Community water fluoridation online: an analysis of the digital media ecosystem

Mohammad Helmi, BDS[1,2]; Mary Kate Spinella[1]; Brittany Seymour, DDS, MPH[1]

1 Harvard School of Dental Medicine, Oral Health Policy and Epidemiology, Boston, MA, USA
2 King Saud University, College of Dentistry, Periodontics and Community Dentistry, Riyadh, Kingdom of Saudi Arabia

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Correspondence
Mohammad Helmi, Harvard School of Dental Medicine, Oral Health Policy and Epidemiology, 188 Longwood Ave., Boston, MA 02115. Tel.: 857 204 3966; Fax: 617 432 0047; e-mail: mohammad_helmi@hsdm.harvard.edu. Mary Kate Spinella and Brittany Seymour are with the Harvard School of Dental Medicine, Oral Health Policy and Epidemiology.

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Abstract

Objectives: Research demonstrates the safety and efficacy of community water fluoridation (CWF). Yet, the digitization of communication has triggered the spread of inaccurate information online. The purpose of this study was to analyze patterns of CWF information dissemination by a network of sources on the web.
Methods: We used Media Cloud, a searchable big data platform of over 550 million stories from 50 thousand sources, along with tools to analyze that archive. We generated a network of fluoridation publishers using Media Cloud's keyword identification from August 1, 2015 to July 31, 2016. We defined the media type and sentiment toward CWF for each source and generated a network map of the most influential sources during our study period based on hyperlinking activity.
Results: Media Cloud detected a total of 980 stories from 325 different sources related to water fluoridation. We identified nine different media types participating in the dissemination of information: academic, government, scientific group, natural medicine, blogs, mainstream media, advocacy groups, user-generated (e.g., YouTube), and "other." We detected five sub-networks within the overall fluoridation network map, each with its own characteristics. Twenty-one percent of sources were pro-fluoridation, receiving 57 percent of all inlinks, 22 percent of sources were anti-fluoridation, and the rest were neutral (54 percent).
Conclusions: The dominant neutral sentiment of the network may signify that anti- and pro-sides of the debate are viewed as balanced, not just in number but also in quality of information. Despite high inlinks to pro-sources, anti-fluoridation sentiment maintains influence online.

Introduction

Numerous studies have discussed the benefits of community water fluoridation (CWF) in safely and effectively preventing tooth decay; it is considered the most cost-effective strategy to prevent and control dental caries in large communities (1,2). In 2015, both The Cochrane Oral Health Group and US Public Health Service recognized the reductions in caries in children's permanent and primary teeth associated with CWF (3,4). However, some debate remains about the health risks of CWF. For example, in 2012, a systematic review and meta-analysis was published to assess developmental fluoride neurotoxicity (5). The authors suggested that exposure to "high" levels of fluoride may affect children's neurodevelopment. Reversely, a prospective study in New Zealand published in 2015 which was conducted to examine the possible correlation of CWF and intelligence, found that, after following up participants between 1972 and 2012, there was no significant association between fluoride exposure due to CWF and intelligence quotient (IQ) (6). Some researchers maintain there is not enough evidence to conclude that fluoride in drinking water may impair IQ (7).

Yet, the digitization of mass media communications has led to the far-reaching spread of unrestricted and inaccurate fluoridation information across the web through media and social networks (8). For example, based on the 2012 Choi et al. article (5), an article was released in 2014 by one of the coauthors. According to their review, the authors listed fluoride as one of six newly identified developmental toxins in

children (9). Several limitations in this article were addressed by the scientific community (10,11); however, its publication immediately triggered adverse coverage for fluoridation in the popular press, generating tens of thousands of views and shares over social media within 48 hours of publication, disseminating flawed messages about fluoridation (12). The safety and benefits of CWF continue to be debated online, with reference to the 2014 publication, despite robust scientific evidence that CWF is safe, protective, and effective (1-4). Recently, a new study was published, once again claiming a link between fluoride exposure, this time in utero, and lowered IQ (13); despite the author's statements acknowledging a number of limitations in the study and that additional research is needed, we are already beginning to see the debate rehashed on the Internet.

