A mixed methods study exploring early career doctors' and medical students' seasonal influenza vaccination.

A thesis submitted to Lancaster University for the degree of Doctor of Philosophy in the Faculty of Health and Medicine.

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Abbreviations

WHO	World Health Organisation
HA	Hemagglutinin
NA	Neuraminidase
HCW	Healthcare Worker
CQUIN	National Commissioning for Quality and Innovation
SNA	Social Network Analysis
SIR	Susceptible-Infectious-Recovered
LMS	Lancaster Medical School
PAT	Pennine Acute NHS Hospitals Trust
FY1	Foundation Doctor Year 1
FY2	Foundation Doctor Year 2
MS	Medical Student
FD	Foundation Doctor
CMO	Chief Medical Officer
GMC	General Medical Council

Abstract

Seasonal influenza is an acute, contagious respiratory infection that causes considerable morbidity and mortality each year. The Chief Medical Officer for England recommends that healthcare workers have a seasonal influenza vaccination in an attempt to protect both patients and NHS staff. Despite current recommendations and campaigns targeted at improving vaccination uptake, many healthcare workers do not have a seasonal influenza vaccination. It is clear that more research is necessary to fully understand the vaccination decision of healthcare workers.

This mixed methods thesis employed a range of novel methodological approaches to understanding the influences on the seasonal influenza vaccination decision by medical students and junior doctors. Social network analysis is a well-established research approach that looks at individuals in the context of their social connections. I used an outbreak simulation model to investigate to assess whether an individual's risk of infection could be linked with their position in the social network. Expanding further on this, the auto-logistic regression model was applied to social network data to predict an individual's likelihood of vaccinating given the behaviour of their peers. Finally, a qualitative approach was used to explore the factors informing vaccination decisions.

Findings gathered throughout this programme of work were synthesised together to produce a more detailed evaluation of seasonal influenza vaccination amongst medical students and junior doctors. These have been disseminated widely, particularly to occupational health practitioners and the wider academic community – demonstrating that this public health research has impact in practice.

By gaining a better understanding of the social effects on influenza vaccination it will be possible to improve seasonal influenza vaccination uptake by healthcare workers, in turn better protecting patients and staff.

Declaration

I declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

Dedication

For my dad, Phillip Edge, who taught me to believe in six impossible things before breakfast.

Acknowledgements

Undertaking this PhD has been one of the most challenging experiences of my life, I have learnt more in the three-year process than I ever thought possible. I am humbled by the support I have received throughout this process. I would like to thank my supervisors: Rachel, for going above and beyond, constantly looking out for me and shaping the project into a truly exceptional PhD; Tom, for putting everything in perspective and making work seem like fun; Dawn, for opening my eyes to a new way of thinking; and Peter, for his immense patience and knowledge.

I would like to thank my funders, The Colt Foundation, their support continually encourages me and has given the work additional prestige. I would especially like to thank the Colt Foundation's Director Jackie for not only supporting the project, but my own personal development – more than once her encouragement has come just at the right moment! I have been incredibly lucky to be embedded in a diverse and ever-growing research group, the staff at CHICAS have never failed to help me with theoretical/technical problems.

This PhD has been a rollercoaster of great highs and lows, I could not have coped without the help and support of my family and friends. My parents have been fantastic throughout the project – they deserve to take great pride in the completion of this thesis, it could not have been achieved without their support. I thank my dad for all the times he has patiently listened to me talk through my ideas and worries. I thank my mum for inspiring me to take on great challenges. Both my sisters have reminded me how we are lucky to lead magical lives. One the great highs of the past three years has been meeting and building a relationship with my boyfriend Josh, thank you for your unfailing support during the final stages of my PhD (the last 5% is always the hardest). I would also like to thank the Griffiths' who have quickly become my second family.

Throughout this project my friends have been invaluable. They have kept things in perspective; provided a complete sanctuary away from work; and forgiven me for the countless times I have let work take priority. Shout out to Ellie, Jenny, Alex, Will, Alex, Seb, Ruth, Caitlin, Sam, Sophie, Charlotte, Poppy, Annie, Jess. Over the three years I have spent in Lancaster I have been involved in both Rowing and Netball. I would like to give my teammates a special mention – sport has kept me sane!

"We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard; because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one we intend to win." JFK

Statement about the Author

Rhiannon Edge was born in Blackburn in 1992, and qualified with a BSc in Mathematics and Biology from the University of Newcastle in 2013. In 2014, she began studying at Lancaster University for the degree of Doctor of Philosophy in the faculty of Health and Medicine. This thesis is the accumulation of three years of work on a mixed methods study exploring early career doctors' and medical students' seasonal influenza vaccination. Rhiannon choose to tackle this as part of a wider interest in health research. The complex statistical methods presented are a testament to her interest in statistics, whilst the breadth of methods both quantitative and qualitative demonstrate a unique willingness to embrace novel ideas in the pursuit of scientific knowledge.

In January 2017, she will commence work as a senior research associate at Lancaster University. Rhiannon will continue her statistical development within the CHICAS research group whilst working on data produced by the Trajectories of Outcome in Neurological Conditions (TONiC) study. TONiC is a national study examining the factors impact on the lives of patients that suffer from neurological diseases such as Multiple Sclerosis and Motor Neurone disease, regardless of symptoms, stage of illness, age or social status. It is one of the largest studies on quality of life in neurological conditions ever performed in the UK.

In the future, she hopes to continue to work in the statistical application to health research. Developing her own knowledge of research methods whilst having a significant positive impact on the lives of people suffering.

Chapter 1

This thesis begun to take shape in June 2013 when I approached Dr Rachel Isba at Lancaster University, I was interested in social networks and the application of social network analysis to health research. Over the following summer months, we established a PhD proposal, beginning with a study investigating seasonal influenza vaccination uptake amongst a network of medical students. In January 2014, I arrived at Lancaster University to begin the work under the supervision of Dr Rachel Isba, Dr Thomas Keegan and Dr Dawn Goodwin. During the first year I simultaneously worked on the medical student dataset, developed a research proposal for the remaining months of my PhD, and applied for external funding to continue the work. Towards the end of the first year I was awarded funding from the Colt Foundation to complete the project. During their appraisal of the programme they suggested it would be beneficial for a statistician to advise me, thus Professor Peter Diggle joined the supervision team. During the second study I worked extensively with Peter developing a statistical approach to understand the foundation doctor dataset. Whilst this was ongoing, my supervisors and I were formulating a strategy to best answer remaining research questions. At this point I could have chosen to continue to develop the statistical methodology used in the second study or use a qualitative approach to further my understanding of the vaccination decision within early career doctors. My supervision team were equally split as to which would be the most appropriate direction to take. I made the final decision to use the third study to explore a qualitative approach to understand vaccination habits. I decided that this work was fundamentally motivated by an application and that this was the most logical approach to understanding influenza vaccination behaviour. Thus, in February 2016 I began to conduct qualitative interviews, transcribe them and analysis the data. During this study I worked closely with Dr Dawn Goodwin.

In this chapter, I shall first introduce the motivation for this work, seasonal influenza – it's transmission, the effects, and the vaccination. I discuss seasonal influenza vaccination amongst healthcare workers – why they are encouraged to take the vaccine, and reasons for and against vaccination acceptance. I frame this discussion in the context of their social setting, and its possible influence over the influenza vaccination uptake. I introduce the study participants and the setting. Followed by a brief introduction to the different methodological approaches. This chapter concludes with an outline of the remainder of this thesis.

Seasonal influenza

Seasonal influenza is an acute, contagious respiratory infection that causes considerable morbidity each year and can be a primary, underlying or contributing factor to cause of death (1,2). According to the World Health Organisation (WHO), seasonal influenza occurs globally with an annual attack rate estimated at 5%–10% in healthy adults and increased rates in certain high risk groups – young children, the elderly and persons with complicating medical factors. Worldwide, annual influenza epidemics are estimated to be responsible for between 3 and 5 million cases of severe illness, with up to half a million deaths (3). Pneumonia, cardiopulmonary and other chronic diseases can be exacerbated by influenza further increasing mortality. In the past century there have been three major influenza pandemics with many believing another is overdue (4). Pandemic influenza, although rare, has extraordinary consequences, for example, the 1918 Spanish 'flu is estimated to have caused between 20 and 50 million deaths worldwide(5).

Influenza not only has high costs to an individual's health but also considerable costs to the economy. In 2007, Molinari et al. estimated that influenza costs the US economy approximately $87.1 billion annually(6). This study highlights that whilst medical costs are high, substantial costs to the economy come from lost productivity in absentee days and loss of life. In the event of an influenza pandemic UK gross domestic product could suffer a reduction of up to 4.3% (7).

Influenza is an infectious disease transmitted from person to person via aerosols. Following respiratory transmission, the virus attaches to and penetrates respiratory epithelial cells in the trachea and bronchi. Viral replication occurs, which results in the destruction of the host cell (8). The incubation period for influenza is normally 2 days however, it can range from 1 – 4 days. Due to the nature of the influenza virus, the severity of the infection depends on the infected individual's level of immunity – whether or not they have been exposed to similar strains of the virus previously. Once infected about 50% of people develop symptoms, which usually last 3 - 5 days. Influenza is characterized by the abrupt onset of fever, myalgia, cough, sore throat, and headache. For most people recovery is rapid, it is suggested that taking medicines such as paracetamol, resting, and drinking plenty of fluids, may reduce symptoms (9).

Seasonal influenza cases tend to increase over the winter months. Unfortunately, the exact reason for influenza seasonality is unclear; however, numerous possibilities have been given. Seasonal outbreaks begin abruptly, peak within the first three weeks and rarely last longer than ten weeks(10). Epidemic influenza typically follows a similar pattern; however, multiple waves of influenza outbreaks are observed. There appears to be huge variability in the severity and spread of different influenza epidemics. It is widely accepted that influenza is spread between humans through contact with large respiratory droplets and small particle aerosols. A recent study by Cowling et al. found that aerosol transmission is responsible for around half of all transmissions (11).

There are three forms of influenza virus: influenzas A, B and C, which are members of the Orthomyxovirus family, these enveloped viruses contain a segmented RNA genome(2). Influenza A is responsible for most seasonal influenza and all pandemics to date. Influenza A can be sub-typed according to its surface glycoproteins: hemagglutinin (HA) of which there are 15 different subtypes; and neuraminidase (NA) of which there are 9 different subtypes. Influenza B has similar surface glycoproteins; however, unlike Influenza A they do not form multiple different subtypes. Influenza B viruses formed a homogenous group and started to diverge into two antigenically distinguishable lineages only in the 1970s - the Victoria and Yamagata lineages (12). Influenza C is structural quite different from both Influenza

A and B, it has only one glycoprotein: hemagglutinin-esterase fusion (HEF). Nearly all adults have been infected with influenza C virus, which causes mild upper respiratory tract illness. There is no vaccine against influenza C virus (13).

Influenza A and B's surface glycoproteins are numbered sequentially for example: H1, H2, H3. HA binds to the cellular receptor sialic acid and NA cleaves sialic acid from budding viruses(10). Influenza's specificity is attributed to the complementary structure of HA to its receptor sialic acid. Both surface proteins HA and NA can vary significantly over a series of replications. This is due to influenza's RNA polymerase which lacks the ability to proofread the transcribed influenza genome. This is known as antigenic drift and leads to many polymorphisms of HA and NA - which leaves an individual susceptible to specific types of influenza despite previous vaccination or infection by other strains. Influenza's capacity for antigenic drift is a contributing factor to its viral success.

Influenza A's multiple HA and NA subtypes have been isolated from avian sources; however, only a limited number have been found in humans and even fewer are associated with widespread epidemics – i.e. are capable of human-human transmission. A variety of non-avian animals can also carry specific subtypes of influenza A – including, importantly, swine. Avian Influenza provides a reservoir with all the genetic variation needed for a human pandemic. However, there is some debate over the evolutionary status of avian influenza viruses (14). It has been suggested that swine facilitate an intermediate mixing group between avian and human influenza due to swine sialic acid being similar to both mammalian and bird sialic acid. Genetic re-assortment can lead to replacement of either HA or NA gene segments, causing major changes in the molecules, and is known as antigenic shift (15). It is the genetic re-assortment of avian, swine and human influenza viruses that can lead to severe pandemics, as we have very little natural immunity to 'new' strains of influenza (16,17). Influenza B viruses cause the same spectrum of disease as influenza A. However, influenza B viruses are not thought to cause pandemics. This may be a consequence of the limited host range of the virus – Influenza B has only been found in humans and seals – which limits the generation of new strains by genetic re-assortment (18).

Preventing seasonal influenza

Constant evolution of the influenza virus means that vaccines must be produced seasonally. Scientists predict the strains most likely to be circulating in the following season and develop vaccines to target these. This is achieved using information available at the time, for example, the strains circulating in the southern hemisphere inform predictions for the likely virus' circulating in the following winter for the northern hemisphere. Usually the vaccine targets two strains of influenza A and one of B; unfortunately, mismatched seasons' are common (19). The vaccine is mismatched when it does not target the dominant strain of influenza virus in circulation during a particular season. Due to the constantly changing nature of the influenza vaccine and the necessity to rely on seasonal prediction of likely strains the vaccine is not 100% effective. A meta-analysis by Tricco et al. found that during mismatch seasons the vaccine efficacy was between 56-60% depending on vaccine category and during match seasons the efficacy improved too between 65-77% (20). Furthermore, understanding the country specific temporal characteristics of influenza epidemics is essential for planning influenza vaccination programs because vaccine effectiveness wanes over time (21).

Other prevention methods include handwashing and facemasks. Work by Cowling et al., suggest hand hygiene and facemasks prevented household transmission of influenza virus when implemented within 36 hours of the initial patient symptom onset (22).

Vaccine uptake in healthcare workers

In hospital, influenza poses a risk to both medical staff and patients; it is one of the leading causes of respiratory infection and can be fatal in the elderly (23). Vaccination is used as a method of influenza prevention and control, even during seasons when the vaccine is poor match to the circulating strains (24). Current policy suggests that in a healthcare setting influenza vaccination is important despite the imperfections described above. There are a number of different perspectives as to why HCWs should receive an influenza vaccine. The occupational health perspective is that HCWs have a high exposure to the influenza virus; therefore, should they be protected against infection? A patient welfare perspective is that HCWs work in a setting with vulnerable patients; thus, must they play an active part in the reduction of infectious disease spread? There is also an economic argument for NHS staff to receive the influenza vaccine; to what extent does encouraging HCW vaccination reduce staff absences and is financially beneficial? HCWs are able to make judgements about their own vaccination, whether or not the vaccination is an effective influenza prevention method, and whether this is important at an individual level.

There is a limited body of evidence that supports influenza vaccination by HCWs. A randomised controlled study by Carman et al. has found that vaccination of HCWs was associated with a substantial decrease in mortality among hospital patients (25). A pair matched cluster randomised controlled trial conducted by Hayward et al., found that vaccinating care-home staff against influenza can prevent deaths, health service use, and influenza-like illness in residents during periods of moderate influenza activity. These results were found with only 48% vaccine coverage in the intervention care-homes (26). Lemaitre et al. provides further evidence in support of influenza vaccination of staff caring for institutionalized elderly people (27). However, the age, size and quality of some of these studies led to a lack of confidence in the evidence to support vaccination by HCWs.

A number of systematic reviews have been conducted to attempt to synthase the evidence for and against influenza vaccination by HCWs. Unfortunately, there are conflicting opinions surrounding the need for HCWs to be vaccinated – possibly adding to the confusion surrounding the perceived benefits of the vaccine. For example, Thomas et al. found there was a lack of quality evidence that HCW influenza vaccination had a protective effect for patients (28), in 2013, the subsequent Cochrane review suggested that there was no evidence that vaccinating HCWs prevents influenza cases in patients (29). Whereas Dolan et al. suggests that a protective effect is likely (30). A more recent review, by Ahmed et al., attempts to clarify this disparity (31). They found that there is low evidence of there being no effect, moderate evidence that vaccination of HCWs reduced patient mortality and low evidence of a reduction in influenza cases in patients. However, overall the evidence was only classified as moderate. Ahmed et al conclude that the benefits of HCW influenza vaccination outweigh the possible harms. These reviews are primarily concerned with the benefit of vaccination to patient welfare.

A recent appraisal of the systematic reviews by Kliner et al, attempts to unpick why there are discrepancies between the findings from different systematic reviews of HCW influenza vaccination(32). They find that the efficacy of the influenza vaccination against laboratory-confirmed influenza is consistently around 60% in healthy adults, thus they suggest we could expect to prevent 2.5 episodes of influenza per 100 HCWs vaccinated. Whether this is appropriate justification for HCW vaccination can be interpreted differently. It is ultimately for policy-makers to decide whether it is beneficial to recommend and invest in seasonal influenza vaccination for HCWs. And it is for individuals to decide whether to vaccinate or not. Currently, seasonal influenza vaccination for HCWs remains a priority for NHS Trusts throughout the UK and is globally recommended.

Medical communities and government commonly recommend seasonal immunisation against influenza to reduce the occupational risk of infection for HCWs and medical students. As an additional incentive the recently announced national commissioning for quality and innovation (CQUIN) standard will provide financial rewards for any NHS Trust achieving 75% seasonal influenza vaccination coverage, amongst its staff. A suitable seasonal vaccine is available and supplied to HCWs for free, and is highly encouraged for anyone in the health care profession.

Despite this only 54.8% all frontline HCWs choose to be immunised - substantially below the 80% to 90% levels required to achieve herd immunity (34).

Survey studies suggest that seasonal influenza vaccine uptake by HCWs may be poor for a number of reasons, such as: a lack of spare time to get vaccinated (35); fear of side effects (e.g. soreness at injection site) (36); and a lack of knowledge about the benefits and risks of receiving the influenza vaccine (37). Reasons for receiving an influenza vaccine have been cited as: protection of oneself, family members or patients (36,38); convenience; and, following the example set by supervisors or peers (39). Current intervention policies have had little success in significantly increasing vaccination, strategies combining a number of interventions seem slightly more successful (40). This suggested that the reasons behind a lack of influenza vaccination amongst HCWs are complex. Clearly more research is needed to fully understand the complexities involved in the influenza vaccination decision for HCWs.

There is considerable debate as to the best strategy to encourage vaccination with some recommending policies to make seasonal influenza vaccination mandatory for HCWs (41). Whilst this debate is ongoing, and evidence suggests it is unlikely to be easily resolved, confusion surrounding the justification for vaccinating grows, with individuals likely to become disenfranchised with the vaccination debate.

Health and social relationships

Individuals are required to make a choice about whether or not to accept the influenza vaccination. However, the evidence for and against the effectiveness of the influenza vaccination is equivocal. It is also the case that, individuals are reliant on others to vaccinate in order to benefit from herd immunity, and an overall reduction in influenza circulating in the population. Vaccination takes place in a social setting - individuals are given information by a medical professional prior to accepting or declining the vaccination. In a healthcare setting, vaccination is often offered to a group of medical professionals. Thus, individuals could be influenced by others when making the vaccination decision. Thus, in this setting social relationships affect an individual's risk of influenza both directly and indirectly.

There are a number of mechanisms through which social relationships affect an individual's health:

1. Social support - both emotional and instrumental, is beneficial to an individual's health (30)
2. Social influence - people tend to imitate their peers, when considering behaviours related to health including exercise, smoking, drinking, and vaccination, this becomes particularly important(31)
3. Social engagement –involvement in group activity builds social ties and reduces mortality (32)
4. Person-to-person contact – more ties can increase the likelihood of exposure to pathogens, thus the same network characteristics that promote good health can serve as a mechanism for transmission of infectious disease (42). Mathematical modelling in this area has been developing recently.
5. Access to resources - both material and information diffusion.

An individual's health is indelibly linked with their behaviour. In the past, studies have shown that there is an increased risk of death among persons with a low quantity, and sometimes low quality, of social relationships (43).

The people we interact with play a role in establishing our behaviour (44). We learn from our peers, this includes behaviour that may impact our health – for example, an individual may be encouraged to take up smoking by their peers, and the negative consequences associated with smoking are well established. (45).

The act of choosing whether or not to accept the influenza vaccination is a health behaviour – thus is potentially influenced by an individual's social relationships. When considering social relationships, we must acknowledge that people do not exist in isolation – rather, they belong to communities and groups, and there are also sub-sets of relationships within groups. Individuals within a group could be indirectly affected by others despite not having a direct connection. For example, information may diffuse from a friend of a friend, through links of relationships to an individual (46). These links of relationships within a group form a social network – the underlying social structure of a group. The 'six degrees of separation' anecdote - the premise that everyone in the world is connected to everyone else in the world by an average chain of six degrees (47,48) - suggests that humans are highly interconnected by virtue of their social relationships, thus, it is more likely that friends of a friend may influence an individual. Intuitively, a social network will affect disease epidemiology – a sparse network with few connections between people would reduce the potential of disease transferring from one individual to another, whereas, denser networks might encourage infectious disease spread (49). Social relationships have an effect on individuals, their behaviour and their health. How social networks affect health behaviour is a research area that is rapidly gaining attention. If we can understand health behaviours in the context of social networks, maybe these networks can be used to facilitate wider social changes to health behaviours throughout a network. Social networks are therefore an underlying theme of this research.

An Introduction to social network analysis

Social network analysis (SNA) has become an increasingly popular tool in public health and epidemiological studies (50). Unlike some other statistical approaches, SNA does not assume random mixing within a population, rather it presupposes that a population has a non-random structure which influences interactions within it. A social network is made up of nodes - representing individuals, – and edges - representing a connection between individuals. Figure 1, shows this graphically - where nodes are characterised as circles, and edges are the lines joining the circles. Analysing network structures can be highly informative, particularly when studying phenomena such as transmission pathways for infectious diseases.

The field of social network analysis has exploded in recent years, and is highly multi-disciplinary – its intriguing history is well documented by Freeman in "The development of Social Network Analysis"(38). It is important to note that the field of network analysis was developed simultaneously by researchers working in a number of different disciplines. Thus, how a researcher describes the development of SNA may depend on the researcher's background. Below I have attempted to identify notable contributions to SNA from a variety of fields.

Social Network Analysis is largely based on graph theory. The first recognised use of graph theory is in 1736, when a mathematician, Euler, solved the Konigsberg bridge problem. He constructed a diagram of points and lines from which he derived the proofs necessary to solve the problem of whether it was possible to take a particular route though Konigsberg and cross each of seven bridges only once. He found it was not. Unfortunately, this work was largely unheard of until the 1950s when the paper was translated into English.

Sociologists and physcologists might argue that SNA stems from gestalt theory, in particular, those developed by Köhler and Koffka. Gestalt theory suggests thoughts and perceptions can be structured into meaningful patterns - "the whole is different than the sum of the parts" (39-41). Many gestalt theorists settled in the US during the 1930s as a result of the Nazi occupation of Germany (42). In the US their influence was felt by Jacob Moreno – often considered the founder of SNA.

Jacob Moreno focused on identifying the structure of friendship choices. He developed systematic formal methods for charting social relationships among children with the aim of producing visualisations of measured relations, he named these diagrams sociograms (43). This work defined social network analysis as a unique discipline.

During the next few decades researchers from fields including sociology, mathematics, and anthropology worked towards solidifying the foundations of social network analysis. In 1960, Paul Erdos and Alfred Renyi presented their random graph model – one of the first and most widely studied network models (51). Providing the tools that allowed future researchers to explain small worlds mathematically. Stanley Milgram is usually credited with the development of the 'small world' theory in 1967 – that is most people on the planet could be reached using very few steps – widely publicised as the 'six degrees of separation' (52).

Building on the small world principle, in 1973 a Sociologist, Mark Granovetter, wrote 'The strength of weak ties'(44). Granovetter proposed that whilst people formed strong ties with their families and close friends they also met acquaintances randomly – it is these weaker ties that hold the network together. This was one of the first attempts to use social network analysis to explain human behaviour.

Following the 1970s the field developed rapidly, the International Network of Social Network Analysis (INSNA) formed in 1977 and continues to hold its annual conference: Sunbelt. Advances in technology and its availability have had a profound effect on the discipline. Researchers from a range of backgrounds now have much greater access to social network analysis tools developing outside of their area of expertise. Increased computational power has been vital in applying analytical techniques to social network data – the analysis of large social network datasets often relies on the manipulation of large matrices. In the last decade we have seen an explosion in social media providing a wealth of 'big data' in the form of Facebook or Twitter networks.

Although social network analysis is rapidly growing there are a range of areas that require development both theoretical and empirically. For example, future work will likely focus on longitudinal, dynamic networks, undoubtable more representative of the real world problems commonly studied. Thus longitudinal, dynamic networks are better able to elucidate the properties of diffusion behaviours over time within social networks (53,54).

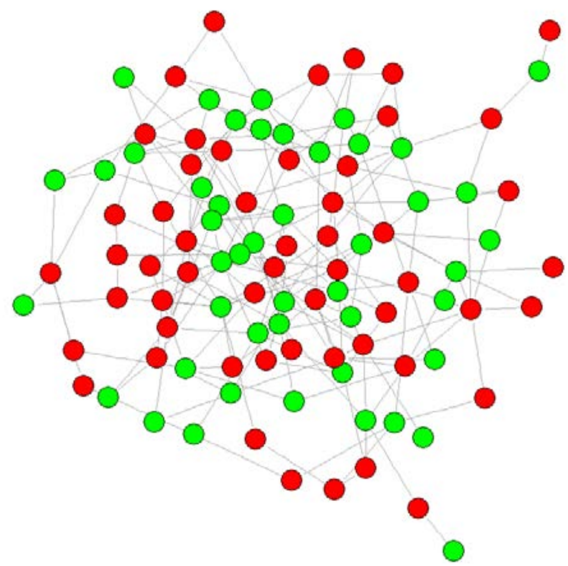

Figure 1. Graphical representation of a social network graph, here green represents females and red represents males.

Social network analysis has helped formulate a number of novel epidemiological advances - for example, people are inter-connected and so their health is inter-connected. Better understanding of social connections and their effects has potential for improving public health. An individual's location in their social network has impacts on their health: intuitively, a person with a large number of contacts is more likely to be exposed to infectious pathogens and will be more at risk of disease. Networks may have a more subtle relationship to health, for example; people with more social contacts tend to be healthier (28) and obesity shows signs of clustering within a network (29). As suggested by Christakis and Fowler, the argument that the health and well-being of one person affects that of another in their social network is justification for the use of SNA in public health research (33).

As indicated earlier there is growing interest in the application of SNA to infectious disease modelling. Small scale studies into contact networks for infectious disease spread have yielded interesting results. It is widely accepted that social mixing patterns have varying effects on disease transmission parameters (34). For example, differences in the mixing patterns of different age groups have been studied and applied to models for various diseases (35, 36). It is hoped that models developed using a social network approach will be helpful when forming disease prevention and control policies. Indeed in the case of influenza, there are indications that children are largely responsible for spreading infection thus targeting this group for vaccination or school closure in the event of an epidemic are advisable tactics for combating pandemic spread (37).

Setting and participants

Lancaster Medical School

(http://www.lancaster.ac.uk/lms/)

Lancaster Medical School is a part of Lancaster University, located in the north west of England. The Medical School opened in 2006 and delivered the University of Liverpool School of Medicine MBChB degree curriculum. In 2012, the school began delivering its own medical degree independently from the University of Liverpool (55). Lancaster Medical School enrolls around 50 students each year, to a five-year degree programme (56). At Lancaster Medical School the core curriculum is delivered through combining a problem-based learning structure with early patient contact. In problem-based learning small groups are presented with a clinical scenario and the groups work through it identifying their learning needs, this process is facilitated by a tutor, who is seen as a guide rather than a teacher.

Lancaster Medical Students

Lancaster Medical Students are predominately aged between 18-23, and studying for their first degree. The entire medical school is made up of only around 250 undergraduate students across five years, thus the students tend to form tight knit relationships with others in the school. The students are diverse in ethnicity, and both sexes are represented. Entry requirements stipulate that students must have achieved the equivalent of three As at A-level and must demonstrate proficiency in English. Thus, the population is similar in having a high academic attainment, motivation to study, and interest in medicine.

Pennine Acute Hospitals NHS Trust

The Pennine Acute Hospitals NHS Trust (PAT) is a large Trust serving the North-East sector of Greater Manchester, which has a population of around 820,000. The Pennine Acute Hospitals NHS Trust operates from four distinct hospital sites: Fairfield General Hospital; North Manchester General Hospital; The Royal Oldham Hospital; and Rochdale Infirmary. Of these the North Manchester General Hospital and The Royal Oldham Hospital are the largest. Thus, mayor services are largely situated at these two sites (57).

The North Manchester General Hospital is located 3.5 miles north of Manchester City Centre. The hospital has a full accident and emergency department, comprehensive surgical services, and is the base for the region's specialist infectious disease unit. The Care Quality Commission recently rated this hospital inadequate (58). Rochdale Infirmary is located in Rochdale Town Centre, 14 miles north east of Manchester. It is the smallest hospital in the Trust, providing limited services including: a 24/7 urgent care centre, day surgery, a specialist rheumatology centre, and a specialist eye unit. The Care Quality Commission recently rated this hospital as good (67). The Royal Oldham Hospital is located in Oldham Town Centre, 8 miles north east of Manchester. The hospital has a full accident and emergency department, comprehensive surgical services, and specialist services including clinical haematology and gynaecological services. The Care Quality Commission recently rated this hospital as inadequate (60). Fairfield General Hospital is located in the centre of Bury, 10.5 miles north of Manchester. It is one of three primary stroke units in Greater Manchester and is the main site for elective surgery in North Manchester (61). The Care Quality Commission recently rated this hospital as requires improvement (62).

Foundation Doctors

The General Medical Council describes the foundation programme for doctors as: "a two-year training programme for doctors who have just graduated from medical school." Doctors in their first year of this programme are known as FY1s, and those on the second year are FY2s. They are responsible for caring for patients under the supervision of more experienced healthcare professionals (63). This type of training programme is compulsory for newly qualified doctors in the UK, and offers an opportunity to gain experience in a series of posts in a variety of specialties and healthcare settings over a two-year period.

