



J Med Internet Res. 2015 Jun; 17(6): e144.

PMCID: PMC4526932

Published online 2015 Jun 10. doi: [10.2196/jmir.4343](https://doi.org/10.2196/jmir.4343)

## Associations Between Exposure to and Expression of Negative Opinions About Human Papillomavirus Vaccines on Social Media: An Observational Study

Monitoring Editor: Gunther Eysenbach

Reviewed by Chupei Zhang and Rowena Briones

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### Abstract

#### Background

Groups and individuals that seek to negatively influence public opinion about the safety and value of vaccination are active in online and social media and may influence decision making within some communities.

#### Objective

We sought to measure whether exposure to negative opinions about human papillomavirus (HPV) vaccines in Twitter communities is associated with the subsequent expression of negative opinions by explicitly measuring potential information exposure over the social structure of Twitter communities.

#### Methods

We hypothesized that prior exposure to opinions rejecting the safety or value of HPV vaccines would be associated with an increased risk of posting similar opinions and tested this hypothesis by analyzing temporal sequences of messages posted on Twitter (tweets). The study design was a retrospective analysis of tweets related to HPV vaccines and the social connections between

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users. Between October 2013 and April 2014, we collected 83,551 English-language tweets that included terms related to HPV vaccines and the 957,865 social connections among 30,621 users posting or reposting the tweets. Tweets were classified as expressing negative or neutral/positive opinions using a machine learning classifier previously trained on a manually labeled sample.

## Results

During the 6-month period, 25.13% (20,994/83,551) of tweets were classified as negative; among the 30,621 users that tweeted about HPV vaccines, 9046 (29.54%) were exposed to a majority of negative tweets. The likelihood of a user posting a negative tweet after exposure to a majority of negative opinions was 37.78% (2780/7361) compared to 10.92% (1234/11,296) for users who were exposed to a majority of positive and neutral tweets corresponding to a relative risk of 3.46 (95% CI 3.25-3.67,  $P < .001$ ).

## Conclusions

The heterogeneous community structure on Twitter appears to skew the information to which users are exposed in relation to HPV vaccines. We found that among users that tweeted about HPV vaccines, those who were more often exposed to negative opinions were more likely to subsequently post negative opinions. Although this research may be useful for identifying individuals and groups currently at risk of disproportionate exposure to misinformation about HPV vaccines, there is a clear need for studies capable of determining the factors that affect the formation and adoption of beliefs about public health interventions.

**Keywords:** HPV vaccines, Twitter messaging, social media, public health surveillance, social networks

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## Introduction

In the last decade, vaccination refusal has increased in the United States and many countries have recorded substantial proportions of parents expressing concerns about the safety of vaccines [1,2]. Although variability in access to health care is an important factor influencing vaccine coverage rates, vaccination refusal also directly affects these rates and is a significant contributor to outbreaks—especially where vaccination refusal is geographically clustered and population immunity is compromised [3]. Outbreaks of pertussis and measles are known to spread through populations where rates of vaccination refusal are high [4-7].

Refusal has also been a problem for the recently introduced human papillomavirus (HPV) vaccine. The vaccine was first licensed for use in the United States in 2006 with the purpose of reducing the incidence of HPV, to which the majority of cervical cancers are attributed, as well as genital warts and some oral, anal, and penile cancers [8]. HPV vaccination in Australia has led to a marked reduction in rates of high-grade cervical abnormalities and early evidence of herd immunity [9-12]. However, uptake of HPV vaccines varies substantially across and within countries [13-16].

The introduction of HPV vaccination was hampered by controversy in some countries, where some parents attributed illness or death in their children to the vaccine despite evidence affirming the vaccine's good safety record [17]. The quality and variety of information available online about the safety and efficacy of HPV vaccines varies [18], as does the representation of HPV vaccines in the news media [19]. Evidence from a study set in Greece suggests

Vaccination policies and rates of exemption from immunization, 2005-2011. [N Engl J Med. 2012]

Target the fence-sitters. [Nature. 2011]

Nonmedical exemptions to school immunization requirements: secular trends and association of state policies wi [JAMA. 2006]

See more ...

**Review** Global burden of human papillomavirus and related diseases. [Vaccine. 2012]

Incidence of cervical lesions in Danish women before and after implementation of a national HP [Cancer Causes Control. 2014]

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**Review** Safety of human papillomavirus vaccines: a review. [Drug Saf. 2013]

Sorting through search results: a content analysis of HPV vaccine information online. [Vaccine. 2012]

Australian newspaper coverage of human papillomavirus vaccination, October 2006-December [J Health Commun. 2012]

Increasing fear of adverse effects drops intention to vaccinate after the introduction of prophylacti [Arch Gynecol Obstet. 2012]

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The use of Twitter to track levels of disease activity and public concern in the U.S. during the influenza A H1 [PLoS One. 2011]

OMG U got flu? Analysis of shared health messages for bio-surveillance. [J Biomed Semantics. 2011]

Pandemics in the age of Twitter: content analysis of Tweets during the 2009 H1N1 outbreak. [PLoS One. 2010]

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that the perception of risks in the community appears to have negatively influenced the intention to vaccinate [20]. More generally, there is some evidence to suggest that influence from online media and celebrities can increase vaccine risk perception and rates of vaccination refusal [21-23]. Given the importance of information sources in influencing vaccination decision making, social media platforms are seen as an opportunity for both the tracking and influencing of vaccination decision making [24].

