Tip of the Spear: Artificial Intelligence Powered Event Based Epidemiology

A thesis submitted for the degree of Master of Philosophy (Applied Epidemiology)

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ORIGINALITY STATEMENT

I hereby declare that this submission is my own work and, to the best of my knowledge, it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at ANU or any other educational institution, except where due acknowledgement is made in the text. Any contribution made to the research by others, with whom I have worked at New South Wales Health, ANU, or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation, or linguistic expression is acknowledged.

Jared Edgeworth

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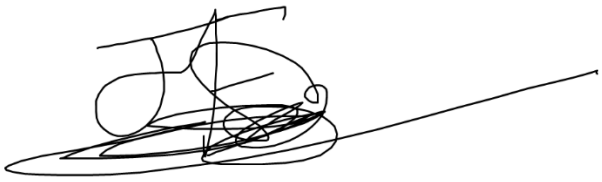

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ABSTRACT

This volume contains four projects, as well as additional public health experiences that satisfy the competencies of the Master of Philosophy (Applied Epidemiology), conducted through placement at UNSW's Kirby Institute's Biosecurity Program, which features the EPIWATCH® Open-Source Outbreak Early Warning system.

These projects address the mandatory competencies for the MAE, and contain an evaluation of the syndromic surveillance component of EPIWATCH®; an epidemiological investigation using survey data into Australian attitudes and behaviours related to COVID-19 public health measures including predictors for satisfaction to government's removal of mandatory isolation; an analysis of potential outbreaks following two laboratory incidents in the United States of America using the event-based capabilities of EPIWATCH®; and a measles outbreak investigation that occurred in early 2024 in Southeast Sydney.

The final chapter includes my additional experiences while undertaking this thesis, including teaching epidemiology to my peers as well as to graduate students. As well as my presentations to my colleagues at the Biosecurity Program, as well as my presentation to the general community at the Communicable Diseases and Immunisation Conference in Brisbane in Mid-2024.

The conclusions from my projects, as well as the experiences I was able to obtain, have contributed to the wider body of research in applied epidemiology and informed public health policy.

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Chapter 1: Introduction

Field Placement Overview

Kirby Institute's Biosecurity Program

My field placement was undertaken with the University of New South Wales (UNSW) Kirby Institute's Biosecurity Program (BSP). The BSP comprises multiple groups focusing on several research scopes, including artificial intelligence, respiratory transmission, risk analysis and global health surveillance. The primary focus of the group is EPIWATCH®, an event-based surveillance system that I evaluated (Chapter 2). I was involved in the daily operational tasks of managing this system, including data analysis, scanning and filtering of signals captured by the system, and co-authoring weekly summaries of signals and focused summaries of outbreaks of interest to external stakeholders. I was also involved in multiple research projects using the system, including an investigation of signals in response to laboratory incidents (Chapter 4). I was privileged to also take part in research that was not related to EPIWATCH® research, including an investigation into the behaviours of Australian adults in response to isolation measures (Chapter 3). Working at BSP was an eye-opening experience and gave an incredibly valuable level of knowledge and experience in global health and biosecurity. It was during my time at UNSW that I was also given the chance to undertake secondary employment as both a marker and class demonstrator for postgraduate students in epidemiology and biostatistics (Chapter 6), providing my first-ever experience in teaching a class of students while also live coding in R along the way. This was in addition to my time teaching my MAE peers during both course block and online, through the needs and requirements of remote laboratories in response to disease outbreaks, as well as giving my classmates a taste of working with event-based surveillance data.

Southeast Sydney Public Health Unit

I had the added pleasure and privilege of being placed on secondment with Southeast Sydney Local Health District to respond to a measles outbreak in early 2024 (Chapter 5), which provided a wonderful insight into the workings of New South Wales (NSW) health operations and was an exciting and appreciated change of pace to the research projects I was conducting. Although my time with the wonder team was brief, I savoured every moment of it.