The Pennine Acute Hospitals NHS Trust delivers a foundation programme across the four sites within the Trust. For the purposes of teaching, the PAT is split into east and west axes – each foundation doctor is a member of either the east or west axis. The east axis includes the Royal Oldham Hospital and Rochdale Infirmary. The west axis is made up of the North Manchester General Hospital and Fairfield General Hospital. There are approximately 200 foundation doctors enrolled on the foundation programme at the PAT, these are split evenly across two year groups and the two axes. Foundation doctors are more likely to be situated at either the North Manchester General Hospital or the Royal Oldham Hospital, due to the size of these hospitals. Teaching sessions are held once a week for each year group (FY1 or FY2) and each axis (east or west) in Education Centre's, and are a compulsory part of the programme.

Aim and Research Questions

This thesis is framed in a social network analysis context – albeit with a variety of methodological approaches used to answer the research question:

Explore the influences on junior doctors' and medical students' decision making around the seasonal influenza vaccination?

- How are social networks relevant for influenza vaccination?
- Are there clusters of vaccinated and non-vaccinated individuals in medical school or in a hospital setting?
- What are the seasonal influenza vaccination uptake practices and perceptions of medical students?
- What are the potential network influences on the seasonal influenza vaccination uptake practices and perceptions of foundation doctors?
- How do medical students' and early career doctors' perceive seasonal influenza vaccination and how may their social interactions have influenced them?
- Do people change their seasonal influenza vaccination habits often and if so, what causes this change?

To fully explore the research questions above I employed a range of different methodological approaches. Thus, I include an introduction to the methodological concepts used throughout this report below.

Chapter 2

Methodological Introduction

Social Network Data Collection & Study Design

Typically, public health research involves collecting anonymous, independent data at the individual level. The data required for social network analysis studies are slightly different. The 'gold standard' network analysis involves collecting data on the relationships between every member of a group and every other member. Thus it is necessary to identify clearly the entire study population before data collection commences (64). Such a network is known as a bounded network

Depending on the study population the boundaries for of a bounded network can be hard to define. For example in chapter 3, in which I report on the medical school network, every student in the network was identified, and asked about every other student in the network.

Such relational data collected for network analysis is often presented in a binary N x N square matrix for N subjects – called an adjacency matrix. Each entry represents a tie between the individuals in the corresponding rows and columns (Table 1). For very large dataset's this can mean that the adjacency matrices contain a large number of zero values – this may cause problems when computational power is an issue – in these cases storing data in an edge or vertex list is preferable (Figure 2). An edge list describes a network by simply listing all its ties.

	A	B	C	D
A	X	1	0	1
B	1	X	0	0
C	0	0	X	1
D	1	0	1	X

Table 1. A fictional example to illustrate an adjacency matrix.

Edge List

A – B

A – D

B – A

C – D

D – A

D – C

Figure 2. The corresponding edge list to the adjacency matrix given in Table 1.

If the network boundaries cannot be clearly defined it may be necessary to use a different data collection technique. For example, contact tracing is often used to identify an individual's sexual partners. Respondent-driven data collection can be less intensive than mapping the entire network, however, individuals are included into the network in an inherently biased way, and this can lead to an unrepresentative sample.

An alternative approach is to collect data for the set of ties surrounding a sample of individual nodes – this is known as egocentric data. The person of interest, referred to as the ego is asked to nominate others in their immediate network, referred to as alters. The ego is then asked to provide information about their alters. Information can be in the form of:

- Attributes, such as age, sex, or ethnicity,
- properties of the tie between them, such as duration of contact,
- or reports of ties between different alters(65).

Missing data

Social network studies often suffer from having a large amount of missing data. Incomplete data arises from a number of sources in social network studies including the so-called boundary specification problem, respondent inaccuracy, non-response in network surveys, or can be introduced via study design (66).

Missing data can have quite substantial effect on network structure. Network structure is dependent on all the nodes within the population and the effect can be exacerbated when missing data are not evenly distributed across all nodes. For example, missing a 'key member' of the group can, in some cases, change the network structure dramatically whereas missing a node that lies on the peripheries of the network can have very little impact. There are still many open questions regarding missing network data such as, who is likely to be missing and what is the best way of dealing with incomplete data?

To limit bias due to the effects of missing data it is possible to reconstruct the network by assuming reciprocal ties, this is based on methods developed by Stork and Richard (67). Huisman found that for undirected networks with small amounts of missing data this method gives better results than ignoring the missing data (68). For example, assigning the reciprocal score where a pair of individuals had rated each other only once i.e. if person x is missing and person y has rated their relationship with 5, we assume that x would also rate person y with a 5.

Social network questionnaires used in this thesis

The data collection questionnaires used in this thesis were designed with input from doctoral supervisors (RI, DG, TK, PJD) and a social network methodologist (Bob Hanneman). We intended to analyse the social network of medical students and foundation doctors, (see above for details) and the attitudes to influenza vaccination amongst the participants. Using a paper-based questionnaire we collected relational data during the 'flu season. We used an observational study design due to the ethical and practical restrictions on collecting this type of data. For example, due to the pressures on hospitals to maintain high levels of staff vaccination and the occupational risk to participants, a RCT would have been unethical. We decided against the use of a cohort study due to the intense data collection required to map the social network multiple times. For each study the questionnaire was revised based on previous research (examples can be found in the appendices at the end of this thesis).

Each participant received a participant information sheet, a consent form and the questionnaire. Each questionnaire contained a section for social network data and a section for demographic data.

Social network data inputting used in this thesis

Once the data collection period was completed the identifiable social network data was anonymised. Each participant's name was removed from their questionnaire and replaced by a randomly generated code. Anonymous data was then inputted into an excel spreadsheet. The social network data was inputted in the form of an adjacency matrix. Accuracy was ensured using a variety of checks: only values between 0-5 can be entered into the spreadsheet; every 20th individual's data entry was repeated to ensure consistency; and 5% of the data entry was randomly selected to be checked by a second researcher. The demographic and influenza data was inputted into a separate database and subjected to similar data validation checks as those described above. These two databases were combined in R, using the unique identifier code. Thus, we were able to construct the social network using the adjacency matrix, where the individuals were represented as nodes. Attributes can were assigned to the nodes using the demographic and influenza data.

Network visualisation

A natural initial step in network analysis is to create a network visualisation of the relational data. Networks are rarely constrained by spatial location (none of the networks presented in this thesis represent fixed points in space). Thus, network diagrams can be heavily manipulated, and so care must be taken to ensure that they present information effectively whilst not misleading the viewer.

Network analysis software often contains algorithms which plot the network in visually appealing ways and readers may associate network analysis with the beautiful graphics that are commonplace in this field. For example, the Kamada-Kawai algorithm iteratively repositions nodes to reduce the number of edges that cross one another; or the Fructerman Rheingold algorithm places groups of nodes with a large number of ties closely together this can highlight clusters of nodes.

Node Centrality Measures

Node centrality measures indicate the most important nodes within a network. Calculating centrality on a network is not necessarily straight-forward. There are several different ways of defining centrality on a network, popular measures include: degree, between-ness, eigenvector centrality etc. (see below for details). These are often assimilated with influence in the network. Degree purely measures the number connections a node has and this can be equated to the popularity of a person. Between-ness measures the number of shortest paths that traverse the node – this reflects its ability to act as a gatekeeper. Eigenvector centrality considers the number of connections your connections have, so can be thought of as more of a measure of power. For example, if a node has lots of connections, but these connections have few other connections, then its degree would be high but not its eigenvector centrality.

Significance

It is common practice to produce a value of significance with statistical estimates, for example by giving confidence intervals for a mean value. Unfortunately, traditional methods for calculating significance become invalid when applied to network data – this is because data are not independent. Rather, in social network analysis we compare statistics obtained to a reference distribution. For example, the calculation for assortativity provides a coefficient within the range -1 to 1, we then compare this value to what we would expect if the assortativity was random. In the following chapters we calculate vaccination assortativity – whether vaccinated individuals are more likely to form ties with other vaccinated individuals or not. To confirm random assortativity we generated a reference distribution using permutation. Multiple networks (n=1000) were generated with the same topological structure however vaccination status was permutated randomly. The assortativity value for each can then be calculated – this provides information on the range of assortativity values we would expect under random permutation. Similar techniques are outlined by Barclay et al. (69).

R_0 calculation

R_0 is a fundamental calculation in epidemiology. Classically R_0 is defined as the average number of secondary infections. Thus for an SIR model in a completely susceptible and homogenously mixed population the effective R_0 is given by:

$$R_0 = \beta \, \mathrm{x} \frac{1}{\gamma} \; x \; \frac{S}{N}$$

where N is population size, β is the contact rate and 1/γ is the average infectious period and S/N is the fraction of contacts that are susceptible.

R_0 is widely used to calculate the transmission potential of diseases and the likely size of emerging epidemics (70,71).

When considering disease epidemiology on a network defining a sensible R_0 is much more difficult. The number of possible secondary infections is limited by the individual's neighbourhood size and epidemics can quickly become locally saturated depending on the network structure. Developing suitable methods to define outbreak severity on networks is an ongoing research problem. One method of estimating severity is to simulate the outbreak on the network multiple times and assess each individual's risk.

Glossary of terms used in the field of social network analysis

Node level

Isolate

An Isolate is a node without any edges connecting it to the network.

Cliques

A sub-graph of nodes where each node is connected to every other node is known as a clique. In real social networks large cliques are uncommon thus the concept was extended to include n-clique – in which pairs of nodes can be connected at a path distance of n and still be included in the clique(72).

Transitivity

Transitivity (or clustering) measures the extent to which node's tend to form 3-cliques – i.e. if B has ties with A and C transitivity measures the probability that A and C will form a tie (64).

Point centrality measures

Local centrality (degree)

In undirected graphs this is the number of connections a node has, known as its degree. This describes a node's connectivity within its local environment. Local centrality can be extended to connections at various path lengths. However, examining connections after those at distance 2 is unlikely to be informative as this will begin to include all edges in a graph - intuitive when considering the idea of 6 degrees of separation. Unfortunately, local centrality is dependent on the number of nodes in a graph; therefore, can only be used to compare nodes in the same graph or graphs of equal size. In 1979, Freeman proposed a relative local centrality in which the degree was given as a proportion of the total number of possible connection the node could have achieved (73).

Closeness (Global Centrality)

Closeness is a measure of distance from a node to all other nodes in the network - where the distance is the length of the shortest path between them. A node is close to many other nodes if it is a short distance away from them, therefore, the node is globally central.

Betweenness

Between-ness measures to what extent a node lies between other nodes in the network thus can assume a 'gatekeeper' role - in that a node is dependent on the gatekeeper node if the paths that connect it pass through the gatekeeper. The calculation for between-ness was proposed by Freeman in 1980 (74) based on ideas drawn from Bavelas (75) and is as follows:

$$\beta(P_k) = \sum_{i \neq P_k \neq j} \frac{g_{ij}(P_k)}{g_{ij}}$$

Where i, j and P_k are nodes and g_{ij} is the total number of shortest paths from i to j and $g_{ij}(P_k)$ is the number of those paths that pass through P_k giving a betweenness value for P_k: $\beta(P_k)$.

Eigenvector centrality

Eigenvector centrality expands on the notion of degree centrality. Eigenvector centrality is the sum of all the nodes connected to a central node weighted by the degree of each connecting node. Thus this measure takes into account a wider scope of the network. Eigenvector centrality is found using an algorithm rather than a formula; developed by Bonacich, the algorithm searches for the largest eigenvalue of the adjacency matrix (76).

Assortativity

Newman developed assortativity as a measure which describes the extent to which node's connect to similar vertices (the formula given are for undirected networks) (77). This is commonly described in terms of degree; as in nodes of a high degree are more likely to connect to other nodes of a high degree. However, assortativity can also be used to describe whether or not nodes connect preferentially to nodes displaying similar characteristics i.e. displaying homophily:

$$r = \frac{\sum_i e_{ij} - \sum_i a_i b_i}{1 - \sum_i a_i b_i}$$

where e_{ij} is the fraction of edges in a network that connect nodes of type i to type j. And a_i and b_i are the fractions of each type of an edge's end that is attached to nodes of type i.

Assortativity values lie in the range (-1,1), an assortativity value of 0 indicates that the hypothesis that nodes tend to like-nodes is not true, 1 implies positive assortative mixing and -1 implies negative assortative mixing.

Network level structure

Network Density

The proportion of connections that are actually present out of the number of potential connections i.e.:

$$d = \frac{E}{\frac{n(n-1)}{2}}$$

where E is the number of edges in the network and n is the number of nodes.

Unfortunately, network density isn't a very robust measure, it can be influenced by node centralization, network size and the number of cohesive subgroups.

Geodesic

The shortest distance between two nodes – the fewest number of edges that must be traversed to travel from one node to the other.

Diameter

The diameter is the longest geodesic in the network.

Average Path length

An average of all geodesics in a network.

Introduction to spatial analysis techniques applied to social network data.

Analysis of spatial data has a long-established history in both statistics and epidemiology. One of the earliest and best-known examples of disease mapping was Dr John Snow's map of the cholera outbreak on Broad Street in London in 1854. Mapping deaths in the area allowed him to identify the source of the outbreak as a contaminated water pump. Since then the field of spatial epidemiology has grown to include applications in epidemiological surveillance and ecological modelling.

A common assumption applied in spatial epidemiology is that of spatial dependency – that is the assumption that the location of data points with respect to other data plays an important role in the analysis. As a result most spatial statistics methods operate on the premise that data collected over a region in space found more close together are more likely to be highly correlated with each other than points further apart (78). The exact determination of which data points should be deemed close together is a matter of debate and often a modelling choice dependent on other information within the data. Commonly, the data space is reduced to connections between points that are close together and therefore likely to be highly correlated. For example, figure 3 shows a map of Scotland reduced to a network for analysis. The points on this map represent geographic regions, with lines drawn between regions indicating a spatial connection. Thus, we can begin to identify similarities between spatial statistics and social network analysis. If we apply the assumption that the actions of an individual are more likely to correlate with those in their social group rather than others in the population, we might apply methods developed in spatial analysis to social network data. We would evaluate an individual's behaviour, taking into account the influence of their spatial position within the social network.

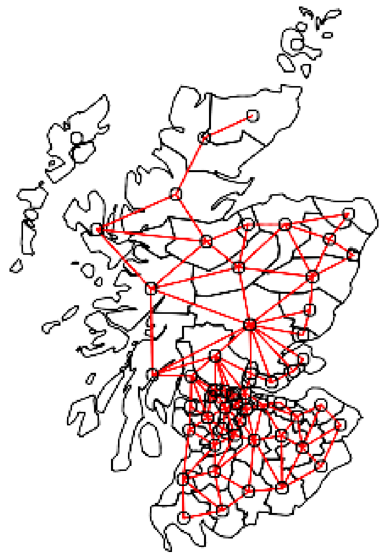

Figure 3. Map of Scotland giving an example of how a spatial network might be drawn. This gives an indication as to the similarities between a spatial network and a social network.

Theoretically, the assumption defined above allows any human behaviour to be studied using spatial methods to analyse an individual's social network. For example, health behaviours such as: smoking, likelihood to breast feed, or vaccination choice. An implication is that we wish to model a process on a Markov random field, that is, we wish to incorporate information from a node's neighbours into a model. Below, we discuss the application of the auto-logistic class of model to social network data.

In this thesis, we are interested in the decision to vaccinate which is a binary outcome. Consequently, logistic regression is an obvious initial model however, spatial dependency may be incorporated in a number of ways. First, we shall consider autoregressive models. Autoregressive means that the dependent variable regresses with itself, so the spatial autocorrelation in the dependent variable can be modelled. Autoregressive models are constructed similarly to regression models with spatially-lagged values of the response variable treated as explanatory variables. In 1954, Whittle defined the simultaneous autoregressive model (SAR model) (79). Following this, in 1974, Besag proposed auto-models for analysing lattice data (80,81). The auto-logistic (auto-binomial) and conditional autoregressive models (CAR models) are two examples. Figure 4, depicts the relationship between these different models. Besag's models make use of the Markov property inherent in the dependency assumption on the data – that the effects from all others in the network/lattice can be included by conditioning only on an individual's neighbours.

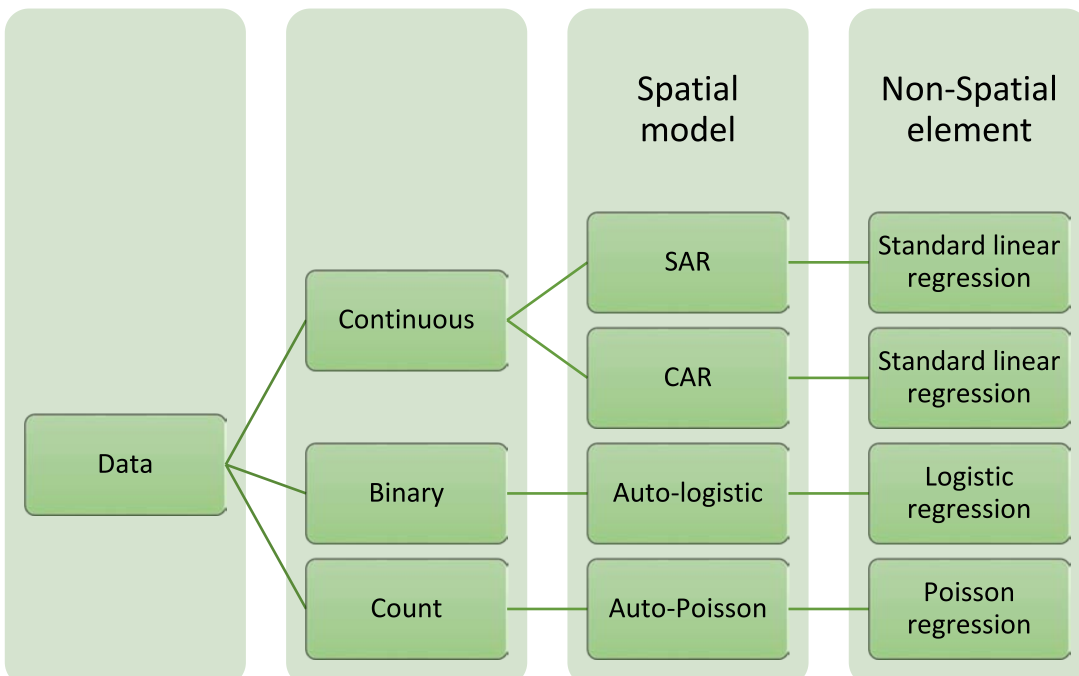

Figure 4: Diagram depicting the relationship between different data types and spatial models.

Auto-logistic Model

The auto-logistic model incorporates spatial correlation into the logistic model for binary data. The specification is as follows: let Y be our variable of interest, where $Y_i \in (0,1)$ represents the observation at the ith data point for $i = 1 \ldots n$, the full conditional distributions are given by:

$$logit[Y_i | all\ other\ Y_j\ ] = \boldsymbol{\beta} + \boldsymbol{\gamma} \sum_{\boldsymbol{j \sim i}} (Y_j = 1)$$

where, $\boldsymbol{\beta}$ are the regression parameters.

Parameter Estimation

In principle, we would maximise the likelihood to infer the parameters. Unfortunately, an analytical form of the full likelihood is intractable because observations are conditionally dependent on one another. This leads to a particularly awkward normalizing function introduced when maximising the likelihood. Thus, we use Monte-Carlo maximum likelihood, details of which are given in chapter four.

Qualitative methodology

Much like social network analysis, qualitative research methods originated in the social and behavioural sciences: sociology, anthropology and psychology. Qualitative research offers a flexible methodology that can produce an in-depth understanding of why individuals behave in a certain way (82). Qualitative research tends to focus on research into questions that are best be answered using data that cannot easily be measured or counted, such as results from interviews with study participants (83). In qualitative research, the term data is used to mean the material collected in the course of research, such as interview transcripts. Thus, although both qualitative and quantitative research are involved in the collection and analysis of data, the two disciplines have different perspectives.

Dr Dawn Goodwin is a social scientist; I undertook the qualitative part of this work largely under her direct supervision. The interviews were conducted and transcribed by RE, subsequent analysis and reporting of the data was largely done by RE with input from DG, RI and TK.

Qualitative rationale

The fifth chapter in this thesis consisted of a qualitative analysis exploring the issues important to early career doctors among around occupational seasonal influenza vaccination. A series of semi-structured interviews were used to investigate how social relationships shaped seasonal influenza vaccination uptake by medical students and early career doctors. A semi-structured interview allows the researcher the freedom to fully explore each participant's vaccination decision making process.

Quantitative methods were used to observe the social network and assess the structures that form within it. However, from purely observing this network it is not possibly to specify how certain social structures form – for example, it is almost impossible to ascertain whether clusters form due to imitation (people copying the behaviour of their peers) or homophily (individuals affiliating with those who act in a similar way) or a mixture of both (84). A qualitative approach sheds light on how behaviour within the group might affect an individual's vaccination attitudes.

Human behaviours are derived from a series of decisions, ranging in complexity,each potentially interlinked. One example is that an individual's decision to vaccinate may be informed by the perceived risk that harm will occur if no preventive action is taken - a central idea in most decision-oriented theories of health behaviour is (85,86). An individual's assessment of risk is affected by the overall vaccination coverage in the population. However, vaccination is a hidden behaviour, which adds complexity as individuals may not be able to predict confidently vaccination coverage among their peers. Furthermore, the effectiveness of the seasonal influenza vaccine varies from year to year. These factors complicate an individual's risk assessment. Thus, there is complexity even in this simple example of a single factor (risk perception) that may inform vaccination decisions.

Ultimately, a vaccination decision is formed from the interaction between multiple factors – a highly complex system. Thus, given this complexity it is no surprise that medical professionals have wide ranging views on their requirement to comply with seasonal influenza vaccination (87).

Qualitative interviewing

Semi-structured interviews were used to allow the researcher freedom to explore the participant's unique experiences whilst maintaining a central narrative within individual interviews. An interpretivist approach was used in data collection and analysis - my position as the researcher in this setting is that reality is socially constructed, and that individuals interpret their own reality in different ways. During the interviews I remained sensitive to this position, allowing participants to explore their own reality of vaccination. Interviews do not simply record views impartially, they are instrumental in the construction of views (88). In this, both the researcher and the respondent contribute to the data generated during the interview. As such, quantitative notions of sample size, representation, and bias are inappropriate when using this methodology. However, it is common practice to examine the effects the researcher may have had on the data generated during qualitative interviews, in subsequent analysis and reporting, therefore, my reflections on this process are included in the sixth chapter (89).

Epistemology and decision-making

Each year many HCWs take a decision to comply with or abstain from having the influenza vaccination. Many factors may influence the decision-making process, such as previous experiences and peer influences. During the qualitative part of this study we intended to try to understand participant's attitudes towards the seasonal influenza vaccine, and why they chose to vaccinate, or not. As such we were interested in participants knowledge of the vaccine and its validity, in how their knowledge about vaccination was formed, and in how this knowledge informed the vaccination decision. Thus, we describe an epistemological problem. Investigating the way in which participants acquired knowledge about the influenza vaccine is important as this is integral to the decision-making process. Although ultimately an individual may take a decision with autonomy, they do so in a social and professional setting thus may be influenced by a multitude of factors – subtle, complex, and at times conflicting (90). Previous experience, knowledge, social influence, practicalities, incentives, and deterrents may all affect an individual's decisions regarding the influenza vaccine. Therefore, when we explore these decisions, and the factors involved in making them, we must be aware that they are influenced externally. These concepts of epistemology, decision-making and accountability informed the context and content of the interviews.

Thematic analysis

Thematic analysis is a method for describing a qualitative data set in a coherent and detailed manner, and allows for interpretation of aspects of the research topic (91). Thematic analysis provides a flexible and useful research tool, it is not tied to any pre-existing theoretical frameworks (92). In this programme of work, we used thematic analysis with the aim of understanding the complexities involved in HCWs' influenza vaccination decisions. We highlighted key themes as those which appear of the most importance to the participant, though this is not necessarily correlated with those ideas which occur most frequently. Thus, RE played an active role in data analysis - identifying and reporting key themes. Data were coded inductively, without trying to fit it into a pre-existing coding frame, thus, the themes identified are data driven. Analysis was an iterative process, continual cycling back and forth between theory construction and examination of data – gradually developing a theory on the network and social determinants of vaccination compliance in HCWs (83). Further details of the qualitative methodological approach are given in the relevant chapter.

Quality in qualitative research.

Qualitative research has emerged with a requirement to produce findings that can be supported by high quality evidence, and assurances that they can be trusted (93). Hammersley, suggests reflections on truth and relevance should be used to improve research quality, rather than a rigid assessment of it (94). Throughout the analysis and reporting of my qualitative work I have been sensitive to issues of quality, this is clear from a well theorised, clearly contextualised and in depth discussion presented in chapter five. In this thesis, qualitative interviews were used to provide a large amount of data pertaining to influenza vaccination. We have worked to ensure that findings were based on a critical investigation of all of the data. In order to ensure this and maintain quality, findings were derived using the maximal amount of data, and divergent cases were used to evaluate provisional findings. Thus, data were treated comprehensively, iteratively moving between data and analysis, and ensuring that all parts of the data were inspected. I ensured that this protocol was implemented by interviewing, transcribing, and analysing the data. By providing transparency I feel that the findings presented in this research warrant trustworthiness (83).

Chapter summary

Seasonal influenza causes considerable morbidity each year. Vaccination is used as an effective method of influenza prevention and control. HCWs are advised by the Chief Medical Officer for England to get the seasonal influenza vaccine as it is believed that this may protect both themselves and their patients and reduce overall infection transmission within a hospital (95). Despite increased interest (via CQUIN rewards) in improving vaccination uptake, HCW's seasonal influenza vaccination coverage remains stagnant and below target levels.

Social networks are important factors in infectious disease transmission and may have an effect on some human behaviour. The network topology may influence disease spread and therefore subsequent perceptions of disease risk. Spatial statistics provide a methodology to quantitatively assess the effects of an individual's neighbours' vaccination on his own decisions. And qualitative research methods may be used to investigate social behaviour. This work will use a mixed methods approach to explore the seasonal influenza vaccination uptake within early career doctors and medical students.

Paper 1

Seasonal influenza vaccination amongst medical students: a social network analysis.

By: Rhiannon Edge, Joseph Heath, Barry Rowlingson, Thomas Keegan and Rachel Isba.

Published in PLOS One.

This presents a social network approach to studying vaccination uptake within a population. The medical student population was assessed for signs of individuals with a seasonal influenza vaccination clustering in the network. We presented a novel approach combining social network analysis techniques with an individual based model to suggest how these might be used to explore disease epidemiology from a network perspective. I was lead author on the manuscript with co-authors editing and reviewing the document.

Paper 2

Assessing the effects of social networks on vaccination behaviour.

By: Rhiannon Edge, Rachel Isba, Thomas Keegan and Peter Diggle.

This study utilised tools based in spatial statistics to better understand social network effects on individual behaviour. We used an auto-logistic modelling approach with the social network structure as an input, along with covariate effects to assess an individual's likelihood of receiving the influenza vaccination. We observed a repulsion effect from having more vaccinated neighbours i.e. as the number of an individual's vaccinated neighbours increased the likelihood of themselves being vaccinated reduced. This effect could not be accounted for by covariates in our model.

Paper 3

Ambivalence, convenience, and socialisation: exploring the uptake of influenza vaccine amongst medical students and early career doctors.

By: Rhiannon Edge, Dawn Goodwin, Rachel Isba and Thomas Keegan.

Published in Qualitative Health Research

This study aimed to provide a deeper insight into the influenza vaccination practices of HCW using a qualitative approach. We conducted a series of semi-structured interviews, to explore the factors informing influenza vaccination decision-making.

We found that socialisation, either encouraging or discouraging vaccination, was important although its effects were attenuated by participants' previous experiences and a lack of clarity around the risks and benefits of vaccination. Many medical students and early career doctors demonstrated some ambivalence towards the seasonal influenza vaccine as many did not have strong intentions to accept or decline vaccination. Moreover, we found that there was considerable disparity between an individual's opinion of the vaccine, their intentions, and their vaccination status.

Chapter 3

Seasonal influenza vaccination amongst medical students: a social network analysis based on a cross-sectional study.

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Abstract

Introduction

The Chief Medical Officer for England recommends that healthcare workers have a seasonal influenza vaccination in an attempt to protect both patients and NHS staff. Despite this, many healthcare workers do not have a seasonal influenza vaccination. Social network analysis is a well-established research approach that looks at individuals in the context of their social connections. We examine the effects of social networks on influenza vaccination decision and disease dynamics.

Methods

We used a social network analysis approach to look at vaccination distribution within the network of the Lancaster Medical School students and combined these data with the students' beliefs about vaccination behaviours. We then developed a model which simulated influenza outbreaks to study the effects of preferentially vaccinating individuals within this network.

Results

Of the 253 eligible students, 217 (86%) provided relational data, and 65% of responders had received a seasonal influenza vaccination. Students who were vaccinated were more likely to think other medical students were vaccinated. However, there was no clustering of vaccinated individuals within the medical student social network. The influenza simulation model demonstrated that vaccination of well-connected individuals may have a disproportional effect on disease dynamics.

Conclusions

This medical student population exhibited vaccination coverage levels similar to those seen in other healthcare groups but below recommendations. However, in this population, a lack of vaccination clustering might provide natural protection from influenza outbreaks. An individual student's perception of the vaccination coverage amongst their peers appears to correlate with their own decision to vaccinate, but the directionality of this relationship is not clear. When looking at the spread of disease within a population it is important to include social structures alongside vaccination data. Social networks influence disease epidemiology and vaccination campaigns designed with information from social networks could be a future target for policy makers.

Key Words

Seasonal influenza vaccination, social network analysis.

Introduction

Globally, influenza affects an estimated 5 million people per year (3). Influenza causes considerable morbidity each year and can be a primary, underlying, or contributing factor to cause of death (2). Seasonal influenza vaccination remains the best method of preventing influenza spread through populations by generating herd immunity (96). Many researchers in this area suggest that higher vaccination coverage within a hospital will have positive benefits such as: a reduction in patient mortality, less staff absence, and a reduction in influenza transmission within long-term care homes (23,25–27,97). Despite this, in 2013, only 55% of healthcare workers (HCWs) had a seasonal influenza vaccine, and uptake varied across different healthcare trusts in England and Wales. This figure was also considerably lower than the 75% target set by the Chief Medical Officer (CMO) for England (98). Commonly cited reasons for HCWs not having seasonal influenza vaccination include: a lack of knowledge about the vaccine, fear of side effects, doubts about risk of influenza infection, concerns about vaccine effectiveness, and a dislike of injections (99–101). Educational campaigns designed to address these issues appear to have had little effect on uptake amongst HCWs (102). There is a need, therefore, for novel approaches to improving seasonal influenza vaccination uptake amongst this group. Social network analysis approaches have been used to study the uptake of other vaccinations in different populations, so lend themselves to the study of seasonal influenza vaccination.

