Who is Spreading Rumours about Vaccines? Influential User Impact Modelling in Social Networks

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ABSTRACT

Vaccine hesitancy, traditionally linked to issues of trust, misinformation and prior beliefs, has been increasingly fuelled by influential groups on social media (SM) and the Internet.

Analysis of news media and social networks (SN) accessible in real-time provides a new opportunity for detecting changes in public confidence in vaccines. However, different concerns are important in different regions, and reasons for hesitancy and the role of opinion leaders vary between sub-controversies in the broader vaccination debates. It is therefore important for public health professionals to gain an overview of the emerging debates in cyberspace, identify influential users and rumours, and assess their impact in order to know how to respond.

The *VAC Medi+Board* project aims to visualise the diffusion of rumours through SN and assess the impact of key individuals. We include, as a case study, discussions during winter 2015-16 pertaining to the alleged side-effects of the HPV vaccine.

Keywords

vaccination, social networks, social media, integrated interactive dashboard

1 INTRODUCTION

Real-time Internet, social media and news monitoring has changed the way we think about public health [1], with implications for understanding public concerns and information needs around outbreaks [2], and in particular, the factors driving or inhibiting confidence in vaccines. Rapid analysis of news media and blogs provides a new opportunity for detecting changes in public confidence in vaccines and prompters of public concerns, and is particularly important given the increasing use of these platforms by activist groups that share concerns about vaccination.

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Medi+Board investigates a dashboard for infectious disease surveillance and outbreak management [3]. The novel aim of *VAC Medi+Board* is to design a visualisation framework integrating heterogeneous, near real-time data streams with SN data in an interactive manner for use by public health experts.

2 BACKGROUND AND RELATED WORK

Social media provides a space where like-minded people can share their interests and concerns in real-time, regardless of their location. This has implications for public health, as platforms like Twitter can spread correct information about outbreaks, for example in the 2009 swine flu pandemic [4-5], or disseminate unfounded anti-vaccination scares. Vaccination is a model of a successful public health intervention [6], but due to anti-vaccination campaigns, once-high vaccination levels have fallen in some places [7]. This can lead to outbreaks of vaccine preventable diseases [8], especially if refusal is concentrated locally, creating vulnerable populations [9].

The influence of SM and news coverage on vaccine attitudes has been widely studied: Salathe and Khandelwal [10] investigated vaccination sentiments using publicly available data during the swine flu pandemic to measure spatial-temporal sentiment towards a new vaccine. Studies of confounding of influence-driven and homophily-driven contagion in SN (e.g., Aral et al. [11], Shalizi et al. [12]) have wider implications for public health interventions, prevention measures and disease control. Salathe [13] also found that exposure to negative sentiment "spreads" and is predictive of future negative sentiment expression, while exposure to positive sentiments is generally not, and can even predict increased negative sentiment expression. Larson et al. analysed the global spread of vaccine sentiment in response to Japan's suspension of HPV vaccine in 2014 [14] and studied vaccine confidence through media surveillance data [15].

However, actionable analysis of rumour-transmission via SM is still in its infancy in its applications for public health. The *VAC Medi+Board* [16] offers two main functions:

1. Firstly, a customisable dashboard gives a visual overview of vaccination mentions in news and social media, supporting date selection and interactive network graphs.
2. Secondly, a customizable analysis of SN activity spreading particular vaccine issues and concerns on Twitter, highlighting the most active influencers and the most widely spread Tweets.

In this paper we focus on defining an information diffusion model and Impact Score to assess users’ influence and rumour diffusion, to assist experts to intervene appropriately.

3 USER IMPACT MODELLING THROUGH SOCIAL NETWORK

Graph theory has been the fundamental paradigm for modelling and representing SNs. We identified two representations visualizing nodes to illustrate "what information is spread" or "who spreads the information" to portray user interaction and the diffusion of information.

3.1 Two approaches to graphing

The first visualisation method developed showed tweets’ popularity in terms of number of retweets (RTs), indicating the magnitude of active spreading.

