Open access, readership, citations: a randomized controlled trial of scientific journal publishing

Philip M. Davis[1]

Department of Communication, Cornell University, Ithaca, New York, USA

ABSTRACT **Does free access to journal articles result in greater diffusion of scientific knowledge? Using a randomized controlled trial of open access publishing, involving 36 participating journals in the sciences, social sciences, and humanities, we report on the effects of free access on article downloads and citations. Articles placed in the open access condition (*n*=712) received significantly more downloads and reached a broader audience within the first year, yet were cited no more frequently, nor earlier, than subscription-access control articles (*n*=2533) within 3 yr. These results may be explained by social stratification, a process that concentrates scientific authors at a small number of elite research universities with excellent access to the scientific literature. The real beneficiaries of open access publishing may not be the research community but communities of practice that consume, but rarely contribute to, the corpus of literature.—Davis, P. M. Open access, readership, citations: a randomized controlled trial of scientific journal publishing. *FASEB J.* 25, 2129–2134 (2011). www.fasebj.org**

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Citations are an indicator of scholarly impact. They measure the diffusion of new knowledge (1, 2), acknowledge the contribution of peers (3, 4), and, in many fields, form the basis of professional reward (5, 6).

Prior studies have argued that free (or open) access to the scientific literature leads to a large increase in article citations (7, 8), suggesting that the traditional subscription-access journal distribution model is inadequate for disseminating scientific articles. Others claim that open access publishing accelerates the citation process (9, 10) or demonstrates beneficial effects for researchers in low-income countries (11).

These studies, however, are based on unobtrusive, observational analysis, many lacking statistical controls. As a result, it has been difficult to determine whether the relationship between open access and citations is causal, the direction of causality, or whether the relationship is merely spurious (8, 12, 13).

Using an interventional approach in a randomized controlled trial of open access publishing in physiology (14, 15), we report that treatment articles received no more citations than subscription access articles; they did, however, receive more downloads from a broader group of readers.

The purpose of this study is to isolate and quantify the effects of open access publishing on article readership and citations. We extend our prior study (14, 15) to include a total of 36 academic journals covering the biological, medical, and multidisciplinary sciences, social sciences, and humanities.

MATERIALS AND METHODS

There are 3245 research articles and reviews published in 36 journals covering the sciences, social sciences, and humanities that form our study group. These 36 journals (listed in **Table 1**) are produced by 7 separate publishers but hosted on the same online platform (HighWire Press; http://highwire.stanford.edu), ensuring comparative analysis. Prior work indicates that online publishing platforms exert independent effects on article downloads (16) and article citations (13). Our data set includes 1619 articles published in 11 physiology journals, the readership and citation results of which were reported previously (14, 15).

This study measures the effect of open access on article downloads at 12 mo and article citations within 36 mo. Our rationale for limiting the download analysis to 12 mo is pragmatic: 19 of the 20 participating science journals provide free access to articles at the end of their first year.

Treatment allocation

In all, 712 articles were randomly assigned to the open access treatment group, leaving 2533 articles as the control group. As our experiment included several issues per journal, some of which publish on a quarterly basis, our randomization period extended from January 2007 to February 2008.

Treatment articles were made freely available from the publisher's website upon online publication. Control articles were available to subscribing individuals and institutions. Many participating journals, however, made all articles freely available after a period of delay. Table 1 provides treatment allocation and access details.

Only research articles and reviews were included in the randomization. Editorials, letters to the editor, corrections, retractions, announcements, *etc.*, were ignored in the sampling. If the journal included multiple sections, a stratified

[1] Correspondence: Department of Communication, Cornell University, Ithaca, NY 14853, USA. E-mail: pmd8@cornell.edu

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TABLE 1. *Treatment allocation*