Moreover, previous work found that 88 to 100 percent of CWF groups and pages on *Facebook*, 64 percent of CWF tweets on *Twitter*, and 99 percent of CWF videos on *YouTube* disseminated anti-fluoridation messages (14). In 2012, it was estimated that 72 to 90 percent of adults Internet users sought health information online (15). In 2015, findings published by The Pew Research Center showed that 97 percent of 18- to 29-year-old, 95 percent of 30- to 49-year-old, 82 percent of 50- to 64-year-old, and 63 percent of 65+ year-old adults were using the Internet in the United States (16). News sites, *Facebook*, *YouTube*, and blogs are viewed as the "most trustworthy" sources for information, and all have a strong influence over purchasing decisions (17). Emerging data suggest that these Internet users also utilize social media sites to obtain health information (18).

Multiple studies found that a considerable amount of false health information is spreading on the Internet (8,19-21). So concerning is the issue that the US Departments of Labor, Health and Human Services, and Education Senate Appropriations Bill 2015 subcommittee draft report stated, "the Committee is concerned about conflicting information in the media regarding the benefits of community fluoridation" (22). Expert reports on the matter, including those recently released by the US Community Preventive Services Task Force (23) and the US Public Health Service (4) support CWF, citing decisive evidence that it prevents dental caries among both children and adults. Furthermore, the US Department of Health and Human Services' new recommendations for the optimal fluoride level in drinking water (24) have been repeatedly misinterpreted and misreported by number of news outlets and media publications.

The purpose of this study was to assess and describe the patterns of information dissemination about CWF by a network of sources on the World Wide Web during a specific time period in order to better understand how information, and misinformation, spreads. Utilizing new tools and big data application approaches developed by our research team members, we built a comprehensive database of fluoridation publishers, their media networks, and descriptive network characteristics from the open web. While previous studies evaluated social media platforms (14,17,20,21), to our knowledge, this study is the first of its kind to describe publishing patterns and content regarding CWF from the open web, allowing us to begin to build a comprehensive online media network of publishers who share information about CWF.

Methods

This study design is based on distinct fields of network science and behavioral economics (25). To analyze the content of the online media ecosystem for CWF, we used Media Cloud (26), a searchable, open access, big data platform of over 550 million stories from 50 thousand media sources, and growing, along with tools to analyze the platform. Researchers add new sources daily to the platform. A source is defined as an online publishing entity under the editorial control of an institution (e.g., mainstream media outlet such as the New York Times) which includes at least one story at the time we conducted the fluoridation query using Media Cloud. Media Cloud is a collaborative project of the Berkman Klein Center for Internet & Society at Harvard University and the Center for Civic Media at MIT. It was launched in 2009 and has been used in developing previously published studies to determine the influence of online publishing on public opinions and attitudes (27). More detailed information about the platform itself can be found on the Media Cloud project website mediacloud.org. Using Media Cloud, we identified the sources that published about fluoridation during our study period, then coded them for source type, sentiment, and hyperlink degree centrality for all sources. We lastly generated a visual network map of the most influential sources in the set, based on hyperlinking activity. The Office of Human Research Administration, Harvard Faculty of Medicine, approved the study as Not Human Subjects Research [45 CFR 46.102(f)], Protocol # IRB16–1090.

Source identification

We conducted keyword identification with Media Cloud (searching for keyword stem [[:<:]] "fluori," which means include any word that begins with "fluori") in any story published online. We included all stories that had been detected by Media Cloud from any source in the archive from August 1, 2015 to July 31, 2016. For each fluoridation story discovered by Media Cloud, we downloaded the HTML for that story. Using the automated feature in Media Cloud, we eliminated advertisement, navigational, and other content on the webpage so that only substantive text related to the story remained. We supplemented this initial set of stories and sources by downloading each additional link found in every story and adding to the set any more stories and sources that

included the stem "fluori" not yet included in our data set. We repeated this iterative "spidering" process until very few to no new stories had been found and we determined we had reached saturation. These stories were then used to identify all sources that had published them.

Source type

Media Cloud is programmed to sort sources based on the type of media (mainstream, government, blog, etc.). If media types were not categorized by Media Cloud, two independent members of the research team categorized them based on the nature of the specific website by reviewing the website's content and "about" page. Consensus agreement for all source types by the three study members was achieved.

Sentiment

Fluoridation sentiment (point of view/attitude) was determined in a manner similar to previous studies about vaccine hesitancy (28). It was coded by the same two independent research members followed by consensus coding of any disagreements by all three members. For each source, sentiment scores were coded 0, 1, or 2 based on whether the website was a CWF opponent ("anti-fluoridation") that is contradictory to scientific agreement regarding the safety and cost-effective benefits of CWF, a CWF supporter ("pro-fluoridation") that is coherent with scientific evidence and promoting the safety and cost-effective benefits of CWF, or neutral websites that did not have a distinct attitude or advocacy toward or against CWF, respectively.

