



Normalization of Mendeley reader impact on the reader- and paper-side: A comparison of the mean discipline normalized reader score (MDNRS) with the mean normalized reader score (MNRS) and bare reader counts



Lutz Bornmann^{a,*}, Robin Haunschild^b

^a Division for Science and Innovation Studies, Administrative Headquarters of the Max Planck Society, Hofgartenstr. 8, 80539 Munich, Germany

^b Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany

ARTICLE INFO

Article history:

Received 20 November 2015

Received in revised form 22 April 2016

Accepted 22 April 2016

Available online 14 June 2016

Keywords:

Altmetrics

Mendeley

Field-normalization

Citing-side normalization

Journal reader impact

Mean discipline normalized reader score

MDNRS

Mean normalized reader score

MNRS

ABSTRACT

For the normalization of citation counts, two different kinds of methods are possible and used in bibliometrics: the cited-side and citing-side normalizations both of which can also be applied in the normalization of “Mendeley reader counts”. Haunschild and Bornmann (2016a) introduced the paper-side normalization of reader counts (mean normalized reader score, MNRS) which is an adaptation of the cited-side normalization. Since the calculation of the MNRS needs further data besides data from Mendeley (a field-classification scheme, such as the Web of Science subject categories), we introduce here the reader-side normalization of reader counts which is an adaptation of the citing-side normalization and does not need further data from other sources, because self-assigned Mendeley disciplines are used. In this study, all articles and reviews of the Web of Science core collection with publication year 2012 (and a DOI) are used to normalize their Mendeley reader counts. The newly proposed indicator (mean discipline normalized reader score, MDNRS) is obtained, compared with the MNRS and bare reader counts, and studied theoretically and empirically. We find that: (i) normalization of Mendeley reader counts is necessary, (ii) the MDNRS is able to normalize Mendeley reader counts in several disciplines, and (iii) the MNRS is able to normalize Mendeley reader counts in all disciplines. This generally favorable result for the MNRS in all disciplines leads to the recommendation to prefer the MNRS over the MDNRS—provided that the user has an external field-classification scheme at hand.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Normalization of citation counts regarding subject category and publication year of publications started in the mid-1980s (Schubert & Braun, 1986). The comparison of units in research (e.g., researchers, research groups, institutions, or countries) publishing in different disciplines and time periods is only possible with normalized citation scores. Basically, one can distinguish between two levels of normalization:

* Corresponding author.

E-mail addresses: bornmann@gv.mpg.de (L. Bornmann), R.Haunschild@fkf.mpg.de (R. Haunschild).

- (1) In the case of normalization on the cited side, the total number of citations of the paper i to be evaluated is counted (see e.g., the times cited information in Web of Science, WoS). This number of times cited is compared with other publications published in the same year and subject category (the reference set). Since one can expect different citation rates for papers with different document types, the document type is also frequently considered in the constitution of the reference set. The mean citation rate over the papers in the reference set determines the expected value. The comparison of times cited of paper i with the expected value results in the normalized citation score (NCS) for i . This procedure is repeated for all papers in a paper set (e.g., of a researcher, research group, institution, or country) and a mean NCS (MNCS) on a higher aggregation level is calculated (Waltman, van Eck, van Leeuwen, Visser, & van Raan, 2011).
- (2) In the case of normalization on the citing side, each citation of a paper is multiplied with a weighting factor (Zitt & Small, 2008). This weighting factor reflects the citation density of the discipline: since it is assumed that the number of references in publications reflects the field-specific citation density, the inverse of the field-specific citation density is usually used as a weighting factor. The sum of all weighted citations is the normalized citation impact of a publication. The results of Waltman and van Eck (2013b) offer considerable support for the use of citing-side bibliometric indicators. In Section 3.2, the citing-side concept of citation impact normalization is described in more detail, since it is central to the paper.

In recent years, scientometrics started to explore alternative metrics (altmetrics) to study the impact of publications (Priem, 2014; Priem, Piwowar, & Hemminger, 2012; Priem, Taraborelli, Groth, & Neylon, 2010). Here, notes, saves, tweets, shares, likes, recommends, tags, posts, trackbacks, discussions, bookmarks, comments etc. are counted (Bornmann, 2014a). Altmetrics seems to have two advantages over citation counts: they allow (1) an impact measurement within a shorter time period after the appearance of a paper than citation counts (Lin & Fenner, 2013) and (2) a broader impact measurement, which is not only restricted to the area of science but also to the rest of society (Altmetric & Scholastica, 2015). The possibility of a broad impact measurement using altmetric counts is part of the current scientometric research (Bornmann, 2014b, 2015). Data from Mendeley (Elsevier) which reflect the readership of papers are one of the most important sources for altmetrics.

Haunschild and Bornmann (2016a) introduced the paper-side normalization of “reader counts” (see also Fairclough & Thelwall, 2015), because several studies have shown that Mendeley reader impact – similar as citation impact – varies across scientific disciplines (Haustein & Larivière, 2014a; Jeng, He, & Jiang, 2015; Mafrahi & Thelwall, 2015; Zahedi, Costas, & Wouters, 2014; Zahedi & Eck, 2014): in one discipline papers are read more often on average than in other disciplines. The new indicator on the paper-side was named mean normalized reader score (MNRS). The normalization also considers the document type of publications, because it has an influence on reader counts, too (Haunschild & Bornmann, 2016a; Haustein & Larivière, 2014b). Since citing-side normalization is a promising alternative in scientometrics to cited-side normalization and the MNRS needs further data besides data from Mendeley, we introduce the mean discipline normalized reader score (MDNRS) in this study. The MDNRS is an adaptation of the citing-side normalization to reader data and is solely based on Mendeley data.

The manuscript is organized as follows: subsequent to the Methods section (see Section 2), we demonstrate differences in reader impact between disciplines (see Section 3.1) and introduce the MDNRS after explaining the citing-side normalization methods in bibliometrics (see Section 3.2). In Sections 3.3 and 3.4, we test the MDNRS in its ability to field-normalize reader counts (theoretically and empirically) and compare the MDNRS with the MNRS and bare reader counts. Finally, MDNRS values are presented for the best performing scientific journals and correlations between MDNRS and MNRS are calculated.

2. Methods

2.1. Mendeley

Mendeley is both a citation management tool and social network for academics (Gunn, 2013). Mendeley data are very attractive for scientometric use because (1) the coverage of the worldwide publications is high (Haustein & Larivière, 2014b; Priem, 2014), (2) the data can be downloaded relatively easily via an API (Bornmann & Haunschild, 2015; Mohammadi & Thelwall, 2013), and (3) the use of Mendeley as a citation manager is part of the research process of many scientists: literature is added to the library for reading or citing later on. However, the use of Mendeley is not only restricted to researchers, but also to other people reading scientific publications (e.g., students, journalists, or research managers) (Bornmann & Haunschild, 2015; Mohammadi, Thelwall, Haustein, & Larivière, 2014). One basic assumption for using Mendeley data as altmetrics is that Mendeley users who add publications to their libraries can be counted as readers of the publications. Although Mendeley users have also other reasons for adding publications to their library, the results of Mohammadi, Thelwall, and Kousha, (2016) show that “82% of the Mendeley users had read or intended to read at least half of the bookmarked publications in their personal libraries”. Thus, adding of publications to a Mendeley library should reflect reading of the publications (in most of the cases). In the following sections, we generally treat the Mendeley data as readership data.