Few studies have considered the surveillance of opinions about vaccination on social media as a precursor to vaccination decision making. Existing studies on public health surveillance applications in social media have focused primarily on finding early indicators of infectious diseases incidence [25-28]. The exceptions include examinations of responses to an influenza outbreak [29] and influenza vaccination [30]. Beyond social media, media surveillance systems have been built to track news media and other reports online [31,32]. One example considered negative sentiment in online news media and notes that systems that rely on manual classification of documents are prohibitively resource intensive [33].

Our aim was to examine the association between exposure to negative opinions about HPV vaccines and the expression of negative opinions about HPV vaccines among Twitter users. To do this, we examined sequences of messages posted on Twitter (tweets) as well as a static view of the social connections between every user that posted a tweet about HPV vaccines in a 6-month period.

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## Methods

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### Data

Tweets posted by public users were retrieved programmatically via the Application Programming Interface (API) using repeated searches of combinations of the terms human papillomavirus, HPV, vaccine, vaccination, Gardasil, and Cervarix, and labeled by Twitter as English language. These terms were fixed throughout the data collection period, which was from October 1, 2013 to April 1, 2014. We additionally collected metadata associated with the tweets, including the date and time, information about the user, related tweets such as retweets and replies, and the geo-tag (location) information if it was available. For each user who posted one or more tweets about HPV vaccines in the period, we separately used the API to retrieve the lists of users they followed and the users that followed them shortly after the first time they posted a tweet about HPV vaccines during the period.

Tweets were classified as negative if they rejected the safety or value of HPV vaccines or promoted refusal. Due to the very large number of tweets collected in the period, we used a supervised machine learning approach to classify the tweets that involved the manual labeling of a random sample of tweets, which were then used to train algorithms that recognized similar patterns in the remaining tweets. For each tweet, we determined an estimate of the likelihood of it being the expression of a negative opinion about HPV vaccines. The specific classifier we constructed was an ensemble of 4 classifiers that used the content of the tweets (the words and word combinations in the tweets themselves) or the social relations between users (the users followed by the user responsible for the tweet). A set of 2098 tweets were randomly sampled and then independently graded by 2 investigators (95% agreement, Cohen's  $\kappa=.87$ ), with disagreements resolved by discussion to produce the final training set. The accuracies of the 4 machine learning classifiers ranged between

87.6% and 94.0% when trained and tested in a 10-fold cross validation. The complete details of the development of the classifier are described elsewhere [34].

## Analyses

To analyze population-level information exposure, we measured how users may have been exposed to tweets about HPV vaccines during the 6-month observation period. For each user that tweeted at least once about HPV vaccines during the period, we created timelines of their own tweets about HPV vaccines and the tweets about HPV vaccines posted by the users they followed. For the purpose of measuring information exposure, we handled retweets in the same way as other tweets to conserve the definition for exposure. This means that we defined an exposure as the potential flow of information between users along social connections. Not all tweets are seen by all followers, but by observing the aggregate flow of exposures through network structure, it was possible to estimate how the heterogeneous mixing of the population might affect the information to which each user is exposed.

We determined the prior exposure of a user each time they posted a tweet about HPV vaccines during the time period by compiling the list of tweets to which they were potentially exposed prior to the timestamp of the index tweet. This proportion served as an indicator of the prior exposure to negative information about HPV vaccines in the time period. To account for a potential length sampling bias (later tweets tended to be preceded by a greater number of exposures), we limited the sequence-based analysis to tweets that were preceded by at least 3 exposures.

To test our hypothesis directly, we counted how many times a user posted a negative tweet following a majority of prior negative exposures and compared that count with the number of times a posted tweet was negative when the majority of prior exposures were neutral or positive. These counts were then used to calculate the relative risk of posting a negative tweet about HPV vaccines given majority prior exposure to negative tweets. To avoid sampling biases resulting from counting the same users repeatedly, we randomly sampled only 1 tweet from each eligible user and repeated the analysis until the median proportions and relative risk measures did not change value at 3 significant figures.

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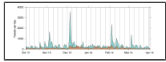
## Results

We identified 83,551 tweets or retweets from 30,621 users relating to HPV vaccines between the period October 1, 2013 to April 1, 2014, after eliminating tweets that were eventually deleted and tweets from users that became protected or suspended after the initial collection. Of the 83,551 tweets and retweets, 20,994 (25.13%) were classified as negative by an ensemble of supervised machine learning classifiers. [Table 1](#) includes some examples of the different classes of tweets. There were 10 days (5.5% of 183 days) in which the number of negative tweets outnumbered the number of positive and neutral tweets about HPV vaccines ([Figure 1](#)).



[Table 1](#)

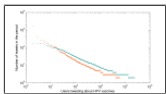
Examples of different classes of Twitter messages identified in the searches.



**Figure 1**

The number of tweets posted each day during the data collection period, including tweets rejecting the safety or value of HPV vaccines (orange) and all other HPV vaccine tweets (cyan). Gray vertical lines indicate Sundays. No corrections for time zone ...