Hyperlink degree centrality

Hyperlink degree centrality is a characteristic in the field of network science defined as measure of online influence based on online connectivity (number/count of inlinks) to a given source from other sources in the network (29), which means, how many other web pages contain links connecting to that specific source. The more links, the more influential a source may be within a network. This characteristic was recorded based on the number of inlinks during the specific time period of our study. Although linking behavior does not necessarily mean agreement, it has been found to indicate an influence on behaviors (30). Hyperlink degree centrality is explained further in Figure 1.

Media network mapping

We then generated a network map of fluoridation publishers, for optimal visualization, limited to the most influential 235 sources (out of the total 325 sources) that published about fluoridation during our study period. Five distinct subnetworks were generated within the overall fluoridation network using the Louvain community detection algorithm (31). We explored generating fewer than five and more than five communities, and found that five communities provided enough data to optimally detect differences between the communities and contribute to meaningful results; fewer than five did not distinguish enough differences that were otherwise detectable and more than five diluted the results into too many similar communities. The layout of the map was made using the graphviz neato algorithm and colored each source (node) based on its Louvain community. We analyzed the network characteristics of this fluoridation media map. [Note: This is the standard methodology for using Media Cloud-to date, over 175 research queries have been conducted using this approach (26)].

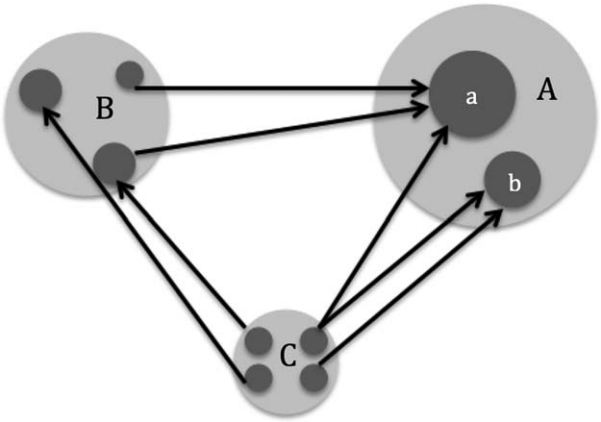

Figure 1 This example network map visually illustrates online information sources and their hyperlink degree centrality for source A, source B, and source C. Each dark gray story node (circle) within the light gray area (source node) is a story published online by that source, and each line from one story node to another is an edge, otherwise known as a hyperlink or inlink. Source A has two stories; "a" and "b." Story "a" has three inlinks (three other stories by other sources are linking to it) and story "b" has two inlinks (two other stories by other sources are linking to it). For source A, the total number of inlinks is five. Source B has a total of two inlinks (because two other stories from a different source are linking to stories within B) and Source C has zero inlinks (because no stories from other sources are linking to its stories). Hence, source A has highest hyperlink degree centrality (bigger nodes) compared to sources B (smaller nodes) and C (smallest nodes). Note the different nodes' sizes for different degree centrality.

Results

The Media Cloud query detected a total of 980 stories from 325 different sources related to CWF during our study period. Nine different media types participating in the dissemination of information were identified; Table 1 shows the nine different types with their sentiment toward CWF listed based on their frequencies. Eleven sources were coded as missing due to expired or broken links (seven sources), because they were foreign language sources that we could not

Table 1 Descriptive Characteristics of Study Sample ($N = 325$)

Variable	Pro-fluoride	Anti-fluoride	Neutral	Missing	Total
Media type	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Mainstream media	0 (0%)	20 (14%)	122 (85.3%)	1 (0.7%)	143 (44%)
Advocacy group	15 (30%)	22 (44%)	13 (26%)	0 (0%)	50 (15.3%)
Blog	5 (14.7%)	12 (35.3%)	16 (47%)	1 (2.9%)	34 (10.4%)
Scientific group	21 (77.8%)	1 (3.7%)	4 (14.8%)	1 (3.7%)	27 (8.3%)
Government	20 (80%)	0 (0%)	4 (16%)	1 (4%)	25 (7.7%)
Other	2 (12.5%)	3 (18.7%)	10 (62.5%)	1 (6.2%)	16 (4.9%)
User generated	1 (7.7%)	5 (38.4%)	4 (30.8%)	3 (23.1%)	13 (4%)
Natural	0 (0%)	8 (100%)	0 (0%)	0 (0%)	8 (2.4%)
Academic	4 (66.7%)	0 (0%)	2 (33.3%)	0 (0%)	6 (1.8%)
Not typed	0 (0%)	0 (0%)	0 (0%)	3 (100%)	3 (0.9%)
Total	68 (20.9%)	71 (21.8%)	175 (53.8%)	11 (3.4%)	325 (100%)

