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Is the Relationship between Numbers of References and Paper Lengths the Same for All Sciences?

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ABSTRACT

In each of 41 research journals in the physical, life, and social sciences there is a linear relationship between the average number of references and the normalized paper lengths. For most of the journals in a given field, the relationship is the same within statistical errors. For papers of average lengths in different sciences the average number of references is the same within ±17%. Because papers of average lengths in various sciences have the same number of references, we conclude that the citation counts to them can be inter-compared within that accuracy. However, review journals are different: after scanning 18 review journals we found that those papers average twice the number of references as research papers of the same lengths.

Introduction

Scientists in all fields use a similar deductive logic to compare their new observations, data, or theories with the previous knowledge to determine the validity of the new results and/or that of the published results. However, scientists in different fields study different kinds of objects and use different vocabularies, so when we compare research papers published in various sciences, what are their significant similarities and differences? For instance, we have assumed that citation counts measure the importance and/or usefulness of research papers. Citation counts are correlated with reference frequencies because if the researchers in some fields use many references and others use them sparingly, the resulting citation counts would mean different things in those different fields, and the usefulness of citation counts would be questioned.

Of course individual papers receive high, moderate, or low numbers of citations depending upon the importance or usefulness of their results. However, if we average over many papers, what are the parameters independent of individual papers that determine the mean citation rate? Before doing any studies, we can guess that some of the pertinent parameters determining citation counts are (1) the length of the paper because long papers tend to have more content, (2) publication in journals with high impact factors because those are the journals more widely read, (3) rates of growth of the field because rapidly-growing fields will quickly produce more papers that will refer to the older ones, (4) the number of authors because they and their colleagues tend to spread knowledge of their results to wider audiences, and (5) the location in the journal because Ayres (2000) found that the first article in the journal tended to produce more citations than later ones, perhaps because the editors recognized them to be especially important. Thus this could be a multi-variate parameter set. However two previous studies, mentioned below, have already shown that the primary factor is the first one. Thus we will consider first the dependence of mean reference counts upon paper length and then later treat other parameters as perturbations.

Two previous studies were made of the dependence of reference counts on paper lengths in the physical sciences. The first (Abt 1987) responded to the statement that astronomers use more references in their papers than physicists and therefore the high citation counts in astronomy should not be compared with those in physics. That paper and the second (Abt 2000) yielded the following results:

1. In each of 13 journals in the physical sciences, there is a linear relation between the average number of references, R, in a paper and its normalized length, L, in 1000-word pages.
2. These linear relations between R and L are the same for all those 13 journals, although they are different for review papers, which have many more references, or for data-rich compilations, which have fewer references.
3. The reason why astronomy papers have more references than physics papers is simply because the former are longer (average of 11.3 pages) than the latter (6.2 pages). One recalls the informal discussions in physics of the "least publishable unit"; in the life sciences it is called "salami science." However the practice of dividing a major study into many small separate papers is rare in astronomy.
4. The slope of the linear relation may depend slightly on the Impact Factor of the journal. Also the slope increases slowly with time as the amount of published information grows.

Seglen (1992) explored citation rates for journals of various Impact Factors and found very little correlation. He also showed that for one journal (*Journal of Biological Chemistry*) there is a roughly linear relationship between mean citation rates and paper lengths. Sengupta (1986) counted mean paper lengths in pages and words in 10 chemistry journals but he did not study the relationship between paper lengths and numbers of references for individual papers. Similarly, Dimitroff (1992) counted mean paper lengths and mean numbers of citations in the *Bulletin of the Medical Library Association* but did not consider the relationship of lengths and references of individual papers. We are unaware of additional studies relating numbers of references and paper lengths.

The results by Abt are far-reaching in showing that in the physical sciences the average reference counts are the same for papers of the same length in different sciences. As one would expect, a major study leading to a long paper and including many references is likely to receive more citations than a short one; that produces the relationship between citation counts and reference counts.

In the present study we explore whether the same results apply to the life and social sciences. If they do, then citation counts can be used to evaluate the relative importance of papers in different physical, life, and social sciences, and to evaluate the relative research efforts of their authors and institutions. If they do not, then one should not compare the citation counts in different sciences.