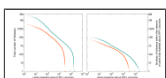
There were 30,621 users that tweeted about HPV vaccines in the period. Each user in the set posted between 1 and 1842 tweets about HPV vaccines during the period with a median of 2 tweets per user (IQR 1-2) ([Figure 2](#)). The distributions differed between users posting mostly negative tweets and users posting mostly neutral or positive tweets. Although there were more users posting neutral/positive tweets overall, the most prolific users during the time period were posting mostly negative opinions about HPV vaccines.



**Figure 2**

The ordered distribution of tweets per user related to HPV vaccines posted to Twitter between October 1, 2013 and March 31, 2014. Each user's number of tweets is represented by a dot and illustrated separately for users that posted a majority ...

We defined social connections as the sets of users that followed, or were followed by, the users that tweeted about HPV vaccines. The total number of unique followers for all users that tweeted about HPV vaccines in the 6-month period was 51,397,377. The total number of followers per user varied between 0 and 5,136,595 with a median of 274 followers per user (IQR 36-996) ([Figure 3](#), left). Considering only the connections between users that tweeted about HPV vaccines, 957,865 social connections were identified and this defined the internal network of social connections among the 30,621 users. Followers per user in this internal network varied from 0 to 10,945 with a median of 8 followers per user (IQR 2-33) ([Figure 3](#), right). Although news organizations and magazines made up the majority of users with the greatest number of followers overall, government health organizations and academic institutions or groups were more consistently featured among the set of users with the most followers in the internal network. Practitioners and writers (books and blogs) of specific forms of alternative medicine as well as antivaccine activists and celebrities did not feature among the set of users with the most followers overall, but occupied higher ranks when counting the number of followers in the internal network.



**Figure 3**

The ordered distribution of users according to the total follower counts (left) and follower counts within the network of 30,621 users (right). Each user is represented by a dot and colored by users that tweeted mostly negative tweets (orange) compared ...

Homophily and Contagion Are Generically Confounded in Observational Social Network Studi [Sociol Methods Res. 2011]

Assessing vaccination sentiments with online social media: implications for infectious disease dy [PLoS Comput Biol. 2011]

Homophily and Contagion Are Generically Confounded in Observational Social Network Studi [Sociol Methods Res. 2011]

The simple rules of social contagion.

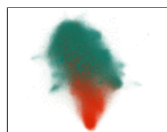
[Sci Rep. 2014]

Measuring vaccine confidence: analysis of data obtained by a media surveillance system used to ana [Lancet Infect Dis. 2013]

Risk messages about HPV, cervical cancer, and the HPV



Although only 25.13% (20,994/83,551) of tweets were classified as negative, 29.54% (9046/30,621) of users that tweeted about HPV vaccines appeared to be exposed more often to negative tweets than to neutral and positive tweets. This difference, and a visual interpretation of the network, suggests that users posting negative tweets about HPV vaccines were not evenly mixed in the network and often belonged to communities primarily consisting of users who also posted negative tweets about HPV vaccines ([Figure 4](#)).



**Figure 4**

The network of 30,621 users that tweeted about HPV vaccines during the period between October 2013 and April 2014 organized via heuristic so that users are closer to other users with whom they are connected. The sizes of the nodes are proportional to ...

Among the 30,621 users that tweeted about HPV vaccines, 18,657 users had timelines in which at least 1 tweet was posted after at least 3 exposures and were thus eligible for a temporal analysis of exposures and subsequent tweets. The likelihood of posting a negative tweet about HPV vaccines following a prior majority exposure to negative tweets was 37.78% (2780 of 7361 users). For users whose prior exposures were mostly neutral/positive, 10.92% (1234 of 11,296 users) subsequently posted a negative tweet. These results corresponded to a relative risk of 3.46 (95% CI 3.25-3.67,  $P < .001$ ) indicating that users with greater prior exposure to negative opinions about HPV vaccines were more likely to express negative opinions.

To further test the association between exposure and expression within different groups of users, we undertook a post hoc subgroup analysis. Among the set of users that met the inclusion criteria and also had fewer than 1000 followers ( $n=11,845$ ), we calculated the relative risk in the same way and found that the relative risk of posting a negative opinion about HPV vaccines after having been more often exposed to negative opinions about HPV vaccines was 3.61 (95% CI 3.32-3.93). For users with fewer than 500 followers ( $n=8790$ ), the relative risk was 3.57 (95% CI 3.23-3.95) and for users with fewer than 300 followers ( $n=6521$ ), the relative risk was 3.76 (95% CI 3.33-4.24). The results suggest that the association between previous exposure and subsequent expression was slightly stronger among Twitter users with fewer followers.

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## Discussion

### Principal Findings

Approximately one-quarter of the tweets about HPV vaccines that were posted in the period were critical of the safety or value of HPV vaccines or actively encouraged vaccine refusal. These tweets, which included misinformation, anecdotes, and opinions that may result in vaccine hesitancy or refusal, made up the majority of HPV vaccine-related information exposures for nearly 30% of users that tweeted about HPV vaccines in the period. Our analysis of the network of follower relationships suggests that users expressing negative opinions about HPV vaccines tended to be more closely connected to users

vaccine Gardasil: a content analysis of C [Women Health. 2009]

Parents with doubts about vaccines: which vaccines and reasons why. [Pediatrics. 2008]

Newsprint media representations of the introduction of the HPV vaccination programme for cervical cancer [Soc Sci Med. 2010]

Tracking parental attitudes on vaccination across European countries: The Vaccine Safety, Attitudes, Trainir [Vaccine. 2010]

Australian newspaper coverage of human papillomavirus vaccination, October 2006-December [J Health Commun. 2012]

**Review** An attempt to swindle nature: press anti-immunisation reportage 1993-1997. [Aust N Z J Public Health. 1998]

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expressing the same opinions. Our analysis of the sequences of HPV-related tweets demonstrated an association between prior exposure to negative tweets about HPV vaccines and the subsequent posting of negative tweets about HPV vaccines. Together, these results suggest that homophily or contagion may play a role in the expression of negative opinions about HPV vaccines, but the study does not help to quantify their specific contributions [35].

