

Dynamics of Cross-Platform Attention to Retracted Papers (Supplemental Materials)

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I. SI METHODS

Four types of platforms. We categorized the 14 major platforms tracked by Altmetric into 4 groups: (1) social media (“twitter”, “facebook”, “googleplus”, “linkedin”, “pinterest”, “reddit”, “video”), (2) news media (“news media”), (3) blogs (“blogs”), and (4) knowledge repositories (“wikipedia”, “patent”, “f1000”, “q&a”, “peer reviews”). Three platforms (“policy”, “misc”, and “weibo”) were excluded as they do not fit into these categories and make up only a tiny fraction of mentions (less than 1%). During data cleaning, we relabelled as “news media” 30 mislabelled “blogs” (out of 1,262), such as “Scientific American”, “Medical Daily”, and “Popular Science”.

Top news outlets. We compiled a list of 27 top news outlets that are believed to be trustworthy, have high-quality science reporting, and represent popular media brands across a range of platforms according to the Pew Research Center [3, 5]. These outlets (hereafter referred to as “top news”) are: *ABC News*, *BBC News*, *Breitbart News Network*, *Business Insider*, *Buzzfeed*, *CBS News*, *CNN News*, *FOX News*, *Huffington Post*, *MSNBC*, *NBC News*, *NPR*, *New York Post*, *New York Times*, *Newsweek*, *PBS*, *Politico Magazine*, *TIME Magazine*, *The Daily Caller*, *The Guardian*, *The Hill*, *USA Today*, *Vice*, *Vox.com*, *Wall Street Journal*, *Washington Examiner*, and *Washington Post*.

Four broad disciplines. The Altmetric database also provides the research fields for each paper based on the 26 Scopus Subject Areas, which belong to 4 broad disciplines including Social Sciences, Life Sciences, Physical Sciences, and Health Sciences [2]. The subject classification was performed by in-house experts based on the aim and scope of the content a journal publishes. Note that a paper can belong to several subject areas and therefore multiple disciplines.

Establishing publication date. Our analysis relies on identifying the correct publication and retraction date for each paper. A paper can have different online and print publication dates (online is usually earlier). The Altmetric database provides both “pubdate” and “epubdate” for each paper. The Retraction Watch database also provides the publication date of retracted papers. We thus set the publication date for each retracted paper as the earliest date recorded by the two databases.

Correcting retraction date. Similarly, the retraction date can be considered to be the online or the print version of the retraction notice. For example, the official retraction announcement for the paper “Molecular Characterization and Biological Activity of Interferon- α in Indian Peafowl (*Pavo cristatus*)” [6] was published in print on October 1, 2017, while it was posted online already on September 22, 2017. The retraction date recorded in Retraction Watch contains some inconsistencies, which could influence our analysis of pre- and post-retraction attention if not resolved. To ensure that we accurately separate mentions posted before the retraction from those posted after it, we utilize Twitter posts, the largest single platform in terms of attention volume (nearly 80%), to correct the retraction date for each paper. Our assumption is that if any tweet mentions the retraction of a paper (e.g., “.@PLOSONE announced #retraction of this @XYZ paper, notice will come in 2 weeks. [URL]”) posted before the recorded retraction date, the effective retraction date

should be at least as early as the time of this tweet.

We first identified 572 tweets posted before each paper’s retraction date (as per the Retraction Watch database) such that the tweets contain the string “retract” in its lowercase text. Not all such tweets are announcing a retraction (e.g., “Please retract this paper!!!” and “How is it possible that this study hasn’t been retracted?”). Hence, we manually labeled these tweets and found that 469 of them contained a statement of retraction. We corrected the retraction date for 381 papers based on this set of labeled tweets. A manual inspection of a random sample of 20 papers from the remaining retracted papers shows no error in the retraction date recorded in the Retraction Watch database.

76 criticism keywords Our iterative process to develop a heuristic for pre-selecting potentially critical tweets has resulted in the following keywords:

verify, problem, really, pretend, fake, raise, believe, story, possible, data, concern, crackpot, intelligence, standard, correction, possibly, wonder, laughable, stupid, distrust, pseudoscience, conclusive, insult, surprise, dumb, unclear, peer review, suspect, criticism, suspicious, replication, unsure, manipulation, ?, validate, plausible, controversy, shame, plausibly, non-expert, confounding, confusing, serious, academic, joke, chance, question, shock, fraud, controversial, nonsense, uncertain, manipulated, replicate, embarrass, verified, confounder, validation, peer-review, claim, publish, not sure, lol, intelligent, reputable, reviewer, reputation, warrant, lying, doubt, lie, academy, flaw, retract, believable, confuse.