"Mainstream Media" is defined as general, regional, and local news websites as well as general information and life advice. "Advocacy Group" is defined as sources for organizations or collaborations that were advocating for a specific cause or project. "Blog" is defined as an individual blog not under the editorial authority of a media outlet, any blogs that is under an editorial authority were categorized under the source type of that authority (e.g., American Dental Association, Academic, etc.). "Scientific" is defined as sources of recognized scientific associations or peer-reviewed content. "Government" is defined as websites that are established, monitored, or directed by government authorities. "User Generated" is defined as websites that give their users ability to create their own content, such as YouTube, Twitter, Facebook, and Wikipedia. "Natural" is defined as sources that are interested in promoting natural and green medicine and health. "Academic Group" is defined as academic institutes, academic press, or websites directly sponsored or administered by academic institutes. "Other" category is defined as any remaining websites that could not be categorized into the eight previous types, such as business corporates, or amazon.com. Sources that are missing had broken links, even though they showed up in the query, and thus could not be evaluated further.

translate (one source), or they were duplicates of the same link in different languages (three sources).

"Mainstream Media" was defined as general, regional, and local news websites as well as general information and lifestyle advice pieces. "Advocacy Group" was defined as sources for organizations or collaborations that were advocating for a specific cause or project. "Blog" was defined as an individual blog not under the editorial authority of a media outlet; any blog that was under an editorial authority was categorized under the source type of that authority [e.g., American Dental Association (ADA) was source typed as advocacy, etc.]. "Scientific" was defined as sources of recognized scientific associations or peer-reviewed content. This category contains sources that follow a scientific methodology of conduct even if the source is related to an advocacy group [e.g., Journal of American Dental Association (JADA) is a scientific source but ADA is an advocacy source]. "Government" was defined as websites that are established, monitored, or directed by government authorities. "User Generated" was defined as websites that give their users ability to create their own content, such as *YouTube*, *Twitter*, *Facebook*, and *Wikipedia*. "Natural" was defined as sources that are interested in promoting natural and "green" medicine and health. "Academic Group" was defined as academic institutes, academic press, or any type of website directly sponsored or administered by academic institutions. Finally, the "Other" category was defined as any remaining websites that could not be categorized into the eight previous types, such as business corporations, or *amazon.com*.

It is worth noting that Natural sources category was the only category with 100 percent anti-fluoridation sentiment; however, there were only eight sources that satisfied this category. Moreover, among all anti-fluoridation sources, Natural sources composed only 11.3 percent while Advocacy Group and Mainstream Media composed 31 percent and 28.1 percent, respectively.

Based on hyperlink degree centrality (number of inlinks), the first two highest ranked sources were *cdc.gov* and *ncbi.nlm.nih.gov*, both of which are Government sources. Although the previously mentioned sources had the most inlinks, *fluoridealert.org* was ranked first based on the number of stories published. Table 2 shows the 10 sources with highest degree centrality, along with their media types, sentiments toward CWF, and the number of stories published by each during our study period. Overall during our study period, 21 percent of sources were pro-fluoridation ones, 22 percent of all sources were anti-fluoridation sources, and the rest were neutral (54 percent). Two of the five most inlinked sources (those with highest hyperlink degree centrality) in the network were anti-fluoridation groups (*fluoridealert.org* and *fluoridation.com*).

Our hyperlink degree centrality analysis generated a map of the 235 most inlinked sources within the network (Figure 2). A source with higher degree centrality (higher number of inlinks), thus has more online connectivity, is represented with a bigger node on the map compared to a source of lower degree centrality. This map illustrates five distinct sub-networks, described in Table 3. Sub-networks

Table 2 The 10 Sources with Highest Degree Centrality

Rank	Name	Media type	Sentiment	Stories	Degree centrality
1	cdc.gov	Government	Pro-fluoridation	49	100
2	ncbi.nlm.nih.gov	Government	Pro-fluoridation	64	82
3	ada.org	Advocacy	Pro-fluoridation	13	22
4	fluoridealert.org	Advocacy	Anti-fluoridation	113	21
5	fluoridation.com	Blog	Anti-fluoridation	18	21
6	bmj.com	Scientific	Pro-fluoridation	7	19
7	wiley.com	Scientific	Pro-fluoridation	12	17
8	Nature	Scientific	Pro-fluoridation	6	11
9	YouTube	User gen.	Anti-fluoridation	4	10
10	prweb.com	Mainstream	Neutral	2	10

Note: Stories represent the number of different pages discussing water fluoridation in that specific source. Degree centrality represents the number of stories of different sources that link to this specific source.

form when certain sources linked to one another more frequently than others in the network. As mentioned in our methodology, five sub-networks provided the richest data and most distinguishable differences between them without diluting the results by including too many sub-networks.