Publisher and journal	Open access (*n*)	Control articles (*n*)	Open access (%)
American Physiological Society (Jan.–Apr. 2007), delayed access: 12 mo			
American Journal of Physiology—Regulatory, Integrative and Comparative Physiology	34	161	17
American Journal of Physiology—Endocrinology and Metabolism	21	126	14
American Journal of Physiology—Renal Physiology	18	122	13
American Journal of Physiology-Heart and Circulatory Physiology	32	201	14
American Journal of Physiology—Lung Cellular and Molecular Physiology	14	95	13
American Journal of Physiology—Gastrointestinal and Liver Physiology	22	112	16
American Journal of Physiology—Cell Physiology	36	119	23
Journal of Applied Physiology	27	174	13
Journal of Neurophysiology	39	239	14
Physiological Reviews	2	14	13
Physiology	2	9	18
Total	247	1372	15
American Heart Association (June–Sep. 2007), delayed access: 12 mo			
Arteriosclerosis, Thrombosis, and Vascular Biology	20	85	19
Circulation	20	76	21
Circulation Research	19	41	32
Hypertension	20	75	21
Stroke	22	110	17
Total	101	387	21
Duke University Press (June–Dec. 2007), delayed access: never			
Journal of Health Politics, Policy and Law	7	10	41
American Speech	3	5	38
Neuro-Oncology	12	15	44
Public Culture	6	5	55
Ethnohistory	5	6	45
GLQ: A Journal of Lesbian and Gay Studies	6	7	46
Social Science History	4	6	40
Total	45	54	45
SAGE Publishers (June 2007–Feb. 2008), delayed access: never			
Comparative Political Studies	11	17	39
Communication Research	8	11	42
New Media & Society	8	22	27
Social Studies of Science	8	17	32
American Behavioral Scientist	10	31	24
Progress in Human Geography	8	18	31
Administration & Society	9	15	38
Theory & Psychology	10	23	30
Applied Psychological Measurement	7	13	35
Organization	8	16	33
Total	87	183	32
Federation of American Societies for Experimental Biology (June–Oct. 2007), delayed access: 12 mo			
FASEB Journal	81	84	49
Genetics Society of America (June–Sep. 2007), delayed access: 6 mo			
Genetics	103	108	49
American Association for the Advancement of Science (June–Nov. 2007), delayed access: 12 mo			
Science	48	345	12
Grand total	712	2533	22

random selection approach was used to ensure adequate representation from each section.

Approximately 1 in 5 articles received the open access treatment, with some journals receiving a higher allocation based on their size and frequency of publication (Table 1). The proportion of treatment articles was determined in consultation with the publisher in advance of the study and was set to avoid radical alteration of the appearance and performance of the journal. Based on prestudy analysis of citation variation, our sample size provides us with a 0.8 power to detect a 25% difference in citations between treatment and control articles for all journals (P=0.05, 2-sided).

The randomization, selection, and manipulation of access status for treatment articles were controlled entirely by the researcher, who was provided with direct access to the administration of the journal websites. Authors and editors were not alerted as to which articles received the open access treatment. For some journals, treatment articles were indicated on the journal websites by an open lock icon.

Data gathering

For each article, usage statistics (abstract views, full text views, and PDF views) and unique visitors [as measured by Internet

Protocol (IP) addresses] were gathered monthly for the first year from the journal websites. Known robot activity (software robots downloading all free material for indexing purposes, *e.g.*, Google) was removed from the data set before analysis to arrive at a more accurate estimate of human activity. Citation figures were gathered monthly from the Web of Science (http://www.isiknowledge.com) for the first 3 yr after article publication.

While journals control the primary access route to articles, it is common in some disciplines and at some institutions for authors to self-archive some version of their articles on public websites or in digital repositories. To obtain an estimate of the extent and effects of self-archiving, we wrote a Perl script to search for PDF copies of articles anywhere on the Internet (ignoring the publisher's website) 1 yr after publication. We attempted to identify as many instances of self-archiving as possible, while minimizing the number of false positives.

Statistical methods

Readership analysis was conducted on the 20 science journals in our data set (n=2903). Articles published in the social sciences and humanities journals (n=350) were omitted from the readership analysis, as many did not include abstract or full-text versions of their articles, and, in some cases, reference views were added to full-text views, resulting in indeterminate and incomparable results. Citation analyses were conducted on the entire article data set (n=3245).