II. SI FIGURES

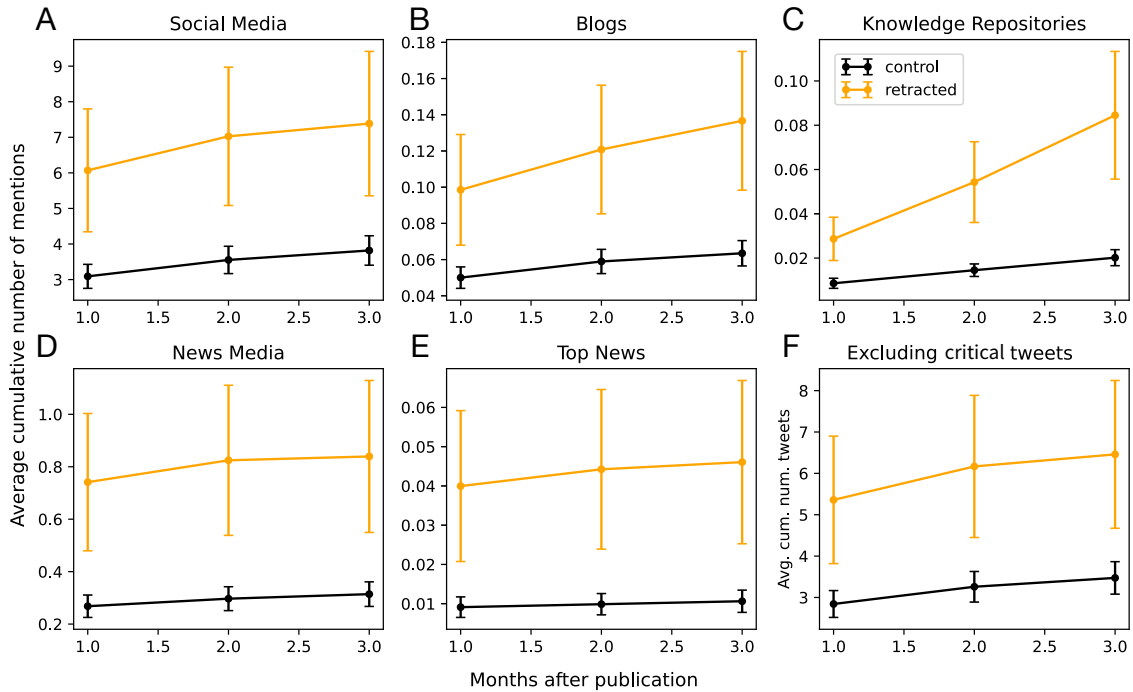


FIG. S1. **After-publication mentions.** **A-E**, Average cumulative number of mentions received within 3 months after publication on four types of platforms and in top news outlets for both retracted and control papers. **F**, Average cumulative number of mentions on Twitter after excluding critical tweets. Comparisons across different types of platforms show that retracted papers receive more attention after publication than non-retracted papers. Error bars indicate 95% confidence intervals.

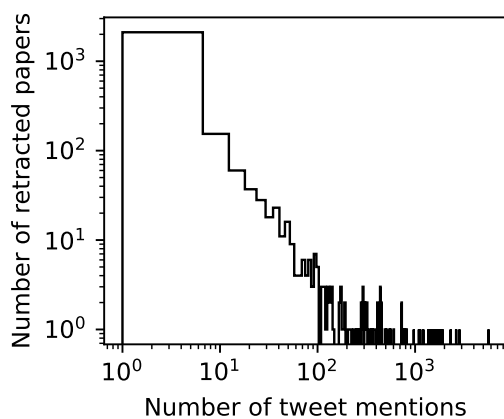


FIG. S2. **Distribution of the number of mentions on Twitter for retracted papers.** The distribution of online attention to retracted papers on Twitter is right-skewed as only a few papers can become very popular.