2.2. Data

It is common practice in bibliometrics to include only articles and reviews in a study. Other document types are usually discarded, although letters are sometimes also considered (e.g., with a weight factor smaller than one). We retrieved the

Table 1

Basic variables to construct the MDNRS: Mendeley reader counts of WoS papers (articles and reviews) from 2012 and average number of Mendeley readers broken down by the different Mendeley disciplines (sorted in decreasing order of the raw Mendeley reader counts).

Mendeley discipline	Mendeley reader counts		Average number of readers	
	Abs. readers	% readers	Reviews	Articles
Biological sciences	3,518,931	32.94	14.30	6.85
Medicine	1,610,631	15.08	6.81	3.84
Chemistry	852,261	7.98	5.99	3.42
Engineering	709,525	6.64	4.66	3.26
Physics	578,831	5.42	4.35	3.46
Psychology	567,297	5.31	7.41	4.92
Environmental sciences	406,960	3.81	4.42	3.81
Computer and information science	363,337	3.40	2.68	2.77
Social sciences	354,877	3.32	2.54	2.76
Earth sciences	319,943	2.99	1.78	2.58
Materials science	289,464	2.71	4.13	2.39
Electrical and electronic engineering	194,604	1.82	4.24	2.62
Business administration	173,815	1.63	3.11	3.52
Economics	133,370	1.25	1.86	2.17
Education	133,026	1.25	2.67	2.26
Management science	91,340	0.86	1.95	2.02
Astronomy, astrophysics, and space science	80,713	0.76	3.06	2.89
Mathematics	77,496	0.73	1.55	1.54
Sports and recreation	54,699	0.51	2.36	2.16
Humanities	45,094	0.42	1.31	1.38
Design	35,935	0.34	1.33	1.22
Arts and literature	30,756	0.29	1.14	1.15
Linguistics	27,162	0.25	2.33	2.32
Philosophy	21,121	0.20	1.32	1.47
Law	11,545	0.11	1.29	1.3

Mendeley reader statistics for articles and reviews published in 2012 and having a DOI ($n_A = 1,133,224$ articles and $n_R = 64,960$ reviews). The DOIs of the papers from 2012 were exported from the in-house database of the Max Planck Society (MPG) based on the WoS and administered by the Max Planck Digital Library (MPDL). We used R (R Core Team, 2014) to interface to the Mendeley API. We used the Mendeley API which was made available in 2014. DOIs were used to identify the papers in the Mendeley API. We found 1,074,407 articles (94.8%) and 62,771 reviews (96.6%) at Mendeley.

In total, the articles were registered 9,347,500 times and the reviews were registered 1,335,233 times with a sub-discipline. The sub-disciplines are self-assigned by the Mendeley users. Only 4,924 (0.05%) of the Mendeley article readers and 531 (0.04%) review readers did not declare any discipline information. For 118,167 articles (10.4%) and 4,348 reviews (6.7%) we found the paper at Mendeley but without a reader. In total, 956,105 articles with 9,347,500 reader counts (approximately 10 readers per article) and 58,420 reviews with 1,335,233 reader counts (approximately 23 readers per article) were used in this study. The papers without any reader are not used in the normalization procedure introduced here (the MDNRS), because it is not possible to identify a discipline for a reader count which was not declared by the user. However, papers without any reader and papers not found at Mendeley were used for the calculation of the MNRS as zero-reader papers which are included in this study for the comparison with the MDNRS.

The requests to the Mendeley API were made from December 11–23, 2014. All data in this study are based on a partial copy of our in-house database (last updated on November 23, 2014) supplemented with the Mendeley reader counts.

3. Results

3.1. Differences in reader impact between disciplines

The Mendeley reader counts broken down by discipline are shown in Table 1. 95.5% of the readers are within 15 of the 25 disciplines while the remaining 4.5% of the readers are in the 10 disciplines with less than 1% each. The disciplines biological sciences and medicine comprise 48% of the Mendeley readers of the WoS papers from 2012.

The arithmetic average number of Mendeley readers per paper is also shown in Table 1 because this is the basic variable to construct the new indicator. In cases where publications have readers from multiple disciplines (X and various other disciplines), we calculated the average number of readers for discipline X by taking all publications with at least one reader from discipline X and by calculating an (unweighted) average over these publications of the number of readers from discipline X.

The results in Table 1 reveal that the average number of readers varies significantly across the Mendeley disciplines. The reader spread across the disciplines is somewhat smaller than the reader spread across WoS subject categories (see the results in Haunschild & Bornmann, 2016a). Obviously, one reader count has a different value in biological sciences compared to arts and literature: the average number of reader counts is $\bar{X}_{\text{reviews}} = 1.14$ ($\bar{X}_{\text{articles}} = 1.15$) in the discipline arts and literature

while in the discipline biological sciences an average reader count of $\bar{X}_{\text{reviews}} = 14.30$ ($\bar{X}_{\text{articles}} = 6.85$) is observed for reviews (articles). The average number of Mendeley readers per paper is larger for reviews than for articles in 15 of the 25 disciplines. In the case of business administration, education, and social sciences, articles have a higher reader count on average than reviews.

For the discipline biological sciences, an article has to have 15 readers to be among the 10% most frequently read papers (top-10%) and 62 readers to be among the 1% most frequently read papers (top-1%). Eight readers are needed to be among the top-10% and 23 readers to be among the top-1% in medicine. Seven readers are necessary for an article to be among the top-10% and 24 readers to be among the top-1% in chemistry.

3.2. Reader-side normalization of reader impact

The method of citing-side normalization was formulated for the first time in a paper by Zitt and Small (2008). They used the Journal Impact Factor (JIF) modified by fractional citation weighting. The citing-side normalization which is also referred to as fractional counting of citations or a priori normalization (Waltman & van Eck, 2013a) is not only used for journals but also in other contexts. The normalization tries to account for the different citation densities from where a citation originates from (Haustein & Larivière, 2014b; Leydesdorff & Bornmann, 2011; Leydesdorff, Radicchi, Bornmann, Castellano, & de Nooy, 2013; Radicchi, Fortunato, & Castellano, 2008; van Leeuwen, 2006; Zitt, Ramanana-Rahary, & Bassecouard, 2005). Each citation is weighted with regard to its citation density: a citation from a discipline where many papers are cited has a lower weight than a citation from a discipline where fewer papers are cited.

The number of cited references plays an important role in citing-side normalization: “Citing-side normalisation is based on the idea that differences among fields in citation density are to a large extent caused by the fact that in some fields publications tend to have much longer reference lists than in other fields. Citing-side normalisation aims to normalise citation impact indicators by correcting for the effect of reference list length” (Wouters et al., 2015, p. 19). In one of the proposed methods of citing-side normalization, the number of references is used to weight the citations from a paper (Leydesdorff & Bornmann, 2011; Leydesdorff & Opthof, 2010; Leydesdorff, Ping, & Bornmann, 2013; Leydesdorff, Radicchi et al., 2013; Waltman & van Eck, 2013b). That means a citation from a paper with fewer references has a higher weight than a citation from a paper with more references. This method assumes that the number of references in a particular paper reflects the typical number of references. This variant of the citing-side normalization has been named by Waltman and van Eck (2013b) as $\text{SNCS}_{(2)}$ and is defined as follows:

$$\text{SNCS}_{(2)} = \sum_{i=1}^c \frac{1}{r_i} \quad (1)$$

Thus, each citation i of a publication is divided by the number of references in the citing publication r_i , whereby c is the total number of citations the publication has received.

In another previously proposed method of citing-side normalization ($\text{SNCS}_{(1)}$), the average number of references of the papers which appeared in the same journal as the paper in question is used in calculation of the weighting factor.

$$\text{SNCS}_{(1)} = \sum_{i=1}^c \frac{1}{a_i} \quad (2)$$

Here, a_i is the average number of references in those publications which appeared in the same journal and in the same publication year as the citing publication i (c is the total number of citations the publication has received). The definition of $\text{SNCS}_{(1)}$ is based on the audience factor proposed by Zitt and Small (2008).

