
publication year			<.0001	

Cox & Snell's pseudo- R^2: 0.3081

Supplementary material

Methods

Data sources

Two sources of data are used: Thomson Reuters' Web of Science (WoS) and all articles published by the Public Library of Science (PLOS), available on the PLOS website in XML format.

The WoS database includes the Science Citation Index Expanded (SCIe), the Social Science Citation Index (SSCI), and the Art & Humanities Citation Index (AHCI). As of 2014, the WoS covers more than 50 million articles published in almost 20,000 journals.

The Public Library of Science (PLOS) publishes 8 peer-reviewed scientific journals. PLOS Biology (2003) and PLOS Medicine (2004) were the two first journals founded, followed by PLOS Genetics, PLOS Computationnal Biology and PLOS Pathogens in 2005, by PLOS ONE in 2006 and PLOS Neglected Tropical Diseases in 2007. PLOS Clinical Trials was published between 2006 and 2007.

Between 2003 and 2014, 127,911 articles were published in PLOS journals (eTable 1). PLOS ONE is the most prolific, with 106,460 documents published between 2006 and October 9th 2014. Other documents (n=21,451) were published across the seven other journals.

eTable 1. Number of documents per journal, 2003–2014

Journal	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	All
PLOS Biology	98	456	431	423	321	327	264	304	276	230	292	196	3,618
PLOS Computational Biology			72	168	251	287	376	414	418	521	553	423	3,483
PLOS Clinical Trials				40	28								68
PLOS Genetics			77	208	230	352	473	471	565	721	874	552	4,523
PLOS Medicine		68	434	487	346	250	199	193	206	208	219	128	2,738
PLOS Neglected Tropical Diseases					42	179	224	350	445	525	623	533	2,921
PLOS ONE				137	1,230	2,716	4,405	6,750	13,797	23,464	31,524	22,437	106,460
PLOS Pathogens			41	123	198	286	459	534	556	640	739	524	4,100
All journals	98	524	1,055	1,586	2,646	4,397	6,400	9,016	16,263	26,309	34,824	24,793	127,911

Data processing

Download and extraction

In order to create the corpus on the contributions of each of the authors, we used the data compiled by PLOS within the framework of the Article-Level Metrics[1]. Available in an Excel file[2], these data provide various citation and usage indicators but, more importantly for this project, the DOI of each of the articles, which was used to 1) download the full text of each PLOS article and 2) match each PLOS article with its record in the WoS.

In addition to full-text, PLOS journals make available PDF, RIS, BibTex and XML versions of the articles. In order to build the URLs of each of these articles, PLOS uses a standard format, which includes the journal URL, DOI, and type of format. For example, the link

[1] See : http://article-level-metrics.PLOS.org/alm-info/

[2] Available at : http://article-level-metrics.PLOS.org/PLOS-alm-data/.

[http://www.PLOSone.org/article/fetchObjectAttachment.action?uri=info%3A**doi**%2F10.1371%2Fjournal.pone.0004048&representation=XML] retrieves the XML format of the article "The Effects of Aging on Researchers' Publication and Citation Patterns".

Using this structure, we built a code for automatically downloading the XML format of each PLOS paper. Using the DOIs found in the Article-Level-Metrics table, the URL of the XML format of each of the documents was built and queried using the SQL Server Integration Services (SSIS) as well as a Visual C# code (see eAppendix 1). This uploads automatically the XML format of each article to the user's computer (see eAppendix 2).

Given that the metadata of each PLOS paper is available on WoS, only two elements are needed from the PLOS articles' XML structure: the DOI and list of authors' contributions. DOIs are kept in order to match articles with the WoS. In order to isolate and retrieve the author's contribution from the full text of the articles, another Visual C# script integrated to SSIS was written. Articles' DOIs were obtained through their URLs.