Summary of Degree Requirements

Table 1: Summary of projects and activities undertaken while at UNSW Kirby Institute's Biosecurity program fulfilling the core competencies of the Master of Philosophy in Applied Epidemiology

MAE Competencies	Chapter 2: Evaluation of EPIWATCH® Syndromic Surveillance	Chapter 3: Epidemiological Investigation: Breath Study	Chapter 4: Data Analysis: Laboratory Incident	Chapter 5: Measles Outbreak	Chapter 6: Teaching Activities
Investigate an Acute Public Health Threat				✅	
Data Analysis	✅	✅	✅	✅	
Surveillance system evaluation	✅				
Epidemiological Study		✅	✅	✅	
Literature Review	✅	✅	✅	✅	
Prepare for peer-review publication.			✅		
Oral Presentation	✅				
Lay Summary				✅	
Teaching					✅

Evaluate a surveillance system

Chapter 2 describes my method of evaluating the respiratory syndromic component of the EPIWATCH® event-based surveillance system.

Event-based surveillance represents the tip of the spear in disease surveillance, capturing signals of disease before an official diagnosis is confirmed or reported. Syndromic surveillance acts as the very point of the tip of the spear, the earliest potential method of disease detection effectively possible. Such early detection is vital to the goal of EPIWATCH®: preventing the next pandemic. I devised, developed and implemented the evaluation of the surveillance system under the advisement of my supervisors, Ashley Quigly and Raina McIntyre, with additional advice and guidance from Davoud Pourmarzi. I focused on the United States Centers for Disease Control and Preventions' "Guidelines of evaluation a surveillance system" characteristics of representativeness, timeliness and acceptability. To evaluate the system, I identified appropriate methods suited to the unique nature of event-based surveillance data. I then designed and implemented the assessment tools, including a stakeholder engagement survey and a custom filtered dataset of two years' worth of syndromic articles, as well as focusing on a large-scale outbreak of pneumonia of unknown cause in Argentina in 2022. I recommended several courses of action to improve the reporting quality and representativeness of the system to further its goal of detecting and preventing the next pandemic. It was during this evaluation that I was able to present my findings to the Communicable Disease and Immunisation Conference (CDIC) in Brisbane in 2024 on the language and timeliness breakdown of EPIWATCH®. My work regarding the unknown pneumonia outbreak in Argentina also contributed to a publication in Emerging Infectious Diseases. (Honeyman D, Gurdasani D, Notaras A, Akhtar Z, Edgeworth J, Moa A, et al. Global epidemiology of outbreaks of unknown cause identified by open-source intelligence, 2020–2022. Emerg Infect Dis. 2025 Feb)

Plan and conduct an epidemiological study

Chapter 3 represents details of my epidemiological study that I conducted using the BSP's Bushfire, Respiratory protection, Emphysema, bronchitis and Asthma Triggering Health Effects (BREATHE) survey study, a population-based survey of over 2000 Australians.

This epidemiological study investigated Australian adults' behaviours and opinions during late 2023 in response to the COVID-19 pandemic, focusing on the behaviours and opinions of non-therapeutic methods of transmission of COVID-19. I conducted descriptive analysis to determine percentages of people undertaking personal risk management behaviours. I also gained the public's opinions on the Australian government's response to the removal of mandatory isolation. This aspect was then further expanded on through a logistic regression

to determine demographic and behaviour factors that affected participants' agreement or disagreement with the government's decision to remove the isolation of infected persons. It was found that women were more risk-aware than men. Those with chronic diseases, as well as older populations, were found to be more likely to disagree with the removal of isolation. In contrast, those who showed lower perceived risk of transmission by being happy to share spaces with those infected were much more likely to agree with the removal of isolation requirements. These results could provide potential avenues for focused engagement by government institutions in future pandemics to reduce the likelihood of disengagement or disapproval of government decisions.

Analysis of a public health data set

Chapter 4 showcases the usage of EPIWATCH® in response to specific public health events through the analysis of a subset of the EPIWATCH® dataset.