Since this variant considers an average number of references (instead of the references in one publication), it has a higher probability of estimating typical citation densities with a higher accuracy than $\text{SNCS}_{(2)}$ (Bornmann & Marx, 2014). However, this is true as long as the citation does not originate from a multi-disciplinary journal, such as PLoS One.

A combination of both variants is also possible, as described by Waltman and van Eck (2013b).

$$\text{SNCS}_{(3)} = \sum_{i=1}^c \frac{1}{p_i r_i} \quad (3)$$

In $\text{SNCS}_{(3)}$ r_i is the number of references in the citing publication (analogously to $\text{SNCS}_{(2)}$). p_i is the share of the publications which contain at least one linked reference among those publications which appeared in the same journal and in the same publication year as the citing publication i . c is the total number of citations the cited publication has received.

Following the citing-side normalization variant $\text{SNCS}_{(2)}$, we propose the reader-side normalization of reader impact. Since the journal in which a citing paper was published cannot be considered with readers (readers are independent of journals), both other citing-side normalization variants $\text{SNCS}_{(1)}$ and $\text{SNCS}_{(3)}$ are not transferable to the normalization of reader impact.

In $\text{SNCS}_{(2)}$, the paper's citation impact is normalized with respect to the disciplines where the paper is cited from. Cited references of citing publications are used as proxies reflecting citation densities in disciplines: the longer the reference lists of publications, the more intensive the citation activity in a discipline. Analogously, in the reader-side normalization, the

Table 2
DNRS threshold values for top-1%, top-10%, and top-50% papers.

Threshold	Top-1%	Top-10%	Top-50%
DNRS _{<i>i</i>}	19.1	5.8	1.5

paper's reader impact is normalized with respect to the (Mendeley) discipline in which it has been read. Whereas in the citing-side normalization the number of references is used as a proxy for citation density, the reader-side normalization can directly focus on disciplinary differences on the reader side by using the average reader counts in a discipline as the discipline-specific reader density.

As Table 1 shows that the readers differ on average between the document types “article” and “review” for most Mendeley disciplines, the normalization procedure is done separately for both document types.

The procedure for normalizing reader counts on the reader side is as follows: first, the average number of reader counts in each Mendeley discipline (ρ_d) is determined (see Table 1):

$$\rho_d = \frac{1}{I_d} \sum_{i=1}^{I_d} R_{id} \quad (4)$$

Here, I_d is the number of papers in Mendeley discipline d and R_{id} is the raw Mendeley reader count of paper i in Mendeley discipline d . A paper is in discipline d if at least one of its readers is in this discipline. The average reader count (ρ_d) should reflect differences between disciplines in reading papers.

Second, the Mendeley reader counts (R_{id}) of paper i and Mendeley discipline d is divided by the average reader count (ρ_d) in discipline d :

$$\beta_{id} = \frac{R_{id}}{\rho_d} \quad (5)$$

Third, the sum over the normalized reader counts (β_{id}) in the disciplines in which a paper i was read is calculated:

$$\text{DNRS}_i = \sum_{d=1}^D \beta_{id} \quad (6)$$

In Eq. (6), D is the number of Mendeley disciplines. Currently, $D = 25$.

We obtain a normalized reader score (discipline normalized reader score for each paper i , DNRS_{*i*}). Similar to the citing-side normalization of citation counts, where each citation is weighted by the citation density in a discipline (reflected by the number of references), each reader of a publication is weighted by the corresponding reader density (reflected by the average readers in a discipline). Since reader counts are dependent on time (the longer the time window between the publication of a paper and its impact measurement, the more readers can be expected), the DNRS_{*i*} should be calculated separately for papers published in different years (Lin & Fenner, 2013).

In order to clarify our procedure, we present it in detail using the example of an article published by Cuthbert and Quartly (2012). We found 9 readers who all shared their discipline: 5 in medicine, 1 in psychology, and 3 in social sciences. The average reader counts for these disciplines are: 3.84, 4.92, and 2.76 (see Table 1). Therefore, we obtain the normalized reader score of 1.30 for medicine ($5/3.84 = 1/3.84 + 1/3.84 + 1/3.84 + 1/3.84 + 1/3.84$), 0.20 for psychology ($1/4.92$), and 1.09 for social sciences ($3/2.76 = 1/2.76 + 1/2.76 + 1/2.76$). The sum over the three normalized counts is 2.59 (1.3 + 0.2 + 1.09). Thus, the normalization leads to more or less reduced reader counts in the disciplines—depending on the overall discipline-specific readership patterns.

The reader-side normalization does not lead to a score like the MNRS which has a mean value of one and can be interpreted as an “average” impact. It only leads to reduced reader counts whereby the reduction is dependent of the reader density in the corresponding reading disciplines. This makes the interpretation of the DNRS somewhat more difficult than the MNRS, but this is a characteristic which the DNRS shares with citing-side indicators. However, we provide threshold values in Table 2, which a paper has to have at least in order to reach the 1% (top-1%), 10% (top-10%), and 50% (top-50%) most frequently read papers in 2012—independent of the discipline.

The overall reader impact for aggregation levels (e.g., single researchers, research groups, institutions, countries, or journals) can be analyzed in terms of averages over a set of N papers:

$$\text{MDNRS} = \frac{1}{N} \sum_{i=1}^N \text{DNRS}_i \quad (7)$$

3.3. Theoretical analysis of the discipline normalized reader score

In the theoretical analysis of the MDNRS, we study whether the indicator fulfils several properties as desirable conditions for proper impact measurements (Waltman et al., 2011).

Table 3
Example of publications and reader counts for two researchers (A and B) and two disciplines (X and Y).

Paper	Researcher A		Researcher B	
	R_{iX}	R_{iY}	R_{iX}	R_{iY}
1	6	1	4	4
2	6	1	4	4
3	6	3	4	4
4	1	10	4	4

Table 4
DNRS values for publications of two researchers (A and B).

Paper	Researcher A			Researcher B		
	β_{iX}	β_{iY}	DNRS _i	β_{iX}	β_{iY}	DNRS _i
1	1.37	0.26	1.63	0.91	1.03	1.95
2	1.37	0.26	1.63	0.91	1.03	1.95
3	1.37	0.77	2.15	0.91	1.03	1.95
4	0.23	2.58	2.81	0.91	1.03	1.95

First, we analyse the MDNRS regarding the property of consistency. The property of consistency has been defined for citation-based indicators of average performance by [Waltman and van Eck \(2009\)](#) and [Waltman et al. \(2011\)](#). Here, we reformulate this definition for average performance indicators based on reader counts: a performance indicator is said to be consistent if the ranks of two publication sets of equal size (e.g., of two different researchers) do not change if both publication sets are expanded by an additional publication with the same number of reader counts in the same disciplines. It can be seen when Eqs. (4)–(7) are reformulated that the MDNRS has this property of consistency:

$$\text{MDNRS}(S_1) = \frac{1}{N} \sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} \tag{8}$$

$$\text{MDNRS}(S_1 \cup S_3) = \frac{1}{N+1} \left(\sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} + \sum_{d=1}^D \frac{S_{3d}}{\rho_d} \right) \tag{9}$$

$$\text{MDNRS}(S_2) = \frac{1}{N} \sum_{j=1}^N \sum_{d=1}^D \frac{R_{jd}}{\rho_d} \tag{10}$$

$$\text{MDNRS}(S_2 \cup S_3) = \frac{1}{N+1} \left(\sum_{j=1}^N \sum_{d=1}^D \frac{R_{jd}}{\rho_d} + \sum_{d=1}^D \frac{S_{3d}}{\rho_d} \right) \tag{11}$$

