



Short communication

Temporal trends in anti-vaccine discourse on Twitter

Keith Gunaratne^{a,1}, Eric A. Coomes^{b,*,1}, Hourmazd Haghbayan^{a,c,d}^a Department of Medicine, University of Toronto, Toronto, Ontario, Canada^b Division of Infectious Diseases, Department of Medicine, University of Toronto, Toronto, Ontario, Canada^c Division of Cardiology, London Health Sciences Centre, Western University, London, Ontario, Canada^d Department of Social and Preventive Medicine, Université Laval, Québec, QC, Canada

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ABSTRACT

Despite vaccination's role in preventing communicable diseases, misinformation threatens uptake. Social media may disseminate such anti-vaccination messages. We characterized trends in pro- and anti-vaccination discourse on Twitter. All tweets between 2010 and 2019 containing vaccine-related hashtags were identified. Pro- and anti-vaccine tweets and users per quarter (3-months) were tabulated; discussion subcommunities were identified with network analysis. 1,637,712 vaccine-related tweets were identified from 154 pro-vaccine and 125 anti-vaccine hashtags, with 86% of users posting exclusively pro-vaccine and 12% posting exclusively anti-vaccine hashtags. Pro-vaccine tweet volumes are larger than anti-vaccine tweets and consistently increase over time. In contrast, anti-vaccine tweet volumes have decreased since 2014, despite an increasing anti-vaccine user-base. Users infrequently responded across pro/anti-vaccine alignment (0.2%). Despite greater volumes of pro-vaccination discourse in recent years, and the anti-vaccination content userbase being smaller, the anti-vaccine community continues to grow in size. This finding coupled with the minimal inter-communication between communities suggests possible ideological isolation.

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1. Introduction

Despite the crucial role of vaccination for the prevention of communicable disease, misinformation threatens to limit uptake [1,2]. Incited, in part, by discredited research linking the measles-mumps-rubella vaccine with autism, mistrust of vaccines propagates via the contemporary anti-vaccination movement [3], with resultant vaccine hesitancy prompting global declines in immunization [4]. The consequent resurgence of vaccine-preventable illnesses, such as the ongoing measles outbreak, has led the World Health Organization to name vaccine hesitancy as a leading global health threat in 2019 [1].

As the internet is increasingly used to identify and disseminate health information [5,6], growing interest has emerged in harnessing social media to promote public health [7,8]. Indeed, social media interventions communicating accurate information have been demonstrated to promote vaccine uptake [8]. However, direct communication between the producers and consumers of content

on social media may conversely also facilitate the spread of unvalidated misinformation, with the potential for mass dissemination across trusted peer networks [6,7,9]. Consequently, substantial concerns have been raised that social media may play a key role in disseminating anti-vaccination messages [6,7,9].

Previous studies have confirmed that anti-vaccine content figures prominently across social media platforms, with criticisms encompassing themes of safety, personal freedom, and pharmaceutical and medical skepticism [7,9]. As many as 41% of parents report exposure to anti-vaccination content on social media [2]. Further, individuals exposed to such content may be more likely to spread anti-vaccine messages, cyclically propagating misinformation [10]. In response to the effects of online anti-vaccine messaging, Dr. James Madara, the chief executive officer of the American Medical Association, formally published a public letter urging leading technology companies, including Twitter and Facebook, to ensure access to accurate information on the safety and efficacy of vaccinations [11].

Given this widespread concern regarding social media's role in propagating vaccine hesitancy, we sought to characterize the temporal trends in pro- and anti-vaccination discussion on Twitter, as reflected by hashtags, and to determine the extent of inter-communication between these communities.

* Corresponding author at: Department of Medicine, University of Toronto, Suite RFE 3-805, 200 Elizabeth Street, Toronto, Ontario M5G 2C4, Canada.

E-mail address: eric.coomes@mail.utoronto.ca (E.A. Coomes).

¹ Denotes co-first authorship, these authors contributed equally to this manuscript.