Table 3 provides the number of PLOS articles retrieved and the number of PLOS articles in WoS, as well as the proportion of PLOS articles that were matched with the WoS. As shown, 97.6 % (n=94,879) of all PLOS articles were indexed in the WoS. However, given that not all PLOS articles were assigned a DOI in the WoS, there is a small fraction of PLOS articles that could not be matched to the WoS. On the whole, more than 95.5% of PLOS articles published between 2008 and 2013 were matched to the WoS (92,845). Most of the articles are published in the journal PLOS ONE (more than 85%), and the large majority of these could be matched with the WoS (98.2%). The journal PLOS Clinical Trials, which was only published between 2006 and 2007, was excluded from the analysis, as it did not published any articles during the period covered (eTable 2).

eTable 2. Number and percentage of papers published in PLOS journals indexed in the WoS, 2008 - 2013

Journal	PLoS	WoS	Direct link with DOI	Match (%)
PLOS Biology	1,693	1,380	988	58.4%
PLOS Computational Biology	2,569	2,429	2,090	81.4%
PLOS Genetics	3,456	3,251	2,865	82.9%
PLOS Medicine	1,275	1,214	975	76.5%
PLOS Neglected Tropical Diseases	2,346	2,197	2,098	89.4%
PLOS ONE	82,656	81,393	81,208	98.2%
PLOS Pathogens	3,214	3,015	2,621	81.5%
All PLOS Journals	97,209	94,879	92,845	95.5%

Selection of the corpus

The dataset of PLOS articles, including authors' contributions as well as all WoS metadata, served as the sampling frame for the study. From this, any document types that were not standard articles and review articles were excluded, given that these are more likely to represent original contributions to knowledge (Moed, 2006). Furthermore, only articles published between 2008 and 2013 were included, as WoS only provided full first names and links to institutional addresses for this period (this was fundamental in the gender-name assignment procedure). This reduced the total number of articles to 88,067. Also excluded were articles lacking author contribute data (n=962) as well as those for which a match could not be established between PLOS and WoS (n=369). Four duplicates were also excluded. The final dataset included 87,002 articles published in the seven PLOS journals between 2008 and 2013.

Parsing the contributions field

For each article, each PLOS journal provides a list of each author's contribution to predetermined categories of contributions. The most common contributions are:

- Analyzed the data
- Performed the experiments
- Conceived and designed the experiments
- Wrote the paper
- Contributed reagents/materials/analysis tools

However, these statements of contributorship can take several forms. The most common form is this one:

> Conceived and designed the experiments: SD RK. Performed the experiments: SD MM MJH. Analyzed the data: SD MM. Contributed reagents/materials/analysis tools: MJH. Wrote the paper: SD RK.

In this case, the name of the contribution is followed with a colon, a space, and then the initials of each of the authors who have performed this task. Each author is separated by a space. There are, however, other forms which are more difficult to parse. In the following example, all authors' initials are separated by a comma, and are followed by the specific contribution.

> MS, CS, NC, CT, FGB, DR, NSF, MCP, HF, MPF, FB, PVA, PEC, SO, AG, FAS, PD, AM, MLA, and OS conceived, designed or performed the experiments. MS, CS, NC, CT, FGB, DR, NSF, KLR, MCP, HF, FB, PVA, PEC, SO, AG, IS, FAR, FAS, PD, AM, MLA, and OS analyzed the data or corrected the paper. BV, AZ, and AS contributed reagents/materials/analysis tools. MS, MLA, and OS wrote the paper.

This one, on the other hand, has the names of the authors written at length.

> Conceived and designed the experiments: Ohad Yogev, Orli Yogev, Eitan Shaulian, Michal Goldberg, Thomas D. Fox, Ophry Pines. Performed the experiments: Ohad Yogev, Orli Yogev, Esti Singer, Thomas D. Fox. Analyzed the data: Ohad Yogev, Orli Yogev, Eitan Shaulian, Michal Goldberg, Thomas D. Fox, Ophry Pines. Contributed reagents/materials/analysis tools: Michal Goldberg, Thomas D. Fox, Ophry Pines. Wrote the paper: Ohad Yogev, Michal Goldberg, Ophry Pines.

Extraction of authors' contributions

The first step in extracting author contributions was to identify the most common form of contribution statements. In order to do so, we have limited the first step to the 86,725 statements that start by seven characters (without a space) or by the following words: *wrote, final, first, icmje, model, this, the, took, idea, for, gave, data, built, study.* The name of the contribution was then isolated, as well as the initials (or names) of the researchers who have performed them.