Here, S_{3d} is the reader count of the additional publication for discipline d . S_1 and S_2 consist of N papers each: $i = 1, 2, \dots, N$ for S_1 and $j = 1, 2, \dots, N$ for S_2 . Now, we start with the given condition that $\text{MDNRS}(S_1) \geq \text{MDNRS}(S_2)$ and analyse if $\text{MDNRS}(S_1 \cup S_3) \geq \text{MDNRS}(S_2 \cup S_3)$ holds true:

$$\text{MDNRS}(S_1 \cup S_3) \geq \text{MDNRS}(S_2 \cup S_3) \tag{12}$$

$$\frac{1}{N+1} \left(\sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} + \sum_{d=1}^D \frac{S_{3d}}{\rho_d} \right) \geq \frac{1}{N+1} \left(\sum_{j=1}^N \sum_{d=1}^D \frac{R_{jd}}{\rho_d} + \sum_{d=1}^D \frac{S_{3d}}{\rho_d} \right) \tag{13}$$

$$\sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} + \sum_{d=1}^D \frac{S_{3d}}{\rho_d} \geq \sum_{j=1}^N \sum_{d=1}^D \frac{R_{jd}}{\rho_d} + \sum_{d=1}^D \frac{S_{3d}}{\rho_d} \tag{14}$$

$$\sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} \geq \sum_{j=1}^N \sum_{d=1}^D \frac{R_{jd}}{\rho_d} \tag{15}$$

$$\text{MDNRS}(S_1) \geq \text{MDNRS}(S_2) \tag{16}$$

It follows from Eqs. (8)–(16) that $\text{MDNRS}(S_1 \cup S_3) \geq \text{MDNRS}(S_2 \cup S_3)$ if $\text{MDNRS}(S_1) \geq \text{MDNRS}(S_2)$. Therefore, the MDNRS has the property of consistency. We provide an illustrative example in [Tables 3 and 4](#) for clarification.

According to [Tables 3 and 4](#), one obtains MDNRS = 2.05 for researcher A and MDNRS = 1.95 for researcher B. If both researchers write a fifth paper which has 6 readers in discipline X and 1 reader in discipline Y, the MDNRS of researcher A drops to 2.03 and the MDNRS of researcher B rises to 1.97 but the ranking of both researchers remains unchanged.

Second, we turn to the question how the (M)DNRS behaves when publications get an additional reader. Well behaving indicators must not decrease (worsen) when a publication gets another reader. Eqs. (5) and (6) clearly show that the performance indicator $DNRS_i$ increases when additional reader counts occur. Therefore, the (M)DNRS has the desired property that the indicator value does not decrease (worsen) when additional reader counts occur for a publication set.

The third property we would like to study is the mean value over all papers. It is desirable to obtain a mean value of 1 over all papers (published within one year) so that it is easier to judge if a paper has an above or below average impact. Eq. (6) and the examples in [Tables 3 and 4](#) show that the average MDNRS value over all papers differs from 1. It follows from Eqs. (4) and (5), that the basic components which the MDNRS is based on (β_{id}) do have the property that the mean value over all papers equals 1. Therefore, the MDNRS has this property, too, under the assumption that all reader counts for a paper are from the same discipline, e.g., $d = 1$:

$$MDNRS = \frac{1}{N} \sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} = \frac{1}{N} \sum_{i=1}^N \frac{R_{i1}}{\rho_1} \quad (17)$$

Due to the definition of ρ_d , Eq. (11) shows that in this extreme case the MDNRS over a full publication year equals 1.

The β_{id} values are added in Eq. (6) to obtain the DNRS values. Therefore, the mean value of all DNRS values (the MDNRS of a full publication year) is greater than or equal to 1.

There is another extreme case: each publication has at least one reader count from each discipline:

$$MDNRS = \frac{1}{N} \sum_{i=1}^N \sum_{d=1}^D \frac{R_{id}}{\rho_d} = \sum_{d=1}^D \frac{1}{N} \sum_{i=1}^N \frac{R_{id}}{\rho_d} \quad (18)$$

The last term in Eq. (18), $1/N \sum_{i=1}^N R_{id}/\rho_d$, equals 1 for each discipline d . Therefore, the MDNRS over a full publication year equals the number of disciplines in this extreme case. However, as the reader distribution is skewed across papers and disciplines, the MDNRS for a full publication year is between those two extreme cases and varies between 1 and the number of disciplines: $1 \leq MDNRS \leq d$. The deviation from 1 increases with increasing reader counts from different disciplines per paper. Therefore, the deviation from 1 can be seen as an interdisciplinarity measure of the publication set of a full year. The MDNRS over the full publication set (publication year 2012) is 2.7 in our case. The MNRS has the property of a mean value over all papers of 1 in general. Additionally, the MNRS has also the property of consistency and the MNRS does not decrease (worsen) when additional reader counts occur. One could obtain the property of a mean value of 1 also for the (M)DNRS by a slight change in Eq. (7) following [Haunschild and Bornmann \(2016b\)](#):

$$MDNRS' = \frac{1}{N} \sum_{i=1}^N \frac{DNRS_i}{\overline{DNRS}} \quad (19)$$

In Eq. (19), \overline{DNRS} is the average value over all $DNRS_i$ values of a full publication year. This scaling allows an easier interpretation of the MDNRS values (average, above or below average impact of a paper set). However, this property has no bearing on the question whether a performance indicator has the property of field-normalization. This more important property is studied empirically in Section 3.4.

3.4. Empirical analysis of the discipline normalized reader score

Although the definition of the MDNRS follows proposals of citing-side normalization in bibliometrics and fulfils certain desirable properties (see Section 3.3), it is not clear whether the MDNRS reaches the desired goal of field-normalizing reader impact. [Bornmann, de Moya Anegón, and Mutz \(2013\)](#) introduced a statistical procedure which can be used to study the proposed ability of the MDNRS to field-normalize (see also [Radicchi et al., 2008](#)). In order to compare the results for the MDNRS with other reader indicators, the procedure is also applied to the MNRS and bare reader counts.

In the first step of the procedure (done for each indicator separately), all papers from 2012 are sorted in descending order by an indicator. Then, the 10% most frequently read papers are identified (a new binary variable is generated).

In the second step, the papers are assigned to main disciplines using the OECD field classification scheme.¹ The main OECD disciplines aggregate WoS subject categories which consist of sets of disciplinary journals to the following broad disciplines: (1) natural sciences, (2) engineering and technology, (3) medical and health sciences, (4) agricultural sciences, (5) social sciences, and (6) humanities. Since many journals are assigned to more than one WoS category, many papers in

¹ <http://ipscience-help.thomsonreuters.com/incitesLive/globalComparisonsGroup/globalComparisons/subjAreaSchemesGroup/oecd.html>.

Table 5

Number of papers and proportion of papers belonging to the 10% most frequently read papers in six main disciplines (as defined by the OECD). All proportions with a deviation outside the range of tolerance (see text) are printed in bold.