The United States Army Medical Research Institute of Infectious Diseases (USAMRIID) was reported to have two separate laboratory incidents in 2018 and 2019. These incidents involved their external wastewater tanks, which contained wastewater collected from wash-off from the veterinary cages, suit decontamination, and laboratory investigation run-off. In both events, the tanks had a pressurised leak leading to 2000-3000 gallons in the first instance and 100 gallons in the second event, evacuating into the surrounding environment, including into a neighbouring storm drain which led to an adjacent river system. Using previously collected EPIWATCH® articles captured during this period, I was able to conduct a geo-spatial analysis with help from the geospatial expert at the Biosecurity Program, Associate Professor Samsung Lim, to investigate if there was a potential increase in cases of disease associated with those diseases that were reported to be being experimented on at USMARIID at the time of the leaks. No associated signals of concern were found. However, the EPIWATCH® system was able to detect the seasonal trends of West Nile Virus during the period of the investigation, as well as independently detect the large-scale Eastern Equine Encephalitis outbreak that was occurring in the United States at the time. The findings of this analysis have now formed the basis of further investigations of biosecurity incidents using the EPIWATCH® system. The findings were also then prepared for publication in a scientific journal.

Investigate an acute public health event

Chapter 5 includes an outbreak investigation that I was involved in as part of my field placement with Southeast Sydney Local Health District.

I investigated a case of measles that was detected in a returning traveller from Southeast Asia in early 2024. The returning traveller had visited two states, multiple tourist and recreational

facilities, and had used several modes of transport while within their infectious period. As part of this outbreak, I was part of a wider epidemiology team and conducted phone-based interviews with suspected exposed persons. I also reviewed and followed up on the vaccination history of exposed persons in a high-risk setting and helped implement a rapid vaccination campaign in under 72 hours for those found to be susceptible. I found that in populations with a high percentage of the population born overseas, vaccination records can be inconsistent, requiring intense follow-up and communication skills to effectively ensure vaccine protection. This included creating a lay summary of the health risks of measles, as well as potential exposure sites. This was then disseminated to the wider Sydney community. Due to the team's rapid response and tracing of the case and contacts, no further measles cases were detected or linked to the contact in either state or city. I also conducted a literature review of previous measles outbreaks within Australia over the past 10 years to help shape and elaborate on my chapter.

Prepare a scientific manuscript for a peer-reviewed journal

In addition to the USAMRIID Lab incident event, I also assisted in several papers for publication as a co-author and secondary author. Most of these are in preprint and are published in peer-reviewed journals. I prepared and delivered two separate teaching opportunities to my MAE peers, both in a classroom environment and online. This included an exercise in understanding the capabilities and capacities of medical laboratories in assisting in outbreak investigations, as well as in presenting an exercise in analysing and collating event-based surveillance data to create a situational report for external stakeholders. I also attended my fellow MAE colleagues' own exercises throughout the two years of the program, as well as at course block. I also gained employment through UNSW as a marker and tutorial demonstrator in postgraduate epidemiology and biostatistics classes using the R programming language. This included presenting and elaborating on weekly exercises as well as marking assignments of master's and medical students.

Chapter 2: Evaluation of Event-Based Syndromic Surveillance Systems of EPIWATCH® For Diseases of Pandemic Potential

List of Abbreviations

AI	Artificial intelligence
BSP	Biosecurity Program
EBS	Event-Based Surveillance
EIOS	Epidemic Intelligence from Open Source
EWARS	Early Warning, Alert and Response System
ILI	Influenza-Like Illness
NLP	Natural Language Processing
PPP	Pathogens of Pandemic Potential
SARS	Severe Acute Respiratory Syndrome
SOP	Standard Operating Procedures
WHO	World Health Organization

Prologue

Surveillance systems are designed to collect data, including information about person, place and time, to allow public health and policy professionals to monitor, control and prevent disease spread[1]. However, the methods for collecting this information vary depending on the surveillance system's aims and objectives. Indicator-Based surveillance (IBS) systems rely primarily on laboratory-confirmed data for known diseases with specific identification by person, time and place. This information is then collated into notifiable disease surveillance systems[2]. The IBS approach provides a validated method to analyse disease trends, identify specific risk or demographic factors, and track their changes over time, making IBS the gold standard for disease surveillance[2].