To reduce the problems associated with the various forms of author contributions, we have divided our dataset into two categories. The first group comprises all contribution statements where there are equal numbers of colon and end points (n=82,031) while the second group consists of those for which the number of colons and end points is not identical (n=4,694). This allows distinguishing the contributions where end points are used for functions other than the end of a phrase or where points are missing and, would, thus, compromise the parsing of initials in subsequent treatments.

For the first group, we start by dividing the text using the end point found at the end of each contribution. For example, the following statement:

> Conceived and designed the experiments: SD RK. Performed the experiments: SD MM MJH. Analyzed the data: SD MM. Contributed reagents/materials/analysis tools: MJH. Wrote the paper: SD RK.

Is divided into the following sentences:
1. Conceived and designed the experiments: SD RK
2. Performed the experiments: SD MM MJH
3. Analyzed the data: SD MM
4. Contributed reagents/materials/analysis tools: MJH
5. Wrote the paper: SD RK

These contribution statements are then separated into two sections using the colon: the left part, which contains the contribution, and the right part, which contains the initials of the authors who have performed the task. Each initial is also extracted and placed into a specific field.

For the other group of contribution statements where the number of colons and end points is not identical, we cannot use the point as the marker of the end of a contribution. For example, this contribution statement contains a point following one of the authors' initials (Thomas D. Fox):

> Conceived and designed the experiments: Ohad Yogev, Orli Yogev, Eitan Shaulian, Michal Goldberg, Thomas D. Fox, Ophry Pines. Performed the experiments: Ohad Yogev, Orli Yogev, Esti Singer, Thomas D. Fox. Analyzed the data: Ohad Yogev, Orli Yogev, Eitan Shaulian, Michal Goldberg, Thomas D. Fox, Ophry Pines. Contributed reagents/materials/analysis tools: Michal Goldberg, Thomas D. Fox, Ophry Pines. Wrote the paper: Ohad Yogev, Michal Goldberg, Ophry Pines.

Hence, for this type of contribution, we need to find an additional way of separating the various contributions. We thus introduced another marker in each of the statements to parse each of the contributions. A vertical bar ' | ' was thus inserted at the beginning of each contribution to replace the point as a marker of contributions. The colon was then used to isolate the initials from the rest of the contribution field, and then, using the vertical bar, we isolated the contribution label. Here's an example of this treatment:

> |conceived and designed the experiments: ohad yogev, orli yogev, eitan shaulian, michal goldberg, thomas d. fox, ophry pines. |performed the experiments: ohad yogev, orli yogev, esti singer, thomas d. fox. |analyzed the data: ohad yogev, orli yogev, eitan shaulian, michal

goldberg, thomas d. fox, ophry pines. |contributed reagents/materials/analysis tools: michal goldberg, thomas d. fox, ophry pines. |wrote the paper: ohad yogev, michal goldberg, ophry pines.

Then, in a manner similar to the first group, we have isolated each contributing author using the space or comma. After a few treatments on the contribution statements that did not follow exactly the form typically used, we obtained collaboration statements for all 87,002 articles. On the whole, we obtained 20,667 distinct contribution labels, associated with 40,356 initials (contributors), for more than 1.5 million records. After the cleaning of contribution statements with typos, as well as the grouping of contribution statements having the same signification (for example, 'writing the paper' and 'writing the manuscript'), we obtained a list of the most common contributions, as well as the number of articles and of author-article combinations that feature this contribution (eTable 3).

eTable 3. Number and percentage of articles and of article-initial pairs, by contribution label

	Author-initial combinations		**Articles**	
Contribution	**N**	**%**	**N**	**%**
Analyzed the data	320,080	50.6%	85,900	98.7%
Performed the experiments	311,679	49.3%	82,811	95.2%
Conceived and designed the experiments	288,765	45.6%	85,406	98.2%
Wrote the paper	287,796	45.5%	86,517	99.4%
Contributed reagents/materials/analysis tools	220,331	34.8%	64,444	74.1%
Other (20 243)	*79,978*	*12.6%*	*15,900*	*18.3%*
N. distinct papers	**632,799**	**-**	**87,002**	**-**