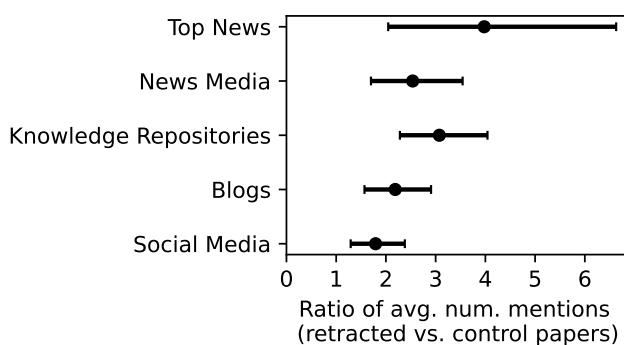


FIG. S3. **Ratio of the average number of mentions of retracted papers to that of non-retracted papers on each type of platform.** Relative to non-retracted papers, retracted ones tend to be favored more in the amount of coverage on news media, including top news, and knowledge repositories than on social media and blogs. However, the differences are not statistically significant due to imprecise estimation. Error bars indicate 95% bootstrapped confidence intervals.

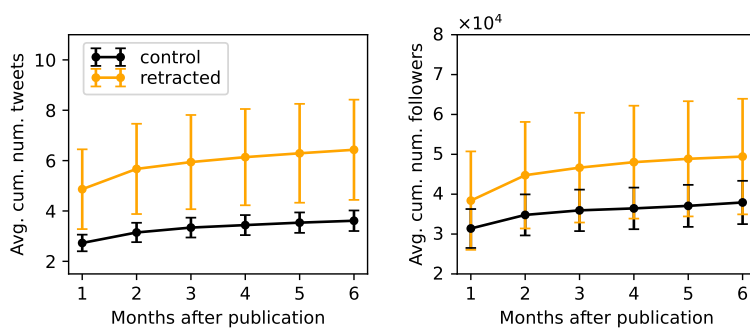


FIG. S4. **Number of followers for tweets that mention research papers within a given number of months after their publication.** *Left*, Average cumulative number of tweets received within 6 months after publication by retracted and control papers. *Right*, Same as *Left* but extended to the number of followers of those tweets.

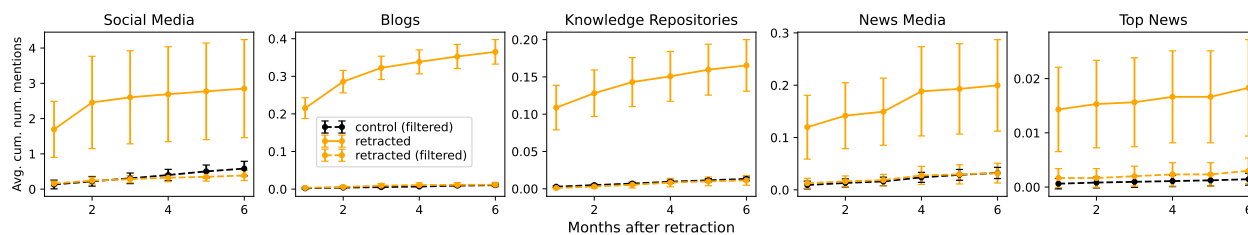


FIG. S5. **After-retraction mentions.** A-E, Average number of mentions received within 6 months after retraction on four types of platforms and in top news outlets for retracted and control papers. Comparisons across different types of platforms show that retracted papers receive more attention even after their retraction than non-retracted papers (solid orange lines). However, excluding retraction-related posts eliminates the surplus of attention that retracted papers receive (dashed orange lines). Error bars indicate 95% confidence intervals.

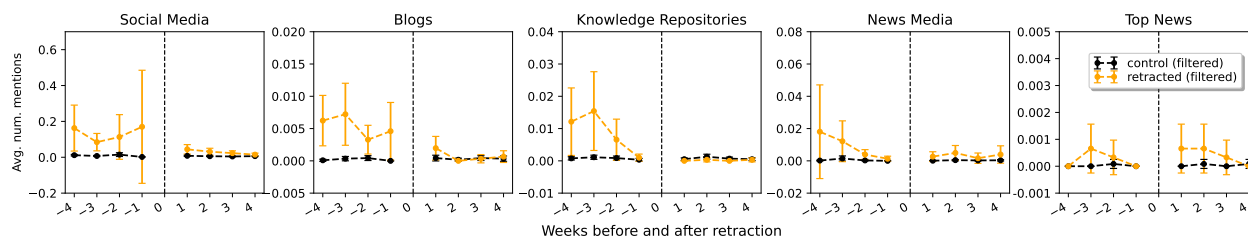


FIG. S6. **Average number of weekly mentions within 1 month before and after retraction.** Trends are shown on four types of platforms and in top news outlets for both retracted and control papers. In the case of retracted papers, we excluded all after-retraction posts that discussed the retraction in some form. For consistency, we also excluded posts that contain the phrase “retract” when referring to both control and retracted papers in the whole time period. Comparisons across different types of platforms show that retracted papers do not receive statistically more mentions than control papers immediately before or after retraction. Error bars indicate 95% confidence intervals.