Main disciplines	Bare reader counts		MDNRS		MNRS	
	Number of papers	Proportion top-10%	Number of papers	Proportion top-10%	Number of papers	Proportion top-10%
Natural sciences	703,380	12.3	703,380	11.3	830,635	10.1
Engineering and technology	318,496	7.4	318,496	11.0	382,496	10.6
Medical and health sciences	440,094	8.3	440,094	6.9	506,721	9.6
Agricultural sciences	52,527	6.9	52,527	5.4	59,108	9.8
Social sciences	129,565	17.9	129,565	25.0	137,551	9.2
Humanities	17,506	4.6	17,506	10.4	24,378	10.3
Mean absolute deviation		3.8		4.2		0.4

our dataset are correspondingly assigned to more than one OECD main discipline. Thus, we used a dataset including several papers multiply. The multiplicative approach does not affect the test of disciplinary biases, because the 10% most read papers are selected on the basis of the dataset with papers included multiply. The category “not categorized” is also used by the OECD scheme, but is not considered in this study.

In the third step, the proportion of papers which belong to the 10% most frequently read papers from the first step is determined for each broad discipline. The expectation is that this proportion equals 10% if the indicator values are independent of disciplines or are properly field-normalized, respectively. Thus, bare reader counts should show greater deviations from 10% than MNRS and MDNRS.

The results of the three-step procedure are shown in Table 5. The MDNRS is compared with the MNRS and bare reader counts. The table shows the total number of papers within the main disciplines and the proportion of papers within a main discipline which belongs to the 10% most frequently cited papers. As the number of papers for bare reader counts, MDNRS, and MNRS show, the paper numbers for MNRS are significantly higher in all main disciplines. This is due to the fact that papers with zero readers and papers from 2012, which could not be found on Mendeley, cannot be considered for the analyses of the bare reader counts and MDNRS.

We expect the most and largest deviations of the proportions from 10% for bare reader counts, because they are not field-normalized. In the interpretation of the proportions in Table 5, we deem deviations of less than 2% points acceptable (i.e., proportions with greater than 8% and less than 12%). Here, we follow rules of thumb given by Belter and Sen (2014) for the interpretation of top-10% proportions. In other words, if the deviation of the proportion is within this range of tolerance, the normalization seems to be approximately valid. Since we selected with 2% points a large error margin, we report also the mean absolute deviation from the expected value of 10. Thus, all proportions in Table 5 are printed in bold with a deviation outside this range of tolerance. As the results in the table show, the bare reader counts fail to reach the range of tolerance in five out of six disciplines. The largest deviation is visible for the social sciences (with 17.9%). Although the social sciences have a still larger deviation for the MDNRS (with 25%), more disciplines are within the range of tolerance for the MDNRS (three out of six) than for the bare reader counts.

The MNRS shows the best results in Table 5: all main disciplines have less than 1% point deviations from 10%. The indicator seems to field-normalize reader counts in all disciplines properly. Following the argumentations of Sirtes (2012) and Waltman and van Eck (2013b), the comparably best results for the MNRS could have a simple reason: the indicator uses the same scheme of subject categories for the field-normalization on which the tests in Table 5 are also based. In other words, the use of the OECD main disciplines in the analyses of this study gives the MNRS an advantage over the MDNRS. Waltman and van Eck (2013b) therefore repeated the analyses using another scheme of field categorization: an algorithmically constructed classification system (ACCS). Waltman and van Eck (2012) proposed the ACCS as an alternative to the frequently used field categorization scheme based on journal sets. The ACCS is based on direct citation relations between publications. In contrast to the WoS category scheme each publication is assigned to only one field category. We downloaded the ACCS for the papers at the homepage of the Leiden ranking.²

The results of the comparison between bare reader counts, MDNRS, and MNRS based on ACCS (applied on the highest field-aggregation level) are shown in Table 6. The results are similar to those in Table 5. The MNRS reveals the best result: the proportions of papers belonging to the 10% most frequently read papers fall within the range of tolerance in all disciplines. MDNRS follows with two out of five disciplines having larger deviations from the expected value. However, the MDNRS improves its results compared to the main OECD disciplines (see Table 5): the proportion for biomedical and health sciences is close to the range of tolerance and the proportions for three disciplines (out of five) are within the range (instead of three out of six in Table 5). However, there is with 22.2% a large deviation for the social sciences and humanities (similar to Table 5). This large deviation for social sciences and humanities is also visible for bare reader counts (with 16.2%), whereby social sciences and humanities are one of four disciplines with larger deviations from 10% for bare reader counts.

² <http://www.leidenranking.com/methodology/fields>.

Table 6

Number of papers and proportion of papers belonging to the 10% most frequently read papers in five main disciplines (as defined by the ACCS on the highest level). All proportions with a deviation outside the range of tolerance (see text) are printed in bold.

Main disciplines	Bare reader counts		MDNRS		MNRS	
	Number of papers	Proportion top-10%	Number of papers	Proportion top-10%	Number of papers	Proportion top-10%
Biomedical and health sciences	476,324	10.6	476,324	7.9	859,504	9.5
Life and earth sciences	205,282	14.4	205,282	11.0	383,988	11.1
Mathematics and computer science	83,412	5.6	83,412	10.4	207,605	9.3
Physical sciences and engineering	326,582	6.6	326,582	8.9	711,010	10.0
Social sciences and humanities	113,710	16.2	113,710	22.2	206,633	11.9
Mean absolute deviation		3.8		3.4		0.8

Taken as a whole, the proportions in [Tables 5 and 6](#) for bare reader counts reveal that field-normalization is generally necessary for Mendeley reader counts. Larger deviations from the expected value of 10% are found in most of the disciplines. The MNRS should be preferred for the field-normalization, because it seems to reach the desired goal in all disciplines. The mean absolute deviation from the expected value of 10 is significantly smaller for the MNRS than for bare reader counts and the MDNRS. The results of the study are ambivalent for the MDNRS: in natural sciences, humanities, and engineering the reader counts seem to be properly field-normalized, but in social sciences they are definitely not.

3.5. Normalized reader impact of journals

Papers from 9,563 journals out of the 12,334 WoS journals in 2012 are covered in the papers found at Mendeley. We calculated the MNRS and MDNRS for all 9,563 journals. [Table 7](#) shows for each OECD main discipline the 10 journals with at least 10 papers in 2012 and highest MDNRS. The minimum of 10 papers published in 2012 ensures that the calculation of the journal indicator values is based on a considerable number of papers (a higher threshold would have excluded too many journals in the humanities for the analysis). Also, we calculated within each discipline the spearman rank-order correlation between MNRS and MDNRS. We used the guidelines of [Cohen \(1988\)](#) and [Kraemer et al. \(2003\)](#) to interpret the coefficients. Much larger than typical coefficients ($r_s \geq 0.7$) would reveal that both indicators lead to similar journal rankings.

[Table 7](#) shows two paper numbers for the journals: number of papers and number of unique papers. Many papers are assigned to more than one WoS subject category and many journals are also assigned to more than one WoS subject category. Since these papers are multiply considered in the calculation of the journal MNRS, this indicator is based on higher case numbers than the MDNRS (where each paper is considered only once).

The results in [Table 7](#) reveal that the best journals in natural science, engineering and technology, medical and health sciences, and social sciences receive MDNRS values of around 30. In other words, an excellent reader performance (on the journal level) is reached at this level in these disciplines. In agricultural sciences and humanities, the best MDNRS values are significantly lower: the best journal in agricultural sciences (*Fish and Fisheries*) reaches a MDNRS of 9.4 and the best journal in humanities (*New German Critique*) a MDNRS of 14.9. Similar deviations, especially for the humanities, are also visible for citing-side indicators (see Fig. 1F in [Bornmann & Marx, 2015](#)).