Establishing a link between the WoS and the PLOS database

As mentioned previously, the DOI was used to match PLOS contributions and bibliographic information found in the WoS. Another link also has to be established between the two data sources, as the initials of the authors from the PLOS database have to be linked with the names of the authors found in the WoS record, in order to obtain each authors' gender. Each authors' name from the WoS was thus transformed into an 'initials' format to match the PLOS contributions using a SQL script. For more than 98% of articles (n=85,260), all authors were assigned to their contribution (eTable 4). Those that were not matched were due to mistakes in the spelling of the names in WoS, or their absence in the authors' list.

eTable 4. Number and percentage of articles and of article-initial pairs matched with the WoS, by contribution label

	Articles not matched with WoS		Articles matched with WoS		Percent difference	
Contribution	**N article-initial pairs**	**N articles**	**N article-initial pairs**	**N articles**	**N article-initial pairs**	**N articles**
Analyzed the data	320,080	85,900	306,592	84,221	4.2%	2.0%
Performed the experiments	311,679	82,811	297,893	81,183	4.4%	2.0%
Conceived and designed the experiments	288,765	85,406	277,302	83,734	4.0%	2.0%
Wrote the paper	287,796	86,517	274,615	84,789	4.6%	2.0%
Contributed reagents/materials/analysis tools	220,331	64,444	208,794	63,049	5.2%	2.2%
*Other**	*79,978*	*15,900*	*67,929*	*15,416*	15.1%	*3.0%*
N. distinct papers	**632,799**	**87,002**	**589,892**	**85,260**	**6.8%**	**2.0%**

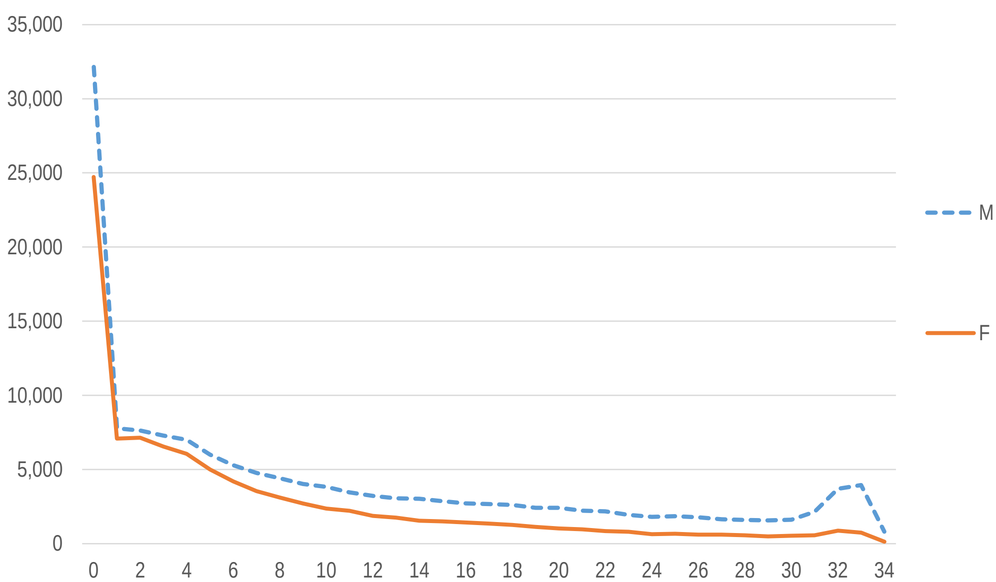
*Including the original wording of "Other" contributions as well as all other categories that did not correspond with these five main categories

Gender and age assignation

The gender of authors has been attributed using gender assignation tables developed in Larivière et al. (2013). This list uses given names and country combinations to assign gender to authors of articles. On the whole, this conversion list managed to assign a gender to 88.1% of authorships – i.e., author-paper combinations – found in the paper, of which 32.5% were female and 55.7% were male. Initials and unisex names accounted for 0.2% and 2.7% respectively, while unknown was 8.9%. This unknown rate is slightly above that obtained by Larivière et al. (2013) for all WoS (8.4%).