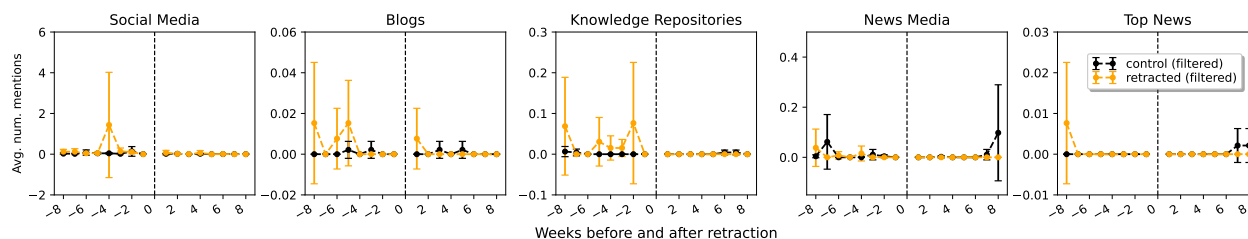


FIG. S7. **Average number of weekly mentions within 2 months before and after retraction.** Trends are shown on four types of platforms and in top news outlets for 131 retracted and 470 control papers in **Social Sciences**. In the case of retracted papers, we excluded all after-retraction posts that discussed the retraction in some form. For consistency, we also excluded posts that contain the phrase “retract” when referring to both control and retracted papers in the whole time period. Comparisons across different types of platforms show that retracted papers do not receive statistically more mentions than control papers immediately (e.g., within two weeks) before or after retraction. Error bars indicate 95% confidence intervals.

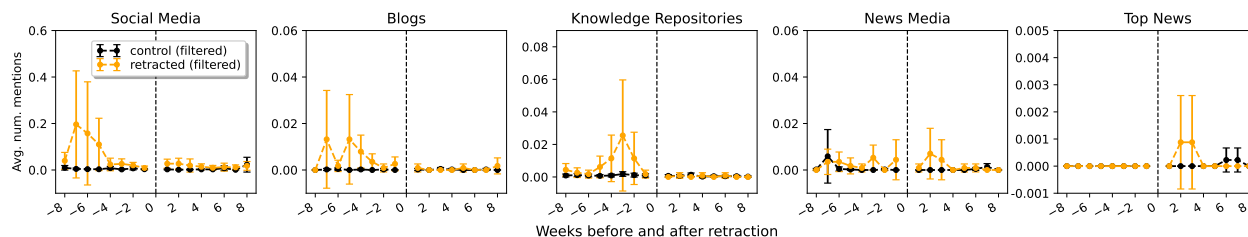


FIG. S8. Same as Fig. S7, but for 1,137 retracted and 4,423 control papers in **Life Sciences**.

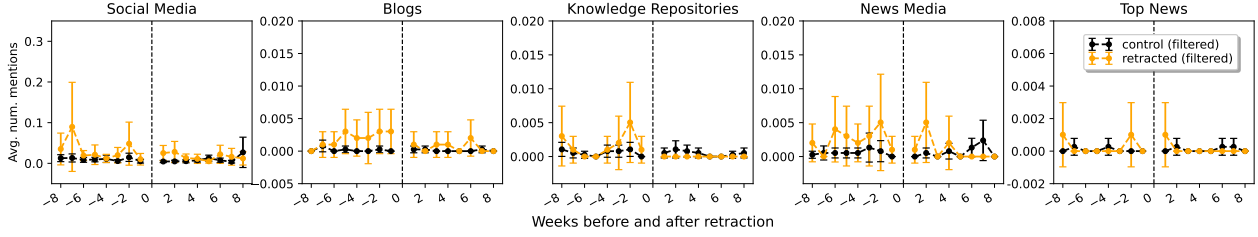


FIG. S9. Same as Fig. S7, but for 993 retracted and 3,780 control papers in **Health Sciences**.