A logistic regression model was used to estimate the likelihood of articles in each experimental group being cited within the first year after publication, controlling for journal and journal category effects.

Multivariate linear regression models were used to estimate the effect of the open access treatment on article readership and citations. Covariates in these models include the journal in which the article appeared, type of article (review, other), length of article (in pages), number of authors, and whether the article was self-archived. Continuous variables (page length, number of authors, and number of citations) were log transformed to adhere to the assumption of normality required for linear regression. As we were not interested in estimating citation effects for each particular journal, but to control for the variation in journal effects generally, journals were considered random effects in the regression models.

In analyzing article citations, 1 was added to each citation count prior to log transformation as some articles received 0 citations during the observation period. While adding 1 shifts the citation distribution to the right, we were interested primarily in the slopes of the regression lines and not their intercepts. To interpret the results of the regression equation, estimates of log-transformed variables were exponentiated in order to arrive at their multiplicative effect (ME). For example, if the logCitation estimate were 0.5, the ME of this estimate would be $e^{0.5}$ or 1.65, representing a 65% increase in citations.

RESULTS

Articles receiving the open access treatment received significantly more downloads and reached a broader audience yet were cited no more frequently, nor earlier, than control articles; 65 instances of self-archiving were detected.

Readership

For the first year after publication, providing free access to journal articles resulted in a doubling of full-text (HTML) downloads on average (115%; 95% CI, 103–129%) and, to a lesser degree, a significant increase in the number of full image (PDF) downloads (62%; 95% CI, 53–72%). As measured by IP addresses, freely accessible articles received roughly a third more unique visitors (31%; 95% CI, 25–37%), while abstract views decreased by 22% (95% CI, −18 to −26%).

Citation frequency

Open access articles were cited no more frequently than subscription-access articles. The estimate of citation effect at 3 yr was ~1%, statistically indistinguishable from 0 (ME 1.01; 95% CI, 0.95–1.08; P=0.669; **Table 2**). Earlier citation estimates revealed similarly small, nonsignificant results (3% at 12 mo, 4% at 18 mo, 2% at 24 mo, and 2% at 30 mo). **Figure 1** provides a visual comparison of results by subject category.

In comparison, review articles, the number of authors, and page length were all significant predictors of article citations (Table 1). Articles that were self-archived showed a positive effect on citations (~11%), although this estimate was not significant (ME 1.11; 95% CI, 0.92–1.33; P = 0.266). Just 65 articles (2%) in our data set were self-archived, however, limiting the statistical power of our test.

Likelihood of citation

Open access articles were no more likely to be cited within their first year (odds ratio 0.96; P=0.74; **Table 3**). The percentage of articles that received at least 1 citation within their first year ranged from just 10% for the humanities journals to nearly all (97.5%) for the multidisciplinary journal. None of the journals—analyzed together or in subject groupings—show significant odds

TABLE 2. *Multiplicative effect of open access on article citations 36 mo after publication*

		95% CI			
Fixed effects	Estimate	Lower	Upper	t Ratio	$P > \|t\|$
Open access	1.01	0.95	1.08	0.43	0.669
Self-archived	1.11	0.92	1.33	1.11	0.266
Review article	1.63	1.46	1.82	8.52	<.0001
Number of authors[a]	1.26	1.21	1.32	10.07	<.0001
Page length[a]	1.56	1.44	1.69	10.66	<.0001

			95% CI		
Random effects	Variance ratio	Variance component	Lower	Upper	Percentage of total
Journal	1.86	0.96	0.62	1.67	65
Residual		0.51	0.49	0.54	35
Total		1.47			100

R^2 = 0.65; mean response (log citations) = 2.33; n = 3253.
[a]Log-transformed variable.