In all disciplines, the MNRS values are expectedly lower than the MDNRS values (see [Table 7](#)). Very high MNRS values of larger than 10 can be found in natural sciences (e.g., *Nature Photonics* has a MNRS value of 13.4). A MNRS value of 10 means that the papers in the journal have been read ten times more frequently on average than an “average” paper in the corresponding subject category and with the same document type.

The correlation coefficients in [Table 7](#) show much larger than typical correlations ($r_s \geq 0.7$) in five out of six disciplines: natural sciences, engineering and technology, medical and health sciences, agricultural sciences, and social sciences. Only in the humanities is the coefficient between typical and larger than typical ($r_s = 0.4$).

Taken as a whole, the coefficients in [Table 7](#) show that one receives similar rankings (of journals), if MNRS or MDNRS are used in five disciplines. However, one can expect (larger) differences between the indicators in the humanities: here, the choice of the indicators makes a larger difference.

4. Discussion

Here, we have proposed the field-normalized indicator MDNRS based on Mendeley data which might complement the paper-side normalization of reader counts (MNRS) proposed by [Haunschild and Bornmann \(2016a\)](#). Since the calculation of the MNRS needs further data besides data from Mendeley (in order to have a field-classification scheme for normalization), the reader-side normalization of reader counts is an attractive alternative: the MDNRS does not need further data and can be exclusively calculated with data from Mendeley, because the MDNRS is normalized with respect to Mendeley disciplines which are reported with virtually all reader counts. The MDNRS is an adaptation of the citing-side normalization used in bibliometrics to altmetrics.

In this study, we tested whether the MDNRS is able to field-normalize reader counts. For comparison, we included also bare reader counts and the MNRS in the analyses. In a first analysis (see [Section 3.3](#)), we studied in a theoretical analysis

Table 7
Top-10 WoS journals with a minimum of 10 (unique) papers in 2012 ordered by decreasing MDNRS.

Journal and correlation coefficient	Number of papers	MNRS	Number of unique papers	MDNRS
Natural sciences ($r_s = 0.75$, $n = 3337$ journals)				
<i>Nature</i>	858	7.2	858	34.1
<i>Nature Materials</i>	417	11.2	139	29.7
<i>Nature Reviews Genetics</i>	66	6.5	66	29.2
<i>Nature Photonics</i>	228	13.4	114	27.2
<i>Nature Methods</i>	148	9.6	148	25.7
<i>Trends in Ecology and Evolution</i>	228	5.1	76	24.9
<i>Reviews of Modern Physics</i>	45	11.8	45	24.7
<i>Science</i>	826	4.8	826	24.6
<i>Cell</i>	830	10.0	415	24.5
<i>User Modeling and User-Adapted Interaction</i>	15	5.6	15	24.0
Engineering and technology ($r_s = 0.81$, $n = 1556$ journals)				
<i>Nature Nanotechnology</i>	240	10.7	120	32.5
<i>Nature Materials</i>	139	10.9	139	29.7
<i>Nature Biotechnology</i>	87	11.5	87	27.8
<i>Design Studies</i>	58	7.8	29	23.9
<i>Communications of the ACM</i>	86	5.0	86	17.7
<i>IEEE Transactions on Pattern Analysis and Machine Intelligence</i>	189	9.4	189	16.9
<i>Genome Research</i>	237	7.6	237	16.9
<i>New Media and Society</i>	77	3.0	77	15.8
<i>Progress in Materials Science</i>	23	2.3	23	15.8
<i>Nature Reviews Drug Discovery</i>	39	4.6	39	14.9
Medical and health sciences ($r_s = 0.82$, $n = 2855$ journals)				
<i>Trends in Cognitive Sciences</i>	54	4.5	54	31.0
<i>Behavioral and Brain Sciences</i>	12	7.0	12	27.7
<i>Nature Reviews Neuroscience</i>	60	5.2	60	25.6
<i>Nature Neuroscience</i>	225	6.8	225	20.9
<i>Annual Review of Neuroscience</i>	26	3.8	26	20.7
<i>Neuron</i>	340	5.5	340	17.8
<i>Nature Reviews Cancer</i>	68	11.8	68	17.0
<i>New England Journal of Medicine</i>	202	8.6	202	15.0
<i>Nature Reviews Drug Discovery</i>	39	9.2	39	14.9
<i>Annual Review of Clinical Psychology</i>	17	5.4	17	14.3
Agricultural sciences ($r_s = 0.89$, $n = 385$ journals)				
<i>Fish and Fisheries</i>	26	5.1	26	9.4
<i>Urban Forestry and Urban Greening</i>	50	2.0	50	8.2
<i>Agricultural Systems</i>	84	3.9	84	8.0
<i>Food Policy</i>	150	2.8	75	7.1
<i>Veterinary Surgery</i>	131	3.8	131	7.0
<i>Agriculture and Human Values</i>	37	2.6	37	6.5
<i>Forest Policy and Economics</i>	132	1.7	132	5.9
<i>Agriculture, Ecosystems and Environment</i>	266	3.3	266	5.8
<i>Veterinary and Comparative Orthopaedics and Traumatology</i>	78	3.1	78	5.7
<i>Journal of Vegetation Science</i>	108	2.5	108	5.6
Social sciences ($r_s = 0.83$, $n = 1920$ journals)				
<i>Annual Review of Psychology</i>	44	4.3	22	37.0
<i>Trends in Cognitive Sciences</i>	108	2.7	54	31.0
<i>The Academy of Management Review</i>	60	4.0	30	29.9
<i>Academy of Management Journal</i>	118	3.9	59	29.0
<i>Behavioral and Brain Sciences</i>	24	7.1	12	27.7
<i>Review of Educational Research</i>	13	3.6	13	26.5
<i>The Academy of Management Annals</i>	11	3.4	11	25.3
<i>Journal of Interactive Marketing</i>	21	2.7	21	23.0
<i>Perspectives on Psychological Science</i>	58	5.3	58	22.3
<i>Strategic Management Journal</i>	156	2.6	78	21.8
Humanities ($r_s = 0.42$, $n = 563$ journals)				
<i>New German Critique</i>	12	8.9	12	14.9
<i>Journal of Second Language Writing</i>	22	3.0	22	11.4
<i>Journal of Archaeological Method and Theory</i>	23	2.7	23	11.3
<i>Annual Review of Applied Linguistics</i>	11	2.8	11	10.7
<i>Journal of Business Ethics</i>	261	2.9	261	9.9
<i>ReCALL</i>	17	2.5	17	9.7
<i>CoDesign</i>	12	4.6	12	9.3
<i>ELT Journal</i>	43	2.4	43	9.3
<i>English for Specific Purposes</i>	22	2.1	22	8.4
<i>Journal of English for Academic Purposes</i>	28	2.2	28	8.3

whether the indicator fulfils several properties (e.g., the property of consistency). The analyses revealed mixed results for the indicator. The analysis has shown that the MDNRS has the property of consistency. However, the analysis has also shown that the MDNRS does not perform field normalization as well as the MNRS. In a second analysis (see Section 3.4), we identified the papers which belong to the 10% most frequently read papers over all disciplines. Then, we calculated the proportion of these top-10% papers within several main disciplines. Deviations from the expected value of 10% in a discipline should reveal problems in field normalization or the field-dependence of an indicator. The MNRS shows the best results in general and can be recommended as a properly field normalized indicator in all disciplines. The results for the MDNRS are ambivalent, whereby the social sciences are the most problematic discipline with large deviations from the expected value. However, both methods of field-normalization received significantly better results than bare reader counts. In a third analysis (see Section 3.5), correlations between MDNRS and MNRS have been calculated on the journal level. Large coefficients indicated for most of the disciplines that both indicators led to similar journal rankings. The only exception in this analysis is a smaller coefficient in the humanities.