Another form of disease surveillance is Event-Based Surveillance (EBS), defined as a system organised for the rapid capture of information about events that are a potential risk to public health[2, 3]. This information could take the form of clinical syndromic surveillance, rumours or informal channels such as media or non-governmental organisational reports[4, 5]. EBS relies less on specific diagnostic criteria and focuses more on capturing any potential event associated with a disease or symptom[5]. Consequently, EBS often generates a broad array of signals, many of which may be irrelevant[6]. Due to its focus on events and unofficial sources, EBS systems are significantly more timely than IBS systems, being able to avoid delays associated with disease presentation, sample collection and laboratory diagnosis[5, 6, 7]. As a result, EBS systems enhance and complement existing IBS systems, serving as an early warning mechanism for specific diseases or symptoms[7]. The rapid development of artificial intelligence (AI) offers a means to reduce labour intensity while increasing the timeliness of early warning mechanisms. Traditionally, EBS systems relied heavily on manual scanning, filtering, and summarisation of information, requiring trained analysts. With the increased usage of AI programs in data processing, there is potential that these weaknesses may be reduced significantly,

One system leveraging the power of AI to enhance the EBS systems is EPIWATCH®, an open-source artificial intelligence early warning detection system with the primary aim of preventing the next pandemic[8, 9]. To achieve this goal, the system has been developed to focus on diseases of high transmissibility and high mortality, known as pathogens of pandemic potential (PPP)[11]. This evaluation focused on the syndromic surveillance capabilities of EPIWATCH® to determine its effectiveness in achieving its primary aim. Syndromic surveillance encompasses signals of diseases that have no diagnosed condition, increasing the likelihood of detecting patterns of disease before laboratory confirmation. A new respiratory pandemic for which there is no laboratory test or diagnostic criteria would present as pneumonia or severe acute

respiratory infection (SARI), as seen during COVID-19 and severe acute respiratory syndrome (SARS). As such, syndromic surveillance for undiagnosed “Influenza-like illness” (ILI) and “pneumonia of unknown cause” is critical in identifying a new pandemic. These were used as the signals for this evaluation.

This chapter evaluated an EBS surveillance system, EPIWATCH®, for syndromic surveillance of pneumonia of unknown cause and ILI syndromes.

This chapter satisfies the requirements for the following competencies of the MAE program:

1- Establish or evaluate a surveillance system or other health information system.
2- Present at a scientific conference.

My Role

To conduct the evaluation, I first needed to understand how EPIWATCH® operates, then interact with it routinely. I participated in EPIWATCH®'s operational use throughout my 20-month placement with the Biosecurity Program (BSP) at UNSW's Kirby Institute. This included weekly scanning of articles collected by the AI system. As a team member, I conducted focused investigations into key signals detected weekly, producing “outbreak in focus” summaries that combined historical data with recently collected signals to provide snapshots of outbreaks of interest. I also contributed to the weekly surveillance digest “EPISCOPE”, which will be distributed to external stakeholders and summarises significant signals detected during the reporting week.