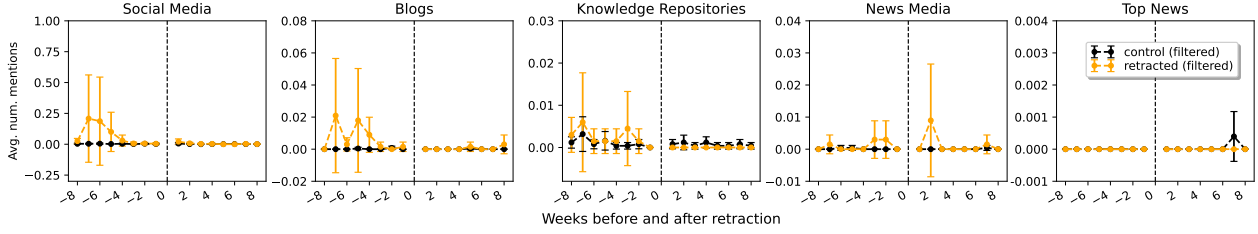


FIG. S10. Same as Fig. S7, but for 669 retracted and 2,524 control papers in **Physical Sciences**.

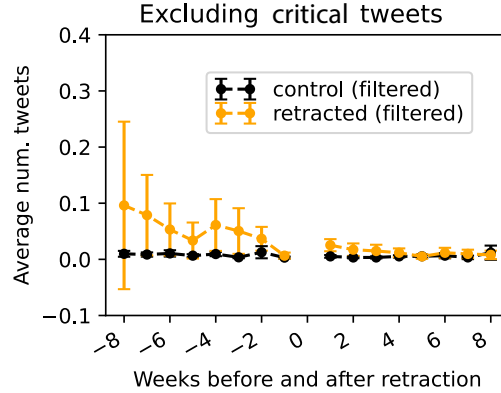


FIG. S11. **Before- and after-retraction mentions on Twitter.** Average weekly number of tweets received within 2 months before and after retraction for both retracted and control papers. We excluded after-retraction tweets that discuss the retraction itself for retracted papers. We also excluded tweets that contain the phrase “retract” for both groups of papers in the whole time period. For all papers, we removed critical tweets before retraction. Error bars indicate 95% confidence intervals. This result shows that retracted papers are discussed not statistically more often than control papers right before their retraction.

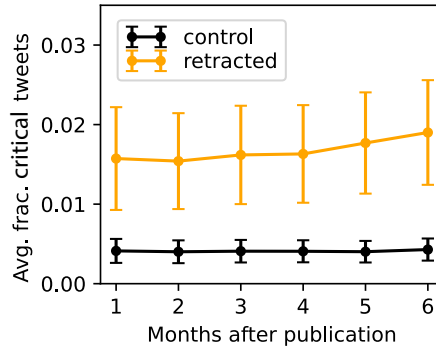


FIG. S12. **Average cumulative fraction of critical tweets within 6 months after publication.** We treat ambiguous tweets as expressing critical concerns. Similar to Fig. 3 shown in the main paper, retracted papers receive a higher fraction of critical tweets. Error bars indicate 95% confidence intervals.