Taken as a whole, the MNRS should be preferred as the field-normalization method for Mendeley reader counts. The indicator shows the best ability to field-normalize. However, if the user does not have an external field-classification scheme at hand (e.g., the WoS subject categories), which is necessary for the calculation of the MNRS, the MDNRS can be calculated—however with caution. This means, for example, that the MDNRS should not be used with publication sets in the social sciences (and only with care in the humanities). Although MDNRS values are more difficult to interpret than MNRS values, our analyses on the journal level reveal one important benchmark: a MDNRS \approx 30 seems to be an exceptional high value in several disciplines.

What are the limitations of our study? Our retrieval strategy in the Mendeley API on reader counts using the DOI could be seen as a limitation. This leads to the exclusion of articles and reviews from 2012 which do not have a DOI. Limiting the data set to the publications which have a DOI reduces the number of publications from 1,390,504 to 1,198,184. Therefore, 86.2% of the articles and reviews of the WoS core collection of 2012 are considered in this study. It might be the case that papers without a DOI are disciplinarily (toward humanities and the social sciences) and geographically (toward developing countries) biased. There might be better options to identify the papers in the Mendeley API. However, this study is not intended as an evaluation study which compares reader impacts of journals. The main aim of the study is to propose and investigate possibilities to normalize Mendeley reader counts.

A further limitation concerns the test, which we used to assess the ability of the MDNRS and MNRS in field-normalizing reader counts. In the first step of the test, all papers in the dataset are sorted by the indicator which is intended to be studied. In the second step, all papers are marked (with the value 1 in a new binary variable x) which belong to the 10% best performing papers and all papers are assigned to a subject category scheme (e.g., the OECD scheme). In the third step, the percentage of papers within each subject category are determined which are marked with $x=1$. The more the percentages within the subject categories deviate from the expected value of 10%, the more the indicator is not able to normalize reader counts. Although the test is able to assess the lack of disciplinary biases in the results, it is not able to assess the value of different metrics. The value of different metrics can be assessed by using other methods, for example, by correlating indicators with other criteria of quality, especially expert judgements (Bornmann, 2014b; Bornmann & Leydesdorff, 2013).

We have proposed the paper-side normalization (MNRS) in Haunschild and Bornmann (2016a) and the reader-side normalization (MDNRS) in this study. The reader-side normalization is only possible due to the availability of Mendeley reader disciplines. The paper-side normalization can also be applied to other altmetrics data, such as tweets, blog posts, as it relies on an external classification system assigned to individual papers (or journals where the paper was published). The transferability of the MNRS points to a further limitation of the MDNRS which does not apply to the MNRS. The MDNRS was obtained through normalization with regard to self-assigned Mendeley disciplines. Fortunately, the share of Mendeley users who report and share their discipline is very high, based on papers from 2012. However, we do not see a viable way to check if the Mendeley users report their discipline information properly and update it constantly.

This study is a first attempt to develop field-normalized indicators on the reader side. We would appreciate if the paper is used as a starting point to develop more complex indicator variants with reduced disciplinary biases. In possible variants, readers of a publication from multiple disciplines could not be fully (as in the MDNRS), but fractionally assigned to each of the disciplines. However, these approaches should be theoretically and empirically investigated in detail.

Acknowledgments

The bibliometric data used in this paper are from an in-house database developed and maintained by the Max Planck Digital Library (MPDL, Munich) and derived from the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AHCI) prepared by Thomson Reuters (Philadelphia, Pennsylvania, USA). The Mendeley reader counts were retrieved via the API of Mendeley. We would like to thank three anonymous reviewers and the Editor-in-Chief of the *Journal of Informetrics*, Ludo Waltman, for their valuable recommendations to improve the manuscript.

References

- Altmetric, & Scholastica. (2015). *The evolution of impact indicators: from bibliometrics to altmetrics*. London, UK: Altmetric and Scholastica.
- Belter, C., & Sen, A. (2014). *Bibliometric performance measures for the evaluation of NOAA R&D*. Silver Spring, MD, USA: U.S. Department of Commerce.