Each sub-network had a general theme or focus area related to CWF. The largest sub-network was the blue sub-network, which included 41 percent of sources from the whole sample, and was composed primarily of "US Government/US Advocacy" sources. 26.9 percent of sources in the blue sub-network were anti-fluoridation, slightly higher than pro-fluoridation sources (22.6 percent). It also contained the highest inlinked sources based on their hyperlink degree centrality scores for both pro-fluoridation (*cdc.gov* and *ncbi.nlm.nih.gov*) and anti-fluoridation (*fluoridealert.org*) websites. Numbers of inlinks for these sources presented in Table 3 under Degree Centrality column.

Sixty-two sources formed the red sub-network, primarily composed of "Scientific/Peer-reviewed" sources. Although only 17.5 percent of sources in the red sub-network were anti-fluoridation, compared to pro-fluoridation (52.6 percent), the source with highest degree centrality (the largest node) for this community was *fluoridation.com*, an anti-fluoridation blog. The second largest source nodes were the peer-reviewed scientific publishers *wiley.com* and *Nature*. The green community was primarily comprised of "UK/Australia Scientific/Mainstream Media" and represented about 20 percent of the overall network. Although Mainstream Media composed almost two-thirds of the green sub-network, *bmj.com* (Scientific Group source type) had the biggest node in online connectivity with highest degree centrality (number of inlinks = 17). Equal numbers of pro- and anti-fluoridation sources were detected within the green sub-network, with a prevalence of 21.3 percent of each. Even though the purple sub-network, comprised of "Conspiracy/Natural" sources (e.g., www.collective-evolution.com) was only 7.2 percent of the sample, 82.3 percent of its sources were anti-fluoridation. *Collective-evolution.com* (Advocacy Group source type) had the largest node (number of inlinks = 7) in the purple sub-network. This sub-network was composed almost entirely of Advocacy Group and Blog sources. Thirteen sources formed the yellow sub-network, containing mostly "US Local News" sources. Almost 85 percent of them were Mainstream Media, and these sources had more regional specific, locally directed content. 15.4 percent of this sub-network had anti-fluoridation sentiment (e.g., www.dallasnews.com). Tables 3 and 4 show more details and quantifications for the five major communities and comparison between sources' and inlinks' sentiments, respectively.

Discussion

Overall, degree centrality (number of inlinks) was highest for pro-fluoridation sources, primarily due to the high number of links to the Center of Disease Control and Prevention (CDC) and National Center for Biotechnology Information (NCBI). Sources with neutral sentiment were the most prevalent in our sample, and anti- and pro-sources were similar in number. The dominant neutral sentiment of the network, particularly mainstream media, may signify a view that anti- and pro-sides of the debate are balanced, not just in number but in quality of information. Linking behavior to anti-fluoridation sources based on these sources' hyperlink degree centrality (about 22 percent of all inlinks), may indicate a level of influence, despite the greater number of inlinks directed to pro-fluoridation sources overall (about 57.4 percent of all inlinks) in the information network. Additionally, the detection of sub-networks within the larger fluoridation information network indicates a kind of "social networking" behavior among publishers of fluoridation information, where like-minded sources link to each other more frequently. These findings begin to portray a division between two forms of communication occurring on the Internet: broadcast diffusion and social diffusion.