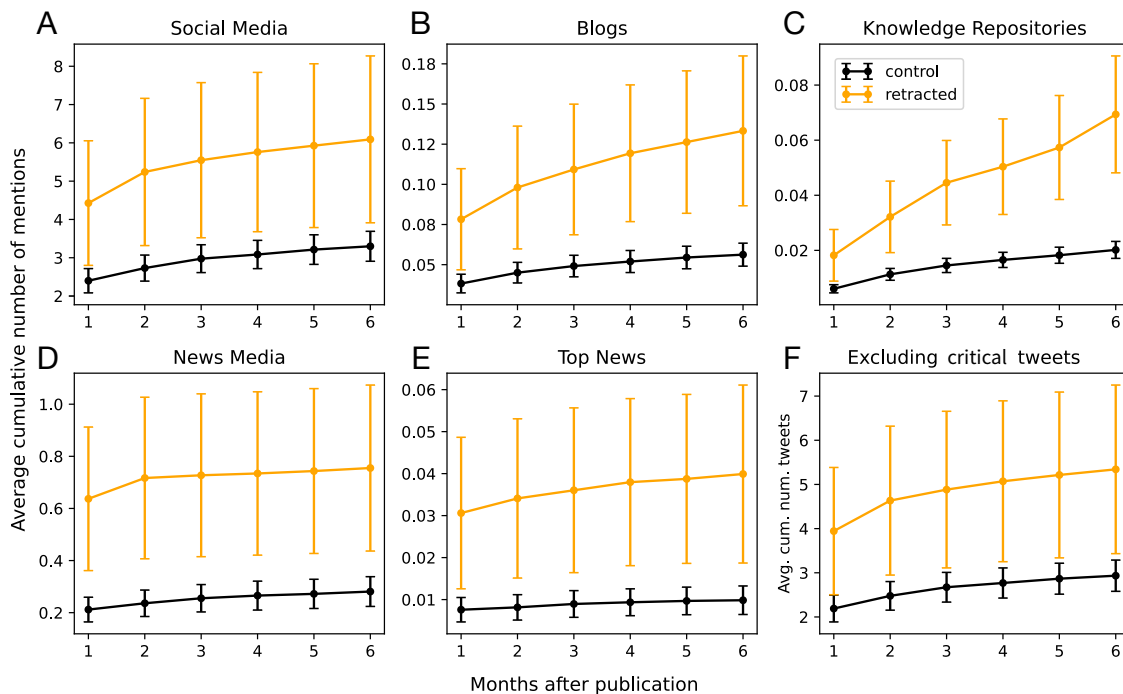


FIG. S13. Same as Fig. 2 in the main text, but after excluding 281 retracted papers (and their control papers) published in 9 multidisciplinary journals, including Nature, Science, PNAS, Nature Communications, Science Advances, Scientific Reports, PLoS One, Philosophical Transactions of the Royal Society A, and Proceedings of the Royal Society A. We compiled this list of general science journals as they are prominent journals classified as multidisciplinary in most journal classification systems [1]. Error bars indicate 95% confidence intervals.

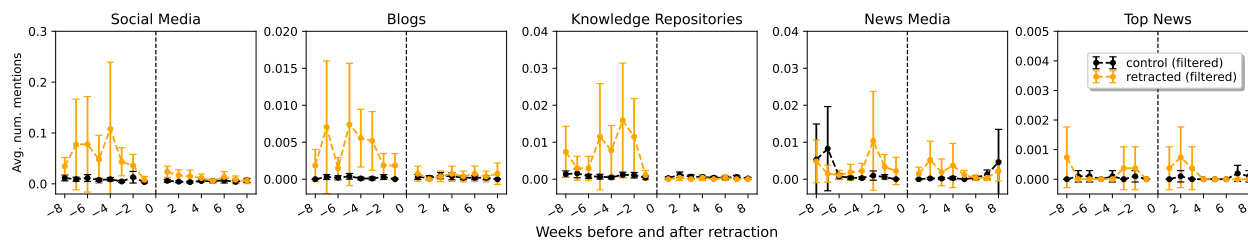


FIG. S14. Same as Fig. 4 in the main text, but after excluding 281 retracted papers and all their control papers published in 9 multidisciplinary journals. Error bars indicate 95% confidence intervals.

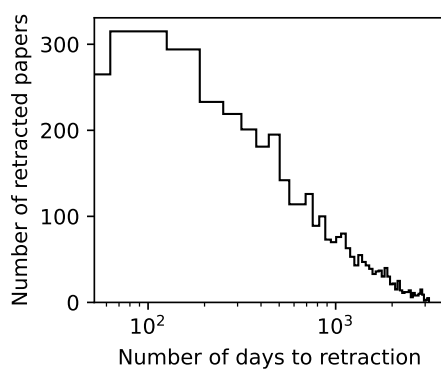


FIG. S15. The histogram of the number of days to retraction for all retracted papers used in our analysis. The median time to retraction is 480 days, and the average time to retraction is 698 days.

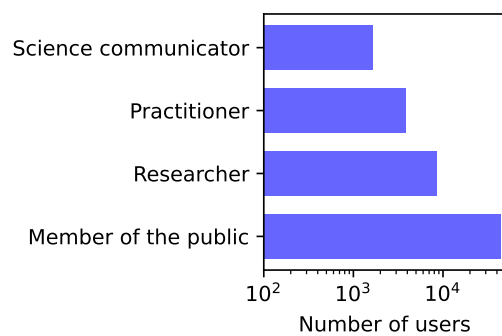


FIG. S16. Frequency of four types of users on Twitter who have mentioned retracted papers. The user classification is provided by in-house experts at Altmetric.