- Bornmann, L. (2014a). Do altmetrics point to the broader impact of research? An overview of benefits and disadvantages of altmetrics. *Journal of Informetrics*, 8(4), 895–903. <http://dx.doi.org/10.1016/j.joi.2014.09.005>
- Bornmann, L. (2014b). Validity of altmetrics data for measuring societal impact: a study using data from Altmetric and F1000Prime. *Journal of Informetrics*, 8(4), 935–950.
- Bornmann, L. (2015). Usefulness of altmetrics for measuring the broader impact of research: a case study using data from PLOS and F1000Prime. *Aslib Journal of Information Management*, 67(3), 305–319. <http://dx.doi.org/10.1108/AJIM-09-2014-0115>
- Bornmann, L., de Moya Anegón, F., & Mutz, R. (2013). Do universities or research institutions with a specific subject profile have an advantage or a disadvantage in institutional rankings? A latent class analysis with data from the SCLImago ranking. *Journal of the American Society for Information Science and Technology*, 64(11), 2310–2316.
- Bornmann, L., & Haunschild, R. (2015). Which people use which scientific papers? An evaluation of data from F1000 and Mendeley. *Journal of Informetrics*, 9(3), 477–487.
- Bornmann, L., & Leydesdorff, L. (2013). The validation of (advanced) bibliometric indicators through peer assessments: a comparative study using data from InCites and F1000. *Journal of Informetrics*, 7(2), 286–291. <http://dx.doi.org/10.1016/j.joi.2012.12.003>
- Bornmann, L., & Marx, W. (2014). The wisdom of citing scientists. *Journal of the American Society for Information Science and Technology*, 65(6), 1288–1292.
- Bornmann, L., & Marx, W. (2015). Methods for the generation of normalized citation impact scores in bibliometrics: which method best reflects the judgements of experts? *Journal of Informetrics*, 9(2), 408–418.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ, USA: Lawrence Erlbaum Associates Publishers.
- Cuthbert, D., & Quartly, M. (2012). Forced adoption in the Australian story of national regret and apology. *Australian Journal of Politics & History*, 58(1), 82–96. <http://dx.doi.org/10.1111/j.1467-8497.2012.01625.x>
- Fairclough, R., & Thelwall, M. (2015). National research impact indicators from Mendeley readers. *Journal of Informetrics*, 9(4), 845–859. <http://dx.doi.org/10.1016/j.joi.2015.08.003>
- Gunn, W. (2013). Social signals reflect academic impact: what it means when a scholar adds a paper to Mendeley. *Information Standards Quarterly*, 25(2), 33–39.
- Haunschild, R., & Bornmann, L. (2016a). Normalization of Mendeley reader counts for impact assessment. *Journal of Informetrics*, 10(1), 62–73.
- Haunschild, R., & Bornmann, L. (2016b). The proposal of using scaling for calculating field-normalized citation scores. *El Profesional de la Información*, 25(1), 1699–2407.
- Haustein, S., & Larivière, V. (2014a). Mendeley as a source of readership by students and postdocs? Evaluating article usage by academic status. *Paper Presented at the Proceedings of the IATUL Conferences* (Paper 2).
- Haustein, S., & Larivière, V. (2014b). A multidimensional analysis of Aslib proceedings—using everything but the impact factor. *Aslib Journal of Information Management*, 66(4), 358–380. <http://dx.doi.org/10.1108/AJIM-11-2013-0127>
- Jeng, W., He, D., & Jiang, J. (2015). User participation in an academic social networking service: a survey of open group users on Mendeley. *Journal of the Association for Information Science and Technology*, 66(5), 890–904. <http://dx.doi.org/10.1002/asi.23225>
- Kraemer, H. C., Morgan, G. A., Leech, N. L., Gliner, J. A., Vaske, J. J., & Harmon, R. J. (2003). Measures of clinical significance. *Journal of the American Academy of Child and Adolescent Psychiatry*, 42(12), 1524–1529. <http://dx.doi.org/10.1097/01.chi.0000091507.46853.d1>
- Leydesdorff, L., & Bornmann, L. (2011). How fractional counting of citations affects the impact factor: normalization in terms of differences in citation potentials among fields of science. *Journal of the American Society for Information Science and Technology*, 62(2), 217–229. <http://dx.doi.org/10.1002/asi.21450>
- Leydesdorff, L., & Opthof, T. (2010). Scopus's source normalized impact per paper (SNIP) versus a journal impact factor based on fractional counting of citations. *Journal of the American Society for Information Science and Technology*, 61(11), 2365–2369. <http://dx.doi.org/10.1002/Asi.21371>
- Leydesdorff, L., Ping, Z., & Bornmann, L. (2013). How can journal impact factors be normalized across fields of science? An assessment in terms of percentile ranks and fractional counts. *Journal of the American Society for Information Science and Technology*, 64(1), 96–107. <http://dx.doi.org/10.1002/asi.22765>
- Leydesdorff, L., Radicchi, F., Bornmann, L., Castellano, C., & de Nooy, W. (2013). Field-normalized impact factors: a comparison of rescaling versus fractionally counted IFS. *Journal of the American Society for Information Science and Technology*, 64(11), 2299–2309.
- Lin, J., & Fenner, M. (2013). The many faces of article-level metrics. *Bulletin of the American Society for Information Science and Technology*, 39(4), 27–30. <http://dx.doi.org/10.1002/bult.2013.1720390409>
- Mafahi, N., & Thelwall, M. (2015). When are readership counts as useful as citation counts? Scopus versus Mendeley for LIS journals. *Journal of the Association for Information Science and Technology*, <http://dx.doi.org/10.1002/asi.23369>
- Mohammadi, E., & Thelwall, M. (2013). Assessing the Mendeley readership of social science and humanities research. In J. Gorraiz, E. Schiebel, C. Gumpenberger, & M. Ho (Eds.), *Proceedings of ISSI 2013 Vienna: 14th International Society of Scientometrics and Informetrics Conference* (pp. 200–214). Vienna, Austria: Austrian Institute of Technology GmbH.
- Mohammadi, E., Thelwall, M., Haustein, S., & Larivière, V. (2014). Who reads research articles? An altmetrics analysis of Mendeley user categories. Retrieved from http://www.academia.edu/6298635/Who_Reads_Research_Articles_An_Altmetrics_Analysis_of_Mendeley_User_Categories Accessed March 18
- Mohammadi, E., Thelwall, M., & Kousha, K. (2016). Can Mendeley Bookmarks Reflect Readership? A Survey of User Motivations. *Journal of the Association for Information Science and Technology*, 67(5), 1198–1209.
- Priem, J. (2014). Altmetrics. In B. Cronin, & C. R. Sugimoto (Eds.), *Beyond bibliometrics: harnessing multi-dimensional indicators of performance* (pp. 263–288). Cambridge, MA, USA: MIT Press.
- Priem, J., Piwowar, H., & Hemminger, B. (2012). *Altmetrics in the wild: using social media to explore scholarly impact*. Retrieved from <http://arxiv.org/html/1203.4745> Accessed March 27
- Priem, J., Taraborelli, D., Groth, P., & Neylon, C. (2010). *Altmetrics: a manifesto*. Retrieved from <http://altmetrics.org/manifesto/> Accessed March 28
- R Core Team. (2014). *R: a language and environment for statistical computing* (version 3.1.2). Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <https://www.r-project.org/>
- Radicchi, F., Fortunato, S., & Castellano, C. (2008). Universality of citation distributions: toward an objective measure of scientific impact. *Proceedings of the National Academy of Sciences*, 105(45), 17268–17272. <http://dx.doi.org/10.1073/pnas.0806977105>
- Schubert, A., & Braun, T. (1986). Relative indicators and relational charts for comparative assessment of publication output and citation impact. *Scientometrics*, 9(5–6), 281–291.
- Sirtes, D. (2012). Finding the Easter eggs hidden by oneself: why fairness test for citation indicators is not fair. *Journal of Informetrics*, 6(3), 448–450. <http://dx.doi.org/10.1016/j.joi.2012.01.008>
- van Leeuwen, T. (2006). The application of bibliometric analyses in the evaluation of social science research. Who benefits from it, and why it is still feasible. *Scientometrics*, 66(1), 133–154. <http://dx.doi.org/10.1007/s11192-006-0010-7>
- Waltman, L., & van Eck, N. J. (2009). A taxonomy of bibliometric performance indicators based on the property of consistency. In B. Larsen, & J. Leta (Eds.), *Proceedings of ISSI 2009—12th International Conference of the International Society for Scientometrics and Informetrics* (Vol. 2) (pp. 1002–1003). Leuven: Int. Soc. Scientometrics & Informetrics—ISSI.
- Waltman, L., & van Eck, N. J. (2012). A new methodology for constructing a publication-level classification system of science. *Journal of the American Society for Information Science and Technology*, 63(12), 2378–2392. <http://dx.doi.org/10.1002/asi.22748>
- Waltman, L., & van Eck, N. J. (2013a). Source normalized indicators of citation impact: an overview of different approaches and an empirical comparison. *Scientometrics*, 96(3), 699–716. <http://dx.doi.org/10.1007/s11192-012-0913-4>
- Waltman, L., & van Eck, N. J. (2013b). A systematic empirical comparison of different approaches for normalizing citation impact indicators. *Journal of Informetrics*, 7(4), 833–849.

- Waltman, L., van Eck, N. J., van Leeuwen, T. N., Visser, M. S., & van Raan, A. F. J. (2011). Towards a new crown indicator: some theoretical considerations. *Journal of Informetrics*, 5(1), 37–47. <http://dx.doi.org/10.1016/j.joi.2010.08.001>
- Wouters, P., Thelwall, M., Kousha, K., Waltman, L., de Rijcke, S., Rushforth, A., & Franssen, T. (2015). *The metric tide: literature review (supplementary report I to the independent review of the role of metrics in research assessment and management)*. London, UK: Higher Education Funding Council for England (HEFCE).
- Zahedi, Z., Costas, R., & Wouters, P. (2014). Assessing the impact of publications saved by Mendeley users: is there any different pattern among users? *Proceedings of the IATUL Conferences, Paper 4*. Retrieved from <http://docs.lib.purdue.edu/iatul/2014/altmetrics/4> Accessed 10.09.14
- Zahedi, Z., & Eck, N. J. v. (2014). *Visualizing readership activity of Mendeley users using VOSviewer*. Retrieved from http://figshare.com/articles/Visualizing_readership_activity_of_Mendeley_users_using_VOSviewer/1041819 Accessed 08.07.14
- Zitt, M., Ramanana-Rahary, S., & Bassecoulard, E. (2005). Relativity of citation performance and excellence measures: from cross-field to cross-scale effects of field-normalisation. *Scientometrics*, 63(2), 373–401. <http://dx.doi.org/10.1007/s11192-005-0218-y>
- Zitt, M., & Small, H. (2008). Modifying the journal impact factor by fractional citation weighting: the audience factor. *Journal of the American Society for Information Science and Technology*, 59(11), 1856–1860. <http://dx.doi.org/10.1002/asi.20880>