A formal evaluation of the syndromic surveillance system against the Centres for Disease Control and Prevention's (CDC) guidelines had not yet been conducted, and the terms "influenza-like illness (ILI)" and "pneumonia of unknown cause" were identified as critical to fulfilling the system's goal of effective syndromic surveillance. I reviewed the ongoing operational use of EPIWATCH® by the BSP analyst team, including standard operating procedures (SOPs), past published materials(e.g. peer-reviewed articles, workshops, presentations), and other documentation provided to me. My evaluation focused on timeliness, representativeness, and EPIWATCH®'s acceptability in its performance in detecting pneumonia of unknown cause and ILI. I mapped out EPIWATCH®'s timeliness in disseminating information once a signal was detected. I also conducted a review of EPIWATCH®'s language translation systems to identify strengths and weaknesses in capturing a representative sample of the global health system. Finally, I determined the internal and external stakeholders of the surveillance system and designed and developed a survey for their feedback. I disseminated a questionnaire using Qualtrics that was distributed to external stakeholders in the weekly

digest EPISCOPE. This questionnaire was used to identify the key needs of external stakeholders and guide future system enhancements.

This work culminated in a presentation to the wider Australian scientific community at the "Communicable Disease and Immunisation Conference". The presentation detailed the breakdown of the signals of ILI and pneumonia of unknown cause by incidence and language. It included a case study demonstrating capabilities in detecting pneumonia of unknown cause.

Key Reflections

This project taught me several valuable lessons. Evaluating the EPIWATCH® system was my most complex project, with a steep learning curve. Translating non-traditional concepts into digestible and visually representable data posed significant challenges, requiring constant rewriting and re-conceptualisation to convey the necessary information effectively. Although these rewrites absorbed considerable time and effort, they were not wasteful. They provided critical insights into the strengths and weaknesses of the EBS system and gave me a deep understanding of what is feasible when evaluating such systems. Through these challenges, I developed essential skills in communicating non-traditional methods of information. I gained the ability to understand in depth myself, skills I believe will serve me well as a field epidemiologist.

Given the inherent nature of EBS, which relies on informal and sometimes unreliable information, conducting this evaluation required me to approach the task from both traditional and non-traditional perspectives. This experience enhanced my understanding of surveillance system evaluations and helped me identify the best methods for undertaking such evaluations. I have gained a profound appreciation for the cyclical nature of evaluations and the critical role EBS plays in public health.

Public Health Implications

The evaluation of the EPIWATCH® syndromic surveillance system over the last few months has resulted in significant developmental milestones. Firstly, before this evaluation, all articles were manually scanned, and the weekly digest required multiple analysts to complete. Secondly, a Hindi-specific mobile application for field investigations was launched and is in use. Thirdly, language expansions and the automation of several previously manual components have been completed. The findings and recommendations from this evaluation may further inform these EPIWATCH® developments. Stakeholder feedback gathered during the assessment has already guided improvements, including refinements when filtering disseminated information and efforts to reduce information overload for EPIWATCH® users.

Internal stakeholder engagement meetings have prompted discussions to address areas of system friction, leading to corrective actions. These improvements have increased system acceptability among analysts, resulting in greater reporting sensitivity. Senior management is also considering potential changes in data collection to improve sensitivity in underreported countries and languages based on the language breakdowns identified during the evaluation. Such changes could enhance the system's specificity in detecting respiratory syndromes globally and improve its timeliness in identifying outbreaks. Ultimately, these advancements increase EPIWATCH®'s capability to detect pathogens of pandemic potential before they pose a global health threat. My work (the unknown pneumonia in Argentina case study) was also included in a publication in Emerging Infectious Diseases on unknown outbreaks.

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EPIWATCH® was supported by funding from the Balvi Philanthropic Fund, whose mission is focused on the advancement of open-source public health tools. The Balvi Philanthropic Fund placed no restrictions on the scope, methods, or reporting of this evaluation.

Abstract

Background: Pathogens of Pandemic Potential (PPP) significantly threaten global health. Through respiratory transmission, PPPs can spread quickly and with little detection. As these novel diseases lack laboratory tests during their initial outbreaks, traditional Indicator-Based Surveillance (IBS) systems are slow and limited in initial detection. Event-based surveillance (EBS) systems, such as EPIWATCH®, can potentially monitor syndromic disease events and detect PPP before traditional systems. An evaluation of the respiratory syndromic surveillance component of EPIWATCH® is required to ensure it continues to meet this objective.