To the best of our knowledge, ours is the first empirical study to consider the association between information exposure and subsequent expression for vaccines on social media. Other studies have used supervised machine learning to automatically classify tweets about vaccination [30] and the frequency of tweets over time exhibits a similar temporal pattern to the one we observed. Other studies have used Twitter as a laboratory to measure the propagation of negative news content, complaints, and rumors [36-38]. Other studies that considered misinformation were specifically aimed at differentiating between credible and not credible information, the containment of misinformation, and the identification of misinformation sources [39-41].

It is important to note that the study design we used precluded conclusions about what proportions of negative opinions expressed in the period were the consequence of exposure (contagion of opinions), the consequence of users creating connections to other users who already hold similar opinions (homophily), or if other external factors caused connected users to express similar opinions [35]. Alternative study designs that measure or model contagion from observable or synthetic networks are common in other application domains and more generally in network science [42-46], including where connections between nodes change over time [47-49].

Other studies have considered the news and online media representation of vaccines in different ways. One study examining the representation of vaccines in the media identified a rate of negative opinions in media reports for vaccines generally of 31% [33], with similar percentages in a study of US and Canadian news articles about HPV vaccines [50]. In comparison, 29% of US parents have reported being unsure about the vaccines for their children or otherwise delayed or refused vaccinations [51]. In the United Kingdom, very few newspaper articles (including tabloids) were classified as negative [52], whereas 19% of parents in England responded that they would not vaccinate their children in the future [53]. An Australian study found that HPV safety concerns were present in 39% of newspaper articles between 2006 and 2009 [19]. A study examining news media in the mid-1990s found that a small number of individuals were responsible for nearly half of all the statements opposing vaccination [54]. We found a similar pattern on Twitter for HPV vaccines using data from nearly 20 years later—where a small number of individuals posting negative opinions on Twitter produced a substantial proportion of the negative opinions. Given that these proportions are much higher than the average rates of vaccination refusal recorded in registries at approximately 2% [55,56], more work is needed to understand how population-level indicators of negative opinions might relate to vaccination decision making.

## Implications

Implications of this work include new avenues for understanding how community affiliation on Twitter corresponds to the exposure to misinformation, the subsequent expression of opinions, and individual decision making. The simple methods we used here may be of practical value for answering questions about how new information becomes established in

different communities. For example, do the results of scientific studies demonstrating efficacy tend to spread primarily through scientific communities and not through communities of hesitant parents? Which popular news websites, influential users, or organizations are better connected to communities that are at higher risk of being exposed to, and subsequently affected by, misinformation? How often do young teenagers or their parents pass along negative opinions following encounters with misinformation or negative experiences with the vaccine process? Using new methods for classifying the location and characteristics of Twitter users [57,58], it may be possible to construct Twitter-derived indicators of skewed misinformation exposure in geographic areas and demographic strata, and these may be useful for predicting or reflecting localized shifts in decision making such as increases in refusal. From a practical perspective, this kind of information risk surveillance could be used to complement existing methods for gathering localized information (surveys, interviews, and registry analysis) and improve community engagement and public health actions by targeting resources more efficiently.

### Limitations

Limitations of this study come from our inability to track social connections as they appear and disappear during the period. Due to limits in the rates at which we access this information on Twitter, the social connections associated with each user were collected only once during the period, shortly after the first time we identified a relevant tweet by the user. However, by checking the consistency of connections between users within the set, we found that 81.6% of users' connections were confirmed by the information from the other user (eg, a user's follower is confirmed as someone the user follows), so we are reasonably confident that the connection structure was relatively consistent over time.

Our search terms were fixed and although we were careful to select search terms that covered the vast majority of the discussion about HPV vaccines without collecting irrelevant tweets, we may have missed a smaller number of tweets about the topic and these tweets may not have had the same proportion of negative opinions. Query-expansion techniques used to improve search strategies over time could be applied to address this limitation in future work [59-61]. Finally, we relied on an ensemble classifier rather than manual labeling, so a small proportion of the tweets will have been misclassified. However, the imperfections in the classifier are unlikely to have affected the results because the study was across large groups, our measure of exposure was based on counting the majority across a number of tweets rather than individual tweets, and the associations were clear.

### Conclusions

We found that Twitter users who were more often exposed to negative opinions about the safety and value of HPV vaccines were more likely to tweet negative opinions than users who were more often exposed to neutral or positive information. Although we were unable to determine the differential contributions of homophily, user characteristics, and contagion to this effect, the results provide a detailed view of negative opinions about HPV vaccines on Twitter in the period and indicate associations between the community structure, information exposure, and expression of negative opinions about vaccines among social media users. Ongoing surveillance of opinions about vaccination on social media may complement surveys and other public health surveillance methods to improve the efficiency and efficacy of public health



communication strategies.