Original Research Papers

We first studied journals containing original research papers; in the following section we will discuss review papers. We first studied journals in four fields of the life and social sciences, namely (1) biochemistry & molecular biology, (2) immunology, (3) general medicine, and (4) the social sciences. In most journals we scanned 200 papers to form five to nine mean data points of the mean numbers of references as a function of paper length. Not counted were news notes, comments, book reviews, errata, reports, obituaries, and review papers. Journals from 1999-2000 were used so that they could be compared with the data of the same years in the physical sciences in Abt (2000). We counted words per page of textual material to derive paper lengths in 1000-word pages. The resulting normalization factors ranged from 0.4 (for small format journals) to 1.2 for large crowded pages. Hereafter all use of the words "pages" and "paper lengths" refers to normalized 1000-word pages.

One should not expect perfect agreement between journals in their relationships between reference numbers and paper lengths because some journals (e.g. astronomy) use acronyms for journal titles and do not include paper titles; nearly all of their references occupy less than one printed line, one column wide. On the other hand, most of the references in the life sciences do not use acronyms for journal titles and give full paper titles, so that their reference lists often constitute 15% of the paper lengths. Therefore one can expect differences of up to 15% between journals because of those differing styles.

A. Biochemistry & Molecular Biology

For biochemistry & molecular biology the 10 journals scanned are listed in Table 1 together with their 1999 Impact Factors. An Impact Factor, IF, for a specific journal is the average annual number of worldwide citations per paper in that journal, averaged over the previous two years. The values were taken from the Institute for Scientific Information's *Journal Citation Reports* based on the *Science Citation Index*.

As we shall see, the mean numbers of references in papers turn out to be linear functions of the paper lengths. They have the form $R = a + bL$ where a and b are constants determined from least-squares regressions. Those linear relations are given in the third column of Table 1. The observed-minus-calculated scatter of the data points about those linear least-squares relations is given in the last column. A typical example is shown in Figure 1 for *Neurochemical Research*, which was selected for illustration because it has a scatter (±2.38) close to the mean in Table 1.

Table 1
10 Journals in Biochemistry & Molecular Biology

Journal	**Impact Factor**	**Ref.-Length** Relation	**O-C** Scatter
Cell	36.24	7.7 + 3.7L	±2.04
FASEB Journal	11.88	10.7 + 4.5L	3.02
Molecular & Cell Biology	9.87	15.9 + 3.6L	3.76
Journal of Biological Chemistry	7.67	13.0 + 4.1L	2.14
Biochemistry	4.49	10.1 + 3.8L	1.90
Biochemical Journal	4.35	17.6 + 2.6L	1.78
Free Radicals in Biology & Medicine	4.08	17.4 + 3.2L	3.35
Molecular & General Genetics	2.54	9.6 + 3.8L	2.03
Archives of Biochemistry & Biophysics	2.39	13.0 + 3.4L	2.22
Neurochemical Research	1.76	6.7 + 5.5L	2.38
Mean		13.3 + 3.6L	2.46