2. Methods

Twitter (<http://twitter.com>) was searched for all tweets containing the English-language index term “vaccine” between 01/01/2010 and 01/01/2019. A systematic programmatic search was employed to interrogate Twitter’s Advanced Search front-end on February 10, 2019 using a modified version of the Python script (<https://github.com/taspinar/twitterscraper>), identifying all existing tweets containing the search term “vaccine.” For each tweet, this script identified the author, unique identifier, text, timestamp, contained hashtags, and reply/re-tweet status.

Hashtags were extracted from all tweets containing the term “vaccine.” Hashtags present in >100 tweets were reviewed by two authors, with a third arbitrating conflicts: after excluding non-vaccine-relevant or ambiguous hashtags, the remaining vaccine-related hashtags were labelled as pro- (score = 1), or anti-vaccination (score = -1) by manual review of associated tweets. Example hashtags by category include: non-relevant (#coffee, #world), pro-vaccination (#vaccineswork, #vaccinessavelives), and anti-vaccination (#cdcwhistleblower, #vaxxed). No hashtags or tweets were specifically excluded because of non-English language.

Twitter.com was re-searched on March 3, 2019, via the Python script for all pro- and anti-vaccine hashtags to create a final dataset of vaccine-related tweets. To validate manual classification and identify subcommunities, Louvain community detection via NetworkX2.2 was employed to perform network analysis [12]. Hashtags were represented as nodes on an undirected graph. Each pair of hashtags that appeared in at least one message together was connected by a weighted edge, with the edge weight equal to the number of unique users that tweeted the pair of hashtags together. Hashtag importance was calculated using the Eigenvector centrality module (also via NetworkX2.2), a quantitative estimate of the influence of each hashtag node within the network [13]. In this model, connections to high-scoring nodes have a stronger influence on the score of an individual node than connections to low-scoring nodes.

The hashtag-scores (pro-vaccine hashtag = +1, anti-vaccine hashtag = -1) were arithmetically summed for all hashtags contained within each tweet or user profile to classify tweets and users as pro-vaccine (sum > 0), anti-vaccine (sum < 0), or ambiguous (sum = 0); ambiguous tweets were excluded. The number of pro and anti-vaccine tweets per quarter (3-months) were counted and linear regression was used to analyze temporal trends, with 95% confidence intervals generated using the Student’s *t*-distribution. Temporal trends in United States measles cases were plotted for comparison [14].

Proportions of users tweeting responses to other posts within the tweet database were tabulated, identifying responses to users with the same alignment (pro-vaccine to pro-vaccine/anti-vaccine to anti-vaccine) or opposite alignment (pro-vaccine to anti-vaccine or anti-vaccine to pro-vaccine). ‘Responses’ were defined as tweets that were posted using Twitter’s ‘Reply’ function.

Anaconda Python 3.6 (<https://anaconda.com>), NetworkX 2.2 (<https://networkx.github.io>), and Gephi 0.9.2 (<https://gephi.org/>) were used for data collection, analysis, and visualization.

3. Results

The index search identified 10,043,087 tweets with 3843 unique hashtags classified into non-vaccine-relevant (*n* = 3382), ambiguous (*n* = 164), pro-vaccine (*n* = 154) or anti-vaccine (*n* = 125) categories (Supplementary Appendix). A second search for all 279 pro- and anti-vaccine hashtags found 1,637,712 vaccine-related tweets.

Louvain clustering identified nine hashtag-communities (Fig. 1). Anti-vaccine hashtags largely coalesced into one community (119 hashtags; central hashtags: #cdcwhistleblower and #vaxxed) with a small remote secondary community regarding the Philippine dengue-vaccine scandal [15]. Pro-vaccine hashtags segregated into one dominant community (113 hashtags; central: #vaccineswork) and several closely-linked secondary communities including opposition to the Australian Vaccination-skeptics Network (six hashtags, central: #stopavn) [16] and multiple others focused on disease-prevention: influenza (24 hashtags; central: #fightflu), polio (four hashtags; central: #endpolio), hepatitis B (two hashtags; central: #nohep) and HIV (three hashtags; central: #hivvaccineawarenessday).

The most frequently used anti-vaccine hashtags were: #cdcwhistleblower (280,779 tweets), #vaxxed (123,382 tweets), #hearthiswell (44,426 tweets), #novax (32,424 tweets), and #cdfraud (21,750 tweets).