Social network analysis (SNA) stems from the concept that an individual's actions are affected by their peers and that people should therefore be studied in their wider social context. A network is formed from individuals (nodes) connected via ties (relationships). Social network models are increasingly being applied to epidemiological studies of, for example, effects on smoking cessation, and in the investigation of sexually transmitted diseases (45,50). Using a SNA approach to study how social structure relates to vaccination attitudes, vaccine uptake, and the effects on influenza transmission among medical students is a novel approach.

In human populations, individuals rarely mix randomly - there is often influence (positive or negative) from social structures. For example, recent work has shown that the percentage of contacts in a parent's social network recommending non-conformity has been found to be a negative predictor for childhood vaccination (103). In a work setting, HCWs seem to be positively influenced by their co-workers' vaccination practices (104). This phenomenon of imitation, has been observed elsewhere in relation to vaccination – a recent study of US high school students found that individuals who vaccinated were more likely to form connections with others who also vaccinated (69,103). Non-random distribution of vaccination in a population (vaccination homophily) is thought to increase the likelihood of infectious disease spread within that population, as clusters of non-vaccinated individuals can form reservoirs from which disease may spread (105–107). Increasingly, researchers in infectious disease epidemiology are recognising the importance of including a contact network when modelling influenza outbreaks (108).

At Lancaster Medical School (LMS) students are encouraged to have a seasonal influenza vaccination in a way that mirrors the recommendations given to HCWs. We used a SNA approach to look at vaccination distribution within the network of the LMS student population and combined these data with the students' beliefs about the vaccination behaviours of others. We then developed a model which simulated influenza outbreaks in the population to study the effects of preferentially vaccinating well-connected individuals within this network.

Methods

Ethics, consent and permissions

Prospective ethical approval was obtained from Lancaster University Research Ethics Committee and, following a verbal and written explanation of the study, each participant gave informed consent prior to taking part. The study was performed in accordance with the Declaration of Helsinki. Identifiable data were collected using a standard SNA approach and then anonymised prior to entry and analysis.

Study population

Lancaster Medical School (LMS) is in the North West of England and offers a primary undergraduate medical degree course over five years of study. At the start of the academic year 2013/14, there were 253 students actively enrolled in the course. All students were invited to participate in the data collection which took place over two months at the end of term 1 and the start of term 2.

Data collection

Each participant gave written consent and completed a paper-based data collection instrument. In addition to providing basic demographic information (age, sex, and year of study), participants were also asked to indicate whether they had received the seasonal influenza vaccination. They were also asked what percentage of medical students they thought had also received the vaccine.

Individuals were also asked to rate the strength of their relationship with every other student in the medical school on a six-point scale:

0 - "I do not recognise this name"

1 - "I recognise this name but I would not recognise the person if I saw them"

2 - "I would recognise the person if I saw them"

3 - "I know this person and see or speak to them once or twice a week"

4 - "I know this person and see or speak to them three or more times a week"

5 - "I live with this person/have a close relationship with them/socialise with them on a regular basis"

This scale was used to gain an understanding of how much time students spent with others in the medical school without having to rely too heavily on participant recall (participants were provided with the names of everyone enrolled in the school). We wanted to include the strongest ties for analysis, however, when the data was dichotomised at level 5 isolates appeared (these individuals would have then been removed from much of the analysis), so we dichotomised the data at level 4 and above.

Missing Data

We dealt with missing data by assigning the reciprocal score where a pair of individuals had rated each other only once i.e. if person *x* had not completed the data collection instrument and person *y* had rated their relationship with a strength of 5, we assumed that *x* would also rate person *y* with a 5. Where neither party had provided data relating to the relationship, an assumption was made that there was no relationship. Both of these approaches are considered acceptable when constructing a social network with a high response rate (67). For the influenza vaccination data, we used three possible states of vaccination for the network – vaccinated, unvaccinated, and unknown (no response) – but for the outbreak model, these options were reduced to vaccinated and unvaccinated (which included those who had not provided a response).

Social Network Analysis

Data were inputted into a Microsoft Excel file after being anonymised. The relationship data were then converted to numerical data, using the values outlined above, and inputted into an adjacency matrix. The adjacency matrix for the medical school had 253 rows and 253 columns – corresponding to the number of students in the school. The social network of the medical students was then dichotomised so that it only contained 'close' relationships i.e. students who met frequently and were therefore more likely to influence each other. Thus, only relationships categorised as: "I know this person and see or speak to them three or more times a week" or "I live with this person/have a close relationship with them/socialise with them on a regular basis" were included in this analysis. These were thought to be the most likely contacts to facilitate infectious disease spread, and we assume that these contacts would be more likely to influence the individual compared with others in the LMS network that they did not meet frequently. The final adjacency matrix therefore contained only 0s and 1s. Reciprocal ties were assumed, according to standard practice in this type of social network analysis so regardless of what the other party had answered if one person in the pair had rated the relationship as a 4 or a 5, a tie was constructed (68). All subsequent statistical analysis and network visualisation was carried using R statistical software with igraph (109).

The adjacency matrix was then used to create and visualise a simple (nodes cannot form ties with themselves), undirected (all ties were assumed reciprocal), un-weighted (all ties post-dichotomisation were either present or absent) network. Vaccination data were then mapped onto the social network data. Data relating to students' beliefs about the vaccination status of others were handled separately.

To investigate whether clusters of vaccinated or unvaccinated individuals existed we measured the assortative mixing of participants based on their vaccination decision, by calculating the assortativity coefficient. Assortativity is a standard network measure developed by Newman (110) and calculation of this measure produces a value between -1 and 1, with values tending to -1 indicating negative assortativity, 0 indicating random (or no) assortativity, and 1 indicating positive assortativity within the network. Newmans assortativity measure was employed as it has been commonly used by the scientific community – therefore widely understood and easy interpreted, gives a coefficient bounded between -1 and 1 rather than a slope, and typically is supported by a statistical test, unlike other measures (such as Pastor-Satorras method (111)). Assortativity was calculated for the entire medical student population as well as for individual year groups. Additionally, a sensitivity analysis was carried out to look at the effect on assortativity of dichotomising the data at a value of greater than equal to 3 and 5, as well as the main study threshold of 4.

Each individual's influence on the network was measured in terms of how well connected they were within the network. SNA defines multiple measures for connectivity - we scored individuals based on their degree and between-ness. In a network, an individual's degree is simply the number of connections they possess (73) and the between-ness score is based on the extent to which they are able to act as a 'gate-keeper' between the others in the network. A high between-ness score indicates that an individual lies between groups and is therefore important for the transmission of information or disease between the groups. Between-ness is calculated for each individual as the number of most efficient paths from every student to every other student, that pass through the individual (73).

The individual-based outbreak simulation model

An individual-based outbreak model was developed using R. Using the network data we simulated an influenza outbreak and assessed the effects of preferentially vaccinating according to the social network analysis data. The probability that an individual was infected at any given time step was dependent on: the adjacency matrix, their vaccination status, and appropriate transmission parameters derived from the literature – these were based on a discrete time step of one day.

Transmission parameters were based on the following assumptions:

- relationships – for the purposes of the simulation, students were judged as having a 'close' relationship if they lived together or met more than three times a week (see above)
- the literature suggests that 11% of un-vaccinated close contacts of cases become infected with the influenza virus based on the H1N1 equivalent (probability 0.11) (112)
- the transmission probability was reduced by 74% (probability 0.0286) for students who chose to vaccinate, based on previous reported vaccine efficacy (113)

- recovery – the probability of recovery was set at 0.334, based on a recovery time of 3 days and did not vary within the population. If an infected individual moved into the recovered stage, they could no longer infect others or themselves be infected a second time.

We identified un-vaccinated individuals with the highest scores for between-ness and degree and additionally vaccinated them to test the effects on the simulated outbreak of influenza. We also ran the simulation with randomly selected un-vaccinated people to vaccinate, as a control. During each run of the simulation, the outbreak was allowed to continue until it became unsustainable i.e. burned out on its own. During each trial the simulation ran 1500 times, with each simulation selecting a random student to introduce the virus into the population. At every time step the infected individuals were given the opportunity to transmit the infection to their susceptible neighbours (the probabilities of infection are given above). For each vaccination strategy, the likelihood of each individual in LMS being infected was calculated as a percentage of the number of times they were infected in the 1500 possible outbreaks. The Kolmogorov-Smirnov test was used to show whether there was any significant difference in the likelihood that individuals in the LMS would contract infection when students were vaccinated according to either their between-ness or degree scores, or randomly.

Results

Initial data exploration

Of those studying at LMS (n=253), 217 (85%) participated in this study. Non-participants were mainly in the final two years of study (response rates: Year 1 89%, Year 2 89%, Year 3 100%, Year 4 80%, and Year 5 70%). Participants were aged between 18 and 38. Sixty-five percent of respondents (141/217) had received a seasonal influenza vaccination, which represented 56% (141/253) of the entire network (76/253 unvaccinated and 36/253 unknown). The data was dichotomised at either 0 (scoring a relationship of 1, 2 or 3, or those who did not provide data) or

1 (scoring a relationship of 4 or 5). The true agreement between individuals relationship scoring was then calculated (number of matching scores/total number of scores) as 90.3%. Descriptive statistics for the network are given in table 2.

n	253
Diameter	5
Average path length	2.69
Transitivity	0.41
Average degree (mean(sd))	18.4 (9.90)
Closeness (mean(sd))	0.0015 (0.0002)
Betweenness (median (IQR))	72.6 (22.2, 236.9)
Eigenvector centrality	0.093 (0.046, 0.202)

Table 2: Network descriptive statistics.

Figure 5 shows the entire medical student social network, dichotomised at a value of 4 (corresponding to the statement "I know this person and see or speak to them three or more times a week"), with the vaccination data superimposed on the structure.

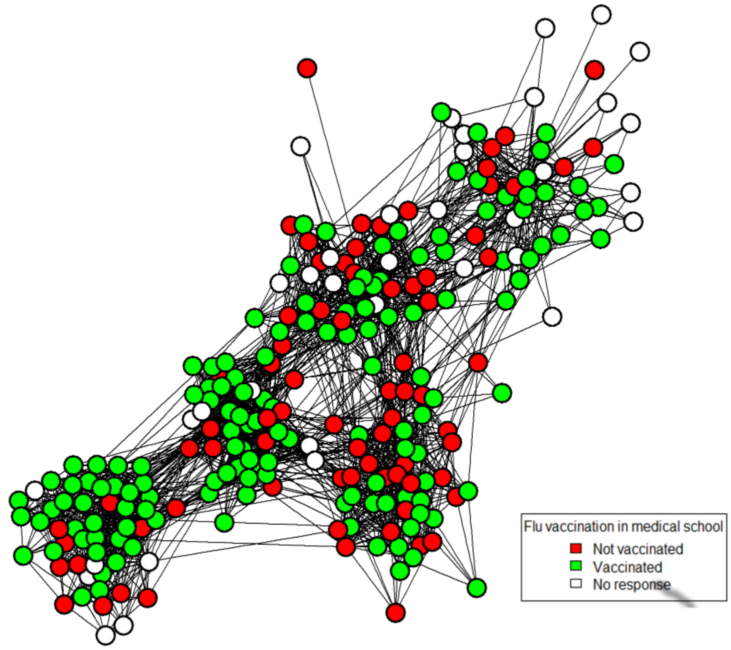

Figure 5. Network map of Lancaster Medical School. A network map of the Lancaster Medical School social network dichotomised at 4 ("I know this person and see or speak to them three or more times a week") and above. Seasonal influenza vaccination status is superimposed: non-vaccinated are red; vaccinated are green; and non-responders are white.

Measures of connectivity – between-ness and degree

When dichotomised at 4 and above, the mean degree (number of contacts per person) was 18 (range 1 to 57) and year groups tended to cluster together. Figure 6 highlights the individuals who had the top 20 scores for between-ness and degree. Both these measures assess connectivity in a different way. This can lead to different sets of people being identified as the most connected; in this case there was some overlap between the groups.

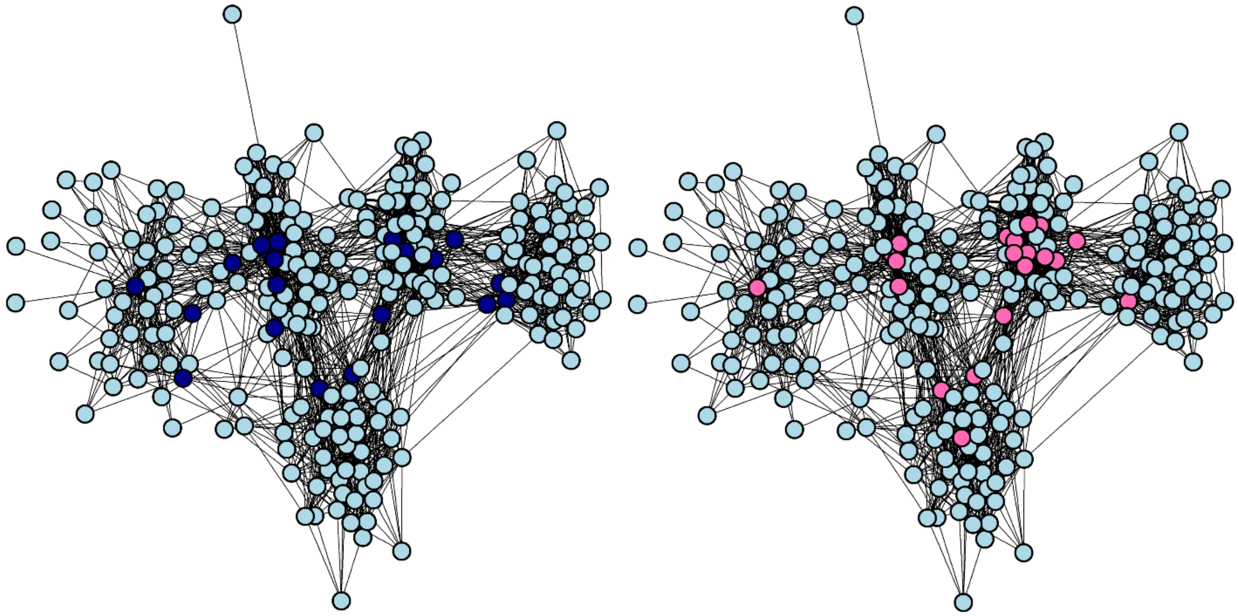

Figure 6. Well-connected individuals in the medical school. The LMS social network, dichotomised at 4 ("I know this person and see or speak to them three or more times a week") and above. On the left, individuals with the 20 highest scores for between-ness are highlighted in dark blue, and on the right, individuals with the 20 highest degree scores are highlighted in pink.

We compared vaccination between the most well-connected individuals (i.e. those with a high degree) and the least well-connected individuals (i.e. those with a low degree). Thirteen of the 20 (65%) most well-connected individuals were vaccinated and 12 of the 20 (60%) least well-connected individuals were vaccinated. Figure 7 shows that the degree density plots for vaccinated and non-vaccinated individuals appear very similar. Applying the Kolmogorov-Smirnov test to these data yielded a non-significant p-value (D = 0.24444, p-value = 0.1359) thus we cannot reject the hypothesis that these two distributions are similar.

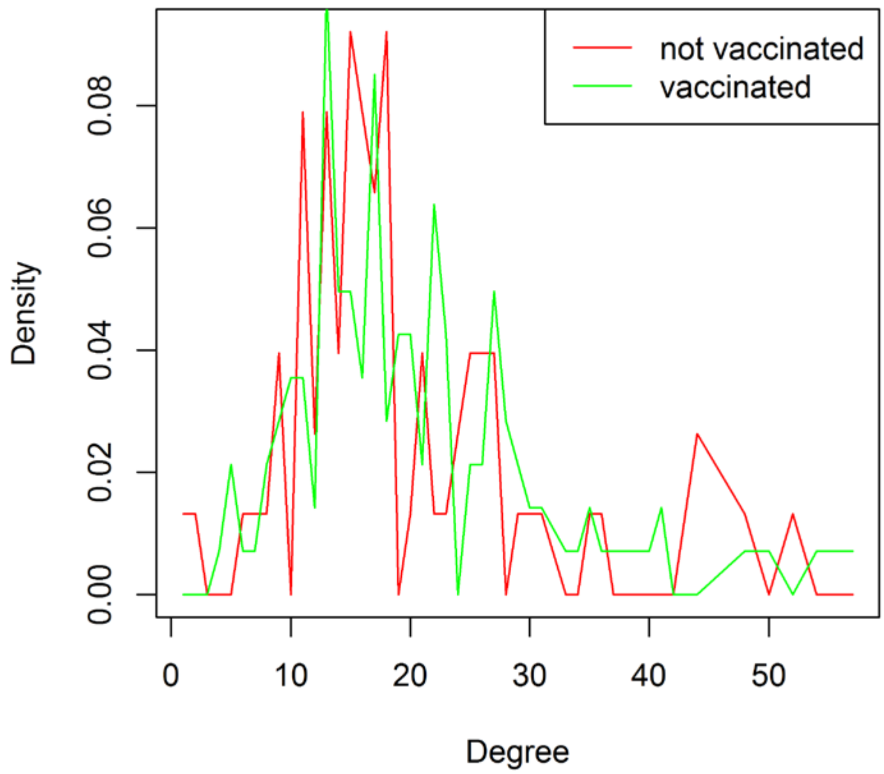

Figure 7. Degree density plot. The degree density of vaccinated (green) and non-vaccinated (red) individuals appears similar.

Perception of Influenza vaccination coverage

Figure 8 shows the medical students' perceptions of their peers' vaccination behaviours. On average, participants believed that 60% of other students at LMS were vaccinated (range 10-100%). When students were grouped based on their perceptions of the vaccination status of others, we found that an individual's vaccination status correlated with perception – i.e. students suggesting high levels of vaccination amongst their peers were themselves more likely to be vaccinated (and the reverse was also true, Figure 8).

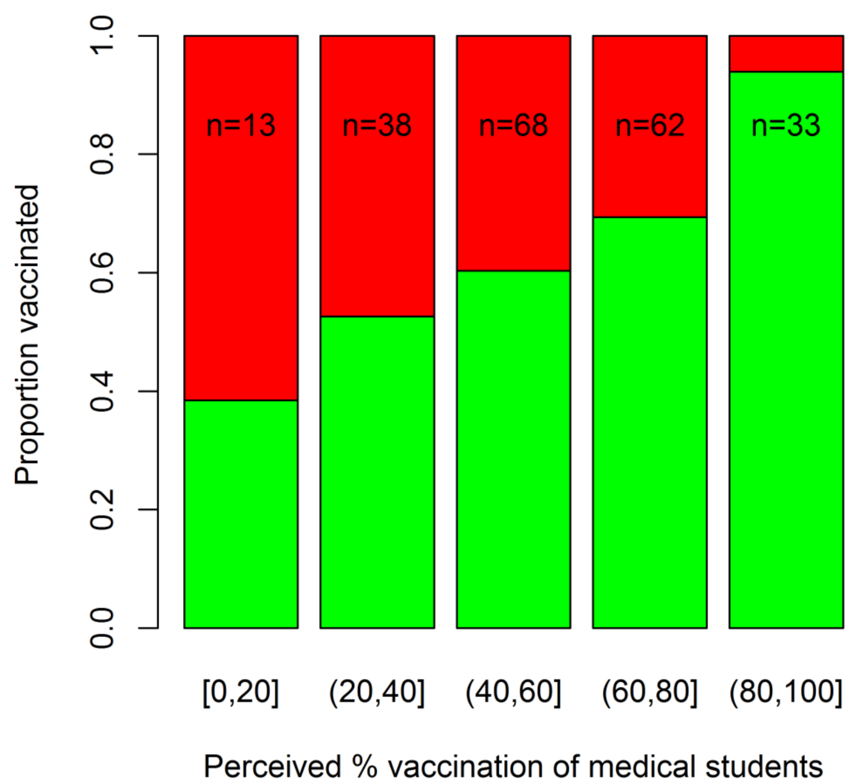

Figure 8. Perception of vaccination within the medical school. Graph showing perception of vaccination and the vaccination coverage within each group. Green represents the vaccinated individuals within each group and red the non-vaccinated. The groups are divided up by level of perceived vaccination coverage and the number of students that fall into each group is given at the top of each bar.

Assortativity

Assortativity of vaccination status was used to test whether individuals preferentially connected with others with similar vaccination status, and to identify any clusters or pockets of highly vaccinated or un-vaccinated students. In this study, assortativity coefficients for vaccination were consistently around zero, regardless of year group or level of dichotomisation, indicating near-random mixing between vaccinated and un-vaccinated students (Table 3).

	Year group	1	2	3	4	5	All years
Contact level	**5**	0.02	-0.10	-0.03	-0.01	-0.09	0.00
	4 and above	0.01	0.02	0.01	-0.06	-0.06	0.03
	3 and above	-0.03	-0.01	-0.02	-0.07	-0.07	0.01

Table 3: Vaccination assortativity at Lancaster Medical School, stratified at various levels of contact.

Outbreak simulation results

From the outbreak model we found that the effect of vaccinating additional individuals based on between-ness and degree were similar i.e. the likelihood of individuals contracting the infection tended to be similar, irrespective of vaccination based on between-ness or degree. As an example, Figure 9 shows the results of the outbreak simulation following the vaccination of an additional 20 students according to either their between-ness score, their degree, or randomly. After vaccination of this additional 8% of the population (20 students), the outcome of the experimental influenza outbreak was similar for between-ness and degree, and considerably better than a random vaccination policy. The Kolmogorov-Smirnov test confirmed this, when the results from the simulation under random vaccination and vaccination according to between-ness were compared, we rejected the hypothesis that the two distributions were similar ($D = 0.22925$, p-value < 0.0001). When comparing the results under the random and between-ness vaccination policies we could not reject the hypothesis that the two distributions were similar ($D = 0.035573$, p-value $= 0.9972$).

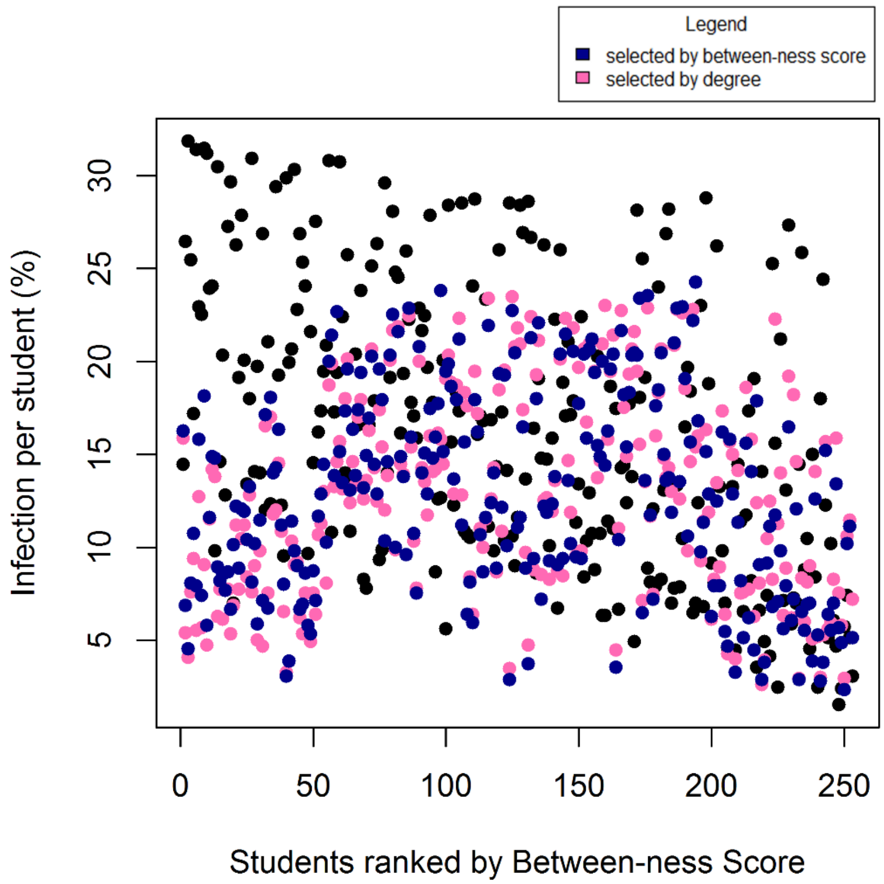

Figure 9. Influenza outbreak simulation results. A scatter plot showing the percentage number of times each individual was infected during the 1500 influenza outbreak simulations. Under the conditions: random vaccination (black); vaccination by between-ness (blue); and, vaccination by degree (pink).

Discussion

Vaccine uptake among participants was 65% - slightly higher than in the wider medical community (98). In contrast to work carried out in other populations, we found that this medical student population did not display vaccination assortativity – individuals at LMS who were vaccinated were just as likely to befriend non-vaccinated individuals as vaccinated individuals. We found a correlation between a student's perception of the vaccination coverage amongst their peers and their own decision to vaccinate. The influenza simulation model demonstrated that well-connected individuals potentially have a disproportional effect on disease dynamics and may provide a focus for targeted intervention.

This study represents a novel approach to looking at seasonal influenza vaccination uptake and outlines potential benefits of this as a methodological approach in infectious disease epidemiological. Whilst missing data is a common limitation in social network studies we dealt with this by using a robust approach that, combined with a high response rate, means that we can be confident in our findings. The simulation model presented in this study is a method of testing the effects of vaccination policy changes that would otherwise be almost impossible to implicate and measure in the real world. The major limitation of this study is that we have artificially created a closed network made up of the LMS medical student body and assumed that meaningful contact only takes place within this network. In reality, medical students interact on a daily basis with a wide variety of individuals outside of the student body, and these interactions will be especially important in the context of disease transmission. Additionally, students are likely to be influenced by a variety of other people, and these influences may have a direct (or indirect) impact on decisions they make around vaccination. This study used social network data as a proxy for the contact network for the purposes of the simulation model. Adequate data collection for the true contact network is an ongoing problem in this field and requires further research. Alternative approaches to data collection include the use of wireless sensors that detect face-to-face contact between participants. These avoid reporting bias and some measurement error. However, this method also has limitations: the network is limited to participants only, and it is generally feasible only to record the network for a limited time period. The data collection method implemented here is a cheaper and simpler alternative, suitable to this study. However, more research is needed to establish the most effective data collection tools. Other limitations of this study are the choice and number of assumptions made when setting transmission parameters – for example, no attempt was made to include differing contact between days and times of day (both of which have an impact on disease transmission) – and the fact that all the data presented are self-reported.

The LMS medical student population did not display vaccination assortativity and this finding is at odds with previous similar studies in other populations (69). There are many possible explanations for this observation, for example, it may be the case that the social dynamics within the medical student network are sufficiently different from other networks as to produce different vaccination structures. Equally it may be that the nature of seasonal influenza vaccination is such that decision-making relating to it is different compared to routine childhood vaccination for example. Only the population of interest was studied, individual's ego-centric data was not collected. The external factors influencing medical students' decisions around seasonal influenza vaccination may have had an impact on assortativity that has not been examined here. Extending this investigation to include ego-centric data is a natural progression of this study and may lead to an explanation for how vaccination assortativity develops in a population and why we might find differences in assortativity. Previous research has suggested that populations with strong vaccination assortativity can lead to an increased vulnerability to disease due to the formation of reservoirs of unvaccinated individuals. Therefore, the lack of assortativity seen at LMS may actually lower the risk of an influenza outbreak compared to other populations. More research is needed to determine the drivers of vaccination assortativity and to examine it in a wider context.

An individual student's perception of the vaccination coverage amongst their peers appears to correlate with their own decision to vaccinate, but the directionality of this relationship is not clear. It may be that either vaccinated individuals perceive higher vaccination coverage amongst their peers or that people who perceive a higher vaccination in their peers get vaccinated as a form of imitation behaviour. It is worth noting that students did not appear to have very good knowledge of true vaccination uptake generally and this has implications for those seeking to increase seasonal vaccination uptake rates in other healthcare professionals. We speculate that it may be possible to increase vaccination uptake by educating individuals about vaccination coverage – perhaps encouraging individuals to vaccinate because their co-workers have. However, game theory might suggest the opposite – if an individual thinks that a large proportion of their immediate neighbours are vaccination, they may choose not to vaccinate instead relying on herd immunity (114). Understanding the effects of peer influence could have huge implications for a range of public health policies. Our results suggest that there is little difference in the degree distribution between vaccinated and non-vaccinated individuals. When looking at the spread of disease within a population it is important to include social structures alongside vaccination data and this work supports the argument for the inclusion of social network analysis in epidemiological studies of infectious disease outbreaks. The simulation model we have developed shows that outcomes of vaccination strategies based on selecting individuals based on between-ness and degree were similar, and both were better than a random vaccination policy. This is important as vaccination campaigns targeting individuals based on a high degree score would be preferential due to its relative ease of calculation. Further investigation into well-connected individuals is necessary – profiling these individuals may highlight demographic proxies for influence – campaigns could then be targeted based on these.

Conclusions

Considering past work in this area and the results outlined here it is clear that social networks influence disease epidemiology - thus vaccination campaigns designed with information from SNA provide a potential target for policy makers. Future work should include further empirical analysis of HCWs, working towards a better understanding of social network phenomena such as assortative mixing or influential individuals.

List of abbreviations

SNA – Social Network Analysis; CMO – Chief Medical Officer; HCW – Healthcare Worker; LMS – Lancaster Medical School

Authors' contributions

RI conceived the programme of research of which this was a part. JH collected the data. RE was responsible for input and analysis of the data, supervised by RI and TK. RE developed the model and BR developed the code. RE wrote the manuscript with input from RI and TK. All authors had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. All authors have approved the original version of the manuscript for publication. RE is the guarantor(s) for the study. The lead author (RE) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Acknowledgements

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Supplementary 1. Seasonal influenza in medical students: an outbreak simulation model based on a social network approach.