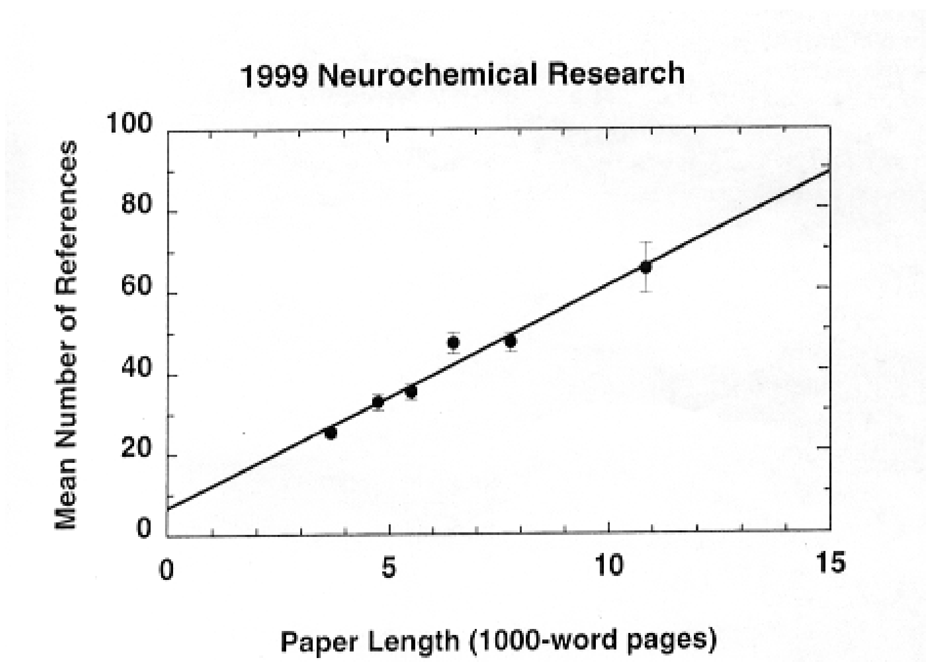

Fig. 1.-The relation between numbers of references and paper lengths for 200 papers in *Neurochemical Research.* This journal was selected as typical because the scatter of the data points around the linear relation is average for papers in biochemistry and molecular biology.

The linear reference-length relations listed in Table 1 do not differ substantially and do not seem to depend upon the Impact Factors, so we plotted all the mean data points for these 10 journals in Figure 2. The mean linear relation is given by R = 13.3 +3.6L. The scatter of the points about the mean linear relation is ±4.31 references, which is less than twice the average (±2.46) listed in Table 1. A scatter of less than 2 σ is not considered statistically significant, so we conclude that in the field of biochemistry &

molecular biology, all the journals have a similar dependence of reference numbers upon paper length, despite a range of Impact Factors from 1.76 to 36.24.

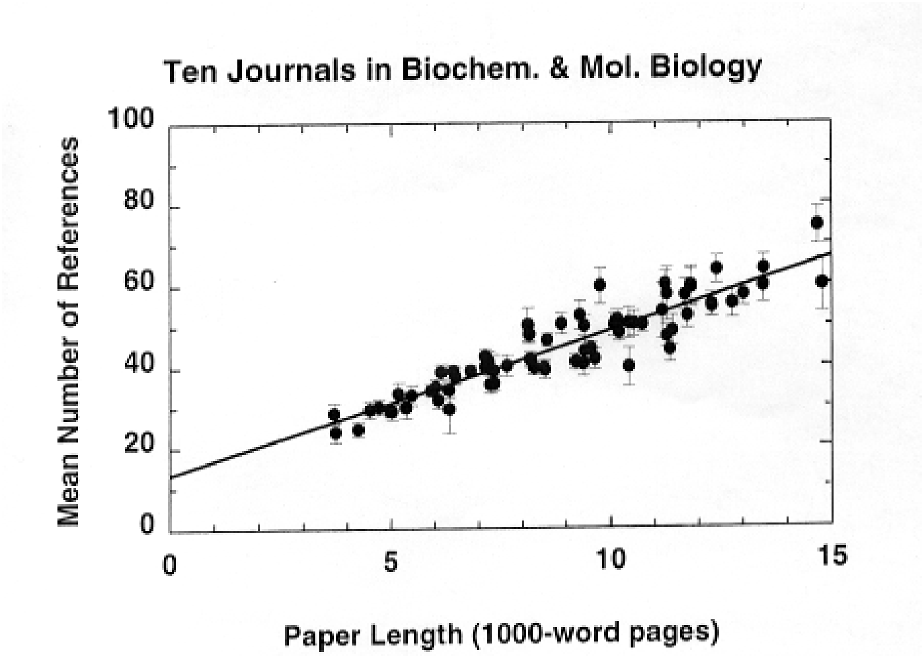

Fig. 2.-The R-L relation for 10 journals in biochemistry and molecular biology. The scatter about the linear relation is 1.8σ, where σ is the mean scatter in Table 1.

B. Immunology

Next we considered papers in five journals in immunology. They are listed in Table 2 and have a range from 2.56 to 15.65 in Impact Factors. Figure 3 shows the result of combining the data points for the five journals. The mean relation is R = 6.9 + 4.2L and the scatter about that relation is ±3.04 references or only 2.0 σ. Again we conclude that there are no significant differences between those journals. Furthermore, the graphs for the biochemistry and immunology journals are similar, so their data points would fit the linear relations in either Figure 2 or 3.