III. SI TABLES

Platform type	Time window	Retraction coeff.	Pub. year coeff.	Num. authors coeff.	Log citation coeff.
Social Media	1	0.583***	0.310***	0.039***	0.178***
Social Media	2	0.607***	0.309***	0.036***	0.178***
Social Media	3	0.583***	0.300***	0.032***	0.180***
Social Media	4	0.581***	0.297***	0.031***	0.177***
Social Media	5	0.572***	0.296***	0.032***	0.175***
Social Media	6	0.568***	0.295***	0.032***	0.171***
Blogs	1	0.735***	0.125***	0.050***	0.306***
Blogs	2	0.776***	0.121***	0.054***	0.287***
Blogs	3	0.803***	0.115***	0.052***	0.279***
Blogs	4	0.835***	0.120***	0.051***	0.269***
Blogs	5	0.840***	0.113***	0.051***	0.259***
Blogs	6	0.856***	0.110***	0.051***	0.253***
Knowledge Repositories	1	1.175***	-0.071	0.086***	0.215***
Knowledge Repositories	2	1.079***	-0.105***	0.081***	0.189***
Knowledge Repositories	3	1.066***	-0.118***	0.089***	0.169***
Knowledge Repositories	4	1.092***	-0.113***	0.095***	0.161***
Knowledge Repositories	5	1.127***	-0.117***	0.090***	0.159***
Knowledge Repositories	6	1.166***	-0.099***	0.085***	0.161***
News Media	1	1.002***	0.388***	0.050***	0.372***
News Media	2	0.988***	0.387***	0.050***	0.354***
News Media	3	0.930***	0.389***	0.048***	0.346***
News Media	4	0.904***	0.389***	0.046***	0.348***
News Media	5	0.896***	0.394***	0.045***	0.347***
News Media	6	0.875***	0.395***	0.046***	0.339***
Top News	1	1.469***	0.283***	0.027*	0.416***
Top News	2	1.497***	0.292***	0.030*	0.397***
Top News	3	1.458***	0.279***	0.029*	0.397***
Top News	4	1.463***	0.283***	0.025*	0.399***
Top News	5	1.452***	0.285***	0.022	0.400***
Top News	6	1.464***	0.282***	0.024*	0.398***

TABLE S1. Association between retraction and the number of mentions within a given number of months after publication. Models control for the publication year, number of authors, the most highly-cited author’s log citation count, and are set up to predict the number of mentions in each type of platform. Negative binomial regression coefficients indicate statistically significant correlations between retraction and the number of mentions. Each row corresponds to each combination of platform type and time window (in months). The coefficients reveal that, compared to control papers, retracted papers receive more mentions on knowledge repositories and top news than on social media and blogs. It also shows that the magnitude of association between retraction and mentions is relatively stable over time on social media, knowledge repositories, and in top news. However, this association is gradually decreasing on news media, indicating that retracted papers enjoy a surplus of popularity mostly in the initial stage of dissemination, and that they experience a faster attention decay on news media than control papers. In contrast, the attention gap between two groups of papers is increasing on blogs. Differences in temporal patterns on the investigated platforms may be related to different spreading mechanisms and platform audiences, which deserves further investigation in future work. Significance levels: *** $p < 0.001$, ** $p < 0.01$, and * $p < 0.05$.

Platform type	Mean value (retract vs. control)	P-value/T-test	P-value/U-test
Social Media	7.180 vs. 4.011	0.000	0.000
Blogs	0.160 vs. 0.073	0.000	0.004
Knowledge Repositories	0.088 vs. 0.029	0.000	0.000
News Media	0.845 vs. 0.335	0.000	0.673
Top News	0.046 vs. 0.012	0.000	0.000

TABLE S2. The average total number of mentions within 6 months after publication on each type of platform. The T-test for the means of two groups of papers shows that retracted papers receive a statistically higher average number of mentions than control papers. The U-test shows that the central tendency of the distribution of mention counts for retracted papers is larger than that of control papers, except for News Media.

Platform type	Time window	Retraction coeff.	Pub. year coeff.	Num. authors coeff.	Log citation coeff.
Twitter	1	0.546***	0.333***	0.038***	0.185***
Twitter	2	0.560***	0.333***	0.034***	0.185***
Twitter	3	0.542***	0.328***	0.032***	0.185***
Twitter	4	0.543***	0.324***	0.032***	0.181***
Twitter	5	0.536***	0.324***	0.032***	0.178***
Twitter	6	0.536***	0.322***	0.032***	0.176***

TABLE S3. Negative binomial regression coefficients for variables: retraction status, publication year, number of authors, and author’s log citations. The dependent variable is the number of mentions on Twitter (excluding critical tweets) within a given time window of publication. Significance levels: *** $p < 0.001$, ** $p < 0.01$, and * $p < 0.05$.