Rhiannon Edge, Joseph Heath, Barry Rowlingson, Thomas Keegan and Rachel Isba

Published in The Lancet: 19 November 2014

Abstract

Background

There is increasing interest in the effects of social networks on disease dynamics. We simulated the spread of influenza through a population of medical students where transmission was related to the social network structure and vaccination status of individuals.

Methods

All students at Lancaster Medical School, Lancaster, UK (n=253) were asked to rate the strength of their relationship with all other students from the medical school. Students also self-reported their influenza vaccination status. An individual-based outbreak model was developed using R statistical software. Using these data, combined with appropriate transmission parameters, we simulated an influenza outbreak and assessed the effects of preferentially vaccinating according to the social network analysis data. We ran the simulation 1500 times. Each simulation selected a random student to introduce the virus into the population. For each vaccination strategy, the likelihood of each individual being infected was calculated as a percentage of the number of times they were infected in the 1500 possible outbreaks.

Findings

215 students (85%) responded. Non-responders were assumed to have reciprocal relationships with responders; therefore, it was possible to construct the entire medical student network. We found that the outcomes of vaccination strategies based on between-ness (the extent to which an individual lies between others in the network) and degree (the number of connections an individual has), which are both measures of connectedness, quickly converged. As more individuals were vaccinated, the likelihood of individuals contracting the infection tended to be similar, irrespective of vaccination based on between-ness or degree. After vaccination of an additional 8% of the population (20 students) the outcome of the experimental influenza outbreak was similar for both strategies.

Interpretation

Our results add to a small pool of evidence supporting targeting vaccination of individuals according to between-ness in an attempt to reduce the spread of influenza. However, in small, densely connected populations, vaccination according to degree might be preferential because of the rapid convergence and the relative ease of locating individuals with a high degree versus those with high between-ness. This study suggests that vaccination strategies that target highly connected individuals within a network might limit spread of infectious disease. Future work could include evaluating current vaccination approaches using social network analysis.

Funding

University Hospitals of Morecambe Bay NHS Foundation Trust funded data collection.

Contributors

RI conceived the programme of research of which this was a part. JH collected the data. RE was responsible for input and analysis of the data, supervised by RI and TK. RE developed the model and BR developed the software. RE wrote the abstract with input from RI and TK. All authors have approved the original version of the abstract for publication.

Declaration of interests

We declare no competing interests

Chapter 4

Assessing the effects of social networks on vaccination behaviour.

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2 affiliated with the Pennine Acute Hospitals NHS Trust.

Abstract

Background

The Chief Medical Officer for England recommends that healthcare workers have a seasonal influenza vaccination, in an attempt to protect both patients and NHS staff. Despite this, only 55% of healthcare workers are vaccinated. Social network analysis is a well-established research approach that looks at individuals in the context of their social connections. Social networks have been found to affect the behaviour of the individuals within them, thus they may be useful in understanding vaccination habits.

Methods

Data were collected from a population of early career doctors split into two year-groups and two geographical areas (east and west axes) who self-reported their seasonal influenza vaccination status, along with basic demographic characteristics and information about their social relationships within the population. We used a social network analysis approach to look at vaccination distribution within this network of doctors. We assessed the network density and the assortativity of influenza vaccination status within the population. We then applied an auto-logistic model to assess how the probability of an individual vaccinating is associated with their peers' behaviour.

Results

Of the 200 eligible early career doctors, 138 (70%) provided complete data, of whom 100 (72%) reported that they had received a seasonal influenza vaccination. The auto-logistic model demonstrated that having vaccinated neighbours reduced an individual’s likelihood of being vaccinated. And, further analysis including adjusting for year-group, geographical area and their interaction did not account for this effect. Using the auto-logistic model with its ability to allow for covariate effects gave us a better understanding of the data than using standard social network analysis tools alone.

Conclusion

This population exhibited vaccination coverage levels higher than those seen in other healthcare groups. Within the network, we observed a heterogeneity in network topology and its effects on behaviour.

Key Messages

1. Network effects on behaviour are complex, but the auto-logistic model provides an effective way of assessing behaviour on a real social network in the presence of other variables.
2. Rather than the expected diffusion of behaviour, we observed that having vaccinated neighbours reduced an individual's likelihood of being vaccinated.

Introduction

Influenza affects millions of people each year - it causes considerable morbidity and is a primary or underlying cause of death for thousands of people worldwide(3). The General Medical Council's (GMC) guidance on Good Medical Practice (2013), advises that healthcare workers (HCWs) in the UK receive immunisation against common serious communicable diseases, such as influenza, in order to protect both patients and colleagues(115). Higher coverage of influenza vaccination within a hospital is believed to reduce patient mortality, staff absences, and potential influenza epidemic size, thus protecting some of those at the greatest risk from influenza(97). Despite this, vaccination rates remain highly variable for HCWs and are below the government target of 75%. Currently around 55% of healthcare workers in England and Wales have a seasonal influenza vaccination (98,116).

There is increasing interest in the effects exerted by social networks on public health(117). A social network is made up of nodes (individuals) connected via ties (relationships) (118). Disease dynamics within a network may be influenced by characteristics such as its density, how the individuals in the network interact, and which individuals are vaccinated against, or susceptible to, the disease. For example, changes in the vaccination status of a few key individuals within a network may have a disproportional impact on disease spread(119).

It has been shown that an individual's behaviour may be influenced by their peers – for example, research has found that smokers are more likely to befriend other smokers (45). The grouping of similar individuals within a population, known as homophily, could have a considerable impact on disease dynamics. For example, if clusters of non-vaccinated individuals exist within a network, a disease could rapidly spread through these groups, reducing the protective effects exerted by herd immunity.

Healthcare workers' vaccination behaviour may be similarly influenced by the behaviour of their neighbours within their social network. Baron et al suggests that healthcare workers seem to be influenced by their co-workers' vaccination practices (104). In the current study, we used network analysis to study the characteristics of a social network of foundation doctors (FDs) - early career doctors in the first two years of postgraduate training in the UK – and related these to the distribution of seasonal influenza vaccination within the same population. We then extended this by investigating how the probability of an individual receiving an influenza vaccine was influenced by the behaviour of his/her neighbours in the network.

Methods

Prospective ethical approval was obtained (15RECNA17) from Lancaster University Research Ethics Committee and the Pennine Acute Hospitals NHS Trust (PAT). Prior to data collection, each participant gave informed consent following a verbal and written explanation of the study. Identifiable data were collected and subsequently anonymised before data entry and analysis, as is accepted practice in SNA studies of this type.

Participants

Data were collected during January/February 2015. All foundation doctors (FDs) working at the Pennine Acute Hospitals NHS Trust during that period were invited to participate. The foundation training programme at the PAT runs over two years and across four different hospital sites in Greater Manchester, forming two geographically distinct axes, east and west. As part of their training, FDs are required to attend compulsory weekly teaching sessions. Data collection took place during several of these sessions to optimise response rates.

Data Collection

Each participant completed a paper-based questionnaire. Participants self-reported their seasonal influenza vaccination status for winter 2014/15, alongside basic demographic information.

Participants were then asked how often they had contact with every other person on the foundation training programme using a six-point scale: 0 - I have never met this person; 1 - I recognise this person's name but wouldn't see them regularly; 2 - I occasionally see this person for very short periods of time; 3 - I see this person briefly at irregular intervals; 4 - I see this person on most shifts/4 or more days a week; 5 - I see this person on almost every shift for long time periods/live with them.

The relational data were then transferred into a numerical adjacency matrix, from which a network was constructed. Prior to analysis, the data were dichotomised at level 4, "I see this person on most shifts/4 or more days a week" and above, in line with previous research (119). Where one person declared a relationship with another at this level, this was assumed to be reciprocal. There may be cases in which neither person declared any relationship, although one was present, this was treated as missing data and excluded. This produced an un-weighted (relationships were binary) and undirected (reciprocal ties were assumed) network.

Social Network Analysis

The FDs' influenza vaccination status was considered with respect to the underlying network structure. Individual-level characteristics, such as a doctor's degree score (the number of ties an individual possesses), were examined along with global measures such as overall network density, and density in different groups within the network (the number of ties throughout the network in relation to the number of individuals within the network).

The assortativity coefficient was calculated to assess whether or not vaccination status showed homophily within the FD population. The assortativity coefficient is a standard network measure originally defined by Newman (110). The coefficient can range from -1 to 1, where -1 suggests negative assortativity (opposites attract) and 1 implies positive assortativity (like attracts like). With the assortativity coefficient we provide a tolerance interval for a random network by calculating the range of assortativity values expected from multiple generated random networks. We generated a reference distribution using permutation. Multiple networks (n=1000) were generated with the same topological structure however vaccination status was permutated randomly. The assortativity value for each was then calculated – this provided the range of assortativity values we would expect under random permutation. Similar techniques are outlined by Barclay et al. (69).

Logistic and Auto-logistic Regression

The auto-logistic model, was used to further investigate the effect of an individual's social connections on their influenza vaccination decision(81). The specification of the auto-logistic model is given in equation 1(54).

For, $Y_i = \begin{bmatrix} 0 : not\ vaccinated \\ 1 : vaccinated \end{bmatrix}$

[Equation 1]

$$\log\left(\frac{\mathrm{P}(\mathrm{Y_i} = 1 \mid \text{all other } \mathrm{Y_i})}{1 - \mathrm{P}(\mathrm{Y_i} = 1 \mid \text{all other } \mathrm{Y_i})}\right) = \underline{x}'_i \underline{\beta} + \gamma \sum_{\mathrm{j \sim i}} (\mathrm{Y_j} = 1)$$

Where j ~ i indicates contact between individuals i and j, and $\underline{x}_i$ is a vector of covariates associated with individual i.

The parameters β describe how the covariates affect the likelihood of an individual being vaccinated, whilst the parameter γ describes how this likelihood is modified by the behaviour of the individual's social contacts in the network. To fit the model, we used Monte Carlo likelihood inference (120), using numerical optimisation with initial values of β derived by fitting a standard logistic regression and initial value of γ = 0. The logistic regression model is a sub-model of the auto-logistic model when γ = 0, thus this was used to give initial parameter estimates for beta, but not for formal inference. We then repeated the optimisation multiple times, using data simulated from the fitted model, to generate parametric bootstrap confidence intervals.

Results

One hundred and thirty-eight of the 200 foundation doctors invited to take part provided complete data (sex, year of training, axis, and vaccination status). Amongst respondents, 100 (72%) were vaccinated (Table 4).

Table 4: Seasonal influenza vaccination uptake by the foundation doctors stratified by their demographic factors.

		Number Vaccinated	Total	Vaccination coverage (%)
Sex	**Female**	51	68	75.00
	Male	49	70	70.00
Year	**1**	55	76	72.37
	2	45	62	72.58
Axis	**East**	47	69	68.12
	West	53	69	76.81

Figure 10 shows the foundation doctors' social network, along with their influenza vaccination status (n=138). The assortativity coefficient for the entire FD social network was -0.034 with a tolerance interval of (-0.12, 0.10), i.e. the estimated assortativity is negative, but not significantly so at the conventional 5% level.

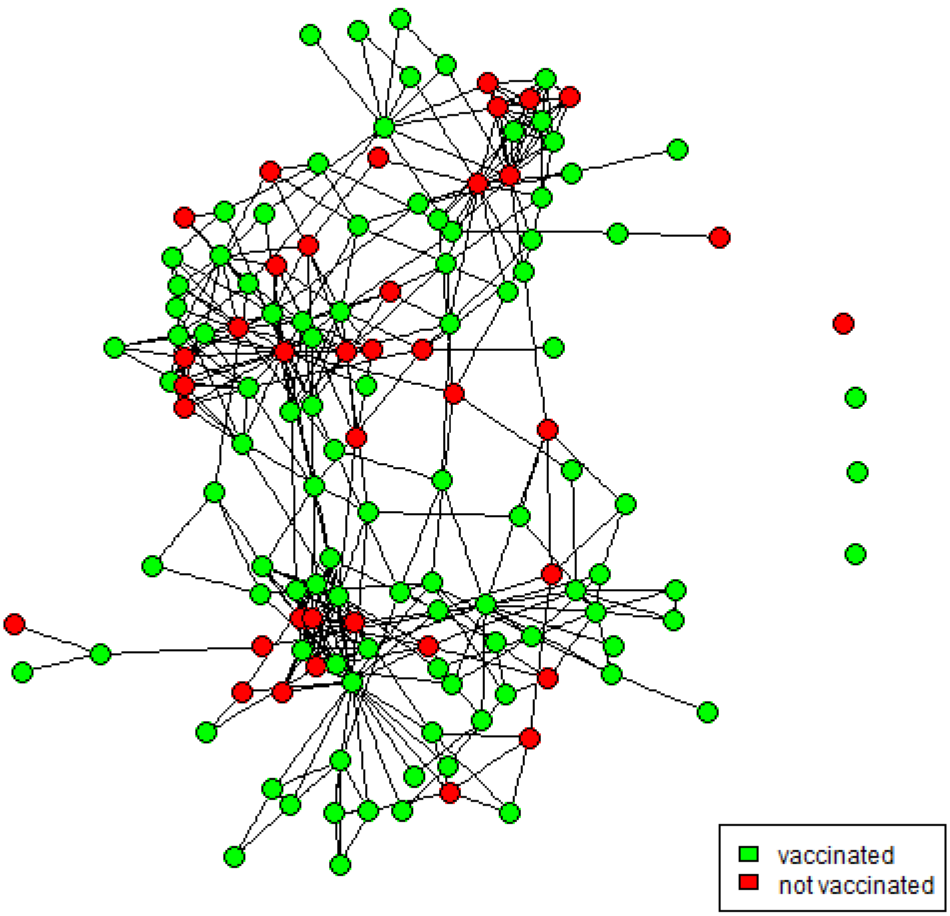

Figure 10. The foundation doctor social network sociogram for those who returned complete data, dichotomised at >= 4 ("I see this person on most shifts/ 4 or more days a week"), and coloured according to individual vaccination status.

The social network structure of the foundation doctors varied between geographical areas and year-groups (Figure 11). For example, amongst second-year doctors, the network density is higher in the east than in the west axis, with 223 ties amongst the n=31 doctors in the east axis compared with 73 ties amongst the same number in the west axis.

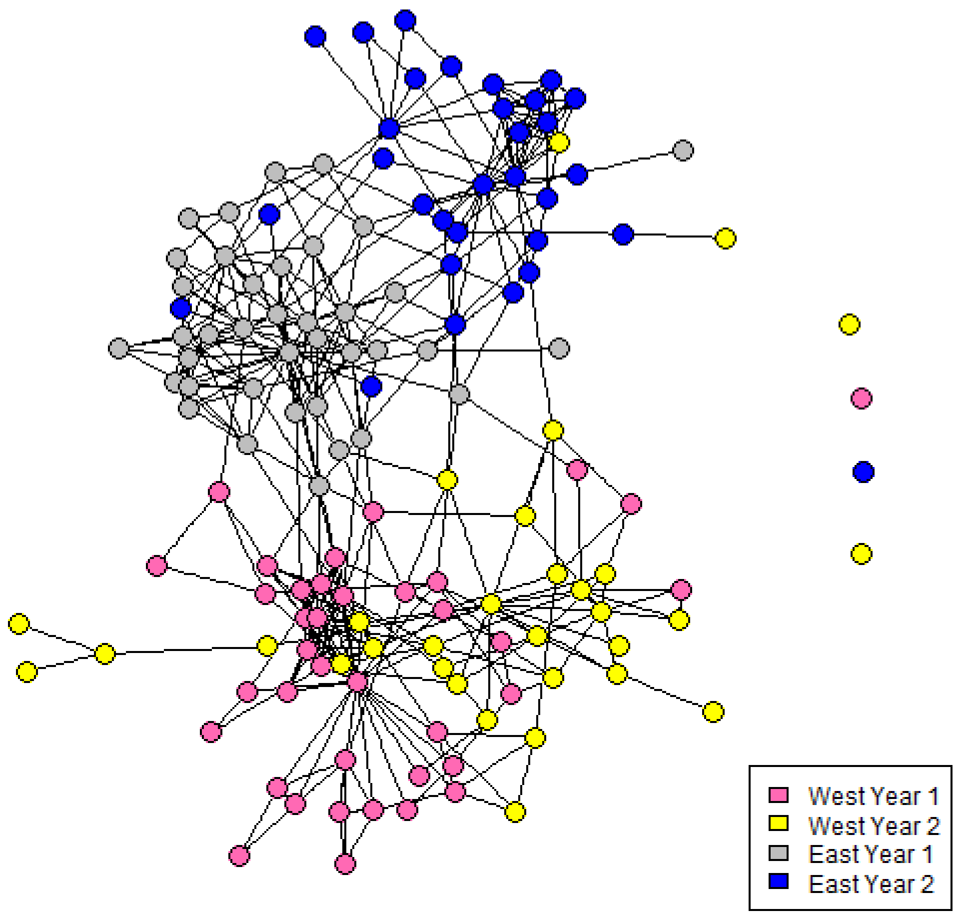

Figure 11. A sociogram depicting the foundation doctor network (n=138), coloured by sub-groups: year and axis

Auto-logistic Regression

We first fitted the auto-logistic model without covariates. The maximum likelihood surface for auto-logistic model 1 is described by Figure 12. The coefficient for γ, the social network parameter, was -0.122, with 95% confidence interval (-0.197, -0.047), i.e. a repulsion effect that is significant at the conventional 5% level.

We then added covariate effects, for year and axis. Followed by a model which included the interaction term between these main effects, however, data were too sparse to fit this model. In this model, the data is effectively split into 4 groups, within these groups there are very small numbers of non-vaccinated and vaccinated individuals, even before adding the complication of the neighbourhood structure (see Table 5). Thus, we explores a model with a dichotomous variable with 1 corresponding to those in year 2 on the west axis, and zero otherwise. This is because we could see clear difference in the network structure for this group and the logistic regression model suggested that this indicator variable may be important (Table 6). The estimate of γ remained significantly negative in the presence of covariates (year and axis, and when an indicator variable was included for those in year two, west). None of the covariates (excluding γ) were statistically significant in the auto-logistic regression model – in all cases the confidence intervals include zero. This suggests that the repulsion effect seen in both the social network analysis and the auto-logistic analysis without covariates may not be an artefact of the heterogeneity within the network.

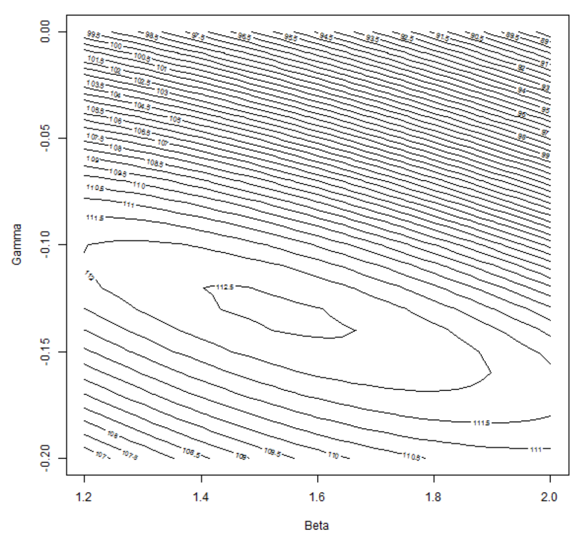

Figure 12. Contour plot showing the likelihood surface for auto-logistic model 1.

Table 5. Contingency table showing the spread of the foundation data between year, axis and vaccination status.

		Axis east		Axis west	
		year 1	year 2	year 1	year 2
vaccinated	yes	23	24	32	21
	no	15	7	6	10

Table 6. Parameter estimates for the auto-logistic regression models fit using the foundation doctor data.

		Parameter Estimate	Lower CI	Upper CI	MC se
Auto-logistic model 1 *(Excluding covariates)*	Intercept coefficient	1.532	0.977	2.087	0.09
	Gamma coefficient	-0.122	-0.197	-0.047	0.01
Auto-logistic model 2	Intercept coefficient	1.342	0.539	2.145	0.136
	Year coefficient	-0.149	-1.045	0.747	0.115
	Axis coefficient	0.498	-0.942	1.240	0.163
	Gamma coefficient	-0.121	-0.223	-0.019	0.010
Final Model	Intercept	1.701	0.937	2.465	0.007
	Year = 2 & Axis = W	-0.501	-1.481	0.479	0.009
	gamma	-0.136	-0.210	-0.062	0.0007

The auto-logistic model has allowed us to assess which areas of the population are the less likely to vaccinate, taking into account their social network structure. For example, those in year 2 working on the west axis are less likely to vaccinate. By taking account of these demographic effects we can better understand the influence of the social network on vaccination uptake. Table 7 provides estimates for the likelihood of vaccinating given an individual's characteristics and number of neighbours.

Table 7: A table of the likelihood of vaccination for foundation doctors given the final model.

Number of Neighbours	1	2	3	4	5	6
Year 2 & West	0.72889	0.703078	0.675902	0.647484	0.617984	0.587587
Other	0.831038	0.812449	0.792325	0.770653	0.747439	0.722721

Discussion

After excluding missing data, the foundation doctors' self-reported vaccination coverage of 72% (100 vaccinated out of 138, with possible range 50% - 81% dependent on the vaccination status of non-respondents), was higher than the national average of 55% (98).

Our social network analysis of the foundation doctor population showed a negative, but not significant, assortativity in the network as a whole. The auto-logistic model without covariates gave asignificantly negative estimate of γ, the network parameter, suggesting that having vaccinated neighbours reduces the individual's probability of being vaccinated (Table 6 and 7). However, the auto-logistic model, unlike the assortativity coefficient, can be extended to allow for covariate effects, thus giving a richer interpretation of the network structure.

We observed other differences in the network structure amongst the four strata defined by year and geographical axis. Second year foundation doctors on the west axis of the Trust had a much sparser social network than the other year/axis groups. In sparse social networks the potential for information transfer (behaviour adoption, infectious disease spread, etc) is fundamentally diminished by social distancing (121). However, Shirley et al. suggest that even when network density is equivalent, network topology may still have an effect on diffusion of information (122). In the auto-logistic model with covariate effects, the repulsion effect remains significant – demographic covariates were unable to account for the repulsion effect (γ). However, only a limited number of covariates were studied, it may be that more research is necessary to investigate alternative factors that may affect information transfer. Interventions aimed at improving vaccination uptake should be sensitive to the differences between sub-groups within the relevant population and may need to be targeted at specific demographic sub-groups. Network effects on behaviour are complex, but the auto-logistic model provides an effective way of assessing behaviour on a real social network in the presence of other variables that affect individuals' responses.

The repulsion effect on vaccination uptake seen in this population is unusual, more commonly diffusion of behaviour is observed. However, vaccination is a complex behaviour in which there is a cost to taking the vaccination (pain of injection, perceived side effects, etc.) to be weighed against the benefits of vaccinating. The behaviour of others directly affects the latter – if more people are vaccinated the risk of infection is lower. Furthermore, it may also be the case that the negative consequences of vaccination are more commonly discussed than the benefits within this population. More research is necessary to fully understand repulsion behaviour on a network.

We have outlined a methodological approach to understanding behaviour in a network. The auto-logistic model could easily be modified in a number of ways, for example, to include the network term using the proportion, rather than number of neighbours who are vaccinated. Furthermore, although the approach has been successful in fitting a parsimonious model to this relatively small dataset, attempts to fit more complex models quickly lead to large standard errors and, consequently, low power to detect more complex network structure. Also, the log-likelihood surface becomes almost flat, and the algorithm may then fail to converge. For example, we experienced this failure of convergence when fitting a model with an intercept, axis term, year term, interaction effect and a gamma term. We believe that sparse data lead to this model being unidentifiable. A larger dataset would enable more complex models to be fitted and more precise inferences. In our analysis, we chose to ignore non-respondents because their social contacts were unknown. Future research into this modelling approach should include investigation into the estimation of missing data to allow subjects with partially observed information to be included in the analysis.

An inherent limitation of our data is that they were self-reported, and therefore potentially subject to reporter bias. Additionally, making a decision about influenza vaccination is a complex process – many people are neither completely for nor against influenza vaccination (see chapter five). There may be varying levels of attitudes to vaccination that could be described using an ordinal or continuous scale, rather than as a simple binary variable. Extracting this more nuanced data is a challenge, and may require qualitative methods such as in-depth interviews with participants (see chapter five).

Using the auto-logistic modelling approach, we have expanded on the results of the social network analysis. This novel approach to analysing social network data allows us to investigate the underlying process that has led to an observed network and its vaccination distribution. Quantitative methods that explore social behaviour are likely to become instrumental in defining targeted approaches to improving public health - this study outlines a suitable approach to investigating how an individual's behaviour might be influenced by the behaviour of his/her neighbours in a network. For example, the results of this particular study suggest a need to improve vaccination campaigns for those in the second year on the west axis particularly, to consider the importance of the social network effects on vaccination, and to explore these in more detail.

Acknowledgments

The Authors would like to thank the foundation doctors at the Pennine Acute Hospitals NHS Trust for generously giving up their time to participate in this study and staff who enabled data collection.

Funding

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Author Contributions

RE wrote the manuscript with input from other authors all of which have approved the final version. RE collected the data. PJD devised the statistical methodology, which RE implemented with input from PJD. This study is part of a larger programme of work devised by RI.

Supplementary 2. Auto-logistic model parameter estimation

The auto-logistic model incorporates spatial correlation into the logistic model for binary data. The specification is as follows, let Y be our variable of interest, where Y_i $\epsilon(0,1)$ represents the observation at the ith data point for $i = 1 \ldots n$, the full conditional distributions are given by:

$$For,\ Y_i = \begin{bmatrix} 0 : not\ vaccinated \\ 1 : vaccinated \end{bmatrix}$$

$$\log\left(\frac{P(Y_i=1 \mid \text{all other } Y_i)}{1-P(Y_i=1 \mid \text{all other } Y_i)}\right) = \underline{x}'_i\underline{\beta} + \gamma \sum_{j\sim i}(Y_j = 1).$$

From Besag 1974, we have

$$\frac{P(\underline{y})}{P(\underline{0})} <=> f\left(\underline{y}\right) = c(\theta)g(y)$$

Where $c(\theta)$ is an intractable constant and $g(y)$ is a known function. We can manipulate this to use Geyer's method of Monte-Carlo maximum likelihood (123):

$$f\left(\underline{y}\right) = c(\theta)g(y)$$

$$\int f\left(\underline{y}\right) = \int c(\theta)\ g(y;\theta)$$

$$1 = c(\theta) \int g(y;\theta)dy$$

$$1 = \frac{c(\theta)}{c(\theta_0)} \int g(y;\theta) * \frac{g(y;\theta_0)}{g(y;\theta_0)}\ c(\theta_0)\ dy$$

$$= \frac{c(\theta)}{c(\theta_0)} \int \frac{g(y;\theta)}{g(y;\theta_0)} f(y;\theta_0)\, dy$$

$$= \frac{c(\theta)}{c(\theta_0)} * E_0 \left[\frac{g(y;\theta)}{g(y;\theta_0)}\right] \quad (1)$$

We can simulate the expectation in equation 1 using a Monte-Carlo approximation to the expectation.

$$\approx \frac{1}{\varphi} \sum_{1}^{\varphi} \frac{g(y;\theta)}{g(y;\theta_0)}$$

Rearranging (1) gives:

$$c(\theta) = \frac{c(\theta_0)}{\widehat{E_0}}$$

Thus, we have:

$$f(y;\underline{\theta}) \approx c(\theta) g(y;\theta) = \frac{c(\theta_0)}{\widehat{E_0}} * g(y;\theta)$$

$$L_{mc}(\theta) = \log\big(f(y;\theta)\big) = \log\big(c(\theta_0)\big) - \log\big(\widehat{E_0}\big) + \log(g(y;\theta))$$

The term: $\log\big(c(\theta_0)\big)$ is a constant, therefore, $\hat{\theta}$ maximises the terms: $-\log\big(\widehat{E_0}\big) + \log\big(g(y;\theta)\big)$.

Maximising this gives a Monte-Carlo approximation to the maximum likelihood estimator (MLE). When n is large maximum likelihood estimators have normal properties:

$$\hat{\theta} \approx N(\theta_0, \frac{1}{n\, I(\theta_0)})$$

where I(θ) is the information matrix.

As we are utilising this methodology with network data, it is necessary to check whether the asymptotic principles hold given our sample size (and network structure) – thus, we used simulation studies to investigate the properties of the model.

Simulation Experiments

For each experiment using the auto-logistic model, fixed parameter θ, and the network structure from our foundation doctor social network data, we are able to generate data samples, Y.

To explore the behaviour of the auto-logistic model and our implementation, we firstly generate multiple new response data sets, Y_i. We then estimate parameters for these realisations using Monte-Carlo maximum likelihood estimation. This results in a set of estimates for θ. Inference on this set allows us to explore the model's behaviour under different conditions i.e. different values of θ. This scheme is outlined graphically by Figure 13. Monte-Carlo maximum likelihood tends to the true values for θ as n tends to infinity. We have a finite value of n, thus we need to check whether we are providing sensible estimates for θ. This is achieved by comparing estimates of $\hat{\theta}$ to known values of θ.

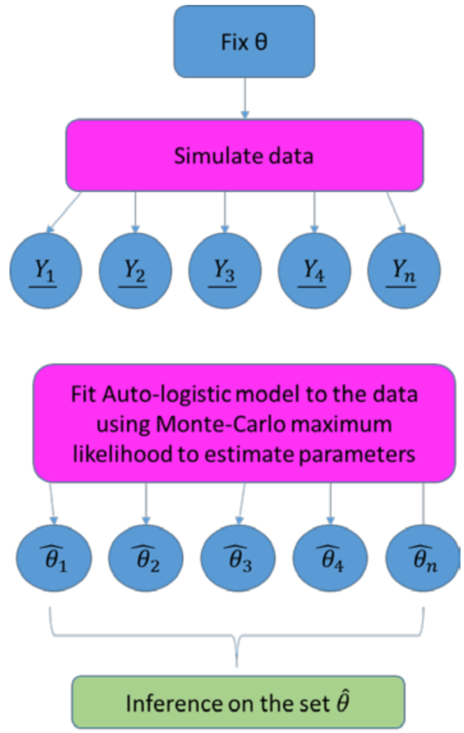


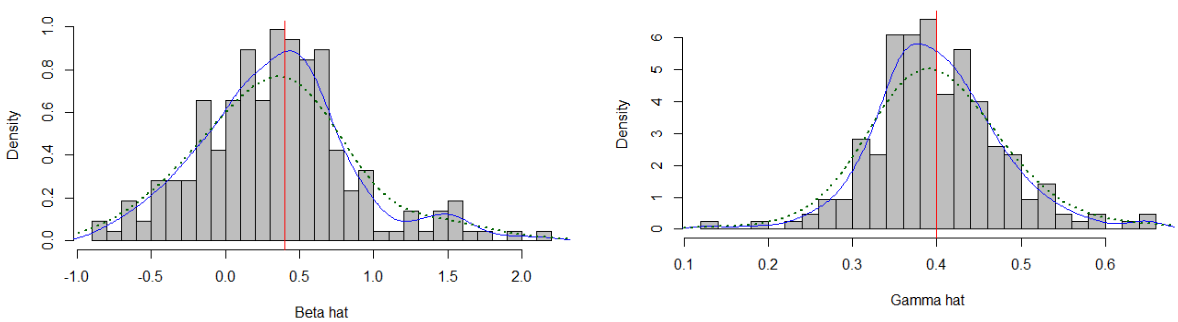
Figure 13: Regime for the simulation experiments using the auto-logistic model.