Table 2
Five Journals in Immunology

Journal	**Impact Factor**	**Ref.-Length** Relation	**O-C** Scatter
Journal of Experimental Medicine	15.65	6.3 + 4.5L	±1.95
Journal of Immunolgy	7.14	7.3 + 4.1L	0.52
AIDS	6.93	2.2 + 4.6L	0.60
Clinical Infectious Diseases	3.20	5.2 + 5.0L	1.68
Human Immunology	2.56	9.5 + 3.7L	2.66
Mean		6.9 + 4.2L	1.48

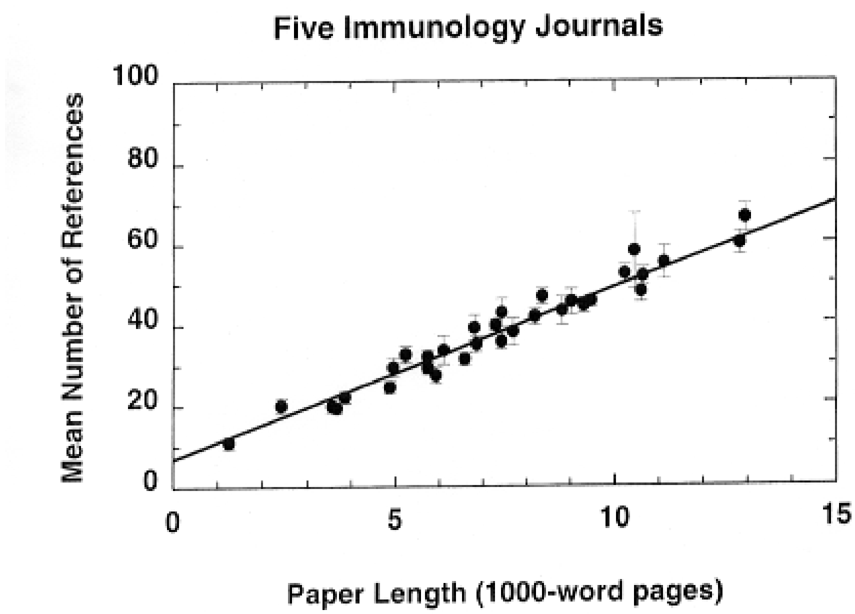

Fig. 3.-The R-L relation for five journals in immunology. The mean relation is not significantly different than for biochemistry in Figure 2.

C. General Medicine

The eight journals scanned in general medicine have a range in IF from 1.22 to 28.86, and are listed in Table 3. Figure 4 shows the combined data points for the first seven of these journals. The mean relation is R = –5.7 +7.3L. The mean scatter about that relation is ±5.93 references or about 2 σ. The linear relations between references and paper lengths are similar for the first six journals (those with IF > 5) but steeper for the last two. However, even those first six journals have a higher mean slope (7.3) than that for the 10 biochemistry journals (3.6) and five immunology journals (4.2). The data points in Figure 4 will not fit the linear relations in Figures 2 and 3. Thus there is a significantly different R-L relation for general medicine than for the other two life sciences, particularly for papers more than 7 pages long. Before exploring that difference, let us look at the data (partly published) for the physical sciences.

Table 3
Eight Journals in General Medicine

Journal	**Impact Factor**	**Ref.-Length Relation**	**O-C Scatter**
New England Journal of Medicine	28.86	4.8 + 5.0L	±2.24
JAMA	11.44	-2.1 + 7.3L	3.48
Lancet	10.20	1.6 + 4.8L	0.88
Annals of Internal Medicine	10.10	-7.7 + 7.3L	3.11
Archives of Internal Medicine	6.70	-1.2 + 5.8L	1.93
British Medical Journal	5.14	-0.6 + 5.6L	1.10
American Journal of Medicine	4.98	-11.4 + 9.2L	5.09
American Journal of Medical Science	1.22	-9.8 + 10.1L	4.51
Mean (first 7)		-5.7 + 7.3L	2.79