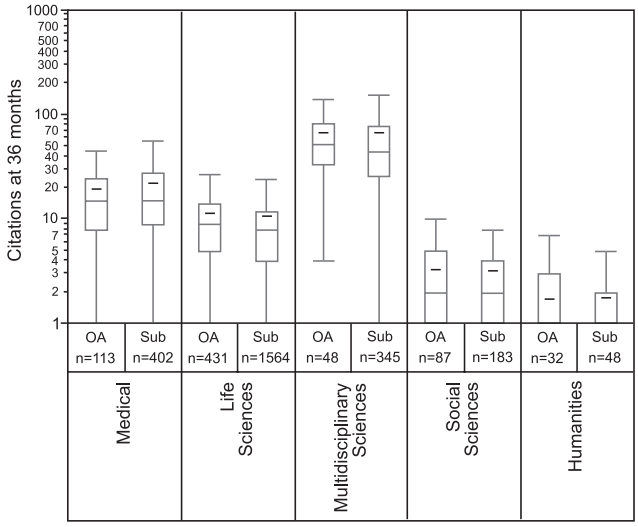

Figure 1. Citation frequency of open access (OA) and subscription access (Sub) articles 36 mo after publication. Interpretive notes: boxes represent the interquartile range (25th to 75th percentile) and contain the median value (horizontal line) and average value (horizontal dash). Whiskers extend 1.5× the length of the interquartile range. Category notes: medical includes 5 journals published by the American Heart Association plus *Neuro-Oncology*, published by Duke University Press. Life sciences includes *The FASEB Journal*, *Genetics*, and 11 journals published by the American Physiological Society. Multidisciplinary sciences includes *Science Magazine*. Social sciences includes 10 journals published by Sage Publications. Humanities includes 6 journals published by Duke University Press. See Table 1 for treatment allocation.

ratio departures from 1.0, meaning neither group was cited preferentially earlier.

DISCUSSION

Free access to scientific articles increases readership (as measured by article downloads) and reaches a broader audience (as measured by unique IP addresses) but has no effect on article citations within the first 3 yr after publication. These results are consistent with earlier trial reports on the physiology literature (14, 15) and suggest that these claims are generalizable across the scientific, social sciences, and humanities literatures.

The increase in full-text downloads for open access articles during their first year after publication suggests that the primary benefit to the nonsubscriber community is in browsing, as opposed to printing or saving, which would have been indicated by a commensurate increase in PDF downloads. The decrease in abstract views suggests a reader preference for the full document when available.

Prior studies comparing the citation impact of open access articles to subscription access articles are based on unobtrusive observational methods and may suffer from the failure to adequately control for confounding variables (8, 13). While some studies attempt to control statistically for differences in article characteristics, such as article type, discipline, and funding source, (9), for example, none were able to control for abstract qualities such as relevance, novelty, and importance to a field of study, variables that are unobservable to the researcher. In addition, an author's willingness and ability to pay open access publishing fees, some amounting to several thousands of dollars, may make simple performance comparisons with subscription-access articles highly problematic (12). By randomly altering access status in an experimental trial, we are able to isolate and measure the effects of access on readership and citations independently of other confounding variables.

Measuring knowledge transfer

Article downloads and citations measure two different dimensions of scientific knowledge transfer. The first measures general interest in a particular new piece of knowledge; the second measures the incorporation of that knowledge into a new document. Most article downloads take place within the first few months after publication (17, 18), suggesting that the primary function of an article is to keep researchers abreast on the latest findings within a field and secondly to serve as a source document for future citation. Article downloads retrieved shortly after publication have been shown to predict future citations, although their strength of prediction is relatively low (17, 19, 20).

A citation, on the other hand, measures a different set of intentions from a much smaller group of participants. To generate new scientific knowledge, in most cases, one must have access to equipment, materials and facilities, technicians, and the infrastructure necessary to support and coordinate them all (21). Authors must be able to analyze their results, capable of presenting their findings, and able to communicate them clearly and coherently. Once submitted, scientific manuscripts must make it through peer-review and be published in an indexed journal in order to be visible

TABLE 3. *Likelihood of being cited within first year*

Category	Articles cited (%)	Odds ratio (OA/sub)	χ^2	$P > \chi^2$
All journals	74.1	0.96	0.11	0.74
Medical	85.2	1.21	0.35	0.55
Life sciences	74.5	0.87	1.10	0.29
Multidisciplinary sciences	97.5	1.26	0.05	0.83
Social sciences	35.6	1.36	1.19	0.28
Humanities	10.0	0.43	0.96	0.33

Logistic regression controls for individual journal and journal category effects. OA, open access; sub, subscription. Medical includes 5 journals published by the American Heart Association plus *Neuro-Oncology*, published by Duke University Press. Life sciences includes *The FASEB Journal*, *Genetics*, and 11 journals published by the American Physiological Society. Multidisciplinary sciences includes *Science Magazine*. Social sciences includes 10 journals published by Sage Publications. Humanities includes 6 journals published by Duke University Press. See Table 1 for treatment allocation.

to those conducting the evaluation. These conditions represent a much stronger barrier to participation than downloading an article.