There were 291,747 unique users who posted vaccine-related tweets, of whom 250,798 (86%) tweeted exclusively pro-vaccine hashtags, 35,583 (12%) exclusively anti-vaccine hashtags, and 5366 (1.8%) a combination. The proportion of anti-vaccine users increased from 8.1% to 16% between 2015 and 2018 (Fig. 2, Panel A). While 13,895 users (4.8%) tweeted responses to others with the same alignment (pro- or anti-vaccine), only 676 (0.2%) responded to the opposite alignment.

Classification of individual tweets by their average hashtag scores demonstrated 1,048,672 (64%) pro-vaccine, 576,695 (35%) anti-vaccine, and 12,345 (0.8%) ambiguous tweets. There were 215 pro-vaccine tweets in the first quarter of 2010, increasing by 1,670 tweets/quarter (95%CI 1370–1970 tweets/quarter, $r^2 = 0.790$) reaching a peak of 73,200 tweets in the last quarter of 2018. A median of 906 anti-vaccine tweets/quarter (IQR 583–1108 tweets, maximum 6871 tweets) was observed until the third quarter of 2014, during which a surge of 57,845 tweets was observed; subsequently anti-vaccine-tagged tweets decreased by 2670 tweets/quarter (95%CI 1340–4000 tweets/quarter, $r^2 = 0.532$) (Fig. 2, Panel B). Increases in pro-vaccine tweets mirrored the growth of the pro-vaccine userbase, with noted seasonal surges. In contrast anti-vaccine tweet volumes declined despite a doubling in the anti-vaccine userbase over the past three years.

4. Discussion

This study systematically quantifies the temporal evolution of pro- and anti-vaccine discourse on Twitter from 2010 to 2019, a period marked by the resurgence of vaccine-preventable diseases, notably measles. Hashtag analysis demonstrates a progressive increase in the volume of pro-vaccination tweets and users over this nine-year period, with such content far more voluminous than anti-vaccination content overall. Further, seasonal patterns of pro-vaccination activity were observed, consistent with the relative centrality of hashtag clusters associated with influenza vaccination campaigns.

Conversely, while few anti-vaccination tweets were posted prior to 2014, a significant surge in anti-vaccine discussion occurred between 2015 and 2016. This period coincides with the 2014–2015 measles outbreak [17], the publication of *Vaccine Whistleblower* [18] – an anti-vaccine book, linked to #cdcwhistleblower, and the release of Andrew Wakefield’s anti-vaccine film *Vaxxed*, linked to #vaxxed [19]. While the resultant volumes of anti-vaccination tweets were not sustained, the anti-vaccination userbase has doubled since 2015. There is minimal intercommunication between communities, with only 0.2% of users engaging across networks. Previous investigation of Facebook identified similar segregation of users into pro- and anti-vaccine