The first of these modes of information distribution is structured so that a single source broadcasts the same

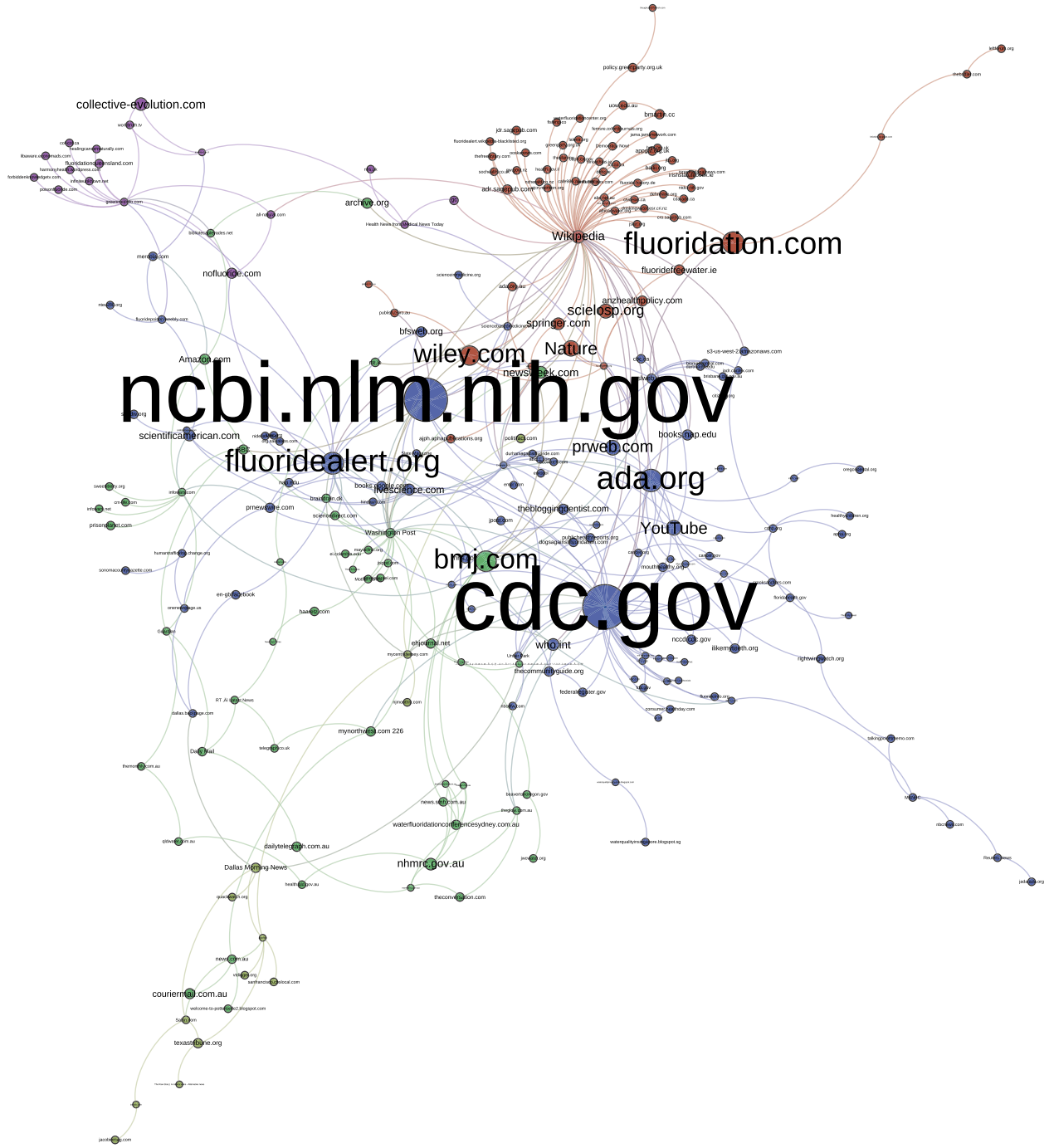

Figure 2 Network map of fluoridation publishers. Each circle/node represents a source and each edge/line represents a hyperlink connecting one source to another. The size of the node is based on the number of inlinks that specific source received from other sources in the network (story nodes are not included in this map, only source nodes). The higher the number of inlinks (links from other sources) a specific source received, the larger the node and subsequently the larger the contribution that source has within the network.

message to an entire audience, by publishing unchanging content on a webpage for example (32). When sources publish scientific evidence to their websites (a form of broadcast diffusion), others link directly to this information. However, the publication remains static, in one place within the network, so only those who link directly to the source are exposed to that information; this may become less likely if a source does not share the same sentiment. The latter mode of

Table 3 Communities Discussing CWF on the Internet (N= 235)