Differentiating communities

As most scientific researchers are concentrated within a relatively small number of elite research universities with excellent access to the scientific literature, a process known as social stratification (22, 23), it is not surprising that providing free access has little (if any) effect on article citations. The fact that we observe an increase in readership and visitors for open access articles but no citation advantage suggests that the increase in readership is taking place outside the core author community. The real beneficiaries of open access may not be the research community, which traditionally has excellent access to the scientific literature, but communities of practice that consume, but rarely contribute to, the corpus of literature. These communities may include students, educators, physicians, patients, government, and industry researchers, who all depend on the publication of scientific literature. Little is known, however, about the use of the primary research literature outside of the scientific community (24).

Last, while we need to be careful not to equate article downloads with readership (we have no idea whether downloaded articles are actually read), measuring success by only counting citations may miss the broader impact of the free dissemination of scientific results beyond the research community (24).

Limitations

Access is not a necessary precursor to citation

An author may cite from an abstract or copy a reference directly from another paper (25, 26). Such behavior may attenuate any observed access-citation effect.

Citation indexes are incomplete

While Web of Science does not index the entire journal literature, it provides a reliable sample of citations comparable to broader citation indexing services such as Scopus (27). As our study was comparative in nature, it did not require having complete citation counts.

Indirect measurements of readership

In this study, we do not measure readership directly but use article downloads as a proxy for readership. A download may reflect completely different reader intentions, from a premeditated search for a specified article to a random browse. Some new software, for example (28), even enables automatic downloading and caching of papers to lessen the wait of the reader between clicks. To deal with pluralistic intentions, we measure readership using several different indicators (abstract, full text, PDF views, and unique visitors). While each of them may measure a different reader intention, together they provide a more complete picture of readership than one indicator alone.

Latent citation effects

Initial access to a journal article may manifest at a later date as a citation effect. While our early results reported between 9 and 12 mo were criticized as premature (29), others have reported large citation effects for open access articles as early as 0–6 mo after publication (9). In analyzing the results at 12, 18, 24, 30, and 36 mo, we detect neither a citation effect nor a tendency for one to express itself at a later date. While many of the journals in our study provided only subscription access for the first 12 mo, we report similar results for 16 journals in our data set that provide no delayed free access. Our main results appear generalizable across all subjects and access models.

Informal routes of access

Readers of scientific articles without access to a journal from the publisher's website may find other avenues of access, such as through colleagues located at subscribing institutions or by contacting the author directly for a copy (30). Authors may self-archive their articles by placing them on the public Internet (31) or in an institutional repository (32). Beginning April 7, 2008, researchers in receipt of federal funding from the U.S. National Institutes of Health are required to deposit their final, peer-reviewed manuscripts in PubMed Central (33). Several departments, universities, and research institutes have also established their own self-archiving requirements (34). Presuming that author manuscripts are adequate substitutes for the published record, that they are easily discoverable by readers, and that they are made available in a timely fashion, the presence of a sizable proportion of article manuscripts may attenuate remaining access inequalities. The presence of papers in multiple locations creates future challenges to estimating total readership through article downloads when the journal's website is but one mode of access (35).

CONCLUSIONS

Open access publishing may reach more readers than subscription access publishing, although additional readership may not translate into more citations. The real benefit of free access to the scientific literature is to those outside the core research community. Very little is known about how scientific papers are transmitted through informal networks. Understanding the degree and extent of article diffusion through these informal networks would greatly extend our understanding of the transmission of scientific knowledge. FJ

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