Test 1: Examine the model implementation.

We chose, $\theta = \{\beta = 0.3, \gamma = 0.4\}$, to test the model code's functionality.

We repeated the experiment 200 times (i = 200) producing Y_i and $\widehat{\theta_i}$.

We are returning reasonably accurate and normally distributed results, even with a relatively small number of simulation runs, particularly for our estimates of γ, which is the parameter that estimates the relational effect of neighbours in the network (Figure 14, Table 8). The variance for the β parameter is much larger - this parameter controls for the intercept / marginal probability of vaccination. However, despite the poor model performance due to a very small number of monte-carlo simulations, we are still returning expected parameter estimates. This adds to the body of evidence that our code is acting as expected, although it is obvious from this test that the model must be run for far longer.



Figures 14a and 14b: The distribution of $\hat{\beta}$ and $\hat{\gamma}$ for test 1

Table 8: Descriptive statistics for the first experiment (2dp).

	$\hat{\beta}$	$\hat{\gamma}$
Median	0.36	0.40
Mean	0.35	0.40
Variance	0.27	0.006

Figure 15 shows that extreme values for γ, tend to correspond with extreme β values, suggesting that more extreme values are mostly likely associated with random noise in the simulation process (Pearson's correlation coefficient: -0.78).

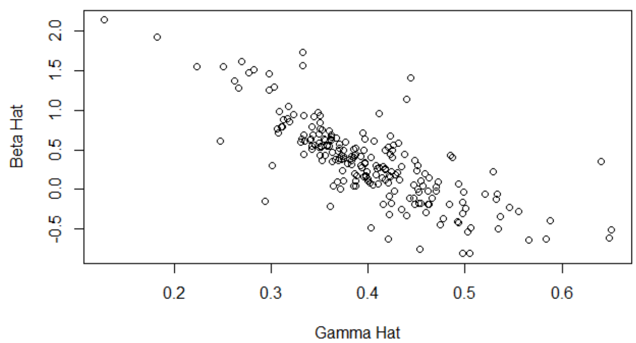


Figure 15: Scatter plot of estimates for beta against corresponding estimates for gamma.

Test 2: Examine the properties of the hessian matrix

The Hessian is a square matrix of second-order partial derivatives. When maximising a likelihood, the covariance matrix of the estimates is (asymptotically) the inverse of the negative of the Hessian. Thus, the standard errors are the square roots of the diagonal elements of the covariance.

$$\boldsymbol{Var(\theta)} \approx [\boldsymbol{I(\theta)}]^{-1}$$

Before using the hessian matrix to derive confidence intervals for our parameter estimates we must confirm, using a simulation study that this principle holds when using our true network (n=138).

We ran this simulation study using β = 0.6, γ = 0.1. The simulation was repeated for 235 runs to generate a dataset of parameter estimates. This was used to generate a parametric bootstrap of the variance. At each iteration, we also saved the hessian matrix, allowing us to derive a dataset of asymptotically estimated variances'.

Figure 16 confirms that again the simulation is producing sensible results for the given values of β and γ - the plots are approximately normally distributed, and returned expected parameter estimates despite a limited number of monte-carlo simulations (see Table 9).

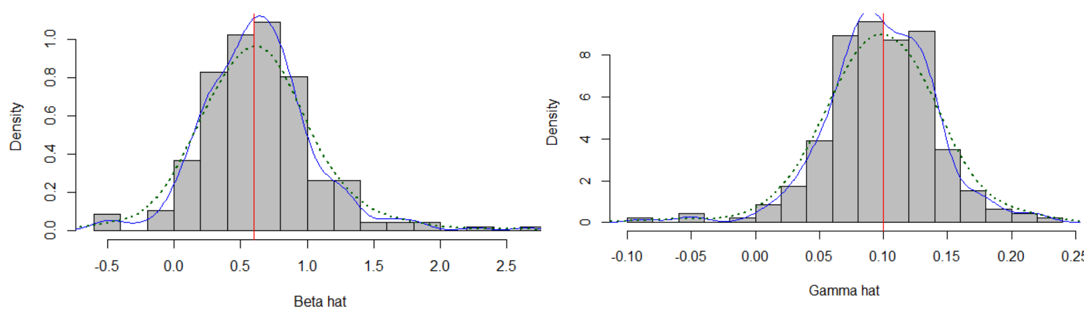


Figure 16: The distribution of $\widehat{\beta}$ *and* $\widehat{\gamma}$ for test 2.

	Beta hat	Gamma hat
median	0.62	0.10
mean	0.63	0.10
variance	0.18	0.002

Table 9: Summary statistics for experiment 3 parameter estimates. The real values are beta = 0.6, gamma= 0.1.

We computed the asymptotic variance for each run of the simulation using the hessian matrix. This generated a set of values for the asymptotic variance for each run of the simulation, the mean for the asymptotic variance for beta was <0.0001, and the mean asymptotic variance for gamma was <0.0001. This is small compared to the bootstrapped variance, however, generating and storing the hessian matrix for each simulation was costly in computational time.

Real data application

The auto-logistic model was imputed using initial values derived from maximising the pseudo-likelihood for β (β = 0.9675), and for γ we initially assumed the null hypothesis (that γ = 0). We can see, from Figure 17 that the model performed as expected under these conditions – the peak is equivalent to the pseudo-likelihood.

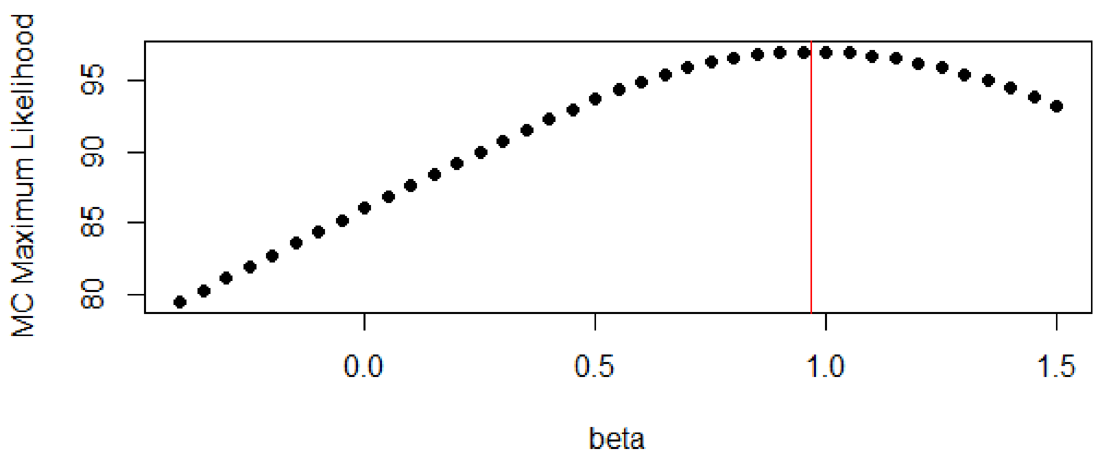


Figure 17. Auto-logistic model performance when applied to the real data, under the null hypothesis.

Parameter estimates were chosen by optimisation of the maximum likelihood function. Figure 18, shows a surface plot of the likelihood for the auto-logistic model with parameter estimates for β, and γ.

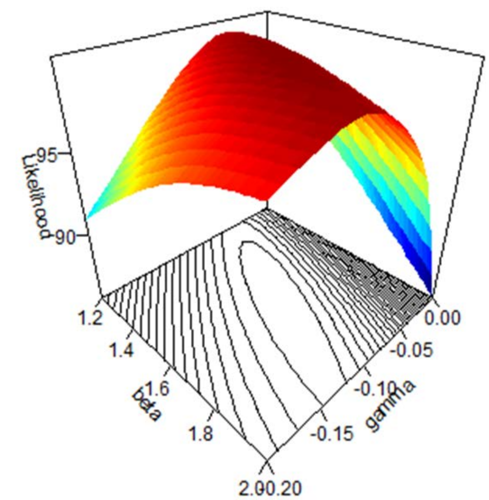
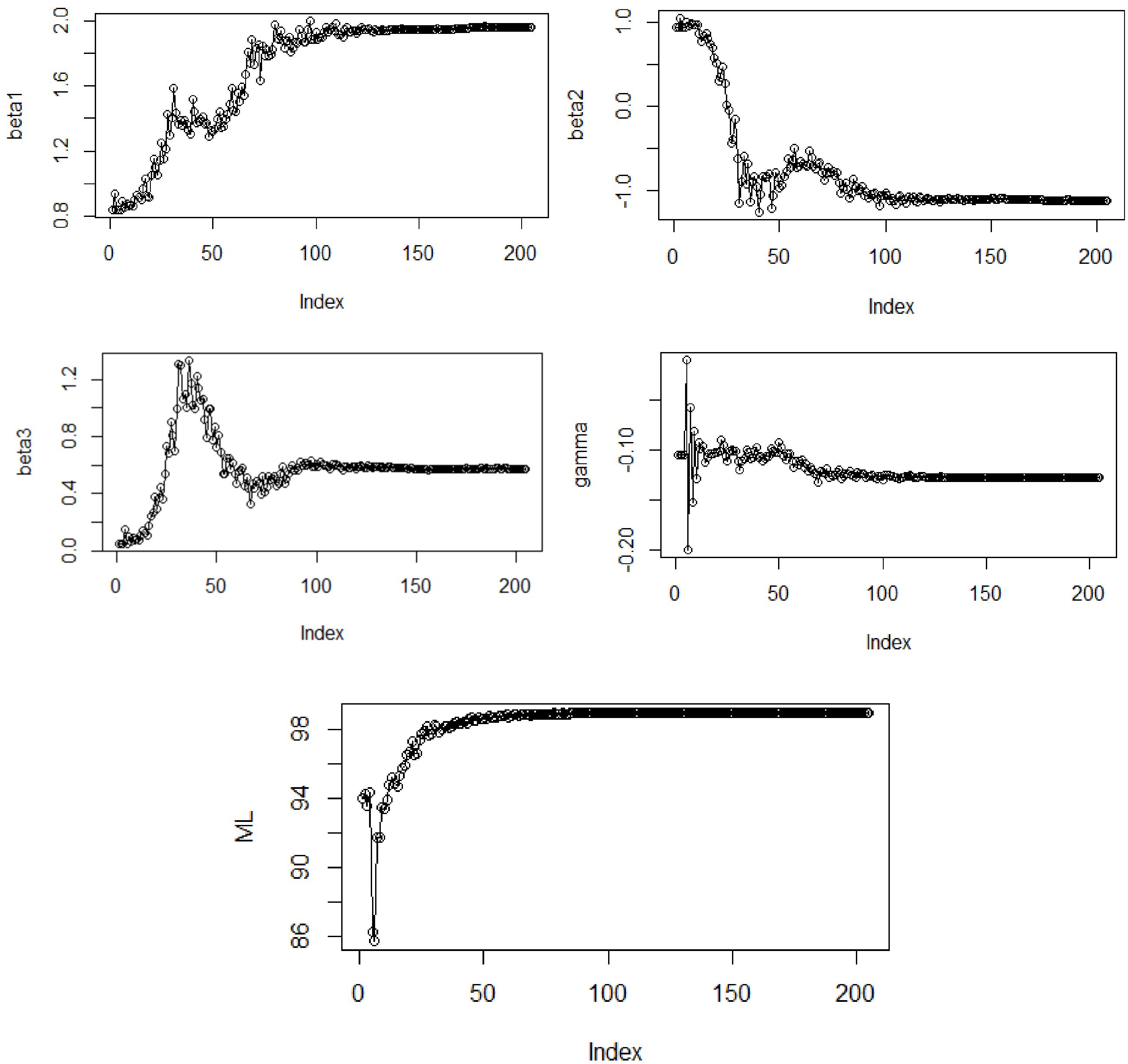


Figure 18. A 3D surface plot of the likelihood for the auto-logistic model with parameter estimates for β, and γ.

Following our analysis of the simulation experiments we felt confident to continue with the analysis of the foundation doctor data as described in the manuscript attached. For the real data analysis we generated many more simulations and increased the number of runs in an attempt to reduce the Monte-Carlo error.

Figure panel 19 shows a trace plot for each of the parameters in the second model (with axis and year as covariates). This is an example of the results from one run of the model, which were combined with many more to produce the parameter estimates and the associated monte-carlo simulation error given previously. It is clear that the model mixes and converges appropriately.

Figure 19. An example of a series of trace plots for each of the parameters in the auto-logistic model with year and axis as covariates, produced from one run of the model.



When we included an interaction term into the model we experienced poor convergence in which parameter estimates did not stabilise at realistic values, but rather showed evidence of numerical instability – the parameter estimates tended to very large values (both positive and negative). We applied a range of diagnostic techniques to investigate this phenomenon. To confirm the code was correct in this case, we fixed the interaction parameter at 0, and re-ran the model, the results were as expected, the parameter estimates converged and the traces plots were comparable to those produced by the second model (Figure panel 19). This suggests that the model code was performing as expected. By plotting the parameter estimates against one another, we deduced that the model with an interaction term was not identifiable. We believe that this is due to a sparsity of data (Table 10).

Table 10. Contingency table of the frequency of foundation doctors by, neighbourhood, year, axis and vaccination status.

			Axis east		Axis west	
			year 1	year 2	year 1	year 2
Neighbours vaccinated = 0	vaccinated	yes	1	1	2	1
		no	0	2	0	1
Neighbours vaccinated = 1	vaccinated	yes	1	4	2	5
		no	0	0	0	2
Neighbours vaccinated = 2	vaccinated	yes	4	10	5	2
		no	2	0	0	3
Neighbours vaccinated = 3	vaccinated	yes	3	4	10	4
		no	2	0	2	2
Neighbours vaccinated = 4	vaccinated	yes	7	3	6	5
		no	4	3	2	0
Neighbours vaccinated = 5	vaccinated	yes	3	0	2	1
		no	1	1	0	1
Neighbours vaccinated = 6	vaccinated	yes	2	0	2	0
		no	4	0	0	0
Neighbours vaccinated = 7	vaccinated	yes	1	0	1	1
		no	0	0	0	0
Neighbours vaccinated = 8	vaccinated	yes	1	1	0	1
		no	1	1	0	1
Neighbours vaccinated = 9	vaccinated	yes	1	0	0	0
		no	3	0	0	0
Neighbours vaccinated = 10	vaccinated	yes	0	0	0	1
		no	0	0	0	0
Neighbours vaccinated = 14	vaccinated	yes	0	0	0	0
		no	0	1	0	0
Neighbours vaccinated = 16	vaccinated	yes	0	0	0	0
		no	1	0	0	0

Chapter 5

Socialisation, indifference, and convenience: exploring the uptake of influenza vaccine amongst medical students and early career doctors.

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Under Review at Qualitative Health Research.

Abstract

Background

The Chief Medical Officer for England recommends that all healthcare workers receive an influenza vaccination annually. Medical students are also encouraged to vaccinate. High seasonal influenza vaccination coverage is believed to be the best form of protection against the spread of influenza within a hospital – protecting both staff and patients, and reducing infection transmission. Despite the current recommendations, seasonal influenza vaccination uptake by healthcare workers remains significantly lower than the target level of 75%.

Methods

We conducted a series of semi-structured interviews with seven medical students and nine early career doctors, to explore the factors informing their influenza vaccination decision-making. Data collection and analysis took place in an iterative process until theoretical saturation was achieved, and a thematic analysis was performed.

Results

Of the sixteen participants, ten had been vaccinated during the 2015/16 season. Socialisation, either encouraging or discouraging vaccination, was important although its effects were attenuated by participants' previous experiences and a lack of clarity around the risks and benefits of vaccination. Many medical students and early career doctors demonstrated some indifference towards the seasonal influenza vaccine as many did not have strong intentions to accept or decline vaccination. Moreover, we found that there was considerable disparity between an individual's opinion of the vaccine, their intentions, and their vaccination status. Practicalities such as convenience emerged as decisive factors contributing to vaccination decision-making.

Conclusion

The indifference demonstrated by this population suggests many are not strongly opposed to the vaccination – thus there is potential to increase vaccination coverage. Influenza vaccination appear to have greater relevance to those working in some specialties compared to others which suggests a more targeted approach to increasing vaccination coverage may be appropriate.

Key Words

Seasonal influenza vaccination, medical education, role models, socialisation, medical identity construction.

Background

Seasonal influenza is an acute, contagious, viral respiratory infection which causes considerable morbidity and mortality worldwide (3). The elderly, young, and those with underlying health conditions are disproportionately affected by the disease.

Constant evolution of the influenza virus means that each year the vaccine must be reformulated. Using information available in February, the World Health Organisation predicts which strains of the virus will most likely be circulating in the northern hemisphere during the subsequent winter (124). Mismatched seasons occur when the predominant strain circulating in the population is not covered by the vaccine – this may happen if the virus mutates unexpectedly. A recent meta-analysis found that during mismatched seasons the vaccine efficacy was between 56-60%, and that this improved to 65-77% during matched seasons (125).

Each year the Chief Medical Officer for England advises that all healthcare workers (HCW) receive a seasonal influenza vaccination (95). Increasing seasonal influenza vaccination amongst HCW is thought to have beneficial consequences including reductions in staff absentee days, the spread of influenza within the hospital, and elderly patient mortality (126). However, the evidence for protection of other groups of patients, conferred by HCW vaccination, is not conclusive. Views on HCW vaccination within the scientific community are often polarised; some recommend mandatory vaccination policies, believing that vaccination of HCWs benefits patients and healthcare institutions have an obligation to promote behaviour consistent with such professional virtues and ethical principles (127,128), others argue that mandatory influenza immunisation of all HCW is an excessive infringement on autonomy and could damage morale (129). Uptake of the vaccine by HCW in England, remains at approximately 55% - well below the target of 75% (130). Also, the recently announced national commissioning for quality and innovation (CQUIN) standard will provide financial rewards for any Trust achieving 75% vaccination coverage. Given previous low vaccination uptake, Trusts will need to adjust their staff vaccination policies if they hope to achieve this (131).

Recent survey studies suggest that a number of factors contribute to HCW declining vaccination, including: fear of adverse reactions; lack of concern; inconvenient delivery; and a lack of perception of their own risk (132,133). The reasons for receiving an influenza vaccine were given as: self-protection; protection of patients; convenience; and, following the example set by peers (134). However, there has been little qualitative research into these phenomena, thus the relationship between these factors and why they arise remains unclear. Previous attempts to improve vaccine uptake have had limited success, however, studies which include a combination of interventions (focused around education, convenience, and leadership) appear slightly more effective (40) - suggesting that some ambiguous complexities remain in current understanding.

Our study aimed to provide a deeper insight into the influenza vaccination practices of HCW. Influenza vaccination takes place within a professional and social setting occupied by medical professionals, patients, and junior staff members. When new members enter this setting they begin to adjust to the social norms of the medical community - a formal and informal process of training and socialisation. Capturing their attitudes as they are adjusting to this environment should provide an insight into vaccination culture across the hospital.

Methods

We conducted a series of semi-structured interviews to investigate the factors that influence seasonal influenza vaccine uptake in medical students and foundation doctors. Ethical approval was obtained from Lancaster University Research Ethics Committee prior to data collection.

Participants and Setting

Participants comprised final year medical students and foundation doctors and were recruited from a medical school and a single, large NHS Trust, both in the North West of England. Foundation doctors work in a variety of settings, including hospitals, for two years of broad training following graduation from medical school. Final year medical students spend the majority of their time working in general practice and hospital settings.

Recruitment took place during mandatory teaching sessions, attendees were given an introduction to the study, then sent a follow up email. Potential participants were asked to email the researcher to arrange an interview. At the time of recruitment, participants were emailed a copy of the participant information sheet (see supplementary 1). Anyone who volunteered was interviewed, up to the point at which we believed no more information could be gained from further interviews.

Interview protocol

Semi-structured interviews were conducted by RE over an eight-week period from February to April 2016, i.e. between vaccination periods (October to January). Before commencement of the interview, participants were given a brief introduction to the project and signed a consent form. Interviews took between 30 minutes and an hour.

An interview schedule was used to guide discussion, although the semi-structured approach allowed for flexibility and elaboration around each participant's unique experiences (see supplementary 2). Interviews were recorded and transcribed verbatim by RE. Data collection and analysis took place in an iterative process, allowing for exploration of emerging themes.

Within the interviews, interactions were shaped by RE being a similar age to the participants, and by being external to the medical professional. These factors, we feel, contributed a non-judgemental characteristic to the interviews, as some participants reportedly shared views they had not discussed with peers. Accordingly, RE did not comment on the accuracy of participants' knowledge, but encouraged participants to elaborate on their beliefs throughout the interviews. Participants often commented that they had not previously reflected on their vaccination choices, their level of risk, and who might have been important in shaping their views. This is indicative of a decision-making process that is not necessarily a well-thought out, rational, cost-benefit analysis. It also shows that during the interviews, data was actively constructed, rather than a recording of pre-existing views.

The data have been reported in participants' own words. Due to constraints on word limit, some descriptive text has been removed and quotes edited (e.g. by deleting repeated words). Additional context and participant's unique identifier codes are included.

Analysis

Initial data analysis consisted of open coding line-by-line using largely descriptive labels – during this process each line of text within a transcript was assigned a label which indicated potential themes within the data. As more data was analysed in this way, consistent themes began to emerge, later transcripts were coded paragraph-by-paragraph (92). Although the initial 'first pass' coding was undertaken by RE, the 'fit' of the codes to interview excerpts, and the interpretation given to them, was the subject of detailed discussion and analysis by RE and DG. The coding schema was then iteratively refined following these discussions. Themes were thus developed inductively, focusing on factors which appeared most important to participants, rather than their overall prevalence (although these were highly correlated). Interviews were repeatedly reviewed, particularly if new themes emerged or in the event of a 'negative case' – an example arising in which an existing theme could be re-evaluated (see discussion on professionalism). Data collection continued until theoretical saturation was observed (135).

Results and Discussion

Of the nine foundation doctors and seven medical students in the sample, ten had been vaccinated during the 2015/16 season. However, all had been vaccinated for seasonal influenza at some point previously. We found the themes of socialisation, understanding of the vaccine, and convenience to be important in whether or not the individual vaccinated (Figure 20).

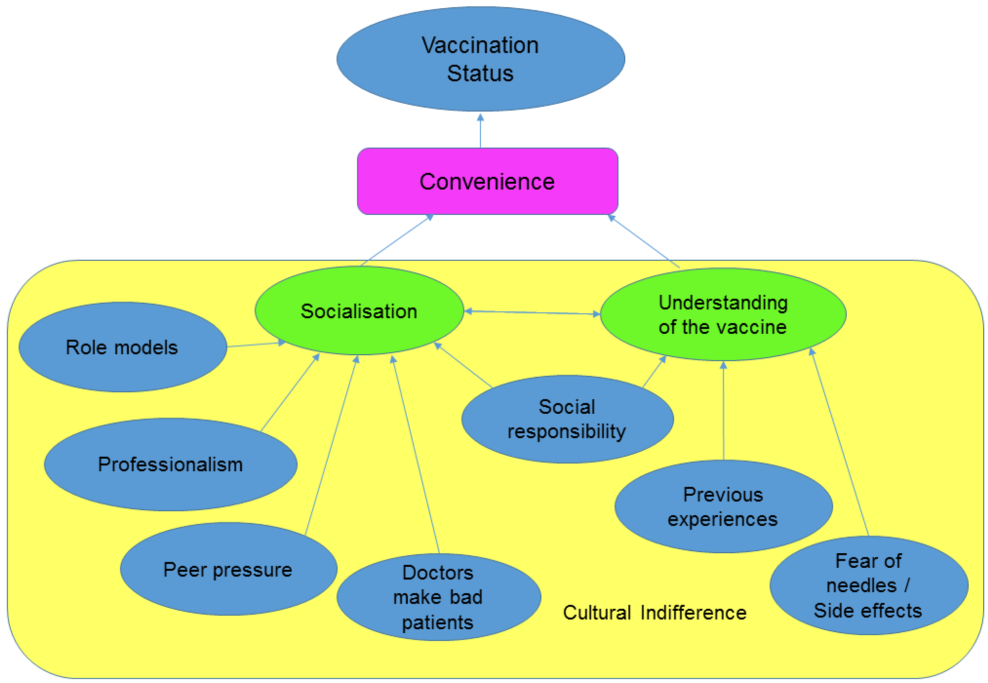

Figure 20: Schematic representation of the factors that affect medical students' and foundation doctors' seasonal influenza vaccination status.

Cultural Indifference

While some individuals were determined to receive or avoid vaccination, this stands in contrast to the position of most participants who did not have strong intentions relating to vaccination. We found elements of indifference towards the vaccine threaded throughout all the themes emergent in this dataset. Below, participants give examples of this:

"I just go and have it done and like it doesn't, I don't know, it's just a bit like... not second nature but it doesn't, I don't think too much about it, I just have it done and I suppose I think other people might think, might weigh up the pros and cons a bit more, like might be a bit more scared of having the injection they might have it a bit more... I

just kind of just have it, just roll up your sleeves stick it in and then just carry on with my day and don't even think about it anymore…" (MS5)

"I was probably a bit blasé, I think it's important to do but I... yeh when I don't see it I don't think about it." (FD9)

"It's just that I guess I don't see the benefit in my own head I don't see enough of a benefit to go out of my way to go and get it." (MS3)

"It's just literally just I'd missed the chance to get it that day with occupational health went round and then kind of put it off and it didn't get done." (FD5)

"It's never really I can't be bothered having it, it's just like oh I've not had it that or not got round to that yet, it's just, yeah people just don't seem to have the time or put it high up on their priority list." (MS4)

We found a lack of clear intention to vaccinate amongst participants. Even some who chose to vaccinate did not have clear reasons for doing so. Blank et al, found that French, German, and US physicians seemed to be ambivalent towards the influenza vaccine – many did not consider the benefits of vaccinating to be worth their perceived risks (136). This indifference suggests that the benefits and liabilities associated with vaccinating were finely balanced. Below we seek to clarify why and how the underlying tone of indifference arose, and the implications such indifference holds for vaccination uptake.

Socialisation

Socialisation is the *"structure, the method, and the route by which initiates move from one status to another and acquire the technical skills, knowledge, values and attitudes associated with the new position or group. Because socialisation involves a passage from one position or state to another, it must enable the initiate to attain a new* *cultural base but must also facilitate movement away from the old status*"(137). Whilst the socialisation process is multifaceted, it is clear that senior staff are instrumental in shaping participants' impressions of medical culture (138). A vaccinated foundation doctor describes the effect of consultants on her behaviour at work:

"I copy what my consultants do… so if they don't do it then I don't do it. And that sounds very... it sounds very... you know that you're just being sheep or whatever but my morning job consists of me following a consultant around and writing everything down that they say and then making a job list of what they want me to do so... they go very quick and just spend half my time having like no idea what's going on and like diving after them into rooms and if they go and don't have any protection I don't have time to actually put on aprons, hand wash, and glove up, and everything so I literally just go straight after them and follow them like that. Otherwise, I'll miss everything that's going on so I kind of feel like it's not really an option." (FD3)

Junior doctors react to the behaviours to which they are exposed. Above, the participant talks about 'copying' the behaviour of the consultant even though she is aware she contravenes infection control procedures in doing so. Medical training emphases the importance of strict infection control procedures, however, she finds that these are not always practised, and by copying the behaviour of her consultant her definition of what it means to be a professional doctor evolves. This is an example of socialisation, during which early career doctors cast off their identities as lay-people and assume those of professional doctors (139). This foundation doctor is being socialised to act in a way that conflicts with her previously-held beliefs and describes the situation as stressful. Under these circumstances, the effects of socialisation are particularly acute (140).

Socialisation is a complex process involving both compliant and dissident behaviours, which are shaped by senior staff and interactions with peers. Through this process participants learnt about their roles as doctors within the hospital.

Below, an unvaccinated foundation doctor discusses her reactions to senior staff advocating vaccination:

"Oh yeh, erm cos there are some consultants you should, like I said it becomes a bit of a team thing, and there were some consultants that said, 'have you had your flu jab, have you had your flu jab' and you know if you haven't had one sometimes they'll ship you to one of the nurses and kind of stand there while you have your jab, and things like that, and we were actively you know avoiding these situations. Erm and every time we saw one of those consultants we would you know go hiding and things it's, it's really strange, it strange how much effort I put into avoiding these the jabs… erm yeah..." (FD6)

This quote demonstrates both the influence senior staff have on the development of the team's attitude and the resistance it can sometimes provoke. This participant demonstrates a defiant attitude towards the consultants - in this comment senior staff have facilitated a situation in which the participant, with support of her peers, rebels against their authoritative demands to vaccinate. This highlights the importance of peer support in the socialisation process.