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## Acknowledgments

The National Health and Medical Research Council (NHMRC) provided funding for the Centre for Research Excellence in eHealth. The NHMRC played no role in the review or approval of the manuscript.

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## Abbreviations

API Application Programming Interface

HPV human papillomavirus

IQR interquartile range

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## Footnotes

Conflicts of Interest:

Conflicts of Interest: None declared.

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## References

1. Omer SB, Richards JL, Ward M, Bednarczyk RA. Vaccination policies and rates of exemption from immunization, 2005-2011. *N Engl J Med*. 2012 Sep 20;367(12):1170–1. doi: 10.1056/NEJMc1209037. [[PubMed](#)] [[Cross Ref](#)]
2. Leask J. Target the fence-sitters. *Nature*. 2011 May 26;473(7348):443–5. doi: 10.1038/473443a. [[PubMed](#)] [[Cross Ref](#)]
3. Omer SB, Pan WY, Halsey NA, Stokley S, Moulton LH, Navar AM, Pierce M, Salmon DA. Nonmedical exemptions to school immunization requirements: secular trends and association of state policies with pertussis incidence. *JAMA*. 2006 Oct 11;296(14):1757–63. doi: 10.1001/jama.296.14.1757. [[PubMed](#)] [[Cross Ref](#)]
4. Sugerman DE, Barskey AE, Delea MG, Ortega-Sanchez IR, Bi D, Ralston KJ, Rota PA, Waters-Montijo K, LeBaron CW. Measles outbreak in a highly vaccinated population, San Diego, 2008: role of the intentionally undervaccinated. *Pediatrics*. 2010 Apr;125(4):747–55. doi: 10.1542/peds.2009-1653. <http://pediatrics.aappublications.org/cgi/pmidlookup?view=long&pmid=20308208>. [[PubMed](#)] [[Cross Ref](#)]
5. Parker AA, Staggs W, Dayan GH, Ortega-Sánchez IR, Rota PA, Lowe L, Boardman P, Teclaw R, Graves C, LeBaron CW. Implications of a 2005 measles outbreak in Indiana for sustained elimination of measles in the United States. *N Engl J Med*. 2006 Aug 3;355(5):447–55. doi: 10.1056/NEJMoa060775. [[PubMed](#)] [[Cross Ref](#)]
6. Najjar Z, Hope K, Clark P, Nguyen O, Rosewell A, Conaty S. Sustained outbreak of measles in New South Wales, 2012: risks for measles elimination in Australia. *Western Pac Surveill Response J*. 2014;5(1):14–20. doi: 10.5365/WPSAR.2013.4.4.002. <http://europepmc.org/abstract/MED/25635228>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]

7. Atwell JE, Van OJ, Zipprich J, Winter K, Harriman K, Salmon DA, Halsey NA, Omer SB. Nonmedical vaccine exemptions and pertussis in California, 2010. *Pediatrics*. 2013 Oct;132(4):624–30. doi: 10.1542/peds.2013-0878. <http://pediatrics.aappublications.org/cgi/lookup?view=long&pmid=24082000>. [PubMed] [Cross Ref]
8. Forman D, de Martel C, Lacey CJ, Soerjomataram I, Lortet-Tieulent J, Bruni L, Vignat J, Ferlay J, Bray F, Plummer M, Franceschi S. Global burden of human papillomavirus and related diseases. *Vaccine*. 2012 Nov 20;30 Suppl 5:F12–23. doi: 10.1016/j.vaccine.2012.07.055. [PubMed] [Cross Ref]
9. Baldur-Felskov B, Dehlendorff C, Junge J, Munk C, Kjaer SK. Incidence of cervical lesions in Danish women before and after implementation of a national HPV vaccination program. *Cancer Causes Control*. 2014 Jul;25(7):915–22. doi: 10.1007/s10552-014-0392-4. [PubMed] [Cross Ref]
10. Gertig DM, Brotherton JML, Budd AC, Drennan K, Chappell G, Saville AM. Impact of a population-based HPV vaccination program on cervical abnormalities: a data linkage study. *BMC Med*. 2013;11:227. doi: 10.1186/1741-7015-11-227. <http://www.biomedcentral.com/1741-7015/11/227>. [PMC free article] [PubMed] [Cross Ref]
11. Tabrizi SN, Brotherton JML, Kaldor JM, Skinner SR, Liu B, Bateson D, McNamee K, Garefalakis M, Phillips S, Cummins E, Malloy M, Garland SM. Assessment of herd immunity and cross-protection after a human papillomavirus vaccination programme in Australia: a repeat cross-sectional study. *Lancet Infect Dis*. 2014 Oct;14(10):958–66. doi: 10.1016/S1473-3099(14)70841-2. [PubMed] [Cross Ref]
12. Niccolai LM, Julian PJ, Meek JI, McBride V, Hadler JL, Sosa LE. Declining rates of high-grade cervical lesions in young women in Connecticut, 2008–2011. *Cancer Epidemiol Biomarkers Prev*. 2013 Aug;22(8):1446–50. doi: 10.1158/1055-9965.EPI-13-0272. <http://cebp.aacrjournals.org/cgi/lookup?view=long&pmid=23704476>. [PubMed] [Cross Ref]
13. Brotherton JML, Liu B, Donovan B, Kaldor JM, Saville M. Human papillomavirus (HPV) vaccination coverage in young Australian women is higher than previously estimated: independent estimates from a nationally representative mobile phone survey. *Vaccine*. 2014 Jan 23;32(5):592–7. doi: 10.1016/j.vaccine.2013.11.075. [PubMed] [Cross Ref]
14. Tsui J, Rodriguez HP, Gee GC, Escobedo LA, Kominski GF, Bastani R. Are HPV vaccination services accessible to high-risk communities? A spatial analysis of HPV-associated cancer and Chlamydia rates and safety-net clinics. *Cancer Causes Control*. 2013 Dec;24(12):2089–98. doi: 10.1007/s10552-013-0286-x. <http://europepmc.org/abstract/MED/24043448>. [PMC free article] [PubMed] [Cross Ref]
15. Fisher H, Trotter CL, Audrey S, MacDonald-Wallis K, Hickman M. Inequalities in the uptake of human papillomavirus vaccination: a systematic review and meta-analysis. *Int J Epidemiol*. 2013 Jun;42(3):896–908. doi: 10.1093/ije/dyt049. <http://ije.oxfordjournals.org/cgi/lookup?view=long&pmid=23620381>. [PMC free article] [PubMed] [Cross Ref]
16. Gertig DM, Brotherton JML, Saville M. Measuring human papillomavirus (HPV) vaccination coverage and the role of the National HPV Vaccination Program Register, Australia. *Sex Health*. 2011 Jun;8(2):171–8. doi: 10.1071/SH10001. [PubMed] [Cross Ref]