Academic age of authors was estimated using their year of first publication, as recorded in the Web of Science. In order to obtain such age, authors found in the WoS were disambiguated automatically by the Center for Science and Technology Studies (CWTS, Leiden University) using the algorithm developed by Caron& van Eck (2014). The distribution of ages for male and female contributorships is presented in eFigure 1. Given that the majority (95%) of authors were (academically) younger than 30 years—and that ages above 30 are overestimated because the first "possible" publication year in our dataset is 1980, the analyses for this paper focus on those whose academic age is between 0 and 30 years.

eFigure 1. Number of female and male contributorships by academic age.



Regression analysis

An analytic sample was constructed for the regression using those observations that contained all necessary variables (i.e., author position, academic age, number of authors, percent of female authors, country, and discipline): 270,103 observations were used of 589,906 possible observations. eTable 5 and 6 detail the differences between these samples. Regressions were run on the entire dataset and using each contributorship type as a dependent variable. The unit of analysis was author-publication combinations.

eTable 5. Differences between the whole and the regression samples

	Whole sample	Regression sample
n	589,906	270,103
Gender		
Females	32.5	32.4
Males	55.7	56.5
Unknown	11.9	11.1
First author	14.5	14.6
Last author	14.5	14.4
Corresponding author	14.4	14.6
Field		
Arts	.0	.0
Biology	5.6	5.0
Biomedical Research	43.2	46.5
Chemistry	.3	.2
Clinical Medicine	47.8	45.8
Earth and Space	.6	.4
Engineering and Tech	.3	.2
Health	.5	.4
Humanities	.0	.0
Mathematics	.1	.1
Physics	.3	.3
Professional Fields	.1	.1
Psychology	1.0	.9
Social Sciences	.2	.2
Unknown	.0	.0
Contributions		
analysis	52.0	52.8
design	47.0	47.0
material	35.4	35.0
perform	50.5	50.5
write	46.6	46.3
Publication year		
2008	3.1	5.9
2009	2.8	5.2
2010	9.6	18.1
2011	17.9	33.9
2012	29.4	34.9
2013	37.3	2.0
Academic age[a]	11.0 (10.3)	11.0 (10.3)
Number of authors[a]	6.9 (4.2)	7.0 (4.4)

Percent female[a]	35.6 (24.9)	35.3 (24.6)

Notes: Values in table show percentage of observations

[a]Descriptive analysis at document level. Numbers in corresponding rows are mean and standard deviation in parentheses. n=85,260 in whole sample and 49,290 in regression sample

eTable 6. Difference between whole and regression samples for countries with more than 0.5% of whole sample

	Whole sample	Regression sample
n	589,906	270,103
number of countries	189	178
missing	1.2	0
AUSTRALIA	2.8	2.8
AUSTRIA	.7	.6
BELGIUM	1.0	1.1
BRAZIL	1.7	1.5
CANADA	3.1	3.2
DENMARK	.9	.9
ENGLAND	5.1	5.7
FINLAND	.7	.7
FRANCE	5.3	5.9
GERMANY	6.3	6.5
INDIA	1.3	1.2
ISRAEL	.7	.8
ITALY	3.5	3.4
JAPAN	4.6	4.2
NETHERLANDS	2.5	2.6
NORWAY	.6	.6
PEOPLES-R-CHINA	12.4	9.1
PORTUGAL	.5	.5
SCOTLAND	.8	.8
SINGAPORE	.6	.6
SOUTH-KOREA	1.4	1.1
SPAIN	2.7	2.8
SWEDEN	1.7	1.8
SWITZERLAND	1.6	1.7
TAIWAN	1.8	1.4
USA	27.5	31.2

Supplemental Cited References

Caron, E., & van Eck, N. J. (2014). Large scale author name disambiguation using rule-based scoring and clustering. In 19th International Conference on Science and Technology Indicators."Context counts: Pathways to master big data and little data" (pp. 79-86). CWTS-Leiden University Leiden.
Larivière, V., Ni, C., Gingras, Y., Cronin, B., & Sugimoto, C.R. (2013). Global gender disparities in science. Nature, 504(7479), 211-213.