Methods: The syndromes of pneumonia of unknown cause and influenza-like illness (ILI) detected by EPIWATCH® were evaluated using the United States Centres for Disease Control and Prevention's (CDC) guidelines for surveillance system evaluations. The evaluation in this project is focused on timeliness, representativeness and acceptability. Methods included an external stakeholder engagement survey of the weekly digest tool named EPISCOPE, descriptive analysis of the language and location of detected signals over two years (categorised by article and outbreak), and an assessment of time delays during a well-detected outbreak of pneumonia of unknown cause in Argentina in 2022.

Results: External stakeholders reported that the system's timeliness met their organisational needs. In a small survey of 9 respondents, the stakeholders found EPISCOPE's dissemination method effective, though some cited information overload and a lack of relevancy. During the two-year study period, few signals originated from the Middle East and Africa. Syndromic events captured by EPIWATCH® were detected approximately 24 hours before official diagnoses were publicly announced. Five languages accounted for approximately 50% of captured reports and outbreaks, with 87% of all reports being in non-English languages. India was the most frequently reported country. EPIWATCH® was able to capture the pneumonia of known cause in Argentina 24 hours before the diagnosis of Legionnaires disease was made. It was also able to capture initial Spanish-speaking articles before English articles were available.

Conclusion: EPIWATCH® demonstrated sufficient timeliness to detect syndromic outbreaks in a timely manner. While the system captured data in multiple languages (87% non-English), regional under-representation, particularly in Africa, was noted. A small stakeholder survey identified areas for improvement, including reducing information overload and enhancing relevancy filtering. EPIWATCH® successfully detected undiagnosed pneumonia signals for conditions without diagnostic tests or with delayed diagnoses. EPIWATCH® is currently fulfilling

its aim of helping prevent the next potential pandemic event through adequate detection of ILI and pneumonia of unknown origin signals.

Introduction

Globally, emerging infectious diseases are increasing in frequency.[10]. Viruses such as the Ebola Virus, Middle Eastern Respiratory Syndrome Coronavirus (MERS-CoV), Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-1) and now SARS-CoV-2 have all highlighted the value of early detection and mitigation. Although these diseases differ in many ways, they all have pandemic potential and the ability to cause mass devastation to both human life and national economies[10]. The United States Department of Health and Human Services has labelled these pathogens as “Potential Pandemic Pathogens” (PPP) due to their high transmissibility, uncontrollable spread in human populations, and significant potential to cause morbidity and mortality[11, 12].

PPP’s are inherently novel in their origins and characteristics. However, most are transmitted via the respiratory route. This transmission mode, facilitated by airborne droplets, allows pathogens to spread undetected from host to host[13]. Consequently, a pathogen’s replication can achieve exponential rates before traditional detection methods - such as PCR, culturing or serology - can identify its presence in a community. This was evident with COVID-19 in 2019, which spread rapidly from a major travel hub in China across the globe[13, 14]. Due to the need to sequence and analyse the previously undocumented virus, significant delays in detection occurred[15, 16].Officially detected in China at the end of December 2019, retrospective serological studies revealed the virus was circulating in the United States and Europe as early as January 2020—months before its official detection[17].

This delay highlights the significant weakness of Indicator-Based Surveillance (IBS) systems in detecting novel infections in a timely manner. IBS systems largely depend on confirmed laboratory tests or established diagnostic criteria, meaning their effectiveness is considerably reduced when a truly novel pathogen emerges for which no such tools yet exist. Relying on laboratory confirmations, diagnostic results from healthcare providers, or symptoms reported to health facilities, IBS systems often lag behind the true incidence or prevalence of disease [8, 18]. This lag is not purely a procedural delay but also reflects an inherent limitation of the IBS framework when encountering previously unknown pathogens. For example, wastewater analysis in Barcelona detected SARS-CoV-2 over a month before the first confirmed case in February 2020, demonstrating the limitations of traditional systems. This example further illustrates how indirect biological signals can precede formal IBS detection, highlighting the constraints traditional surveillance faces during the early stages of a novel outbreak.[19].