Community name (color)	Number of pro-fluoridation sources (%)	Number of anti-fluoridation sources (%)	Number of neutral sources (%)	Number of sources with missing sentiment* (%)	Sources with highest degree centrality based on inlinks	Total (%)
US government/US advocacy (blue)	21 (22.6%)	25 (26.9%)	47 (50.5%)	3 (3.1%)	CDC (100) NCBI (82) ADA (22)	96 (41%)
Scientific/Peer-reviewed (red)	30 (52.6%)	10 (17.5%)	17 (29.8%)	5 (8%)	fluoridealert.org (21) fluoridation.com (21) Wiley (17) Nature (11) Springer (6)	62 (26.3%)
UK/Australia scientific/Mainstream media (green)	10 (21.3%)	10 (21.3%)	27 (57.4%)	0 (0%)	BMJ (19) nhmrc.gov.au (6) Daily Mail (2)	47 (20%)
Conspiracy/Natural (purple)	2 (11.7%)	14 (82.35%)	1 (5.9%)	0 (0%)	collectiveevolution.com (7) no-fluoride.com (4) greenmedinfo.com (1)	17 (7.2%)
US local news (Yellow)	1 (7.7%)	2 (15.4%)	10 (76.9%)	0 (0%)	Dallas morning news (3) texastribune.org (3)	13 (5.5%)
Total	64 (27.2%)	61 (26%)	102 (43.4%)	8 (3.4%)		235 (100%)

Note: The five color-coded sub-networks of the fluoridation network map of sources that published about fluoridation online during our study period, and examples from each. Community names were derived based on their overall media types and information content. Different percentages of sentiments is due to different number of sources included in the analysis of the five major sub-communities (N = 235) compared to the total sample presented in Table 1 (N = 325).
*The link was broken and thus sentiment was not scored.

communication, more commonly known as viral diffusion, is structured so that an initial source publishes a story and then multiple additional nodes within the network continue to share and spread the story through new hyperlinks within their own stories (32). The sharing momentum of the network continues to expose new members of the network to the information through hyperlinking activity, a form of social networking. [We are choosing to use the term social diffusion in this case instead of viral diffusion, since most information cascades are short and shallow and very few actually go "viral" (32)].

The sentiment of sources and their linking behavior appeared, on the surface, contradictory at times. For example, through observation, some anti-fluoridation sources within the network linked to scientific information, from pro-fluoridation sources, to support their point of view, but distorted the information to fit their own narrative. *FluorideAlert.org* published a high amount of content that linked directly to multiple pro-fluoridation governmental and scientific sources; however, this website is dedicated to ending CWF. The site linked to single abstracts that could be framed to support an anti-fluoridation narrative for example, without acknowledging the limitations of the studies or how the results fit within the larger context of evidence for fluoridation. This selective linking behavior to specific sources created sub-networks, each with information "authorities" (such as *fluoridation.com*) that could be driving the overarching narratives and themes within their respective sub-networks. So, although a source links to a scientific abstract, the narrative the publisher creates around that link may

Table 4 Comparing Percentages and Numbers of Sources' and Inlinks' Sentiments for 235 Sources in the Five Major Sub-Communities

Community name	Color	Links to pro-fluoridation sources (%)	Links to anti-fluoridation sources (%)	Links to neutral sources (%)	Total number of inlinks (% of total)
US government/US Advocacy	Blue	241 (67%)	60 (16.6%)	55 (15.3%)	360 (56.3%)
Scientific/peer-reviewed	Red	86 (62%)	35 (25%)	15 (10.8%)	139 (21.7%)
UK/Australia scientific/Mainstream media	Green	36 (36.7%)	20 (20%)	42 (42.9%)	98 (15.3%)
Conspiracy/Natural	Purple	3 (11%)	23 (85%)	1 (3.7%)	27 (4.2%)
US local news	Yellow	1 (6.6%)	0 (0%)	14 (93.4%)	15 (2.3%)
Total		367 (57.4%)	138 (21.6%)	127 (19.9%)	639 (100%)

Note: Inlinks to missing sentiments (broken links) were not presented (1.1%).

change the entire meaning of the abstract. *BMJ* was the largest node in the green community, which means this source had the highest online connectivity among all green-colored sources. Further evaluation found that some sources within the green sub-network linked to a cluster of individual scientific publications by *BMJ* that could be framed to support anti-fluoridation narratives, particularly because study limitations were not included or any additional studies with different results. For example, one cross-sectional study shared in the green sub-network from *BMJ* suggested that CWF could be a risk factor for hypothyroidism (33); even though others concluded there were no adverse effects, they were not referred to in the narrative (34). This example demonstrates how some sources use anti-fluoridation scientific framing as their primary approach to talking about CWF without acknowledging the broader context of those individual studies within the larger body of research. This drives home the concern of "cherry picking" of individual studies to support an anti-fluoridation narrative online when those individual studies contradict the collective body of evidence. This may explain why even though the number of links to pro-fluoridation sources was so high, the anti-fluoridation narratives remain prevalent online. Further analysis is needed to quantify and describe this phenomenon more thoroughly, but it underscores a theory that scientific evidence alone is not enough to successfully disseminate information, thus social proof must be utilized and understood by the scientific community.