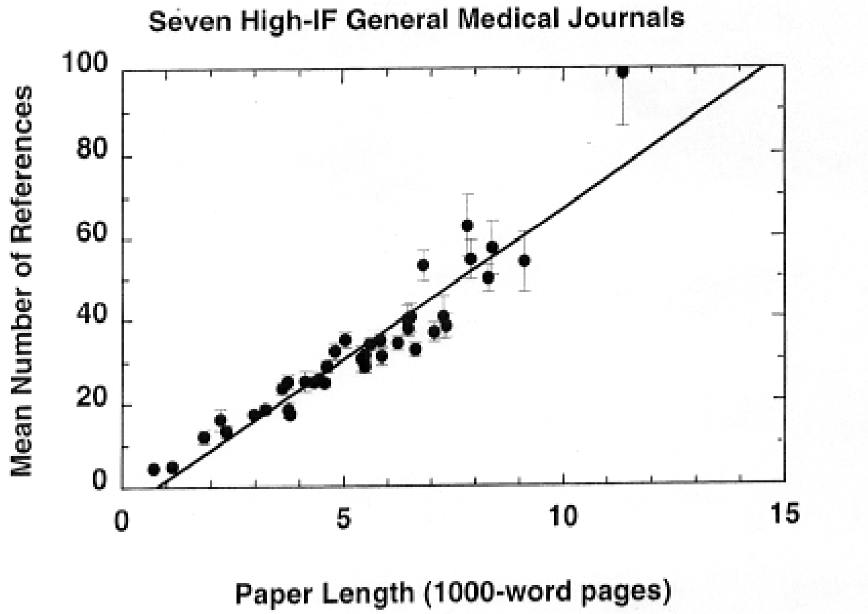

Fig. 4.-The R-L relation for seven journals with high Impact Factors in general medicine. The slope of the linear relation is much steeper than in Figure 2 and 3.

D. Physical sciences

The data from Abt (2000) for the nine journals in the physical sciences are listed in Table 4. The R-L relation for the first seven is similar and the combined graph is shown in Figure 5. The scatter about the mean R-L relation of R = 14.4 + 2.2L is ±3.57 references or 1.3 times the mean scatter in Table 4. Therefore there are no significant differences among these seven journals. However, the last two journals with low IF in Table 4 have a lower ordinate intercept of about 6, rather than 14.4. The main difference between the R-L relation for the physical sciences and the life sciences is the smaller slope of 2.2 compared with 3.6 for the biochemistry journals, 4.2 for the immunology journals, and 7.3 in general medicine. This means that although most of the journals in a given field have a similar R-L relation, that relation may be different than in other fields.

Table 4
Nine Journals in the Physical Sciences

Journal	Impact Factor	Ref.-Length Relation	O-C Scatter
Monthly Notices of the Royal Astronomical Society	4.55	19.3 + 1.7L	2.90
Astronomical Journal	2.88	18.9 + 1.9L	3.10
Icarus	2.80	8.2 + 2.6L	3.37
Physical Review A	2.76	11.9 + 2.0L	1.58
Astrophysical Journal	2.54	18.6 + 1.9L	2.68
Journal of Geophysical Research	2.42	11.4 + 2.2L	3.14
Astronomy & Astrophysics	2.25	13.0 + 2.5L	2.33
Journal of the Optical Society of America	1.84	4.8 + 2.7L	1.86
Publications of the Astronomical Society of the Pacific	1.31	7.9 + 2.4L	4.16
Mean		14.4 + 2.2L	2.79