Syndromic surveillance systems, which collect early indicators of disease outbreaks, can alert health officials before a formal diagnosis is made [3, 20, 21]. However, syndromic signals are inherently broad in their nature, as they are based on clusters of symptoms rather than confirmed diagnoses. This means that a single syndrome, such as fever and respiratory distress, could be consistent with a wide range of conditions, from seasonal influenza to a novel pathogen of pandemic potential. As a result, syndromic surveillance systems will inevitably capture signals that do not represent true emerging disease events. This challenge is further compounded by differences in reporting, language, and medical literacy across regions, which can introduce additional irrelevant or misdiagnosed signals into the system [20]. Other methods, such as collation of news media or social media, can also be conducted to increase the timeliness or representativeness of a system. These may include reports of syndromes in a community without a connected disease[6]. However, media sources may only highlight notable events, potentially missing subtler outbreaks. To address these challenges, many EBS systems collate data from multiple sources, depending on the system's goals and resources.

EBS systems are developed by government agencies, international organisations, or private companies, each tailored to specific needs. The World Health Organization (WHO) has developed multiple EBS systems, including The Epidemic Intelligence from Open Sources Initiative (EIOS), which uses blogs, expert groups, and social media to screen, tag, categorise and translate signals[22]. Despite its wide scope, EIOS requires significant manual monitoring and analysis, with previous evaluations giving the system only a moderate level of sensitivity[7, 23,24]. Another notable system is HealthMap, a free web-based platform that collates data from sources such as Google News, ProMED Mail and WHO-validated alerts[25]. Data is overlaid on an interactive map for user accessibility. However, HealthMap's limited language capabilities—primarily relying on English and a dozen other languages such as Chinese and Hindi- restrict its global representativeness. Private companies, such as BlueDot (Canada-based) and Airfinity, also operate EBS systems[26]. Although promising, their proprietary methodologies are not publicly available, limiting transparency.

Launched in 2016, EPIWATCH® is an AI-driven open-source EBS system. Initially a semi-automated system, it now incorporates advanced features such as natural language processing (NLP) and prioritising algorithms [10,27]. EPIWATCH® monitors signals in 46 languages and includes validated tools, such as a Hindi-language app. It is increasingly used by Australian national partners and international organisations. EPIWATCH®'s prioritisation algorithm achieves 88.2% accuracy in detecting relevant articles[9]. Trained epidemiologists further review signals before being uploaded to an internal dashboard and a limited public database[9]. The dashboard includes an interactive map displaying signals from the past 30

days, which supports the creation of summarised products such as EPISCOPE—a weekly digest highlighting important outbreaks. Tailored products, such as in-depth avian influenza bulletins, are also produced based on stakeholder needs.

Rationale for evaluation

The rationale for evaluating the syndromic surveillance component of the EPIWATCH® EBS system is multifaceted. Key motivators include the recognition of public health threats posed by PPPs, the need for an updated evaluation of the EPIWATCH® system for syndromic surveillance against the CDC guidelines. Finally, the stakeholder interest in the syndromic surveillance component has been increasing both domestically and internationally as EPIWATCH® continues to develop.

The WHO and individual countries have acknowledged the significant global threat of PPPs[28]. While the world is still recovering from the last PPP event, the emergence of novel pathogens with pandemic potential, such as highly pathogenic avian influenza, continues to increase[10, 29]. As the frequency of such discoveries rises, international and national institutions are updating their pandemic response plans and methods for detecting future pandemics[30]. EPIWATCH® addresses these critical interests and has been developed to support organisations in detecting potential pandemics.