Platform type	Time window	Retraction coeff.	Pub. year coeff.	Num. authors coeff.	Log citation coeff.
Twitter	1	0.002**	0.000	0.000	0.000
Twitter	2	0.002**	0.000*	0.000	-0.000
Twitter	3	0.002**	0.000	0.000	-0.000
Twitter	4	0.002**	0.000	0.000	-0.000
Twitter	5	0.003***	0.000*	0.000	0.000
Twitter	6	0.004***	0.000**	0.000	-0.000

TABLE S4. Linear regression coefficients for the variables: retraction status, publication year, number of authors, and author’s log citations. The dependent variable is the fraction of critical tweets received after publication within a given time window. Significance levels: *** $p < 0.001$, ** $p < 0.01$, and * $p < 0.05$.

Platform type	Correlation coefficient	P-value
Social Media	0.031	0.30
Blogs	0.019	0.52
Knowledge Repositories	0.005	0.86
News Media	-0.004	0.91
Top News	0.002	0.95

TABLE S5. Pearson correlation coefficient between the fraction of critical tweets and the total number of mentions on each type of platform separately, received within 6 months after publication. This analysis focuses on retracted papers that have at least one tweet mention.

	Social Media	Blogs	Knowledge Repositories	News Media	Top News	Twitter
X1	-0.013***	-0.0001	0.0005	-0.000008	-0.000004	-0.0097***
X2	0.0013	-0.0032	-0.0093	-0.0015	0.0003	0.0044
X3	0.01*	0.00007	-0.0004	-0.0003	-0.00008	0.0077**
Intercept	0.1325***	0.005**	0.0057	0.0046*	0.0002	0.0959***

TABLE S6. Coefficients of the interrupted time series analysis [4] using the average weekly number of mentions on each type of platform for retracted papers (2 months before and 2 months after retraction). For all types of platforms, we excluded retraction-related posts after retraction, as well as posts containing the phrase “retract” throughout. For Twitter, we additionally excluded critical tweets before retraction. $X1$ represents the attention trend before retraction. It is negative and significant for Social Media (and Twitter), indicating that the attention is decreasing over time. $X3$ represents the difference between before- and after retraction slopes. It is positive and significant for Social Media (and Twitter), indicating that the attention volume is still decreasing, but the magnitude has decreased. $X2$ represents the change in attention immediately after retraction, which is not significant on any type of platform, suggesting that retraction has no immediate effect on attention change. Significance levels: *** $p < 0.001$, ** $p < 0.01$, and * $p < 0.05$.

Lol! What a conclusion. [url]
Darlings, another mediterranean diet study claiming lowfat, not lowfat that proves nothing. fat=30% [url] #vegan #dietitian
I can't believe I haven't seen anyone in my feed mentioning this grade. A bull shit [url]
Isn't osmium a tad toxic to be an antitumour agent? (I haven't read the paper yet...) - [url]
Religion and altruism correlated. How exactly is this current biology? [url]

TABLE S7. Five examples of ambiguous tweets in labelling critical tweets. Note that the content of each tweet has been paraphrased for anonymization.

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- [1] Katy Börner, Richard Klavans, Michael Patek, Angela M Zoss, Joseph R Biberstine, Robert P Light, Vincent Larivière, and Kevin W Boyack. Design and update of a classification system: The UCSD map of science. *PLoS ONE*, 7(7):e39464, 2012.
 - [2] Elsevier. All science journal classification codes. <http://bartoc.org/en/node/20290>, 2021.
 - [3] Mark Jurkowitz, Amy Mitchell, Elisa Shearer, and Mason Walker. Us media polarization and the 2020 election: A nation divided. *Pew Research Center*, 24, 2020.
 - [4] David McDowall, Richard McCleary, and Bradley J Bartos. *Interrupted time series analysis*. Oxford University Press, 2019.
 - [5] Harsh Taneja and Katie Yaeger. Do people consume the news they trust? In *CHI*, pages 1–10, 2019.
 - [6] Hongjing Zhao, Yu Wang, Juanjuan Liu, Yizhi Shao, Jinglun Li, Hongliang Chai, and Mingwei Xing. Retracted: Molecular characterization and biological activity of interferon- α in indian peafowl (*pavo cristatus*). *DNA and Cell Biology*, 2017.