Def 1: $NetworkUserGraph1 = (Tw, E)$

where T is a set of retweeted tweets in the selected time period and w is the weight of the node representing the number of RT of T in period

E = (T1nw, T2nw) is an oriented set of edges representing mentions of T1 in T2

Each tweet is represented as a node, whose size corresponds to its retweet count, as a proxy for the magnitude of spreading. However, this notation does not capture the dynamics of information diffusion, and is not illustrated in this paper.

The second graphing approach models connections between the most popular users in terms of the popularity of their tweets, which is again approximated by RTs.

Def 2: $NetworkUserGraph2 = (Uw, E)$

where U is a set of users in the selected time period and w is the weight of the node representing the number of RT of T

$$w = (|T| + |RT|)$$

where |T| is the total number of tweets for that user U, and |RT| is the total number of retweets for that particular user U

$$E = (U1, U2, v)$$

is an oriented set of edges representing RT from U1 to U2.

In these graphs (ex. Figures 3-5), nodes represent users, and edges represent RTs from one user to another, directed so as to show information flow within SN.

3.2 Information Diffusion Challenge

Modelling information diffusion via social media has been the subject of recent research [17]. We specifically sought to model the act of retweeting in NetworkUserGraph2. This is challenging, however, as the Twitter API does not provide information about intermediary retweeters. That is, if user A shares a tweet, user B retweets A’s tweet, and user C retweets B’s retweet of A’s original tweet, the data provided by the API will only show that B and C have both retweeted A’s tweet, making no differentiation between B’s direct retweet and C’s retweet mediated by B. Twitter’s model of information sharing does not preserve the chain of A → B → C, but instead models the sharing as A → B and A → C, which does not preserve the data needed to model diffusion and assess users’ impact.

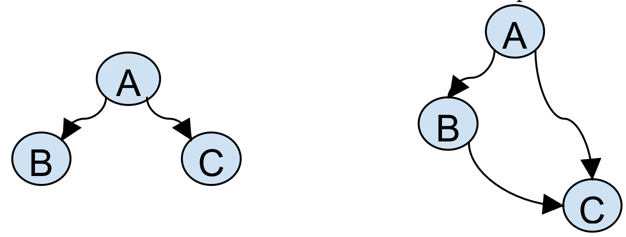

Figure 1. Two network graphs representing information diffusion; a) using the original Twitter model and b) using the novel model which infers diffusion pathways

We therefore used the timestamps associated with each tweet to reconstruct the possible pathways of diffusion. If B and C have both retweeted A, and C’s retweet occurs subsequent to B’s retweet, then A→B→C is a plausible pathway, but A→C→B is not. We still cannot exclude the possibility that C retweeted A directly, but this improves on the API’s assumption of direct RT (Fig 1a) by including the logical possibility that C’s RT was mediated by B (Fig 1b).

Def 3: *Given* $NetworkUserGraph2n = (Uw, E - MAX)$

where E-MAX is the maximum set of oriented edges between nodes ∈ U created by reconstructing the RT routes for a given tweet sent by a user n ∈ U is a clique including n

R =Number of Reached Users

3.3 Influential Users - Impact Score

Using the diffusion model defined in 3.3, we defined an "Impact Score," 3-tuple including three variables for a given single tweet by an influential user n:

1. Number of Reached Users = R
2. Number of Followers = F
3. Number of Reached / Number of Followers = I

Def 4: *Impact Score* IS_n *for user u and a given tweet is a 3-tuple:*

$IS_n = \{R, F, \frac{R}{F}\}$

where R is the Number of Reached Users by the tweet in question and F is Number of Followers of user n.

4 FRAMEWORK IMPLEMENTATION

In this section we provide an overview of the *VAC Medi+Board* framework architecture, SN visualization platform and the data sources integrated so far.

4.1 VAC Medi+Board Framework

The *VAC Medi+Board* dashboard is a customizable interactive framework integrating multiple heterogeneous data streams and analysing information diffusion in real-time. The architecture was designed for assessing vaccination rumours [16] and generic surveillance and early warning functions [3, 18].