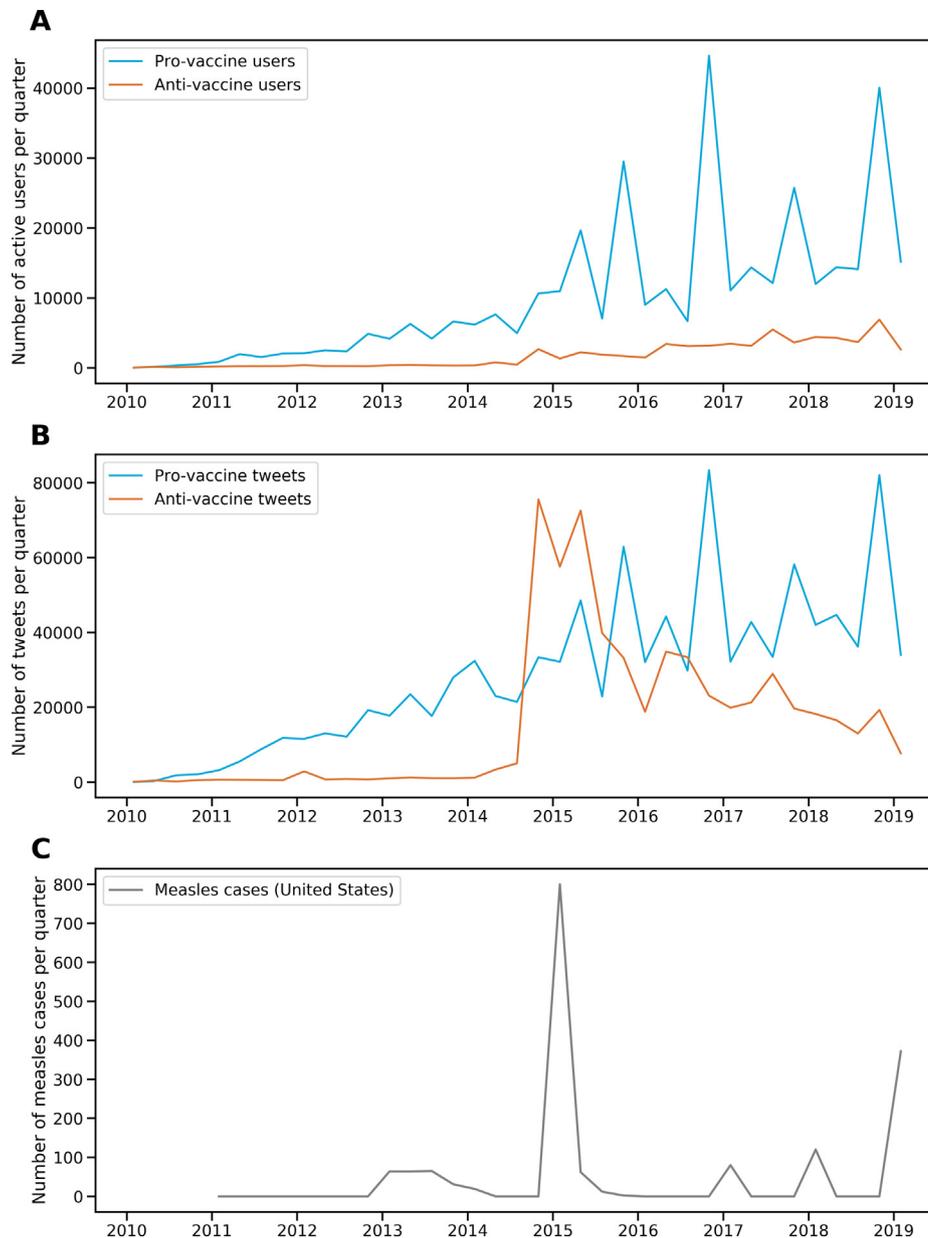


Fig. 2. Temporal trends in the volumes of vaccine-related users (A), tweets (B), and US Measles Cases (C). Legend: Temporal trends in individual users (A) and tweets (B) were classified by computing the numerical average of manually-labelled hashtag scores, with pro-vaccine tweets and users defined by score >0 and anti-vaccine tweets and users defined by score <0 . Ambiguous tweets and users were excluded from analysis. Number of tweets and active users in each category per quarter (3-month period) were counted. US Measles cases were taken from World Health Organization surveillance data (C) [14]. Seasonal patterns of pro-vaccination activity are observed, consistent with the relative centrality of hashtag clusters associated with seasonal vaccination campaigns.

6. Conclusion

This study characterizes the evolution of both pro- and anti-vaccine discourse on Twitter, revealing significant increases in the volume of pro-vaccination tweets coupled to decreases in anti-vaccine discourse since the latter reached a peak in 2014–2015. Despite the greater volumes of pro-vaccination discourse in recent years, and the userbase contributing anti-vaccination content being smaller, the anti-vaccine community continues to grow in size. This finding coupled with the minimal inter-communication between communities suggests possible ideological isolation. Further studies are needed to investigate how Twitter may be used to effectively disseminate accurate vaccine information and the real impact of such discourse on downstream vaccinations.

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Contributor statement

E.A.C and K.G. designed the study and extracted the data. K.G. analyzed the data. All authors wrote and edited the manuscript and reviewed it critically for important intellectual content.

Declaration of Competing Interest

The authors have no actual or potential conflict of interest to declare.

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.vaccine.2019.06.086>.

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