Peer influences

Medical education is intrinsically collaborative; medical students often face challenges as a group, and interaction is an integral part of their experiences (137). Vaccination often takes place within professional, social situations and the peer group acts as an audience, regulating the vaccination performance:

"When you know your friends are taking it, it feels like I will have it too, like I don't want to be different." (FD8)

"As in 'cos I think like ahh, like a lot of them students have had it [the vaccination] and you haven't had it so there's definitely a peer pressure thing going on as well. 'Cos I

think most people have had it whereas I hadn't had it so that was another thing that made me think oh I've got to have it now…" (MS7)

Above, participants describe a desire to conform to social norms of their community, which leads them to vaccinate. However, as alluded to previously, both conformity and dissent are common. Below, an unvaccinated foundation doctor discusses camaraderie surrounding refusal to vaccinate:

"She was one who was with me saying 'yeah I think I'm going to avoid the flu jab this year', because she also had I think a bit of a reaction to the one from the year before sooo yeah in, everybody else in the team kind of had their flu jabs and they were all talking about the jabs and how they were reacting to it, things like that. Erm me and Jenny were in our own little group saying 'yeh, last year was horrific so I think I'm just going to avoid it this year', so I think in that way there are little cliques of the yes's and the no's, so erm yeah that's why..." (FD6)

This participant describes the situation in which cliques have formed based on a shared vaccination status. The two colleagues discussed side effects associated with the vaccine as part of their vaccination decision-making. Clearly, the peer group helps to shape people's understanding of the vaccine as well as influencing their actions. In this instance, we suggest that it is the defiant attitude and camaraderie, both established components of medical culture (141), rather than a fear of side effects that is important in this decision. The discussion of side effects is used to explain the resistance to the peer pressure to vaccinate, but it is the camaraderie that enables the continued resistance. Furthermore, that the two women collaborate and share in the vaccination decision-making, challenges the perception of vaccination as an autonomous decision. A vaccinated foundation doctor described it thus:

"There are definitely more people who do it because we tend to do it in groups, there are people who get swept up into… who kinda don't care either way but everyone else is doing it so…" (FD4)

This participant recognised that attitudes vary and feelings of indifference towards the vaccine exist. However, her comments suggest that peer pressure at the point of vaccine delivery overrides the indifference towards vaccination within the group.

Professionalism

As medical students and foundation doctors are socialised, being a medical professional becomes a defining feature of their identity (142). Consequently, professionalism and social responsibility emerged as themes important in some participants' vaccination decisions as influenza vaccination was intended to protect both HCW and their patients. This vaccinated foundation doctor describes concern for patient welfare as a key element in her vaccination decision:

"We quite often feel frustrated that we're not able to do as much for our patients as we'd like, this is something that might help almost by doing nothing if it can take a little bit of the edge off not feeling like you're doing everything you can... why not?" (FD4)

The cost of vaccination to this individual is low, thus patient welfare was able to 'tip the balance' of her decision towards vaccination. She highlights the high-pressured environment in which these decisions are taken, talking about feelings of frustration and inadequacy. For this participant, influenza vaccination is aligned with the professional value of 'making the patient's welfare your first concern' (115). For some, this value held priority even when considering more significant costs of vaccination, such as side effects or fear of needles:

"I'm getting it and then there's one friend who I know doesn't like needles so she never gets it and that her excuse is 'I don't like needles'... But I mean you do sort of think, being in the healthcare position you probably should because it's about, you know, keeping your patients healthy." (MS2)

The above quotes suggest that there is not only an awareness of peers' vaccination practices but also some appraisal of their decisions. Definitions of professionalism rest on the premise of peer-review and self-regulation – both forms of social control – and thus are embedded within socialisation (140). Individuals are pragmatic, they compromise between trying to express conflicting personal thoughts and being cooperative - they may demonstrate conformist or dissenting views – but, often the social group has some influence over the individual (143). Above, the participant is provoked by a colleague's dissenting views which conflict with her professional values, demonstrating how one's actions are subject to the judgement of one's peers. Social control is facilitated by the individual's internalisation of this judgement (144) - this is illustrated below:

"It's something you wouldn't talk about publically and say I wouldn't feel comfortable for example, around all my uni friends saying 'okay I have not had my flu vaccination', I wouldn't because I know I would be judged because… They'd say, 'well you're a medical student your gunna be a doctor, and your gunna tell people to have it, and you haven't had it yourself', so that's something that's a bit..." (MS6)

Her perceptions of her peers' opinions prevents discussion around the influenza vaccine. She expects that her peers would associate lack of vaccination with hypocrisy, demonstrating the link between vaccination and professionalism. The quote below is not only disapproving of non-vaccination, but positions it as illogical:

"So from a sort of logical point of view I wouldn't really understand why they are against it, because I guess we are quite derogatory with vaccinations. We always think that people that refuse them always are those hippy dippy mums that don't want to like put their children near any sort of medications whatsoever and actually its more detrimental to them in the future... So I associate all people that don't really want vaccinations in that pile, and I think that it would confuse me a little bit if I came across doctors, that are meant to be pro-healthcare, pro-medication and bit more health educated, it would confuse me about that…" (FD3)

The participant quoted above aligns vaccination with professional values; it is part of medical culture, and thus she and her peers should be pro-vaccination. The participant's perceptions of the medical position, encourage her to disparage unvaccinated individuals. However, we found that vaccination is not overtly and universally associated with professionalism. In response to a question about vaccination as an act of professionalism, one unvaccinated foundation doctor replied:

"I've never really thought about it like that… but then if that is like, that would make me feel really, that would make me get it, if people were like oh its associated with professionalism, like it's not a professional thing if you don't get the vaccine because your putting your patients at risk, like I've never even thought about it that way. And if I did I think that would make me get the vaccine, but I've never… I've never considered that." (FD2)

This foundation doctor is concerned about her image and identity as a professional, and while she understands the connection between vaccination and professionalism, concern for patient welfare had not featured as part of her rationale. Understandings of the vaccine are shaped through socialisation, however, experiences of socialisation are variable. This doctor had previously been placed on a surgery rotation where, as we discuss below, exposure to patients with influenza was infrequent and thus awareness of the need for vaccination was lower, which may in turn suggest heterogeneity in attitudes amongst different specialties within the hospital. Below is the response from an unvaccinated foundation doctor when asked if she had considered vaccinating to protect her patients:

"…I definitely didn't think about that, I didn't factor that into the equation of you know, do this, if not for yourself for the safety of the patients cos I think, everybody would do it then, everybody would. You don't want to make someone who's sick worse, because you couldn't be bothered to take the flu jab. I think that's, that's terrible ermm, we would judge you then, I think yeah even if you didn't want to do it the entire

team would judge you then saying, 'do you not care for your patients, why would you not take it?' Ermm so yeah that would be a good campaign strategy actually, if you wanted to get 100% concordance with the flu jab, yeh that's the way to go." (FD6)

For the participants above, social responsibility to vaccinate, or connotations with professionalism, did not inform their decision. However, they suggest that they would vaccinate, if there was a stronger professional message – exhibited by their peers and part of their socialisation – that vaccination was to be a reflection of their professionalism. Interestingly, the mention of judgement by peers, when the foundation doctor (FD6) discusses the notion of vaccination as an act of professionalism, provides further evidence that perception of peers' opinions can influence the actions of an individual within the group.

An example of a strong professional steer is given by the medical student below, who described being under institutional pressure to vaccinate (facilitated by the vaccine appearing as an activity in students' logbooks). The logbook is used to record completed learning objectives and clinical evaluations throughout the course and thus functions as a physical representation of the student's professionalism. Influenza vaccination appeared as an optional section in the logbook, symbolising vaccination as a construct of professionalism, and encouraged them to actively seek it out.

"In my mind this was the university telling me you have to have the flu vaccine this year, so that's, actually, I had forgotten about that, that's the probably the main reason why I had it done last year cos I was afraid that I wouldn't have that signature in the log book." (MS4)

Decision-making, thus, cannot be isolated from professional values which are mobilised through socialisation. Therefore, although participants often felt ambivalent towards the influenza vaccine, and there were variable interpretations of its association with professionalism, when the injection appeared in the medical student's logbook this was interpreted as a clear directive, encouraging vaccination.

Doctors make bad patients

As can be identified in the data above, medical professionals feel subject to an expectation that they should conform to healthcare advice (145). A medical student describes this as a fear of judgement from her peers:

"I think there is judgement, definitely, since some people would judge you: 'oh so you know we should be telling patients to do this, how come you're not doing this? That's hypocritical' and you'll definitely get judgement. Also I think as... doctors, or as healthcare professionals in general, not just doctors, as healthcare professionals I think were expected in a public setting, if were telling the public to do something were expected to do it ourselves. So it's a bit, so I can see, you know, it's a bit, it's not something that I would feel comfortable talking to anyone about..." (MS6)

Although this participant reports that there is an expectation of compliance with healthcare advice, often participants would contradict this. During the interviews it emerged that some participants did not vaccinate against influenza due to a wider defiant attitude towards their own health. The characterisation of doctors as 'the worst patients' has been previously established (146,147). For some even a slight fear of having an injection made them less likely to vaccinate against influenza. Below, two foundation doctors describe a fear of needles leading to their refusal to vaccinate:

"Er I just ... I don't like having any vaccinations really, I really don't like needles." (FD2)

"ah I think it's [the vaccine's] good, erm I think it's good to sort of get people to take it if you can just to stop people getting ill primarily. Stop people sort of taking time off work that sort of thing… Erm I haven't actually had mine yet, but that's cos I don't like needles, but erm yeah I think it's a good thing." (FD5)

Despite a positive attitude towards the vaccine, the fear of needles 'tips the balance' for these participants. However, a stronger justification for having the vaccine may outweigh their fears:

"I mean the needle thing if I have to get over it I will, like I had all my shots when I was at school and stuff, and so erm it's just the thought of doing it but when I'm there I probably would manage ok." (FD2)

Some doctors believe that they will not become ill, as the patient is 'the one with the disease' and they detach themselves from their own morbidity (148). Some participants did not have the influenza vaccine as they did not believe they were at a high risk from the virus. However, it appeared that this was a facet of a general 'bad patient' attitude being, for example, associated with failure to complete courses of antibiotics or denial of asthma symptoms. Some examples:

"As a patient, you know like I'm the worst patient I'm not compliant with anything I'm really terrible … like I never take my inhalers and erm… yeah I'm … I think that doctors are bad patients and I think I'm really bad I'm just not compliant at all <cut three lines of descriptive text> I'm really bad with taking medications, I think that the flu vaccine thing falls in with that. I'm not very good at like going to the GP" (FD2)

"I don't think I really believe that I would catch any virus travelling either, I mean I know logically it's possibly, but I don't think I actually believe that I'm likely to catch anything." (FD4)

"Erm terrible, I am a terrible patient, yes, that's correct, I am a terrible patient, usually on anti-biotics I don't, whatever, I tend to be fine. If I have diarrhoea for example, and erm and I'm given an antibiotic prescription, three times a day, never take them and then… Yeh I am a terrible patient" (MS6)

Being a ‘bad patient’ is a liberty these doctors allow themselves, despite frustration when patients demonstrate similar behaviour, which falls within the heroic, infallible doctor persona (148,149). Nevertheless, there is an expectation that doctors will follow best health practices, thus when they fail to do so they have a sense of guilt. Doctors who are ‘bad patients’ may be more likely to justify refusal of the vaccine due to side effects, inconvenience, or the lack of vaccine efficiency – possibly because of a perceived stigma attached to their attitudes. Below is an example from an unvaccinated foundation doctor:

“I think, so like if there’s something you don’t like doing then you’ll find any excuse to put it off. So the fact that you know, ‘oh I’ve got to go down to occupational health, oh I’ve got to do this’, it adds other reasons to put it off so I think if it was something quick like a nasal spray then yeah 100% it would be a lot easier.” (FD5)

It also emerged that many participants did not know where the occupational health department was and did not make use of it. (150), has previously suggested that the role of occupational health was unclear to doctors. This further highlights this group’s indifference towards their own health needs. Doctor’s courageous attitude towards work and their own health needs has been found to permit self-negligence; often doctors are found to under-report health concerns or go to work when sick (151). Within this theme conflicting elements of an expectation to comply with healthcare advice, and refusal to do so leads to incongruity. This conflict suggests a broader context of ambivalence surrounding the factors involved with influenza vaccination.

Understandings of the Vaccine

Many actors are influential in the construction of our understanding of scientific knowledge. Through the processes of socialisation, peers and role models informed participant’s understanding of the vaccine. Participant’s perceptions were shaped by the unique situations they were embedded within. A vaccinated foundation doctor discusses the effects of a consultant's vaccination on her own decisions:

"I know that our respiratory consultant does, and partly because he's a respiratory consultant and should know what impact flu season has, and partly because he's lovely - I reckon him doing it has an impact." (FD4)

Here, the consultant acts as a positive role model for vaccination. His views were considered authoritative and the respondent values his seniority and the credibility of his knowledge. Cicourel, noted that medical professionals determine value of information dependant on the perceived credibility of the source (152). There was further evidence that there were inter-specialty differences in attitudes towards the influenza vaccine:

"So cos I'm an F1 I've only been in surgery and psychiatry so far, I mean as a doctor and the, I think the surgeons, it wouldn't be very high up on their priorities and things. The medics, maybe the acute medics are probably a bit more aware of it. Cos I did go to a medical grand round, a month or two ago and it was all about flu and how they'd had many cases in the AMU and things erm..." (FD9)

The notion, that doctors from different specialties within the hospital behave differently, is possibly a facet of slight variations in a porous process of identity construction within different specialties (153). Therefore, the idea that influenza vaccination has greater relevance in some specialties compared to others suggests a more targeted approach to changing vaccination understanding may be appropriate in order to improve coverage. We also found marked differences in attitudes towards the influenza vaccine expressed by senior staff. An unvaccinated medical student gives an example of a senior member of staff opposing vaccination:

"One of the GPs at the practice last year and he was telling me about how they sort of guess about what viruses come up next, and the number needed to treat was quite high, so he was very like it doesn't really work, and you know even when it does it's hit

and miss… He was the one person I remember being a bit anti-flu vaccine, but I think that resonated in me" (MS3)

Senior staff appear to have a greater freedom to express more diverse opinions on the influenza vaccination. It has been suggested that senior staff are above reproach, therefore their behaviour is not constrained by peer opinion, in the way our participants' may have been (154).

Previous experiences

Participants gain knowledge and experience during clinical training, and what is learnt through these experiences is shaped by socialisation. As we suggest above, previous experience of influenza and its effects either seen in patients, or personally experienced, also informed participant's awareness. Here, a vaccinated foundation doctor was asked about her experience of influenza patients whilst working on an Acute Medical Unit*:*

"Before I started working I didn't think that the flu could be so bad because you sort of in a in a lay-man's sort of terms you always throw around the word flu like 'oh I've got the flu or you've got man flu or something like that'... And its really trivialised. But this year actually working in a hospital for the first time as a doctor, and seeing what can happen. I've seen patients that are like my age ending up, you know looking so crap, and erm really really ill from the flu, that's quite scared me and I think that would definitely make me want to vaccinate more… Because we've had a erm just had a huge breakout basically." (FD3)

She describes a "trivialized" attitude towards influenza prior to her experiences in the hospital. Her experience is defined by empathising with patients who are similar to herself, which has altered her understanding of the risks associated with influenza. Previously, we heard from a participant (FD6) who avoided vaccination by defiantly hiding from consultants. Below, she describes her changed opinion due to experiences of illness following her refusal to vaccinate:

"I think my opinion was already changed to be honest, erm by the time I had had that you know one major illness, I'd pretty much wised up to you know the advantages of flu jab, and every time we talked about it, it just kind of, validated the opinion I already had. Yeh I regretted it pretty quickly to be honest, even before the major illness, when I started to have all the minor sniffles, and just catching too many colds too quickly. I wised up to it very quickly but it was the major illness that made me really think okay that's it, from now on I'm definitely getting all the flu jabs no questions asked." (FD6)

She associates the minor illnesses with not having the influenza vaccine, in a similar way to a lay-person. Her lived experience changed her intentions regarding vaccination over time, through the intervention of multiple actors. Despite this, even following a major illness (suspected influenza), she still didn't get the vaccine:

"Actually began to properly worry for my health but I didn't then act on it."

This participant was concerned for her own health, suggesting that at this point she had clear intentions to vaccinate. When asked why she didn't act, she was unable to justify failing to fulfil her plans:

"I think that you have to go to occupational health or something, I don't know where occupational health is to be honest. So yeah.... it's just a bit more difficult to get the jab..."

Following her experience of illness, this participant intended to get an influenza vaccine, however, her intent did not translate into action. Discrepancies between intentions and actions are commonplace, because the relation of intent to the actual course of situated action is enormously contingent upon unforeseen events (90). Rarely, when forming an intention, do we take into account all of the specific factors involved. Her intention to vaccinate was formed without consideration of the practicalities involved with vaccinating. The resultant inconvenience associated with finding occupational health then outweighed her intention to vaccinate at the specific moment in time when the decision was made.

Convenience

A disjointed understanding of the vaccine, combined with a fluid socialisation process, suggests that the outcome of a vaccination decision is variable. However, it emerged that convenience appears to circumvent the complex interactions of socialisation and understanding of the vaccine. This principle held despite negative perceptions of the vaccine:

"'I had another flu vaccine, it made my arm hurt again, so definitely not having it next year, and then next year somebody would walk in and be like you should have a flu vaccine, I'll do it right now, and I'd probably have it then', so I think it's more just a convenience thing than anything." (FD2)

Although being provided with a convenient opportunity does not alter opinions of the vaccination, many will accept the vaccination without having a strong justification for it. Likewise, when participants were asked why they hadn't vaccinated, many did not have strongly negative views. Indeed, the act of briefly discussing their thoughts on the influenza vaccine allowed some to re-evaluate their views and found they could not justify their lack of vaccination. This is a good example of how interviews do not simply record views impartially. They are instrumental in the construction of views (88).

Convenience is important as it manifests a common circumstance that is relevant to the vaccination decision. Some foundation doctors reported vaccinating so that they could allow colleagues to get their intra-muscular injection skill signed off in their logbooks. This gave the participants a convenient incentive to vaccinate as they could practise giving the intra-muscular injection:

"Another thing that actually made me want to get the jab is, this really silly ok, but erm the foundations doctors need to get skills signed off, and one of them is an intra-

muscular injection. So actually it was perfect timing that me and alongside a whole other load of doctors, we just took it in turn, stabbing each other, so that we could get our procedure signed off as well." (FD3)

This assessment of competency was a powerful enough incentive to 'tip the balance' in favour of vaccination. The importance of proving one's competency in performing the intra-muscular injection is institutionally established. Combining the influenza vaccination with this is a subtly powerful social construction, which embeds vaccination within a medical task. Participants are more concerned with the procedure rather than the vaccine. The beauty of this is that peer pressure combines with convenience at the specific point of action in which the vaccination decision is made.

The convenience theme could be advantageous or detrimental to vaccination campaigns - slight inconvenience, for example, not knowing the location of occupational health, as we have seen above, would prevent participants from having the vaccine. However, improving convenience may increase vaccine uptake without the necessity for altering attitudes. Below, a vaccinated medical student discusses the importance of convenience:

"Ermm for me it's about convenience, like I probably wouldn't go out of my way to get the flu vaccine, I wouldn't book an appointment to the doctors cos I don't have time really. Erm the only reason I've had it the past two years was because <cut three lines of descriptive text> it's just easy to do it…" (MS4)

Many of the themes discussed in this study have variable and conflicting effects on the individual's vaccination decision, which creates ambivalence towards the vaccine and leads to a finely-balanced decision. Often convenience emerged as the decisive factor which circumvents the complex interactions of socialisation and understanding of the vaccine and 'tipped the balance' of the vaccination decision.

Conclusions

Our research explored cognitive and social elements to the uptake of the influenza vaccine in this population of early career doctors and senior medical students. Results are drawn from a small but diverse sample, and the themes derived are supported by the literature. Participants' attitudes towards the influenza vaccine were influenced by their social environment. An indifferent attitude was prevalent, and thus became a tacitly accepted element of healthcare culture. The effects of medical socialisation were attenuated by participants' understanding of the vaccine – which was often formed from many conflicting factors: previous experiences, role models, and unclear risks and benefits of vaccination. This combination allowed convenience to be a critical element of vaccination uptake. The themes described above create an ebb and flow of factors towards and away from vaccination, this led to an overarching context of ambivalence within which vaccination decisions were made. Crucially, there often seemed to be considerable disparity between an individual's opinion of the vaccine, their intentions, and their vaccination status.

On this basis we suggest a number of recommendations for improving influenza vaccination uptake. Senior staff members (particularly those in acute medical specialties e.g. respiratory medicine) are ideally situated to exploit their potential influence as positive role models and should be encouraged to do so by engaging their junior colleagues around the topic of vaccination. There should be a more targeted approach to raising awareness in areas with the most vulnerable patients – in our study many participants were unaware of the benefits of their vaccination for elderly patients, paediatric patients, and those with underlying health concerns. Policy-makers could sway the feelings of vaccination indifference towards a more receptive view by associating vaccination with professionalism. Scenarios such as the vaccination appearing in the student's log-books and it's facilitation of the intra-muscular injection, is indicative of successfully increasing uptake by positioning vaccination as a convenient exercise to demonstrate one's professionalism, without having to overcome negative evaluations of the vaccine. These recommendations demonstrate the value of a sociological perspective in shifting the conceptualisation of vaccination from one of individual behaviour to one of professional culture.

This work has begun to fill the gap in our understanding of seasonal influenza vaccination by early career doctors, and we hope that future work in this area goes further to give a deeper insight into the influenza vaccination practices of other actors within the hospital setting. Convenience has been noted elsewhere and is likely to apply widely, not just to healthcare professionals. Socialisation and the influence of role models is likely to be important in other healthcare professions although whether it results in indifference will depend on the extent to which those professions share the characteristics of medical training and practice. The study sample from which findings were drawn is small and potentially open to the criticism of a lack of representativeness. However, we believe the analysis in this study demonstrates the strength of the qualitative method for showing more nuanced and novel solutions to the persistent challenge of increasing rates of HCW influenza vaccination.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from Lancaster University Research Ethics Committee prior to data collection. Participants gave informed consent prior to data collection.

Consent for publication

Each participant gave their consent for publication by signing a consent form endorsed by Lancaster University Ethics committee (see supplementary), their data has been made anonymous by using identifier codes or pseudo-names (where participants talked about people not involved in the study).

Availability of data and material

The full datasets generated during and/or analysed during the current study are not publicly available to protect participant's confidentiality but are available from the corresponding author on reasonable request, and ethical approval.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

This study was designed primarily by RE and DG with input from RI and TK. It is one study in a larger programme of research conceived by RI. RE carried out the data collection, RE and DG analysed the results with input from RI. The manuscript was initially drafted by RE and DG, all authors contributed to the ideas discussed in the manuscript and have edited and approved the final submission.

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Supplementary 3

Seasonal influenza vaccination in healthcare workers: exploring the influence of consultants on the uptake of vaccination by medical students and early career doctors.

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Abstract

Background

The Chief Medical Officer for England recommends that all healthcare workers receive an influenza vaccination annually. Medical students are also encouraged to get vaccinated. High vaccination coverage is believed to be the best form of protection against the spread of influenza within hospital settings – protecting both staff and patients, and reducing virus transmission. However, seasonal influenza vaccination uptake by healthcare workers remains significantly lower than the target level of 75%.

Methods

We conducted a series of semi-structured interviews, with seven medical students and nine Foundation Doctors, to explore the factors informing their vaccination decisions. Interviews were transcribed and the data analysed thematically. Data collection and analysis took place as an iterative process, until theoretical saturation was achieved.

Findings

Of the sixteen participants, ten had been vaccinated during the 2015/16 season. A number of key themes emerged and there were found to be inconsistencies between an individual's opinion of the vaccine, their intentions, and their vaccination status. Moreover, individuals did not necessarily vaccinate year-on-year. The influence of consultants as role models emerged as an important theme, with senior staff being reported by juniors as demonstrating both positive and negative attitudes towards the vaccine. Participants often presented this observation in the context of their own conflicting ideals of medical professionalism - thus, the decision-making processes around influenza vaccination appear highly fluid.

Interpretation

This study suggests that senior medical staff have an important role to play in the vaccination practices of their juniors. Vaccination practices vary widely across different clinical contexts, possibly resulting in a culture of ambivalence amongst junior medical staff. The influential role of consultants could be utilised as part of a future strategy to increase vaccination, as positive role models may facilitate a cultural shift in favour of vaccination uptake.

Chapter 6

Reflections on the qualitative research

The interpretivist believes that they were to some degree a participant during the process of qualitative data collection and analysis. Thus, they cannot be detached from the data in the same way that is possible when conducting other types of research. The researcher affects, and is affected by, interactions during interviews and the process of understanding the data. In this chapter, I reflect on how my own experiences, thoughts and observations may have combined to produce the qualitative analysis. Although widely accepted as a method of best practice, whether or not reflective thinking can every truly evaluate researcher subjectivity is subject to ongoing philosophical debate (155). Accepting the limits of the reflective process; I do not hope to escape from the consequences of my position (156). But, by making my position explicit to the reader, I hope that they are able to make their own judgements about the extent to which it may have influenced the study reported in chapter five (83).

My background is in quantitative methods and this is the first time I have undertaken any qualitative research. Prior to this work I had a tendency to approach data in a detached way. However, I am a naturally sensitive and socially-aware person, able to interpret other people emotions easily, I feel that this helped during data collection and interpretation and allowed me to acquaint myself more personally with the participants and their views. Because I am new to this field I feel that the initial coding was almost entirely data-lead. However, following extensive guidance from Dawn Goodwin the thematic development become thoroughly informed by social science theory. Having wide-ranging discussions with my PhD supervisors throughout the thematic analysis resulted in an on-going, yet unrecorded, process of auditing the research during its development.

I conducted every interview myself, made field notes, transcribed the data and developed initial codes, therefore I am uniquely immersed in the data. The data analysis that followed this was built up over a number of weeks by carefully theorising the data – throughout this process myself and Dawn Goodwin discussion the data at length. I felt that I was in the best position to provide the most accurate representation of the data from the interviews, the final reporting of the findings was reviewed and developed with input from my supervisors. We have reached conclusions others may not have, as the data and interpretation had been constructed with my own input. However, any reader of the work should be able to clearly see the integration of data with theory, and understand how the conclusions were reached.

Background

My background and previous experiences will have had an effect on how I have designed and interacted with the qualitative part of research. I have been a quantitative researcher for some years. I graduated in 2013 with a degree in Mathematics and Biology from Newcastle University. I have a background in business and enterprise, my parents are self-employed and I have been involved in the family business. None of my family members is involved in medicine, and prior to starting my PhD I had no involvement with either Lancaster Medical School or the Pennine Acute hospitals NHS Trust. I do have friends who work in healthcare and this may have had an impact on my interpretation of the data. In the period leading up to when I conducted the qualitative research I had read widely on the topic of the seasonal influenza vaccine and the arguments for and against influenza vaccination in healthcare workers. I found it difficult to formulate an opinion whether or not there was enough evidence for healthcare workers to feel that they should vaccinate.

I have never had a seasonal influenza vaccine. I recognised later that I had an ambivalent attitude towards the influenza vaccination. This recognition came following comments from a peer reviewer – a testament to the benefits of the peer review process. This was my own data however, I recognised that this was derived through different experiences to that of the participants – I considered the effect this may have on my understanding of the participant's data (157). I was also very aware that I had no experience of qualitative research or working as a healthcare worker. Whilst I was concerned about this lack of knowledge I chose to embrace it as a way of minimising the power imbalance between researcher and participant (158).

Expectations

I tried to minimise my expectations prior to taking part in this process, I wanted to draw my conclusions from the data rather than preconceived ideals. However, I expected doctors to be generally middle-class, well-educated people, which were likely to have strong opinions on the influenza vaccine - either for or against, this would represent some of the conflicting literature surrounding vaccination. I expected that between 50-70% would be vaccinated, and that these people would probably be more likely to take part in the study. From my previous research using social network analysis in studies one and two, I had hypothesised that there was potentially a social network effect. By identifying these preconceptions and acknowledging them for what they were, I hoped to minimise their subsequent impact on my work.

Interaction with participants

I feel that being a similar age, gender, and background, to many of the participants was beneficial during data collection - these similarities allowed me to build rapport with participants quickly and easily (159,160). I believe that participants felt that they could be comfortable expressing their opinions to someone who lacked medical authority – I am a lay-person rather than a healthcare worker. These factors lead to participants sharing views with me that they stated they had not shared with their peers. There were similarities between myself and many of the participants – both are immersed in an educational setting, I found it easy to relate to the notion of being on the cusp of finishing a very long apprenticeship.

I thoroughly enjoyed the data collection process and I felt participants appreciated the interview time as a period of reflection. Participants seemed to appreciate the time to reflect on their vaccination choices, their risk, and who might have been important in shaping their views on this subject.

Interaction with the data

I have fully immersed myself in my data and embraced qualitative research. I have enjoying the experience of learning about and undertaking a completely new area of research. I feel that it has altered my own perceptions of qualitative research. As a Statistics student, I feel I was given the impression that qualitative research was not as robust or valid as quantitative methods. However, having taken the time to explore it, I have learnt that a qualitative approach provides an alternative way of exploring a problem – and can be used to inform quantitative methods. I now believe a mixed-methods approach is often the best way to tackle a research question.

Reflecting on the quantitative work

The practice of reflexivity seems largely contradictory to the fundamental basis of quantitative research – in which researchers remain objective and detached from the data. Results are calculated numerically using well-defined methods, in which uncertainty can be described. For example, uncertainty in parameter estimates is given by their associated measures of error. However, there is an argument for reflecting on the choice of quantitative approach which is largely driven by the researcher. The approach described in the thesis was shaped by my own prior knowledge, experience, and interaction with the literature. However, the eventual methodological approach was largely influenced by my supervisors. Reflecting on this I am satisfied that deferring to my supervisors in this case was reasonable.

Impact of the research

Following the completion of my third study in the programme of work, I was invited to attend an influenza campaign committee meeting at the Pennine Acute Hospitals NHS Trust. The influenza campaign committee is tasked with organising and encouraging seasonal influenza vaccination amongst staff working at the Pennine Acute Hospitals NHS Trust – where I carried out the majority of my data collection. I presented this research, its findings, and discussed possible methods of increasing influenza vaccination based on this work. During this meeting it became clear that my qualitative interpretation of the data seemed to resonate with the campaign staff, though it was clear that they had not considered vaccination in cultural context before. Subsequently, the team re-evaluated its influenza vaccination campaign strategies and this appeared to have some success, improving vaccination uptake in the initial months. Many of the recommendations drawn from the research were familiar to the influenza campaign team. For example, it was apparent that they were familiar to the importance of the convenience of the vaccination, however, their campaign could have emphasised this more. By approaching the group with the authority of scientific research, I felt they were able to justify campaign strategies that focused on factors such as convenience. I believe that the committee had a prior understanding of the vaccination environment I described, but because these findings now had an authority of research, campaigners were vindicated to apply them.