4.2 Data Streams

The main information sources integrated into this version of the *VAC Medi+Board* are social media and news coverage. We have identified additional sources, such as blogs and multimedia platforms, which may also be relevant, but for the needs of the interactive overview we focus on the two main data streams:

Social media: Twitter data stream

Twitter has become the most popular social media platform for analysis of public debates, largely due to the availability of data over a streaming API. The Twitter Streaming API was set up to collect tweets in real-time based on keywords[1] identified by co-authors – experts from the Vaccine Confidence Project (VCP) at LSHTM. Once collected, these data are filtered again using high frequency keywords[2] expressing negative sentiment, also identified in previous studies by the VCP.

News coverage: MediSys data stream

Mining online news coverage has proven valuable for epidemic intelligence – currently the main systems used include *GPHIN*[3] and *MediSys*[4]. We chose *MediSys* as it provides indexing and categorisation of news in 41 languages over an RSS feed, set up with experts from WHO and ECDC to cover government and other official online sources. *VAC Medi+Board* checks the *MediSys* 'Vaccination' RSS feed every five minutes to update the news stream (currently restricted to English-language articles).

Social Network Visualization

To support public health experts with different needs, the infrastructure has been designed in a modular fashion to allow users to reconfigure the layout or add new widgets as needed.

Visualising SN topology and information diffusion presents a particular challenge. In addition to implementing two types of graphs: tweets-as-nodes and users-as-nodes (see section 3.1), the visualisation provides a *visual colour-coding* of edges representing the chronological order of RTs spreading through the SN. A direct RT of an original tweet is denoted by a red edge, and as this message propagates the subsequent RTs are denoted by edges in yellow, green, cyan, and finally blue, representing the most distant RTs, which have passed through many intermediary users (ex. Figures 3-5).

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[1] antivax, noforcedvaccines, hpv, vaccination, vax, vaxx, vaccine, vaccines, antivaxx

[2] anxiety, doubt, trust, dilemma, attitude, distrust, mistrust, controversy, awareness, dropout, perception, misconception, uptake, opposition, rejection, misinformation, mandatory, delay, compulsory, knowledge, confidence, decision, development, introduction, delivery, programme, death, died, kill, impotency, infertility, conspiracy, tampering, fake, dangerous, secret, lie, cover-up, coverup, propaganda, dilemma, genocide, deliberate, intentional, influence, contamination, doubt, intent, controversy, awareness, anti, government, wash, movement, bill, fuck, god, jesus, christ, freedom, capitol, march, selfish, poisonous, carcinogen, toxin, volatile, reaction, childhood, cancer, autism, juvenile, diabetes, asthma, neurological, disorders, vaccinationdebate, pharmaceutical, company, companies, chronical, unhealthy, unhealthiest, waking up, danger, remove, family values, court

[3] http://www.who.int/csr/alertresponse/epidemicintelligence/en/

[4] http://medusa.jrc.it/MediSys/homeedition/en/home.html

5 HPV VACCINE CASE STUDY RESULTS

The debate around HPV (human papillomavirus) vaccination was identified by the VCP co-authors as ideal for a longitudinal study due to the prevalence of public concerns globally [[14]]. The study period was from 12 October 2015 to 2 January 2016.

We analysed the dataset to obtain overall results for number of tweets, news articles, and their correlation. The subset of social media data related to the HPV vaccine was selected by a case-insensitive keyword search for 'HPV' which is a distinct keyword not requiring semantic disambiguation. However, for the news dataset retrieved from MediSys, we used the provided meta-data for each article including the 'HPV' category.