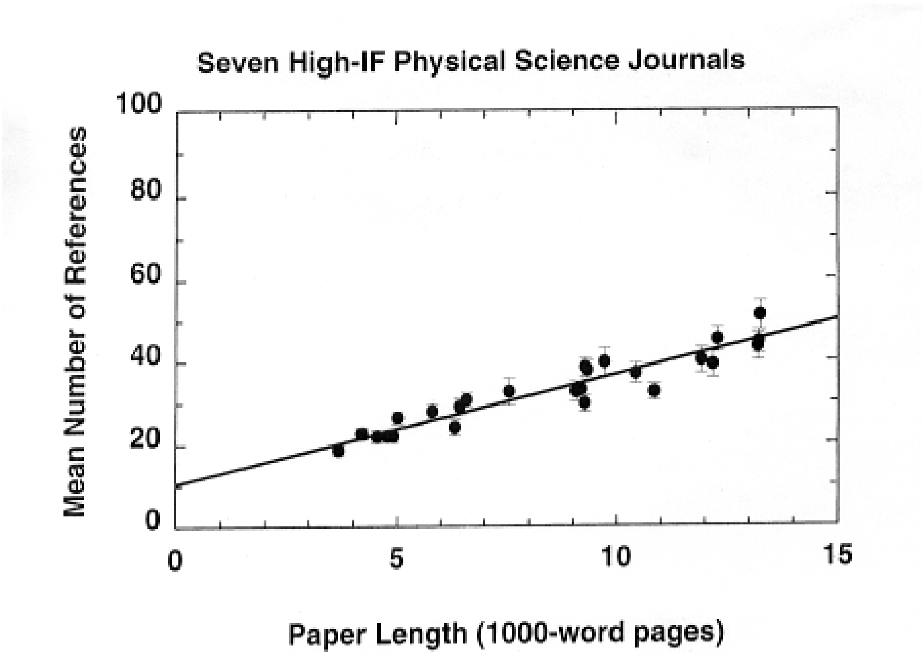

Fig. 5.-The R-L relation for seven journals with moderate Impact Factors in the physical sciences. The slope of the linear relation is much smaller than in Figures 2-4.

Table 5
Nine Original Research Journals in the Social Sciences

Journal	**Impact Factor**	**Ref.-Length Relation**	**O-C Scatter**
Cognitive Psychology.	3.74	+14.5 + 3.0L	±10.4
Journal of Experimental Psychology: General	3.60	+37.0 + 1.2L	8.4
Quarterly Journal of Economics	3.54	+11.5 + 2.2L	5.6
Journal of Experimental Psychology: Learning	2.84	+ 6.8 + 2.6L	3.6
Journal of Political Economy	2.61	+ 5.8 + 1.9L	3.1
American Journal of Sociology	2.56	- 4.2 + 4.7L	13.3
American Political Science Review	2.28	+ 2.1 + 3.8L	7.5
Econometrica	2.07	+ 7.1 + 1.5L	5.1
Political Geography	1.72	+ 2.0 + 5.4L	8.0
Mean		+11.2 + 2.5L	7.2

E. Social sciences

Finally let us look at the results from scanning nine journals in the social sciences. They are listed in Table 5. In this case we list the 1998 Impact Factors. These journals have far fewer research papers, namely an average of 70 in two years, than the journals in the life and physical sciences for which 200 papers were scanned. Therefore our statistical errors are much larger for the social science journals. When we plot in Figure 6 the data for the nine journals, the scatter of ±18.6 references is 2.6σ, indicating significant differences among these journals. The mean relation of R = 11.2 + 2.5L indicates a slope that is not substantially different than that for biochemistry and molecular biology (3.6) or immunology (4.2) or the physical sciences (2.2). This means that the social science papers give similar results to those for the life and physical sciences.

How serious are these differences in R-L relations? The results for the five sciences are summarized in Table 6. The second and third columns give the range of the Impact Factors and the R-L relations. We see that the maximum Impact Factors range over a factor of 10 and the slopes of the R-L relations over a factor of 3. The fourth column gives the mean paper lengths and those range over a factor of 3.3. The last column gives the mean number of references for paper is each field. We see that those means average 42.1 ± 6.9, where the scatter is ±17%. That approaches the expected error of 15% due to differing styles of reference lists. Therefore we can conclude that the mean numbers of references per paper are the same in all five fields, implying that citation counts can be inter-compared among these five fields. No one field is guilty of using substantially more references per average paper than the others.

Other parameters

We suspected (in the second paragraph of the Introduction) that Impact Factors might influence citation rates. Only in the cases of general medicine, where the two journals with the lowest IF had steeper R-L relations, and the physical sciences, where the two journals with the lowest IF had smaller intercepts in the R-L relations, did the Impact Factors affect the results. Otherwise a range by a factor of 10 in IF produced no significant effect upon the citation counts. This confirms Seglen's (1992) evidence of a lack of a correlation between citation frequencies and IF.

We did not explore in this study the effect of different rates of growth among fields. Abt (1998) showed that rapidly-growing fields such as astronomy and (since 1970) geophysics have long half-lives for papers, i.e. 29 years, but after correcting to constant publication rates, they have the same half-lives (6-10 year) as slower-growing fields like chemistry, physics, and general science. The fact that astronomy and geophysics do not stand out in Table 4 implies that different growth rates do not affect mean reference and citation counts. Seglen also found different citation rates in different biochemical fields, but he did not correlate those with different growth rates of those fields.