Whilst this is not a conclusive examination of the validity of the findings of this work, having received such feedback from stakeholders should reassure the reader that the interpretation of the data was accurate and recognisable to others in the environment. This also emphasises the importance of research that is interpretable and of benefit to society.

Chapter Summary

In this chapter I have attempted to disclose my own position and the way in which this may have affected the research. I hope the reader is able to gain a better understanding of my position in relation to that of the participants. As stated above I am new to the discipline of qualitative work – this has had both negative and positive effects – this in combination with a reasonably benign subject matter, has allowed for a more comfortable self-reflexivity than perhaps I will be permitted in the future. During reflection on my own awareness of self, I have appraised the construction of knowledge presented in chapter five, and I am satisfied that this chapter adequately details this process.

Chapter 7

Discussion

Overview of findings

This thesis explores the influences on decision-making around the uptake of seasonal influenza vaccination amongst early career doctors and medical students. Initially, I investigated the importance of an individual's social network and vaccination status when considering infectious disease spread, via the use of an outbreak simulation model. The second study expanded further on this concept, using social network data and auto-logistic regression to predict an individual's likelihood of vaccinating given the behaviour of their peers. Finally, the third study employed a qualitative approach to explore the factors informing vaccination decisions. Below I briefly structure the findings according to the Thesis research questions, followed by an in-depth discussion of findings from an amalgamation of both quantitative and qualitative studies.

Research Questions:

How are social networks relevant for influenza vaccination?

In chapter three, the outbreak simulation model showed that the likelihood of individuals contracting influenza tended to be similar regardless of vaccination based on between-ness (the extent to which an individual may act as a gate-keeper) or degree (the number of neighbours an individual has) – using either network based vaccination strategy was preferable to random vaccination.

The auto-logistic regression model described and applied in chapter four, showed that rather than a diffusion of behaviour, there was a repulsion effect between an individual doctor's vaccination status and that of their neighbours – those with more vaccinated friends were less likely to be vaccinated themselves.

Are there clusters of vaccinated and non-vaccinated individuals in medical school or in a hospital setting?

There was no clustering of vaccinated individuals within the medical student social network studied in chapter three or in the foundation doctor network explored in chapter four.

What are the seasonal influenza vaccination uptake practices and perceptions of medical students?

Vaccination uptake in the study samples was large, 65% of Lancaster medical students (described in chapter three). Medical students who were vaccinated were more likely to think other medical students were vaccinated. Their perceptions of influenza vaccination were explored in chapter five.

How do medical students' and early career doctors' perceive seasonal influenza vaccination and how may their social interactions have influenced them?

In chapter five we fully explored the perceptions of influenza vaccination, these ranged from having a very good opinion of the influenza vaccine to a very bad one. However most participants were somewhat indifferent towards influenza vaccination. Medical students' and early career doctors' perceptions were influenced by their social interactions with peers through the process of socialisation and a diffusion of understanding.

Do people change their seasonal influenza vaccination habits often and if so, what causes this change?

In the qualitative study, we found that there was considerable disparity between an individual's opinion of the vaccine, their intentions, and their vaccination status. Practicalities such as convenience emerged as decisive factors contributing to vaccination decision-making and participants often described ambivalence towards the seasonal influenza vaccine. Because the vaccination decision was fluid we found that many participants had vaccinated during some previous seasons and not others. However, future work should explore this theory in more depth using longitudinal data.

This thesis has highlighted the value of considering social networks when evaluating vaccination decisions – even in small networks such as those found at Lancaster Medical School and the Pennine Acute Trust. We have shown that vaccination of key individuals within a network affects the spread of infection throughout the Lancaster Medical School social network. Thus, an individual's risk of contracting disease is indelibly linked with their position in the social network. The quantitative work and other literature suggest that perceptions of risk are associated with an individual's position in the social network, and their interpretation of the behaviour of others. The qualitative work also suggested that whilst this may be true, the corollary that risk perceptions then impact vaccination status may be unfounded - whether or not an intention to vaccinate (informed by perceptions of risk) translates into an action is complex and involves a range of other factors. Furthermore, the findings described in chapter four suggest that there is heterogeneity within the structure of the foundation doctor network, and that the actions of an individual's neighbours in the network could have an effect on their vaccination uptake. Foundation Doctors in year 2 working on the west axis of the trust had a far sparser social network. However, the inclusion of this covariate could not account for network effects on vaccination. Influenza vaccination campaigns that intend to use social networks to influence vaccination must consider where differences in network structure arise and how these might impact vaccination practices, as well as possible differences in demographic effects.

The quantitative work suggested that individuals may act based on the behaviour of others. Thus, during the qualitative work we were able to explore in detail the effects of social relationships on individual's vaccination habits. The qualitative work confirmed that the actions and opinions of others were important in shaping those held by the individual. However, the qualitative work provided a far deeper understanding of a socialisation process - which the quantitative work had previously eluded too.

The auto-logistic model, in chapter 4, suggests that in the foundation doctor network individuals with a larger number of vaccinated neighbours were less likely to be vaccinated themselves. This finding is uncommon, in most cases we expect behaviour to diffuse throughout a network (161). We hypothesised that this finding may represent individuals taking advantage of the effects of herd immunity. However, the qualitative work suggests that dissenting behaviour is a reasonable and active part of socialisation within this population. Our qualitative work suggests that the process of socialisation fluctuates as individuals establish their identities as medical practitioners. Both dissention and conformation are common however; the cross-sectional data we collected cannot show changes in these trends over time. Future work should aim to better understand the process of socialisation using longitudinal data.

The quantitative analysis suggested that likelihood of vaccination may differ in different groups within the network. Results from the qualitative analysis may provide an explanation as to why this is the case. Participants' attitudes were informed in part by socialisation, largely this was established by senior staff who acted as role models. Role models encouraged individuals in their team to form both positive and negative attitudes towards vaccination, for example, we found some evidence of inter-specialty differences in attitudes towards the influenza vaccine. This could be why vaccination may differ in different groups within the network. Differences in social norms within the population are likely to have an impact on vaccination habits regardless of perceived social networks. I suggest that social norms could spread through a population using channels that were not identified by our social network. This resonates with the qualitative work, a culture was established indirectly, and often formed by external actors rather than the participants friendship group. Our interpretation of the quantitative results has been informed by the qualitative work. These findings suggest that future work should revise the data collection tool to facilitate role model nomination by participants.

The qualitative work suggests that decisions regarding vaccination are largely situated at the exact point of vaccination delivery. Although prior experiences are important in framing the situation, until this point for most people the vaccination decision remains finely-balanced. The quantitative work must be interpreted in light of this finding. The social network data was not collected at the point of vaccination delivery – practically this would have been impossible to do successfully for most people. Instead we collected data after the vaccination period (vaccinations are given between October and December, data was collected in the early months of the following year). As we were assessing the effects of neighbours' vaccination habits on an individual, we used vaccination status as a proxy for vaccination attitude. We assumed that an individual's vaccination status would largely reflect their attitudes towards vaccination and we investigated whether or not this affected their peers. However, following the qualitative work we are now aware that a participant's underlying vaccination attitude may not be represented by their vaccination status. Often there were discrepancies between an individual's influenza vaccination status and their attitudes, intentions, and actions. Thus, an individual who has received an influenza vaccine may not have a positive attitude towards vaccination, they also may not have accurate knowledge of their peers' vaccination decision – this finding distorts our interpretation of the quantitative results. Accordingly, a possible direction for future work might include a reassessment of the data collection approach and statistical model design. Contrariwise, I believe that it would be almost impossible to collect the detail and volume of data used in this this at the time of vaccination and even if this could be achieved it would introduce a significant bias. Thus, further exploration of the statistical approach may be more practical. The qualitative work highlights that individuals have an underlying vaccination opinion separate to their vaccination status, with the former being far harder to quantify than the latter. Thus, we might model the underlying vaccination opinion as a continuous latent distribution for each individual, from which we observe the individuals vaccination status. Introducing this element to our model would synthesis the qualitative findings into our modelling approach.

This work provides a mixed methods approach to understanding influenza vaccination behaviour amongst medical students and early career doctors. The qualitative work has allowed us to reassess findings from the quantitative studies to provide a picture of the complex processes involved in the influenza vaccination decision. Interpreting these studies together has given a deeper understanding of the role social networks play in influencing influenza vaccination choices.

Implications for current practices

Influenza causes considerable morbidity and mortality worldwide, those with underlying health concerns are at a particularly high risk. The seasonal influenza vaccination is designed to reduce the spread of influenza and protect those at a high risk of influenza infection. The Chief Medical Officer for England encourages all medical staff to have a seasonal influenza vaccine to protect both themselves and their patients. Influenza vaccination of healthcare workers remains stagnant at around 55%, well below the 75% target. This work aimed to explore influenza vaccination amongst medical students and early career doctors, to work towards developing recommendations to increase seasonal influenza vaccination uptake.

This programme of work has been shaped around its application in a healthcare setting, and the relevance of the findings to stakeholders is important. During the first year of my PhD I was awarded funding from the Colt Foundation, an occupational health trust – an indication of the value of this work to those with an interest in occupational health. Following the publication of the third chapter, numerous popular news outlets reported on the study (including the BBC News, The Times and the The Telegraph) – which suggests that there is public curiosity about influenza and it's vaccination. In the second year I was invited to write a feature piece for the Occupational Health at Work publication (appendix 3). Again this signifies an interest in the research, but crucially, this suggests a potential impact for occupational health practitioners. Throughout the programme I have given talks about the research to a range of audiences (Healthcare workers, Occupational health workers, Academics, The Colt Foundation – including non-academic members), this is indicative of the significance of this research. The relevance of this thesis is highlighted by the interest shown by academics, practitioners and the public.

The major implication of this work is its application to healthcare worker vaccination campaigns. Following completion of the work we were able to make recommendations to the influenza campaign team at the Pennine Acute Hospitals NHS Trust (see appendix 4). We were able to combine our findings with recent guidance from the NHS wide 'flu fighter' campaign advice (162). We suggested an approach that acknowledged the notion that staff were largely ambivalent towards vaccination and that the vaccination decision was finely balanced. Recommendations based on this work include:

1. Senior medical staff members (particularly those in acute medical specialties e.g. respiratory medicine) are seen by juniors as role models when it comes to vaccination. This could be used to improve overall vaccine uptake by:
    a. encouraging more consultants to get vaccinated with their juniors
    b. encouraging consultants to discuss vaccination with their juniors
    c. identifying one or more "popular and influential" consultants who are willing to be vaccinated and also willing to share this fact e.g. by featuring them in materials around the vaccination campaign launch.

2. There could be a more targeted approach to raising awareness in areas with the most vulnerable patients. Vaccination may be more relevant in some areas of medicine than others. For example, those who work in respiratory medicine may be more receptive to vaccination campaigns and vaccination may be more relevant to them.

3. Our research provides evidence in support of some of the recommendations made by the CQUIN standard to increase influenza vaccination. Ensuring that the vaccine is accessible is of paramount importance. We stress the extent to which the vaccine must be convenient, often participants were under huge time pressures – we would advocate travelling vaccination nurses or foundation doctors being allocated time to get vaccinated.

4. Some foundation doctors reported vaccinating so that they could allow colleagues to get their intra-muscular injection skill signed off in their logbooks. It might therefore be possible to get the foundation programme administrators to arrange vaccination teaching sessions for the doctors who can vaccinate each other and get “signed off” in their logbooks.

5. We suggested that for some people vaccinating with their peers was important, and because this was not practiced throughout the trust there was room for improving vaccine uptake by establishing it as a social norm.

Our recommendations include both opportunities for immediate practical changes and long-term changes to social norms. This advice was well received and has encouraged an evidence-based vaccination campaign within the Pennine Acute NHS Hospitals Trust. Initial vaccination uptake suggested that slightly more people have been vaccinated than last year (appendix 5). Increased influenza vaccination within a hospital is likely to protect both staff and patients from the influenza virus.

The ability to report and disseminate our findings to occupational health practitioners in a timely manner is a key strength of this work, particularly in light of the ongoing shift towards research that has impact (163). This thesis demonstrates a potential shift in public health research. Current research in public health largely involves investigation of risk factors and outcome measures at an individual level (164). This schedule of work has tried to move away from investigating a phenomenon at a single level and towards using a range of tools to better understand population-level effects on vaccination. Thus, moving towards an ability to give advice to policy makers that may have the greatest effect on the populations behaviour as a whole. This is likely to be able to effect a larger change despite some recommendations not being applicable to everyone.

The influenza vaccination decision appears to be informed by socialisation and knowledge of the vaccination, and in some cases their peers. This system may be generalizable to other healthcare professionals or other behaviours in the healthcare environment – for example doctors use of antibiotics (165), handwashing behaviour or bedside manner. Likewise, the auto-logistic modelling approach described in chapter four is applicable to other behaviours that may be influenced socially. Thus, not only is our mixed methods approach a move towards an effective method of evaluating complex public health problems, it is likely to be applicable to a large range of settings.

This work explored a range of methodological approaches, and has provided contributions to current academic research in social network analysis. By combining the findings from all three studies we have attained a deeper interpretation than could be achieved from using one method in isolation. For example, by combining social network analysis, spatial models and qualitative research we have shed new light on the validity of our assumptions. This thesis demonstrates the value of using mixed-methods research with an extensive practical example.

Strengths and weaknesses

To our knowledge this is the first mixed methods investigation of influenza vaccination practices in early career doctors working in the NHS. It has the potential to be extended to other professional groups within the medical setting and beyond. This is a particular strength of the work, and will allow for further work to build on the findings.

Lancaster Medical School provided an ideal setting within which we were able to investigate the influenza vaccination attitudes of the medical students, and due to its small size we were able to feasibly collect detailed social network data. The Pennine Acute Hospitals NHS Trust allowed us to access early career doctors working in two distinct environments – either the east or west axes of the Trust. This organisational structure allows for a ‘natural laboratory’ in which we could compare the east and west axes – in chapter four we describe the difference in network density in the different year groups and axes, and use the information as covariates in the auto-logistic model. There is the potential for the findings of this work to have wide-reaching implications for the delivery of vaccination campaigns – particularly given the similarities in the medical socialisation of early career doctors throughout the medical education system - the issues highlighted resonate with concepts mentioned within the broader literature, suggesting that the findings may have some relevance throughout the population of early career doctors in the UK (166).

The work of this thesis was carried out according to an extensive and well-organised protocol that used a mixed methods approach. By combining findings from both quantitative and qualitative studies it was possible to construct a broader understanding of the vaccination decision. The quantitative work demonstrates a methodology that can be used to investigate the social network effects on vaccination in the presence of demographic factors (this methodology is flexible and could be applied to a range of different scenarios). It allows for a comparison between different demographic groups within the network. And goes some way to describing how vaccination of specific individuals within a network might affect others' risk of infection. Conversely, the qualitative work enabled an exploration of individual vaccination decisions' that would not have been possible using quantitative methods. From this, clear objectives for future work have emerged. For example, it is clear that vaccination status is an unreliable proxy for an individual's attitude towards influenza vaccination – thus future models should allow for this discrepancy.

Consequently, a major weakness of these studies is the assumption that an individual's vaccination status reflected their views on the influenza vaccine. During the course of the qualitative work it became obvious that this was an unfounded simplification of complex vaccination attitudes. Whilst this ultimately led to additional findings, it may be necessary to re-examine the statistical models in light of this – see below for details.

Additionally, there are weaknesses in the data collection approaches. Individuals' interpretations of our social network data collection sheet may have been different, and in turn this may have had an effect on our results. Furthermore, we artificially bounded the network, a common practice in social network analysis - due to practicality restrictions we only included medical students and foundation doctors. Following completion of the qualitative work it was clear that other actors within the environment had an effect on participants' vaccination attitudes. In particular, it was clear that senior staff were key actors in the decision-making process.

To analyse the social network data, we assumed reciprocal ties and reduced the weighted social network data to a binary network. By doing this some of the detail in the data was lost, and it is unclear whether or not keeping a directional network would have produced different results. Although, this is a potential weakness of the work, it remains unclear whether or not directional ties would have a substantial effect on the results, given the complexities of the vaccination decision and the influence from socialisation (established by all members of the group).

Future Work

This work should be extended to explore the vaccination attitudes of other medical professionals within the hospital. It is now clear that the vaccination decision is a complex process including multiple actors. Findings from this work suggest that it is now necessary to explore the vaccination attitudes of senior staff, as they are important in establishing the vaccination attitudes of junior doctors.

Secondly, there is a need to explore further the use of the auto-logistic model in social network research. For example, in our analysis we inferred an effect from the behaviour of peers by counting the number of vaccinated neighbours an individual possessed and it may be the case that this is better represented as a proportion of neighbours who are vaccinated. Also, this work has shown that vaccination status is not an adequate marker for an individual's views on vaccination. Thus, future work should explore the use of latent multivariate normal distributions to model individuals' vaccine attitudes that is in some way linked to the observed vaccination status.

The work presented in this thesis goes part of the way to a better understanding of the influences on early career doctors' and medical students' decision-making around the seasonal influenza vaccination. By exploring this subject further in the future, it will be possible to improve seasonal influenza vaccination uptake by healthcare workers, and in turn better protect patients and medical staff from the effects of influenza.

Chapter 8

Conclusion

In order to improve seasonal influenza vaccination uptake by healthcare workers, we must first gain a better understanding of the decision-making process involved, to effect the greatest change we must understand this at a population level. This goal is common to a range of problems in the field of public health.

This thesis presents a mixed methods approach to understanding the influences on junior doctors' and medical students' decision making around the seasonal influenza vaccination. I believe that the key strength of this work is that the findings are drawn from a combination of quantitative and qualitative approaches, which has allowed for a more in-depth understanding of the factors involved in influenza vaccination than would have been achieved by the use of one method alone. I chose to investigate the risk of vaccination within a network and the social effects on vaccination using quantitative tools. I believe that further exploration of quantitative methods of understanding behaviour on a social network will be vital to understanding the health behaviours of large and diverse communities. Supplementing this work with a qualitative study has allowed for a unique opportunity to reflect on the suitability of the modelling approach and explore our findings from the quantitative work in more depth.

The findings presented here suggest that the social effects on vaccination decisions by early career doctors are subtle and variable – and not easily measured using survey tools. By considering the findings from all three studies together I was able to produce guidelines that were sensitive to differences within the social network yet focused on factors that were likely to affect the most people. I was able to quickly disseminate the findings of this study to occupational health practitioners, this had a direct and almost instant impact on policy at the Pennine Acute Hospitals NHS Trust. I believe that this is an example of best practice in public health research and a key strength of the thesis.

Much work remains to be done to explore the social impact on health behaviours in more depth. It might then be possible to see what impact social relationships have on the behaviour of individuals within social networks. By gaining a better understanding of health behaviours, the subtleties within them, and how they are established, we might in the future be able to construct more effective campaigns that work towards behavioural shifts that will ultimately improve public health.

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Appendices

Appendix 1. Data collection materials for study 2

Study Title: Assessing the Influenza vaccination decision of Foundation Doctors: A network analysis perspective

We are asking if you would like to take part in a research project. The purpose of this study is to look at the interaction between foundation doctors and their vaccination decisions as individuals this is outlined in the information sheet.

Before you consent to participating in the study we ask that you read the participant information sheet and mark each box below with your initials if you agree. If you have any questions or queries before signing the consent form please speak to the researcher, Rhiannon Edge.

	Please initial box after each statement
1. I confirm that I have read the information sheet and fully understand what is expected of me within this study.	☐
2. I confirm that I have had the opportunity to ask any questions and to have them answered.	☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.	☐
4. I understand that once my data have been anonymised and incorporated into themes it might not be possible for it to be withdrawn, though every attempt will be made to extract my data, up to the point of publication.	☐
5. I understand that any information I give will remain strictly confidential and anonymous unless it is thought that there is a risk of harm to myself or others, in which case the principal investigator may need to share this information with her research supervisor.	☐
6. I consent to Lancaster University keeping my data for 5 years after the study has finished.	☐
7. I consent to take part in the above study.	☐

Name of Participant____________________ **Signature**______________________ **Date** ____________

Name of Researcher ____________________**Signature** ______________________**Date** ____________

'Flu Data Sheet

This is the data collection sheet for the 'flu vaccination questions. You **must** write your name in the space provided. However, your name will be coded and removed by the principle investigator, prior to data imputing and analysis. Dr Isba will be the only one who see your name, and after coding this sheet will be anonymous.

Name:

Age:

Sex: male / female

Ethnicity:

Which speciality do you currently work in?

Which ward or wards do you currently spend the most time on?

Have you had your 'flu vaccine this year? Yes / No

If no, are you planning on having a 'flu vaccine this year? Yes / No

What % of foundation doctors do you think will have the 'flu vaccine this year?

What % of consultants do you think will have the 'flu vaccine this year?

What % of ALL healthcare workers do you think will have the 'flu vaccine this year?

In the last 5 years have you had respiratory infection with flu-like symptoms before? Yes / No

On a scale of 1-10 how likely do you think it is that you will have 'flu this winter?

1 2 3 4 5 6 7 8 9 10

On a scale of 1-10 how effective do you think high 'flu vaccination coverage is at preventing influenza outbreaks?

1 2 3 4 5 6 7 8 9 10

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Network Analysis Sheet

This is the data collection sheet for the social network analysis. You **must** write your name in the space provided. However, your name will be coded and removed by the principle investigator, prior to data imputing and analysis. Dr Isba will be the only one who see your name, and after coding this sheet will be anonymous.

Each row contains the name of one of the foundation doctors at the Pennine Acute Hospitals NHS Trust. Each column is a level of connection you have with that person. **Please place one tick only in each of the rows.**

Name:

Age:

Foundation Year: 1 / 2

Sex: male / female

Name	I have never met this person	I recognise this person's name but wouldn't see them regularly	I occasionally see this person for very short periods of time.	I see this person briefly at irregular intervals	I see this person on most shifts/4 or more days a week	I see this person on almost every shift for long time periods/live with them
A						
B						
C						
D						

Note extend table once Foundation Doctors names are known, 1st row of table to be repeated on each sheet of names.

Participant Information Sheet

'Flu vaccine uptake in foundation doctors: a study from a social network perspective.

My name is Rhiannon Edge and I am conducting this research as a student in the Statistics and Epidemiology PhD programme at Lancaster University, Lancaster, United Kingdom.

What is the study about?

The purpose of this study is to look at the interactions between foundation doctors in the context of individual vaccination decision's, this follows on from a study using medical students in 2013-14. Firstly, the study is looking at how much time all the foundation doctors spend with each other. Secondly, the study also looks at individuals attitudes to having the 'flu vaccine.

I will have access to the network data and flu vaccination data along with my supervisors, Dr Rachel Isba, Dr Thomas Keegan and Dr Dawn Goodwin.

Whilst you are being asked to sign a consent form and write your name on the data collection form, Dr Isba will take your name off the form and give you a code instead, before I input the data. This means that nobody will be able to tell who you are or what you have put for your answers.

Why have I been approached?

You have been approached because the study requires information from foundation doctors within the Pennine Acute Hospitals NHS Trust. This study is specifically exploring doctors 'flu vaccination habitats.

Do I have to take part?

No. It's completely up to you to decide whether or not you take part. There are no negative consequences should you decide not to take part in this study.

What will I be asked to do if I take part?

If you decide you would like to take part, you would be asked to sign a consent form and then complete two data collection sheets. One if the forms will ask you about which foundation doctors you know and how much time you spend with them. The other form will ask you: some basic demographic questions; what you think about flu vaccination; and whether or not you have had the vaccine.

Will my data be confidential?

The information you provide is confidential. You will be asked to write your name on the data collection sheet as it is necessary for the data analysis.
However these sheets will be anonymised by Dr Isba by giving you a unique code. The data collected for this study will be stored securely in Dr Isba's office and only the researchers conducting this study will have access to the data once they have been anonymised:

- hard copies of questionnaires will be kept in a locked cabinet to which only Dr Isba has the key and, as is usual research practice, will be kept for five years before being destroyed

- computer files of anonymous data will be used on password-protected and encrypted computers only.

What will happen to the results?

The anonymous results will be summarised and reported in a PhD thesis, may be submitted for publication in an academic or professional journal, and will be used in presentations at conferences and meetings. There will be no way of identifying you.

Are there any risks?

There are no risks anticipated with participating in this study. However, if you experience any distress following participation you are encouraged to inform the researcher and seek help and advice. Some suggested resources are provided at the end of this sheet.

Are there any benefits to taking part?

Although you may find participating interesting, there are no direct benefits in taking part.

Who has reviewed the project?

This study has been reviewed by the Faculty of Health and Medicine Research Ethics Committee, and approved by the University Research Ethics Committee at Lancaster University. This study has also been reviewed by the Research and Development Committee at the Pennine Acute Hospitals NHS Trust, and approved by the Governance Arrangements for Research Ethics Committees (GAfREC).

Where can I obtain further information about the study if I need it?

If you have any questions about the study, please contact the main researcher:

Rhiannon Edge
r.edge@lancaster.ac.uk

Supervisor: Dr Rachel Isba
r.isba@lancaster.ac.uk
(01524) 592450

Complaints

If you wish to make a complaint or raise concerns about any aspect of this study and do not want to speak to the researcher, you can contact:

Research Director for Lancaster Medical School
Title: Prof. Anne Garden
Email: a.garden@lancaster.ac.uk
Tel: (01524) 593383
Lancaster Medical School
Furness Building
Lancaster University
Lancaster
LA1 4YG

If you wish to speak to someone outside of the Medical Programme, you may also contact:

Professor Paul Bates
Tel: (01524) 593718
Associate Dean for Research Email: p.bates@lancaster.ac.uk
Faculty of Health and Medicine
(Division of Biomedical and
Life Sciences) Lancaster
University
Lancaster
LA1 4YD

Thank you for taking the time to read this information sheet.

Resources in the event of distress

Should you feel distressed either as a result of taking part, or in the future, the following resources may be of assistance.

Mind – mental health charity
The Angel
1 St Philips Place
Salford
Manchester
M3 6FA

Telephone: 0161 8393030
Email: advocacy@mindinsalford.org.uk

Appendix 2. Data collection materials for study 3

Health & Medicine | Lancaster University

Study Title: What are healthcare workers' perceptions of seasonal influenza vaccination and how may their social interactions have influenced them?

We are asking if you would like to take part in a research project to study the social effects on healthcare workers perception and compliance of the influenza vaccination.

Before you consent to participating in the study we ask that you read the participant information sheet and mark each box below with your initials if you agree. If you have any questions or queries before signing the consent form please speak to the principal investigator, Rhiannon Edge.

1. I confirm that I have read the information sheet and fully understand what is expected of me within this study ☐
2. I confirm that I have had the opportunity to ask any questions and to have them answered. ☐
3. I understand that my interview will be audio recorded and then made into an anonymised written transcript. ☐
4. I understand that audio recordings will be kept until the research project has been examined. ☐
5. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐
6. I understand that once my data have been anonymised and incorporated into themes it might not be possible for it to be withdrawn, though every attempt will be made to extract my data, up to the point of publication. ☐
7. I understand that the information from my interview will be pooled with other participants' responses, anonymised and may be published ☐
8. I consent to information and quotations from my interview being used in reports, conferences and training events. ☐
9. I understand that any information I give will remain strictly confidential and anonymous unless it is thought that there is a risk of harm to myself or others, in which case the principal investigator will need to share this information with her research supervisor. ☐
10. I consent to Lancaster University keeping written transcriptions of the interview for 5 years after the study has finished. ☐
11. I consent to the researcher sharing and discussing my data with her supervisors ☐
12. I consent to take part in the above study. ☐

Name of participant__________________Signature________________Date_______

Name of researcher__________________Signature________________Date_______

Social Network Data Collection sheet

Network Analysis Sheet

This is the data collection sheet for the social network analysis. You **must** write your name in the space provided. However, your name will be coded and removed by the principle investigator, prior to data inputting and analysis. Dr Isba will be the only one who see your name, and after coding this sheet will be anonymous.

Each row contains the name of one of the **foundation doctors/medical students** at the Pennine Acute Hospitals NHS Trust. Each column is a level of connection you have with that person. **Please place one tick only in each of the rows.**

Name:

Age:

Sex: male / female

Name	I have never met this person	I recognise this person's name but wouldn't see them regularly	I occasionally see this person for very short periods of time.	I see this person briefly at irregular intervals	I see this person on most shifts/4 or more days a week	I see this person on almost every shift for long time periods/live with them
A						
B						
C						
D						

Note extend table with medical students/foundation doctors names, 1st row of table to be repeated on each sheet of names.

Participant Information Sheet

'Flu vaccine uptake in Healthcare workers: a qualitative study.

My name is Rhiannon Edge and I am conducting this research as a student in the Statistics and Epidemiology PhD programme at Lancaster University, Lancaster, United Kingdom.

What is the study about?

The purpose of this study is to look at the interactions between healthcare workers in the context of individual vaccination decisions. This study follows on from two studies using medical students in 2013-14 and Foundation Doctors in 2014-15. The current study seeks to explore individuals' attitudes to having the 'flu vaccine and how social interaction may shape opinions and vaccination behaviour. We are interested in understanding what drives a person to vaccinate or abstine and whether or not their social interactions effect this.

I will arrange an interview time at your convenience. These will be anonymised and then be transcribed and analysed. I will have access to the data along with my supervisors, Dr Rachel Isba, Dr Thomas Keegan, Dr Dawn Goodwin and Prof. Peter Diggle.

Why have I been approached?

You have been approached because the study requires information from foundation doctors within the Pennine Acute Hospitals NHS Trust and Medical Students at Lancaster University. This study is specifically exploring healthcare workers 'flu vaccination habitats.

Do I have to take part?

No. It's completely up to you to decide whether or not you take part. There are no negative consequences should you decide not to take part in this study.

What will I be asked to do if I take part?

If you decide you would like to take part, you would be asked to sign a consent form and then participants will be invited to attend an interview. The interview will take up to an hour and you will be reimbursed for your travel expenses. You will be asked to fill out a data collection sheet – this will ask you about your relationship with others in the medical school.

Will my data be confidential?