5.1 Results

Altogether we collected 875,088 tweets and 4,020 news articles related to vaccination. Of these, 150 news articles and 92,954 tweets were HPV-related. The time series and frequencies of the datasets were analysed in a previous publication [[16]] (see Figure 2). Two particularly robust peaks can be observed, which both coincide with real events – one, in October 2015, includes a period of activism by an Irish organisation concerned with the alleged side-effects of the HPV vaccine; another, in December 2015, coincides with the publication of an article by co-author Dr. Heidi Larson asserting that the HPV vaccine is safe [[19]].

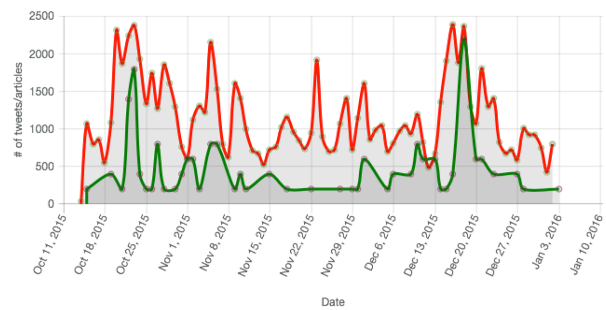


Figure 2. Variation in number of HPV related tweets (red) and news articles *200 (green) collected over time.

HPV-related tweets represented 10.64% of vaccination-related tweets. For the peaks around the 21st-24th October, this figure is 14.84%, and 20.87% for the peak around the 15th-19th December. However, while this graph provides a high-level overview, more actionable information is required for precision public health intervention.

5.2. Influential Users and Key Themes

Using the Impact Score algorithm and the interactive visualisation dashboard's network graphs, we investigated three key aspects of the data collected over the study period:

1. The most influential user over the time period
2. The peak in October 2015
3. The peak in December 2015

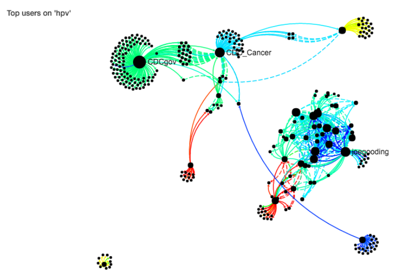
Most influential user: TayoSays

As shown in Figure 3, the user estimated to be most influential during the data collection period was TayoSays, with

Impact Scores of 913 Reached, 1457 Followers and 62.7% Ratio. This shows that TayoSays is actively followed by a relatively small community of users, but those users actively RT his/her tweets, when compared to some of the other users highlighted. Merck, for example, had an outreach/follower ratio of 0.521% – they have the largest number of followers, but only a small proportion of users actively RT their tweets.

October 2015 Peak

The peak seen in the period of 21-24 October 2015 reflects a number of HPV-related events, including the activity of R.E.G.R.E.T[5], an Irish activist group spreading concerns about alleged safety issues surrounding the HPV vaccine.



Most Influential Rumour Initiators	No. Reached	No. of Total Followers	Reached/ Followers Ratio %
TayoSays	913	1457	62.7
CDCSTD	775	30096	2.58
ondaccancer	608	1462	41.6
Merck	458	87926	0.521

@ShantelWireman1 retweeted @PA_Raven's tweet:

07-12-2015 12:30:43

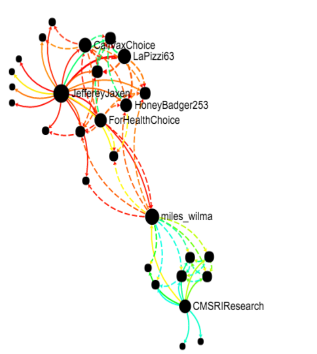
Harm from the HPV vaccine is real https://t.co/zaQ9jjgPZS #hpv #gardasil #vaccines https://t.co/c8xKB1Kh4Q

14-12-2015 8:54:26

Another 18 girls claim adverse reactions to the HPV vaccine https://t.co/C3ijtZ1DSb #hpv #gardasil #vaccines https://t.co/WyeAzeH97K

Figure 3. The network graph for most influential user

The group managed to bring an increased amount of worldwide attention to the HPV debate through mainstream media. The set of tweets which caused this specific peak to occur was related to a story about the Irish Government responding to the controversial HPV vaccine debate in the news and social media [20]. The Impact Score of the highest impact user is 70 users Reached, 29863 Followers and 0.234 Ratio. The colour coding distinguishes the sceptics (orange cluster) and the Irish government response (green cluster). "Miles_Wilma" seems to be the hub user bridging between the two camps (Figure 4).