We wondered (in the Introduction) whether different numbers of authors affect citation counts. Abt (1984) showed that they do by factors up to 2.4, but all fields of science seem to have increasing average numbers of authors per paper, so this effect does not cause major differences in mean citation counts for different fields.

Abt (2000) found that the number of references in astronomy papers grew by 1.5% per year over the past 30 years, undoubtedly because there is more literature to reference each year. We did not explore this effect further in this study, but we were careful to study all 41 journals that were published in the same two years (1999, 2000)

We conclude that the most obvious cause of different reference counts and hence citation counts is paper lengths.

Review Papers

We would not expect the results of counting references in review papers to be the same as for research papers because the aim of the latter is to present concisely new results where references are used only for a brief history of the topic and support from quoted published results, while the aim of review papers is to provide as many pertinent references as possible.

We studied review papers in two kinds of journals: those like the *Annual Reviews* series are wholly devoted to review papers, while others like *New England Journal of Medicine* have one or two labeled review papers per issue. Both the total and partial review journals are listed in Table 7, where a "(P)" designates the latter. The numbers of papers in the review journals tend to be 30-60 in two years (1999, 2000), much less than the 200 papers scanned in the cases of most of the journals of original research papers.

Table 7 gives the results for 18 review journals. The second column gives the Impact Factors for 1999 (life, physical sciences) or 1998 (social sciences). The third column is the linear relation between number of references and paper lengths. The table is separated into blocks of journals from four of the five fields of life sciences studied.

Figure 7 shows the combined results for only the first 14 journals; the relation is given by R = -14.2 + 11.0L. The deviations from the linear relation are given in the last column of Table 7. The mean scatter of ±9.6 references is 1.7σ times the mean scatter. We see in Table 7 that the slopes for the first 14 journals are about the same except for the *Annual Reviews of Biophysics and Biomolecular Structure*; its three data points are the lowest ones in Figure 7. However three of the four review journals in sociology have slopes round 6 and their data points would fall very low in Figure 7, although they would be high for the research sociology journals shown in Figure 6. The general conclusion from Figure 7 compared to Figures 2-6 is that review journals have roughly twice as many references as research journals of the same length.

We also see from an Inspection of Table 7 that in each field the journals with higher Impact Factors generally have the slightly higher slopes in the linear relations. That makes sense in that review papers that are longer and have many references are more useful than ones with fewer. This will lead to higher Impact Factors.

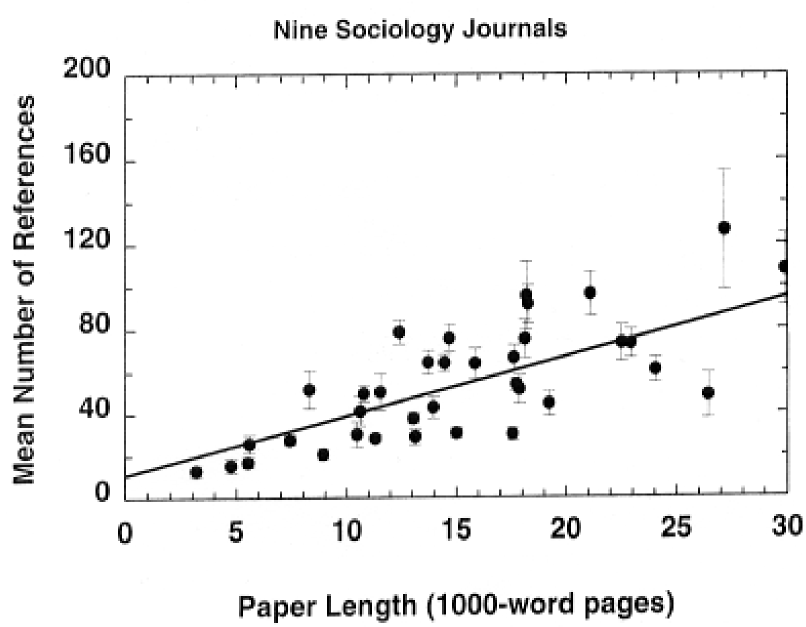

Fig. 6 -The R-L relation for nine journals in the social sciences. Note that the horizontal and vertical scales are double those in the other figures because papers in the social sciences tend to be longer.