The information you provide is confidential. You will be asked to sign a consent form and to write your name on the data collection sheet, as it is necessary for the data analysis. However, these sheets will be anonymised by Dr Isba by giving you a unique code before I input the data. This means that nobody will be able to tell who you are or what you have put for your answers. The data collected for this study will be stored securely in Dr Goodwins's office and only the researchers conducting this study will have access to the data once they have been anonymised. If you decide to take part in the interview the researcher will be aware of who you are however, data from these will be anonymised prior to analysis. Confidentiality will only be broken if I and my supervisors believe you are likely to harm yourself or others. If this is the case we will inform you and the relevent authorities. Some direct quotes may be used during publication of the research – if this is the case your identity will be hidden.

- hard copies of questionnaires will be kept in a locked cabinet to which only Dr Goodwin has the key and, as is usual research practice, will be kept for five years before being destroyed
- computer files of anonymous data will be used on password-protected and encrypted computers only.
- audio files will be destroyed after completion of my PhD and interview transcripts will be destroyed after 5 years.
- whilst every effort will be made, it is not possible to ensure confidentiality of participation where the interview takes place on work premises during the working day

What will happen to the results?

The anonymous results will be summarised and reported in a PhD thesis, may be submitted for publication in an academic or professional journal, and will be used in presentations at conferences and meetings. There will be no way of identifying you.

Are there any risks?

There are no risks anticipated with participating in this study. However, if you experience any distress following participation you are encouraged to inform the researcher and seek help and advice. Some suggested resources are provided at the end of this sheet.

Are there any benefits to taking part?

You may find participating interesting, and whilst there are no direct benefits for you to take part the results from these study may be used to inform future occupational health and safety policy for healthcare workers.

What happens if I want to withdraw?

Participants may withdraw their consent to be directly quoted at any point up to the point of PhD thesis submission (2017).

Who has reviewed the project?

This study has been reviewed by the Faculty of Health and Medicine Research Ethics Committee, and approved by the University Research Ethics Committee at Lancaster University. This study has also been reviewed by the Research and Development Committee at the Pennine Acute Hospitals NHS Trust, and approved by the Governance Arrangements for Research Ethics Committees (GAfREC).

Where can I obtain further information about the study if I need it?

If you have any questions about the study, please contact the main researcher:

Rhiannon Edge
r.edge@lancaster.ac.uk

Supervisor: Dr Dawn Goodwin
d.goodwin@lancs.ac.uk

Complaints
If you wish to make a complaint or raise concerns about any aspect of this study and do not want to speak to the researcher, you can contact:
Head of Medical Education
Title: Dr Colin Melville
Email: c.melville@lancaster.ac.uk
Tel: +44 (0)1524 595240
Lancaster Medical
School Furness
Building Lancaster
University Lancaster
LA1 4YG

If you wish to speak to someone outside of the Medical Programme, you may also contact:
Professor Roger Pickup
Tel: (01524) 593746
Associate Dean for Research
Email: r.pickup@lancaster.ac.uk
Faculty of Health and Medicine (Division of Biomedical and Life Sciences)
Lancaster University
Lancaster
LA1 4YD

Thank you for taking the time to read this information sheet.

Resources in the event of distress

Should you feel distressed either as a result of taking part, or in the future, the following resources may be of assistance.

Mind – mental health charity
The Angel
1 St Philips Place
Salford
Manchester
M3 6FA

Telephone: 0161 8393030
Email: advocacy@mindinsalford.org.uk

Semi-Structured Interview Questions

Begin with a verbal introduction and confirm that they understand what they are consenting too and that they are happy to continue. Remind them that they will be recorded.

Topic	Lead Question	Follow up Questions
Influenza vaccination attitude	What do you think about the seasonal influenza vaccine?	What influences your attitude towards the flu vaccine (prompts: media, research, co-workers)? / Why do you choose to vaccinate/not vaccinate? / Has your opinion of influenza vaccination ever changed? / What do you think encourages & discourages you and your colleagues to take the seasonal influenza vaccine? / how do you think about your risk of infection? / What did you think about when made your vaccination decision?
Peer influence	What's your relationship like with the people you work with?	Do you see them regularly? / Do you do things together outside of work? / Do you think they influence your behaviour at work? / In what way? Do you and your colleagues talk about the seasonal influenza vaccine? / Do you think your colleagues influence your opinion of vaccination?
Role models	Who do you look up to professionally?	Do you see them often? / do you adopt any of their work behaviours? / Do you think they have a flu vaccine regularly? / How does that affect your attitude towards the vaccine?
Homophily	Do you think you socialise with people at work because they are similar to you?	In what way? / In what setting? / are you aware of your friends' attitudes towards the seasonal influenza vaccine?
Social network effects on vaccination	Would you say you are a social member of the group at work?	Do you think you influence your peers' behaviour at work? / Do you ever think about how your social interactions at work could affect infectious spread within the hospital?

Appendix 3. Dissemination.

Conferences and invited talks

Public Health Science 2016: a national conference dedicated to new research in UK, organised by the Lancet, Cardiff 2016.

- Seasonal influenza vaccination in healthcare workers: exploring the influence of consultants on the uptake of vaccination by medical students and early career doctors.

Invited speaker at the Mitchell centre lecture series, Manchester University, November 2016.

- Assessing the effects of social networks on vaccination behaviour.

XXXVI Sunbelt Conference of the International Network for Social Network Analysis (INSNA,) *California, April 2016*

- Assessing the effects of social networks on seasonal influenza vaccination uptake in foundation doctors.

American Public Health Association Annual Conference, Chicago, November 2015

- Seasonal influenza uptake in junior doctors – an investigation using social network analysis.

XXXV Sunbelt Conference of the International Network for Social Network Analysis (INSNA,) *Brighton, June 2015*

- Seasonal influenza in medical students: results from an outbreak simulation model based on a social network approach.

9th UK and Ireland Conference on Occupational and Environmental Epidemiology, Oxford, April 2015

- How can social network analysis inform influenza vaccination campaigns for HCWs? Results from a preliminary study using medical students.

Public Health Science 2014: a national conference dedicated to new research in UK, organised by the Lancet, Glasgow 2014

- Seasonal influenza in medical students: results from an outbreak simulation model based on a social network approach.

1st European Conference on Social Networks, Barcelona, July 2014

- Why does seasonal influenza vaccination uptake by healthcare professionals remain low? An approach using social network analysis.

Published work in the Occupational Health at Work journal

Occupational Health at Work 2016; 12(6): 29–33

Influencing influenza

Despite targets, only half of all healthcare workers vaccinate against flu. What lies behind this reticence?

Despite a Department of Health policy to encourage uptake of the seasonal influenza vaccine among staff involved with direct patient care, only half of all healthcare workers are vaccinated. Rhiannon Edge examines the possible reasons why healthcare workers choose whether or not to be vaccinated and explains how social network analysis is providing new insights into their decisions and motivations.

INFLUENZA is a disease with public and occupational health (OH) consequences. This article addresses some important themes on the immunisation of healthcare workers against seasonal influenza, including:

- ➢why vaccination may be desirable in healthcare populations
- ➢how the seasonal influenza vaccination can sometimes be poorly matched to the virus
- ➢the effects of social interaction on disease spread
- ➢current research involving the application of social network analysis to epidemiology
- ➢whether or not influenza vaccination should be mandatory for healthcare workers.

UNDERSTANDING INFLUENZA IMMUNISATION POLICY

Seasonal influenza causes considerable morbidity and mortality in people worldwide. Symptoms include fever, sore throat, aching muscles, runny nose, headaches and fatigue. Infection can lead to complications such as pneumonia and death, and it is estimated that 250,000 people die due to seasonal influenza each year[1]. Worldwide, annual influenza epidemics are estimated to be responsible for between three million and five million cases of severe illness. The disease is also a burden on the economy. On top of healthcare costs there are costs from lost productivity, as a result of sickness absence and from loss of life.

Some groups of people are more vulnerable to influenza than others. These include older people (ie those over 65), children, pregnant women, and those with underlying health concerns. Some of those at higher risk, such as people with asthma, will be of working age, and among the workforce.

Restricting the spread of influenza can limit the impact to individuals and the burden of widespread infection to society, and everyone can play a part in reducing the transmission of the influenza virus – for example, by regular hand washing and staying at home when infected ('social distancing'). Seasonal influenza vaccine can also provide good protection from the virus, and people who are at a higher risk from the disease are recommended to have annual vaccination.

Developing the seasonal influenza vaccine is an annual challenge. Influenza viruses are highly unstable (see box on p.30). They frequently mutate and there are a number of different strains and subtypes. To combat this, each year the World Health Organization (WHO) selects three strains of influenza virus to include in the trivalent vaccine (two influenza A strains, and one influenza B). The WHO chooses by trying to predict which strains are most likely to be circulating in the population the following year.

Most years this is a reasonably effective strategy. In some years this approach fails, usually when the virus mutates unexpectedly leading to a poorly matched vaccine. This happened in winter 2014/15, where mid-season figures suggested that the vaccine efficiency was only around 3% against the particular strain of H3N2 (a subtype of influenza A) circulating in the population (although there is considerable uncertainty in this estimate).

Later research by Public Health England (PHE) found that the vaccine's effectiveness was not as poor as the 3% figure previously indicated. PHE estimated that the adult influenza vaccine used in the UK was 34% effective against the circulating strains. This improvement was caused by a shift in the dominant strains circulating throughout the rest of the season, with the vaccine giving better protection to the later strains of influenza[2].

Mismatched vaccines are not uncommon, but it is rare that the vaccine is quite so poorly matched as in 2014/15. However, even during poorly matched seasons the vaccine usually still offers some protection – for example, against influenza B strains. Having the vaccination is also likely to reduce the severity of symptoms in those infected, even if it is poorly matched.

HEALTHCARE WORKERS

Along with people in high-risk groups, the chief medical officer for England recommends that healthcare workers have a seasonal influenza

Why doesn't immunity last?

If influenza viruses never changed, predictable defences could be employed. This is not the case; both influenza A and B viruses are prone to antigenic drift, whereby small mutations accumulate over successive replications eventually creating a new strain of virus. This means that individuals resistant to existing strains because of previous vaccination or infection are susceptible. The influenza virus's capacity for antigenic drift is a contributing factor to its viral success.

Another source of new influenza strains is animal reservoirs. All influenza A subtypes have been isolated from avian sources – and avian influenza provides a large reservoir with all the genetic variation needed for a human pandemic. However, only a limited number have been found in humans and even fewer are associated with widespread epidemics – ie are capable of human-to-human transmission.

Birds are not the only animals that provide a reservoir for specific subtypes of influenza A. Of the others, swine are among the most important in terms of disease epidemiology. The reason is this: in humans influenza A viruses bind to sialic acid structures on the surface of the host cell. It has been suggested that swine facilitate an intermediate mixing group between avian and human influenza due to swine sialic acid being similar to both mammalian and bird sialic acid.

Genetic re-assortment causes major changes in the molecules, and is known as antigenic shift. It is the genetic re-assortment of avian, swine and human influenza viruses that can lead to severe pandemics. A genetic change that allows a virus to jump from an intermediate species such as swine to humans could be devastating as we have very little natural immunity to new subtypes of influenza.

vaccination each year. Despite a prolonged effort to increase uptake, seasonal influenza vaccination remains at around 55% in healthcare workers in England. In Europe this figure is much lower. Conversely, in America around 75% of healthcare workers receive the influenza vaccine – with some states, such as Alabama, New Hampshire and Colorado, enforcing a mandatory vaccination policy.

Vaccine uptake may be poor in England for a number of reasons. Some of the reasons given by healthcare workers for not having a seasonal influenza vaccine include: a lack of spare time to get vaccinated; a perceived lack of benefits (for otherwise fit and healthy individuals); concerns about the vaccine's safety and efficacy; and a lack of information around why the vaccination is being given[3,4]. Researchers have also highlighted healthcare workers' need for more information into the benefits and risks of receiving the influenza vaccine[5].

Experts believe that increasing vaccination coverage in healthcare workers would benefit both healthcare workers and patients. Their argument is that increased vaccine coverage among workers will reduce influenza transmission within hospitals, protecting vulnerable patients from the risk of infection. There are also personal benefits to receiving an influenza vaccination, primarily that it is likely to reduce a person's risk of getting influenza. This may be particularly important to healthcare workers given that they are frequently exposed to pathogens by nature of their occupation.

Another argument for vaccination is that healthcare workers are part of the first line of defence against outbreaks of influenza. It is important, therefore, that they are protected so that they remain able to care for others. Reducing staff absence through illness also diminishes the burden on co-workers and the cost to the NHS.

But what influences healthcare workers' decision to have the seasonal influenza vaccine? Can we improve uptake? And what factors affect a vaccine programme's ability to prevent the spread of disease?

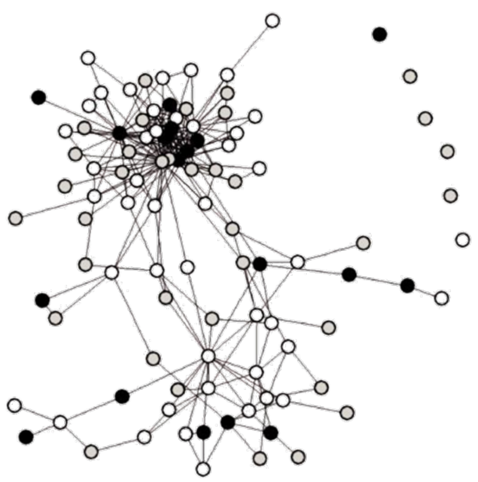
SOCIAL INTERACTION

Influenza is transmitted from person to person. Who we are exposed to affects our own and others' risk. These social interactions can have a major impact on disease spread and, relatively recently, epidemiologists began to investigate what these effects might be.

Understanding the effects of social networks on the spread of diseases such as influenza is likely to be of great importance in preventing the consequences of a future pandemic. Increasingly, contact networks are being included in sophisticated models to try to predict the likely course of an outbreak. By using models similar to these, we should be able to devise effective prevention strategies; for example, testing the impact of school closures, particular vaccination policies, or encouraging some workers to work from home during a pandemic.

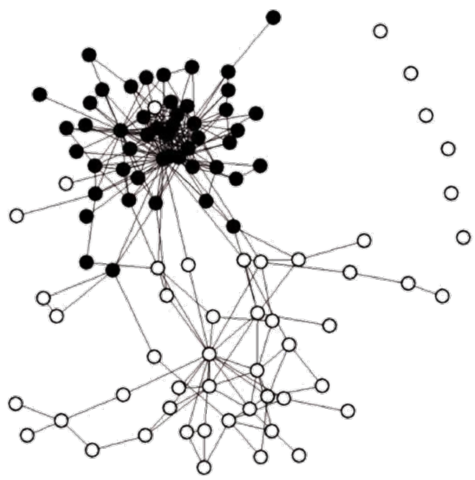
Human behaviour change can have profound effects on the incidence of infectious disease. For example, the 2013 outbreak of measles in Swansea has been attributed to poor compliance with the measles, mumps and rubella (MMR) infant vaccine programme, possibly due to the stigma surrounding the vaccine following publication of a now-discredited and

Figure 1: influenza vaccination



The sociogram shows the social network of the second-year foundation doctors. The spots represent individuals, shaded according to vaccination status: white are vaccinated individuals, black are non-vaccinated and grey are individuals who did not respond. Circles represent individuals and a line indicates a relationship between them.

Figure 2: social network structure in



This figure shows the social network of the second-year foundation doctors. This time the spots are shaded according to which arm of the NHS Trust the individual works within: white are individuals working on the west side and black are those on the east side. The east side appears to have a denser, more tightly knit community.

retracted paper by the former surgeon Andrew Wakefield[6]. (Wakefield falsely claimed a link between MMR and the risk of autism and bowel disease, and was subsequently struck off the General Medical Council register after a misconduct investigation into his research practices and reported findings.) Conversely, it has been suggested that fast communication via social media may have contributed to preventing the spread of severe acute respiratory syndrome (SARS) in Guangzhou, China, by encouraging social distancing[7,8].

People's reasons for their decision to vaccinate or not may be affected by their everyday relationships, so social groups may affect disease dynamics. The principle of homophily suggests that individuals are more likely to interact with people similar to themselves – or, as the saying goes, 'birds of a feather flock together'. This phenomenon has been found to affect some health behaviours, for example a person's likelihood to start smoking. Recently, Barclay *et al* suggested that this was also the case for influenza vaccine uptake in children at a US high school[9]. They suggested that clusters of vaccinated and non-vaccinated children existed within the school. This implies that vaccination homophily may exist. Clustering in this way allows infection to rapidly spread through the non-vaccinated students. Reasons some friendship groups may be more likely to vaccinate remain unclear.

SOCIAL NETWORK RESEARCH

Social network analysis applies techniques from graph theory to investigate social structures by characterising individuals as 'nodes' and relationships between them as 'ties' in a network. Analysts can examine the properties of the network – for example, calculating the social distance between two people to find out how quickly disease might spread between them.

The concept is illustrated in popular culture with the notion that no one is more than 'six degrees of separation' away from another, or that every Hollywood actor is linked in some way to the actor Kevin Bacon. An actor's distance or proximity from Bacon – through their various film links – gives their 'Bacon number'.

Research currently underway at Lancaster Medical School aims to further our understanding of the drivers of vaccination by examining the social networks of healthcare workers and their attitudes towards immunisation. Social network analysis was used to look at vaccination distribution within medical students' networks and these data were combined with the students' beliefs about vaccination behaviours. This enabled us to model influenza outbreaks and examine the effects of preferentially vaccinating individuals within the student network. This influenza simulation model showed that vaccination of well-connected individuals might have a disproportionate effect on disease dynamics. One implication is that future vaccination campaigns could be targeted to encourage the individuals who have the biggest impact on disease spread to vaccinate. If we can improve vaccination uptake by these ‘super spreaders’ of disease it is likely that we would protect many more people than random vaccination policies.

A characteristic of disease spread is that if vaccinated people are evenly distributed throughout a social network the chances of a disease spreading and persisting is reduced. An infectious disease can spread in pockets of unvaccinated people. We did not find any clusters of non-vaccinated individuals within this network. Also, our analysis identified a correlation between students who were vaccinated and the perception that a high number of other medical students in the school were vaccinated. More research is needed to determine whether or not this correlation indicates a causation; as well as its directionality.

In early 2015, we built on this work, using a similar methodology to investigate a population of foundation doctors (FDs) – newly qualified doctors working in various departments in an NHS trust during their first two years. The trust is made up of four hospitals split into the east side of the trust and the west side. Foundation doctors are newly qualified doctors cycling different specialities over two years. We asked the foundation doctors to rate their relationship with every other person enrolled in the programme on a six-point scale, from ‘I do not recognise this person’, to ‘I see this person nearly every day’ or ‘I live with them’. For analysis, we dichotomised the FD network so that only co-workers who saw each other ‘four or more times a week’ would be deemed to have a relationship. Initial analysis suggests, again, a lack of clustering of vaccinated individuals.

It is becoming clear, however, that even in a hospital setting an individual’s social network can vary considerably. Figure 1 (on p.31), shows the sociogram for year-two FDs. Here, the FDs are depicted by the dots with the shades (black, white or grey) corresponding to their vaccination choice; a line connects the FDs if they were deemed to have a relationship, using the dichotomisation method described above. It is clear that the network structure is heterogeneous – in some places the network is sparse with few connections between people, but some people seem to have lots of ties. Figure 2 is coloured to show whether the year-two FDs are currently working on the east or west side of the trust. It seems that FDs working on the east side of the trust have a denser social structure. The reasons for the discrepancy in social network structure in the different trust sites remain unclear. We plan to extend this analysis by implementing a modified regression model that can assess the effects of the social network and demographic factors on the likelihood of an individual having an influenza vaccine.

In 2016, we will revisit the study populations described above and we plan to extend our analysis by conducting a series of qualitative interviews. A qualitative approach provides the tools to assess how behaviour within the group might affect an individual’s position in the network and vaccination attitudes within the social network. We hope that this approach may provide some explanation for our previous findings.

An individual’s decision to vaccinate may be driven by the perceived risk that harm will occur if no preventive action is taken – a central idea in most decision-oriented theories of health behaviour[10]. The effectiveness of the seasonal influenza vaccine varies from year to year, distorting some people’s opinions of it and complicating the decision-making process – we intend to explore this during the interviews. We will also investigate any social influences on the vaccination habits of individuals and the relationship between an individual’s social network and their perceptions surrounding the influenza vaccine.

We hope that by continuing this work we might be able to inform vaccination strategies by acknowledging that, within a population, some individuals possess more contacts than others and can therefore have a disproportionate effect on disease dynamics. These concepts can of course be applied to wider society and other workforces. Social networks may also be important in the event of an epidemic – policies such as school closures are predicted to slow the spread of an epidemic due to the effects of social distancing – similar measures could be advised following future analysis.

MANDATORY VACCINATION

The debate would not be complete without considering the possibility of mandatory influenza vaccination for healthcare workers. Studies have shown that mandatory influenza vaccination is feasible and that very high coverage can be sustained over a number of years. The mandatory vaccination policy implemented in Canada has had a mixed reception, however, with questions over whether or not the evidence of the benefits of the vaccine is strong enough to justify removing a healthcare worker’s choice. For some employees this abuses the trust placed in their employers and has a negative effect on employment relations. The counter argument is that the vaccine provides one of the best means of protection against influenza and the benefits of vaccination outweigh the possible harms.

Some researchers believe that it is unlikely that suitably high vaccination rates can be achieved without a mandatory vaccination policy. However, I would argue that we should explore alternative methods before forcing healthcare workers to accept a controversial policy. Strategic educational campaigns may be explored further; some research has found that there is a lack of influenza vaccine understanding in healthcare workers that could be a contributing factor to poor compliance.

Making it easier for healthcare workers to receive the influenza vaccine and providing incentives for high vaccination coverage have been shown to improve compliance. And more could perhaps be done to improve the vaccine's effectiveness. The influenza vaccination production process is somewhat outdated; speeding up the process would allow the WHO vaccine selection committee more time to decide which strains of influenza to target. Small time savings here have the potential to make a big difference – improving the vaccine efficiency is likely to encourage higher uptake. Recent research into a universal influenza vaccine (a vaccine that targets part of the influenza virus that does not mutate as frequently) has also shown some promise. Removing the need to reformulate the vaccine could be a real game-changer.

And if the aim is to reduce influenza transmission in hospitals, it is fair to suggest that the wider population should also be encouraged to be vaccinated – most of those friends and family of patients are not currently vaccinated and carry a risk of infection. It may, in fact, be prudent to encourage anyone who has regular contact with people especially vulnerable to the disease to receive an annual influenza vaccine.

ROLE OF OCCUPATIONAL HEALTH

Fully understanding the role of social networks in vaccination compliance and the effects on disease dynamics has potential to reduce disease spread. In a society where most people are connected digitally we have a unique opportunity to combine this information with our knowledge from social network analysis to improve the way we combat disease spread in the 21st century. OH practitioners have a crucial role to play in applying the knowledge developed through the rapidly developing field of social network analysis to inform their efforts to reduce the effects of infectious disease in the workplace.

It is important that systems are in place to be able to respond quickly to influenza epidemics, for example preparing for some workers to be able to stay at home – either to care for children during school closures or to reduce disease spread in the workplace. Considering the risk of individuals in the workplace both catching influenza and passing it on prior to an outbreak will allow for a rapid, coherent response in the event of an epidemic. In some circumstances there may be vaccine shortages – preparing for this in advance is likely to have a huge impact on patient safety. ■

CONCLUSIONS

- **Influenza** is a disease with public and occupational health consequences, and can have a considerable economic impact through healthcare costs and lost productivity
- **For** healthcare workers the vaccination debate – whether or not to be vaccinated – is ongoing due to the complex issues involved
- **Social** network analysis is an emerging research area that could be used to inform OH practitioners
- **Understanding** the effects of social networks on disease spread will be vital in future disease prevention strategies
- **Such** research will help policy makers and practitioners prepare for epidemics by providing a detailed understanding of the risks in the workforce

Rhiannon Edge is a second-year statistics and epidemiology PhD student at Lancaster University, funded by the Colt Foundation for her research into the social network effects on influenza vaccine compliance in healthcare workers.

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Appendix 4. Recommendations for the Pennine Acute Hospitals NHS Trust

Influenza vaccination of Healthcare workers: A Pennine Acute Hospitals NHS Trust Influenza Vaccination Report

Study 1

A social network analysis approach was used to investigate the vaccination distribution within the network of the Lancaster Medical School students. We then developed a mathematical model to simulate influenza outbreaks in this population to study the effects of preferentially vaccinating individuals within the network.

We found that students who were vaccinated were more likely to think other students were vaccinated. However, we did not find any evidence of clustering of vaccinated or non-vaccinated students within the network. The influenza simulation model demonstrated the importance of preferentially vaccinating individuals according to network measures, and that well-connected individuals may have a disproportional effect on disease dynamics.

Study 2

Building on the social network analysis techniques the second study utilised advanced spatial statistics to analyse the effects exerted from an individuals' social network on their vaccination status. A social network was constructed using data collected from foundation doctors. Using the fitted mathematical model, inference can be made from the data, e.g. predicting an individual's likelihood to vaccinate given their neighbours' behaviour.

Study 3

We conducted a series of semi-structured interviews with seven medical students and nine early career doctors, to explore the factors informing their influenza vaccination decision-making. Data collection and analysis took place in an iterative process until theoretical saturation was achieved, and a thematic analysis was performed.

Of the sixteen participants, ten had been vaccinated during the 2015/16 season. Within the setting an ambivalent attitude towards influenza vaccination was prevalent, and thus became a tacitly accepted element of healthcare culture. The effects from medical socialisation were attenuated by participants' understanding of the vaccine – which was often formed from many conflicting factors: previous experiences, role models, and unclear risks and benefits of vaccination. Many medical students and early career doctors demonstrated some ambivalence towards the seasonal influenza vaccine and many participants did not have strong intentions regarding influenza vaccination. We found that there was a considerable disparity between an individual's opinion of the vaccine, their intentions, and their vaccination status. Practicalities such as the convenience or availability of the vaccine emerged as decisive factors contributing to vaccination decision-making.

Recommendations

We suggest a number of recommendations that might help in improving influenza vaccination uptake and that came up during the research.

6. Senior medical staff members (particularly those in acute medical specialties e.g. respiratory medicine) are seen by juniors as role models when it comes to vaccination. This could be used to improve overall vaccine uptake by:
    a. encouraging more consultants to get vaccinated with their juniors
    b. encouraging consultants to discuss vaccination with their juniors
    c. identifying one or more "popular and influential" consultants who are willing to be vaccinated and also willing to share this fact e.g. by featuring them in materials around the vaccination campaign launch (for example rather than using a member of staff who works in Trust HQ).

7. There could be a more targeted approach to raising awareness in areas with the most vulnerable patients – in our study many participants were unaware of the benefits of their vaccination for elderly patients.

8. Our research gives future evidence to support some of the recommendations made by the CQUIN standard to increase influenza vaccination. Ensuring that the vaccine is accessible is of paramount importance. We found that there was considerable ambivalence towards the vaccine within the Pennine Acute Trust FDs which led to a finely-balanced decision. Often convenience emerged as the decisive factor which 'tipped the balance' of the vaccination decision. We stress the extent to which the vaccine must be convenient, often participants were under huge time pressures – we would advocate travelling vaccination nurses or foundation doctors being allocated time to get vaccinated.

9. Some foundation doctors reported vaccinating so that they could allow colleagues to get their intra-muscular injection skill signed off in their logbooks. It might therefore be possible to get the foundation programme administrators to arrange vaccination teaching sessions for the doctors who can vaccinate each other and get "signed off" in their logbooks.

10. We believe that promoting vaccination as a norm is also important, given the correlation between perception of peer vaccination and self-vaccination.

Some reported fears of needles or side effects. Myth busting campaign posters seem to have little effect on people with these fears, more effort is needed to pursued these individuals to vaccinated (i.e. nasal spray vaccination, encouraging discussion around the benefits of vaccination.

Appendix 5. Impact statement

Pennine Acute Hospitals NHS Trust Flu campaign 2016/17

Impact Statement

1. Context

Pennine Acute Hospitals NHS Trust has a flu team which plans and coordinates the flu fighter campaign each season and the author has led that team each year for the last five years. Over this period guidance from the NHS England flu fighter programme has been followed to encourage staff to have the flu vaccination – with extensive communications to staff on the value of the vaccine to protect staff and their patients and family. The Trust has also given small incentives at the time of the vaccination (badges, pens, lollies) and ipads and shopping vouchers to nurse vaccinators who vaccinate the most staff.

Despite these and other measures the uptake of flu vaccine in the Trust has always been only a few percentage points above the NHS average. We had peaked at 60% uptake three years ago and only achieved 54% last year which we attributed to widespread awareness amongst staff that the circulating virus was not a good match to the viral strains in the vaccine. The NHS target uptake of flu vaccination of staff is 75%.

2. Process

Each year in July the flu team meets and begins to plan for the flu vaccination season which generally extends from the 1st October to the end of January.

The team meets monthly until the season starts and then meets fortnightly to review progress.

The flu team was made aware of the work that Rhiannon Edge had carried out in the field of the uptake of influenza vaccine amongst medical students and early career doctors in the Trust and she was invited to discuss her results with the flu team in September.

We listened to Rhiannon's presentation on the work she has done, received her paper and had a wide ranging discussion with her on what motivators would be most successful in the forthcoming flu campaign.

3. Results

Following discussion with Rhiannon we adopted the following elements in the campaign:

- Accepting the ambivalence of staff to having the vaccine and the marginal nature of the decision to have it.
- The importance of particular role models – consultants for medical staff and ward sisters for nurses rather than the Chief Executive being the main focal point of the publicity campaign.
- Given the marginal nature of the decision to have the vaccine to emphasise convenience – to provide a vaccination service directly to the wards and departments rather than expect the staff to attend clinics.
- Recognising the benefit of catching a group of a discipline when together to vaccinate e.g. training events
- Emphasising the benefit to the staff's patients in reducing their risk to exposure to the virus after the vaccination of staff.

4. Outcome

Early days yet but the take up is better than last year to date.

As at the 19th October 2015, 1,505 staff have been recorded as receiving the flu vaccine - this year on the same date 1, 877 staff have been vaccinated.

We are grateful to Rhiannon for the time and expertise that she has contributed to the Trust flu campaign.

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