17. Macartney KK, Chiu C, Georgousakis M, Brotherton JML. Safety of human papillomavirus vaccines: a review. *Drug Saf.* 2013 Jun;36(6):393–412. doi: 10.1007/s40264-013-0039-5. [[PubMed](#)] [[Cross Ref](#)]
18. Madden K, Nan X, Briones R, Waks L. Sorting through search results: a content analysis of HPV vaccine information online. *Vaccine.* 2012 May 28;30(25):3741–6. doi: 10.1016/j.vaccine.2011.10.025. [[PubMed](#)] [[Cross Ref](#)]
19. Robbins Spring Chenoa Cooper. Pang C, Leask J. Australian newspaper coverage of human papillomavirus vaccination, October 2006-December 2009. *J Health Commun.* 2012;17(2):149–59. doi: 10.1080/10810730.2011.585700. [[PubMed](#)] [[Cross Ref](#)]
20. Sotiriadis A, Dagklis T, Siamanta V, Chatzigeorgiou K, Agorastos T. Increasing fear of adverse effects drops intention to vaccinate after the introduction of prophylactic HPV vaccine. *Arch Gynecol Obstet.* 2012 Jun;285(6):1719–24. doi: 10.1007/s00404-011-2208-z. [[PubMed](#)] [[Cross Ref](#)]
21. Hoffman SJ, Tan C. Following celebrities' medical advice: meta-narrative analysis. *BMJ.* 2013 Dec 17;347:f7151. doi: 10.1136/bmj.f7151. [[Cross Ref](#)]
22. Mason BW, Donnelly PD. Impact of a local newspaper campaign on the uptake of the measles mumps and rubella vaccine. *J Epidemiol Community Health.* 2000 Jun;54(6):473–4. <http://jech.bmj.com/cgi/pmidlookup?view=long&pmid=10818125>. [[PMC free article](#)] [[PubMed](#)]
23. Betsch C, Renkewitz F, Betsch T, Ulshöfer C. The influence of vaccine-critical websites on perceiving vaccination risks. *J Health Psychol.* 2010 Apr;15(3):446–55. doi: 10.1177/1359105309353647. [[PubMed](#)] [[Cross Ref](#)]
24. Betsch C, Brewer NT, Brocard P, Davies P, Gaissmaier W, Haase N, Leask J, Renkewitz F, Renner B, Reyna VF, Rossmann C, Sachse K, Schachinger A, Siegrist M, Stryk M. Opportunities and challenges of Web 2.0 for vaccination decisions. *Vaccine.* 2012 May 28;30(25):3727–33. doi: 10.1016/j.vaccine.2012.02.025. [[PubMed](#)] [[Cross Ref](#)]
25. Signorini A, Segre AM, Polgreen PM. The use of Twitter to track levels of disease activity and public concern in the US during the influenza A H1N1 pandemic. *PLoS One.* 2011;6(5):e19467. doi: 10.1371/journal.pone.0019467. <http://dx.plos.org/10.1371/journal.pone.0019467>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]
26. Chunara R, Andrews JR, Brownstein JS. Social and news media enable estimation of epidemiological patterns early in the 2010 Haitian cholera outbreak. *Am J Trop Med Hyg.* 2012 Jan;86(1):39–45. doi: 10.4269/ajtmh.2012.11-0597. <http://www.ajtmh.org/cgi/pmidlookup?view=long&pmid=22232449>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]
27. Milinovich GJ, Williams GM, Clements AC, Hu W. Internet-based surveillance systems for monitoring emerging infectious diseases. *Lancet Infect Dis.* 2014 Feb;14(2):160–8. doi: 10.1016/S1473-3099(13)70244-5. [[PubMed](#)] [[Cross Ref](#)]
28. Collier N, Son NT, Nguyen NM. OMG U got flu? Analysis of shared health messages for bio-surveillance. *J Biomed Semantics.* 2011;2 Suppl 5:S9. doi: 10.1186/2041-1480-2-S5-S9. <http://www.jbiomedsem.com/content/2%20Suppl%205/S9>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]
29. Chew C, Eysenbach G. Pandemics in the age of Twitter: content analysis of Tweets during the 2009 H1N1 outbreak. *PLoS One.* 2010;5(11):e14118. doi:

- 10.1371/journal.pone.0014118.  
<http://dx.plos.org/10.1371/journal.pone.0014118>. [PMC free article] [PubMed] [Cross Ref]
30. Salathé M, Khandelwal S. Assessing vaccination sentiments with online social media: implications for infectious disease dynamics and control. *PLoS Comput Biol*. 2011 Oct;7(10):e1002199. doi: 10.1371/journal.pcbi.1002199. <http://dx.plos.org/10.1371/journal.pcbi.1002199>. [PMC free article] [PubMed] [Cross Ref]
31. Brownstein JS, Freifeld CC, Madoff LC. Digital disease detection-- harnessing the Web for public health surveillance. *N Engl J Med*. 2009 May 21;360(21):2153-5, 2157. doi: 10.1056/NEJMp0900702. <http://europepmc.org/abstract/MED/19423867>. [PMC free article] [PubMed] [Cross Ref]
32. Brownstein JS, Freifeld CC, Reis BY, Mandl KD. Surveillance Sans Frontières: Internet-based emerging infectious disease intelligence and the HealthMap project. *PLoS Med*. 2008 Jul 8;5(7):e151. doi: 10.1371/journal.pmed.0050151. <http://dx.plos.org/10.1371/journal.pmed.0050151>. [PMC free article] [PubMed] [Cross Ref]
33. Larson HJ, Smith DMD, Paterson P, Cumming M, Eckersberger E, Freifeld CC, Ghinai I, Jarrett C, Paushter L, Brownstein JS, Madoff LC. Measuring vaccine confidence: analysis of data obtained by a media surveillance system used to analyse public concerns about vaccines. *Lancet Infect Dis*. 2013 Jul;13(7):606-13. doi: 10.1016/S1473-3099(13)70108-7. [PubMed] [Cross Ref]
34. Zhou X, Coiera E, Tsafnat G, Arachi D, Ong M-S, Dunn AG. Using social connection information alone to robustly predict anti-vaccine opinions on social media. Proceedings of the 15th World Congress on Medical and Health Informatics; MedInfo'15; August 19-23, 2015; São Paulo. 2015.
35. Shalizi CR, Thomas AC. Homophily and contagion are generically confounded in observational social network studies. *Sociol Methods Res*. 2011 May;40(2):211-239. doi: 10.1177/0049124111404820. <http://europepmc.org/abstract/MED/22523436>. [PMC free article] [PubMed] [Cross Ref]
36. Hansen L, Arvidsson A, Nielsen F, Colleoni E, Etter M. Good friends, bad news - affect and virality in Twitter. *Future Information Technology*. 2011;185:34-43. doi: 10.1007/978-3-642-22309-9\_5. [Cross Ref]
37. Pfeffer J, Zorbach T, Carley KM. Understanding online firestorms: negative word-of-mouth dynamics in social media networks. *Journal of Marketing Communications*. 2013 Jun 10;20(1-2):117-128. doi: 10.1080/13527266.2013.797778. [Cross Ref]
38. Jin F, Dougherty E, Saraf P, Cao Y, Ramakrishnan N. Epidemiological modeling of news and rumors on Twitter. Proceedings of the 7th Workshop on Social Network Mining and Analysis; KDD'13 The 19th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining; August 11-14, 2013; Chicago, IL. 2013. pp. 1-9. [Cross Ref]
39. Castillo C, Mendoza M, Poblete B. Information credibility on Twitter. Proceedings of the 20th International Conference on World Wide Web; WWW '11 20th International World Wide Web Conference; March 28-April 1, 2011; Hyderabad, India. 2011. pp. 675-684. [Cross Ref]