Table 6

Collected Results for Original Research Journals in Five Fields of Science

Field	Impact factors	R-L relation	Mean Length	Mean ref.
Biochemistry & molecular biology	1.76-36.24	+13.3 + 3.6L	8.9	45.0
Immunology	2.56-15.65	+ 6.9 + 4.2L	7.6	39.2
General medicine	1.22-28.86	- 5.7 + 7.3L	5.3	33.2
Physical science	1.31- 4.55	+14.4 + 2.2L	10.8	37.8
Social sciences	.72- 3.74	+11.2 + 2.5L	14.6	51.0

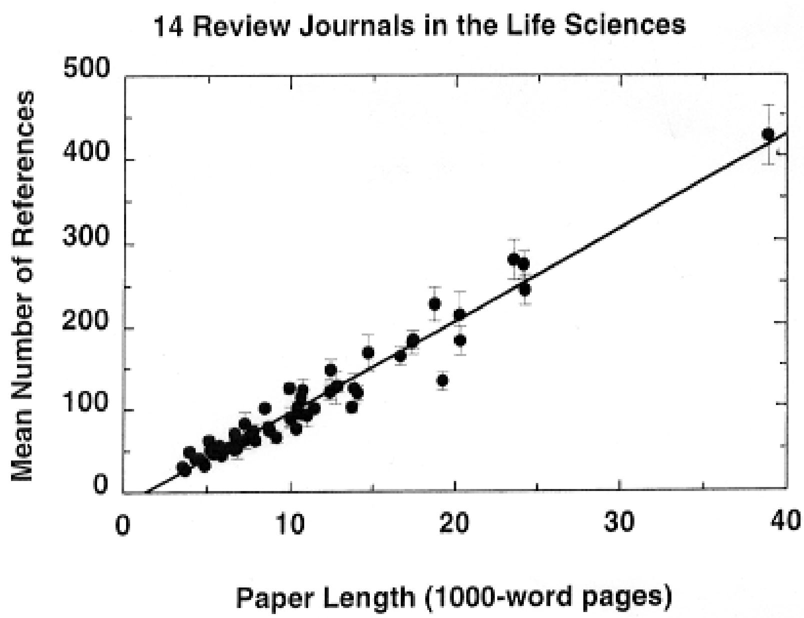

Fig. 7 -The R-L relation for 14 total or partial review journals. Note that both horizontal and vertical scales are larger than in the previous figures. Such journals have roughly twice as many references as papers of the same length that contain original research results.

Table 7
18 Total and Partial Review Journals

Journal	Impact Factor	Ref.-Length Relation	O-C Scatter
Biochemistry & Molecular Biology			
Annual Review of Biochemistry.	37.11	-11.2 + 12.0L	±12.0
Annual Review of Cell & Developmental Biology	26.28	- 8.7 + 10.4L	0.6
Annual Review of Biophysics & Biomolecular Structure	12.03	+33.9 + 5.2L	1.9
Critical. Reviews in Biochemistry Molecular Biology	7.82	+ 6.9 + 10.1L	4.9
Immunology			
Annual Review of Immunology	47.56	-31.1 + 12.5L	2.7
Immunology (P)	20.56	-21.2 + 10.9L	…
Current Opinion in Immunology (P)	11.89	- 0.1 + 9.7L	0.2
Advances in Immunology	9.25	+17.9 + 10.6L	8.3
Immunological Reviews	7.27	-14.7 + 9.7L	4.7
General Medicine			
New England Journal of Medicine (P)	28.86	-13.0 + 13.6L	4.8
Annual Review of Medicine	7.22	-33.4 + 13.4L	4.6
British Medical Bulletin	3.38	-10.5 + 10.2L	4.6
Annals of Medicine	2.57	-14.8 + 11.6L	4.5
Medical Clinics of North America	2.28	- 6.4 + 9.2L	5.9
Social Sciences			
Journal of Economic Literature	6.40	- 3.0 + 5.9L	
Journal of Economic Perspectives	3.08	-12.7 + 6.0L	
American Sociological Review	2.89	-11.1 + 5.5L	
Annual Review of Sociology	1.87	-49.7 + 15.1L	

We appreciate the use of the printed journals in the University of Arizona's Health Sciences, Science-Engineering, and Main Libraries and suggestions for clarifications by the two referees. .

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