eAppendix 1. SQL code for the creation of the URL of each PLOS paper

```
    SELECT DISTINCT idPLOS, SUBSTRING(DOI, CHARINDEX('/', doi) + 1, LEN(DOI)) AS doi,
SUBSTRING(URL, 1, CHARINDEX('.org', url) + 4) +
'article/fetchObjectAttachment.action?uri=info%3Adoi%2F10.1371%2F' +
SUBSTRING(DOI,CHARINDEX('/',doi) + 1,LEN(DOI)) + '&representation=XML'AS url
    FROM dbo.PLOS
    WHERE idPLOS = ? /*parameter*/
```

eAppendix 2. C# code for the download of each paper (through Microsoft SQL server Integration Services)

```
using System;
using System.IO;
using System.Xml;
using System.Data;
using Microsoft.SqlServer.Dts.Pipeline.Wrapper;
using Microsoft.SqlServer.Dts.Runtime.Wrapper;


[Microsoft.SqlServer.Dts.Pipeline.SSISScriptComponentEntryPointAttribute]


public class ScriptMain : UserComponent
{
 string fichiersource = string.Empty;
 string JournalTitle = string.Empty;
 string fntype = string.Empty;
 string contribution = string.Empty;

 public override void CreateNewOutputRows()
 {

   fichiersource = Variables.destination;
   XmlTextReader xmt = new XmlTextReader(fichiersource);


   while (xmt.Read())
   {

     if ((xmt.Name == "fn") && (xmt.HasAttributes))
     {
```

```
        xmt.MoveToAttribute("fn-type");
        fntype = xmt.GetAttribute("fn-type");

        if (fntype == "conflict")
        {
          xmt.MoveToAttribute("fn-type");
          fntype = xmt.GetAttribute("fn-type");
          if (fntype == "con")
          {
            xmt.ReadToFollowing("p");
            contribution = xmt.ReadInnerXml();

            this.Output0Buffer.AddRow();
            this.Output0Buffer.NomFichier = Variables.NomFichier;
            this.Output0Buffer.DOI = "";
            this.Output0Buffer.Contribution = contribution;
            xmt.Close();
          }

        }
        else if (fntype == "con")
        {
          xmt.ReadToFollowing("p");
          contribution = xmt.ReadInnerXml();

          this.Output0Buffer.AddRow();
          this.Output0Buffer.NomFichier = Variables.NomFichier;
          this.Output0Buffer.DOI = "";
          this.Output0Buffer.Contribution = contribution;
          xmt.Close();

        }
        }

      this.Output0Buffer.EndOfRowset();
    }
  }
}
```

Appendix 3. C# code for extraction author's contribution in PLOS articles

```
using System;
using System.IO;
using System.Xml;
using System.Data;
using Microsoft.SqlServer.Dts.Pipeline.Wrapper;
using Microsoft.SqlServer.Dts.Runtime.Wrapper;
```

```
[Microsoft.SqlServer.Dts.Pipeline.SSISScriptComponentEntryPointAttribute]

public class ScriptMain : UserComponent
{
  string fichiersource = string.Empty;
  string JournalTitle = string.Empty;
  string fntype = string.Empty;
  string contribution = string.Empty;

  public override void CreateNewOutputRows()
  {
    fichiersource = Variables.destination;
    XmlTextReader xmt = new XmlTextReader(fichiersource);


    while (xmt.Read())
    {

      if ((xmt.Name == "fn") && (xmt.HasAttributes))
      {
        xmt.MoveToAttribute("fn-type");
        fntype = xmt.GetAttribute("fn-type");

        if (fntype == "conflict")
        {
          xmt.MoveToAttribute("fn-type");
          fntype = xmt.GetAttribute("fn-type");
          if (fntype == "con")
          {
            xmt.ReadToFollowing("p");
            contribution = xmt.ReadInnerXml();

            this.Output0Buffer.AddRow();
            this.Output0Buffer.NomFichier = Variables.NomFichier;
            this.Output0Buffer.DOI = DOI;
            this.Output0Buffer.Contribution = contribution;
            xmt.Close();
          }

        }
      }
      else if (fntype == "con")
      {
        xmt.ReadToFollowing("p");
        contribution = xmt.ReadInnerXml();
```

```
        this.Output0Buffer.AddRow();
        this.Output0Buffer.NomFichier = Variables.NomFichier;
        this.Output0Buffer.DOI = DOI;
        this.Output0Buffer.Contribution = contribution;
        xmt.Close();


      }

      this.Output0Buffer.EndOfRowset();

    }

  }
}
```