40. Nguyen NP, Yan G, Thai MT, Eidenbenz S. Containment of misinformation spread in online social networks. *Proceedings of the 4th Annual ACM Web Science Conference; WebSci '12 Web Science 2012*; June 22-24, 2012; Evanston, IL. 2012. pp. 213–222. [[Cross Ref](#)]
41. Shah D, Zaman T. Rumors in a network: who's the culprit? *IEEE Trans Inform Theory*. 2011 Aug;57(8):5163–5181. doi: 10.1109/TIT.2011.2158885. [[Cross Ref](#)]
42. Hodas NO, Lerman K. The simple rules of social contagion. *Sci Rep*. 2014;4:4343. doi: 10.1038/srep04343. <http://europepmc.org/abstract/MED/24614301>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]
43. Centola D. An experimental study of homophily in the adoption of health behavior. *Science*. 2011 Dec 2;334(6060):1269–72. doi: 10.1126/science.1207055. <http://www.sciencemag.org/cgi/pmidlookup?view=long&pmid=22144624>. [[PubMed](#)] [[Cross Ref](#)]
44. Castellano C, Fortunato S, Loreto V. Statistical physics of social dynamics. *Rev Mod Phys*. 2009 May 11;81(2):591–646. doi: 10.1103/RevModPhys.81.591. [[Cross Ref](#)]
45. Weng L, Flammini A, Vespignani A, Menczer F. Competition among memes in a world with limited attention. *Sci Rep*. 2012;2:335. doi: 10.1038/srep00335. <http://europepmc.org/abstract/MED/22461971>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]
46. Iyengar R, Van den Bulte C, Valente TW. Opinion leadership and social contagion in new product diffusion. *Marketing Science*. 2011 Mar;30(2):195–212. doi: 10.1287/mksc.1100.0566. [[Cross Ref](#)]
47. Holme P. Network dynamics of ongoing social relationships. *Europhysics Letters*. 2003;64(3):427–433. doi: 10.1209/epl/i2003-00505-4. [[Cross Ref](#)]
48. Holme P, Liljeros F. Birth and death of links control disease spreading in empirical contact networks. *Sci Rep*. 2014;4:4999. doi: 10.1038/srep04999. <http://europepmc.org/abstract/MED/24851942>. [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]
49. Liu S, Baronchelli A, Perra N. Contagion dynamics in time-varying metapopulation networks. *Phys Rev E*. 2013;87(3):032805. doi: 10.1103/PhysRevE.87.032805. [[Cross Ref](#)]
50. Abdelmutti N, Hoffman-Goetz L. Risk messages about HPV, cervical cancer, and the HPV vaccine Gardasil: a content analysis of Canadian and US national newspaper articles. *Women Health*. 2009;49(5):422–40. doi: 10.1080/03630240903238776. [[PubMed](#)] [[Cross Ref](#)]
51. Gust DA, Darling N, Kennedy A, Schwartz B. Parents with doubts about vaccines: which vaccines and reasons why. *Pediatrics*. 2008 Oct;122(4):718–25. doi: 10.1542/peds.2007-0538. <http://pediatrics.aappublications.org/cgi/pmidlookup?view=long&pmid=18829793>. [[PubMed](#)] [[Cross Ref](#)]
52. Hilton S, Hunt K, Langan M, Bedford H, Petticrew M. Newsprint media representations of the introduction of the HPV vaccination programme for cervical cancer prevention in the UK (2005-2008) *Soc Sci Med*. 2010 Mar;70(6):942–50. doi: 10.1016/j.socscimed.2009.11.027. [http://linkinghub.elsevier.com/retrieve/pii/S0277-9536\(09\)00841-7](http://linkinghub.elsevier.com/retrieve/pii/S0277-9536(09)00841-7). [[PMC free article](#)] [[PubMed](#)] [[Cross Ref](#)]



53. Stefanoff P, Mamelund S-E, Robinson M, Netterlid E, Tuells J, Bergsaker MAR, Heijbel H, Yarwood J, VACSATC working group on standardization of attitudinal studies in Europe Tracking parental attitudes on vaccination across European countries: The Vaccine Safety, Attitudes, Training and Communication Project (VACSATC) Vaccine. 2010 Aug 9;28(35):5731–7. doi: 10.1016/j.vaccine.2010.06.009. [PubMed] [Cross Ref]
54. Leask JA, Chapman S. An attempt to swindle nature: press anti-immunisation reportage 1993-1997. Aust N Z J Public Health. 1998 Feb;22(1):17–26. [PubMed]
55. Omer SB, Salmon DA, Orenstein WA, deHart MP, Halsey N. Vaccine refusal, mandatory immunization, and the risks of vaccine-preventable diseases. N Engl J Med. 2009 May 7;360(19):1981–8. doi: 10.1056/NEJMsa0806477. [PubMed] [Cross Ref]
56. Hull B, McIntyre P. Mapping immunisation coverage and conscientious objectors to immunisation in NSW. N S W Public Health Bull. 2003;14(1-2):8–12. [PubMed]
57. Jurgens D, Finnethy T, McCorriston J, Xu Y-T, Ruths D. Geolocation prediction in Twitter using social networks: a critical analysis and review of current practice. The 9th International Conference on Web and Social Media, ICWSM-15; May 26-29, 2015; Oxford, UK. 2015.
58. Burger JD, Henderson J, Kim G, Zarrella G. Discriminating gender on Twitter. Proceedings of the Conference on Empirical Methods in Natural Language Processing; EMNLP '11; July 2011; Edinburgh, UK. 2011. p. 1301.
59. Massoudi K, Tsagkias M, de Rijke M. Incorporating query expansion and quality indicators in searching microblog posts. Advances in Information Retrieval: 33rd European Conference on IR Research; April 18-21, 2011; Dublin, Ireland. 2011. pp. 362–367.
60. Kumar N, Carterette B. Advances in Information Retrieval Volume 7814. Heidelberg: Springer Berlin; 2013. Time based feedback and query expansion for Twitter search; pp. 734–737.
61. Carpineto C, Romano G. A survey of automatic query expansion in information retrieval. ACM Comput Surv. 2012 Jan 01;44(1):1–50. doi: 10.1145/2071389.2071390. [Cross Ref]

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