Most Influential Rumour Initiators	No. Reached	No. of Total Followers	Reached/ Followers Ratio %
CDCSTD	70	29863	0.234
megalcapture	69	4505	1.53
tarahaelle	35	3357	1.04
syutoken_sanka	31	12478	0.248

@miles_wilma retweeted @ForHealthChoice's tweet:

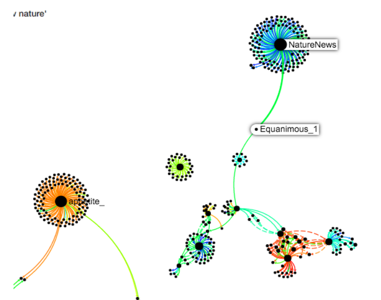
21-10-2015 9:34:43

RT @JeffereyJaxen: Happening NOW Irish Gov't Actively Fighting Unethical #HPV Vaccine Push https://t.co/PXdnmS3LfR

Figure 4. A cluster seen during the October 2015 peak

December 2015 Peak

We specifically looked into an event on 1st December 2015 – a publication in *Nature* by Dr. Heidi Larson, co-author of this study [19], asserting that the HPV vaccine is safe. The SN graph of users who have tweeted on the topic of "HPV nature" around the 1st of December 2015 is shown in Figure 5. In most cases the rate of spread of these rumours/stories tends to decrease quickly, resulting in a very short half-life for information that is shared on Twitter [21]. This was observed by searching for "HPV nature" related tweets after the 1st of December, where no relevant and useful data was found. The *Nature* account impact statistic was 129 Reached users, 991145 Followers, which gives it a Ratio of 0.0130.



Most Influential Rumour Initiators	No. Reached	No. of Total Followers	Reached/ Followers Ratio %
NatureNews	129	991145	0.0130
appetite_	123	4025	3.06
megalcapture	48	6890	0.697
eunhasun	46	3984	1.15

@Equanimous_1 retweeted @NatureNews's tweet:

01-12-2015 4:15:42

The world must accept that the HPV vaccine is safe, says Heidi Larson https://t.co/PaDgmhX7jj https://t.co/KhHEzg7aDV

Figure 5. December 2015 'Nature HPV' peak

6 LIMITATIONS

This is an ongoing interdisciplinary study. Currently the collection system includes only two data streams and is English-language-focused. As vaccination is a global issue, multilingual mining would add significant value in terms of robustness and sensitivity. Due to the digital divide and varying use of social media among different populations, this does not provide a globally representative picture despite vaccine hesitancy being a global phenomenon. Furthermore, access to social media data is subject to privacy and ethics considerations [22].

Additionally, we focused on single user impact. In the future, we anticipate grouping users who share the same concern(s) or spread similar rumours even though they might be using different languages.

7 CONCLUSIONS

Enhancing our understanding of vaccine hesitancy by analysing real-time health discourse on social media, and the Internet more broadly, has demonstrated the potential of visualizing multi-channel data in an interactive manner to provide actionable knowledge for public health experts.

The *VAC Medi+Board* project designed an interactive dashboard integrating social media discourse on Twitter and news coverage from the monitoring tool MediSys to investigate public debates related to the HPV vaccine. In this study we described the metrics for defining the SN graph in two ways, identifying the most influential users and calculating their Impact Score for further analysis by public health experts. We specifically investigated the recent debate around the safety of the HPV vaccine and assessed the key players in the debate around the peaks in Oct and Dec 2015.

ACKNOWLEDGMENTS

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[5] http://regret.ie/

COMPETING INTEREST

The authors have declared that no competing interests exist.

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