These findings begin to demonstrate a media information network in which scientific evidence is not as influential for some communities as "social proof," a phenomenon described by psychologists as a form of imitation where individuals mimic the behavior of others, often the majority, in order to resolve uncertainty (35). If an abstract is linked to within an anti-fluoridation story, a new source may echo the narrative in a follow-up story (e.g., blog) without linking to the original study but instead only to the anti-fluoridation story instead; like a game of Telephone, the original study's meaning and context is lost in translation, yet the study itself is used as proof of anti-fluoridation sentiment as it is shared from one source to another. In contrast to information that is consistent with scientific evidence, information echoed through some sub-networks was actually a form of social proof of anti-fluoridation sentiment, increasing its visibility within the overall network as it was shared with new audiences through new hyperlinks. Indeed, the prevalence of links to pro-fluoridation scientific publications within the sub-communities by anti-fluoridation sources showed that this mode of social diffusion was capable of incorporating scientific evidence within its own message of CWF skepticism. Again, this may to explain why anti-fluoridation sentiment persists even when the number of links to pro-fluoridation sources was so high.

This concept of social diffusion is also supported by the theory of self-determination, that humans are motivated by three psychological needs: the need to feel autonomous, competent, and related to others through connections (36). The empowering nature of social diffusion over broadcast messaging and the social proof forged by networked connections and shared sentiments meet these basic human needs. A possible result of this sort of diffusion could be seen in the significantly higher prevalence of anti-fluoridation views and advocacy on social media compared to scientific views consistent with the body of evidence for fluoridation (14).

Due to the novel nature of our study, limitations exist. Analysis of our data set via Media Cloud does not allow us to fully understand the connection behavior among and within all networks, which limits our comprehension of user-specific behaviors and beliefs. Another limitation is that the linking behavior does not necessarily reflect influence by other definitions of connectivity and influence measurements, such as betweenness centrality, another network characteristic that we did not measure in this study. Betweenness Centrality measures the amount of influence a specific source could have by the source's ability to create new connections and communities. Additionally, our study sample was collected over a single snapshot of time by collecting all sources that discussed CWF in one year; a more extensive analysis would be more informative for future study over longer periods of time and a larger number of sources. Moreover, we could have underestimated the true prevalence of anti-fluoridation content online due to the nature of neutral websites that can contain info about anti-fluoridation but not advocating for it.

Conclusion

Our results suggest that a considerable amount of CWF misconception is spreading on the Internet. Twenty-one percent of sources were pro-fluoridation, receiving 57 percent of all inlinks, 22 percent of sources were anti-fluoridation, and the rest were neutral (54 percent). The dominant neutral sentiment of the network may signify that anti- and pro-sides of the debate are viewed as balanced, not just in number but also in quality of information. Despite high inlinks to pro-sources, anti-fluoridation sentiment maintains influence online. Our findings reflect the challenges faced by the scientific community, especially dental public health professionals, in diffusing evidence-based online awareness and support for fluoridation. Indeed, the behavior of using reputable scientific sources by anti-fluoridation media reflects the eagerness of anti-fluoridation advocates to use these channels to diffuse and support their arguments, without proper context.

Our study highlights the network-dependent social proof of information dissemination that frequently discounts scientific evidence. Users accessing anti-fluoridation sources can experience confirmation biases that exist within these

networks and are strengthened via linking behavior. One source shares a study (minus context or limitations) that backs their views, then another shares it but drops the link to the original study, and the linking momentum propagates the sentiment while the science is lost in the process. Recognizing the role of "social proof" will help public health professionals to generate "shareable" messages and successfully *spread* evidence-based information using network linking and sharing by appealing to different online communities, rather than merely displaying scientific facts statically on a page. Additional analysis of the role of individual stories through the creation of visualization maps could prove useful in better understanding relationships among websites and within subnetworks; these maps allow to visualize the overall information ecosystem and how sources relate to one another, or not. Perhaps public health experts need to ask not only "How we can get our evidence-based information to our target audiences" but also "How can we get our audiences to *share* our evidence-based information."

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