EPIWATCH® has evolved over the past eight years, incorporating various AI methods and expanding its reach to a broad range of international and national stakeholders. [8, 9, 31]. Multiple products have emerged from the core EPIWATCH® system, including the weekly EPISCOPE digest of signals, risk analysis tools, and more in-depth disease analyses in watching briefs. However, despite these developments, evaluations comparing EPIWATCH® to the CDC's guidelines for public health surveillance have not been conducted since 2018. The 2018 evaluation, conducted during an earlier and less developed stage of the system, assessed EPIWATCH® against a selection of CDC surveillance evaluation attributes and found the system to be a promising early warning tool. However, at that time the system was still largely manual in its operations, had a considerably smaller stakeholder base, and had not yet incorporated the advanced AI and natural language processing capabilities that now define the system. Furthermore, the syndromic surveillance component, which is the focus of this evaluation, had not been a primary focus of the prior assessment. As such, the findings of the 2018 evaluation have limited applicability to the current iteration of EPIWATCH® and a contemporary evaluation is warranted. Since EPIWATCH® has reached a critical stage of development, and stakeholders are showing increased interest, an evaluation comparing the system to the CDC guidelines is necessary. This will help assess the system's current capabilities and guide future development to ensure it meets stakeholder expectations.

Organisation of this chapter

This chapter is structured to present the evaluation of the syndromic surveillance component of the EPIWATCH® system. The methods section outlines the evaluation procedure, including the stakeholder questionnaire and the method of determining the timeliness and representativeness of EPIWATCH®'s syndromic surveillance system. The results section explains the design of EPIWATCH® and presents the conclusions from the analysis. The discussion compares the findings to the CDC's "Updated Guidelines for Evaluating Public Health Surveillance Systems" and concludes with proposed recommendations to improve the system.

Aims and objectives

The primary aim of this chapter is to evaluate the respiratory syndromic surveillance component of the EPIWATCH® system.

To complete this aim, the following objectives were determined:

- To identify the timeliness between detecting a signal in EPIWATCH® and dissemination to external stakeholders.
- To determine the representativeness of the languages within EPIWATCH®
- To identify the acceptability of the system through understanding stakeholder interests and expectations regarding the EPIWATCH® system

Methods

Description of the surveillance system

The EPIWATCH® surveillance system's objectives, structure, and day-to-day operations were sourced from publicly available materials on the EPIWATCH® website; further details were gathered through direct discussions with the EPIWATCH® team and a review of internal documentation and published literature. A full description of the system is provided in the introduction.

The EPIWATCH® syndromic system operates through two primary components: automated processes and manual review by trained analysts. At its current stage of development, EPIWATCH® is fully automated in its initial steps, with manual review only during the validation and dissemination stages. Efforts are underway to further streamline the system by removing the manual review step entirely. The automated process begins with the collection of reports from a diverse range of sources using disease and syndrome specific search terms. These sources include curated health websites and other trusted platforms. Searching is conducted in multiple languages, with language-specific keywords independently validated by trained

personnel to ensure cultural and contextual relevance. Once collected, the data is processed through EPIWATCH®'s name recognition software, which identifies key phrases and filters reports for relevance. Following the automated filtration, signals flagged as medium, high, or very high priority are forwarded to analysts for further evaluation. Low priority reports are excluded due to their limited relevance to outbreak surveillance. Analysts review the remaining flagged articles to confirm their relevance and categorise them by disease, location, and time of publication. Once validated, the data is uploaded to the EPIWATCH® database, where continual validation and verification procedures are undertaken to ensure data quality, including a weekly quality assurance investigation. From this database, information is disseminated through multiple channels, including the weekly digest EPISCOPE and watching briefs on high-consequence outbreaks available in the journal Global Biosecurity. Limited data is also uploaded to the public dashboard, providing only the most recent reports.

Analysis of System Attributes

To evaluate EPIWATCH®'s performance, we focused on its acceptability, representativeness, and timeliness, as outlined in the rationale above. A combination of methods was used to evaluate each characteristic, including descriptive analysis of the EPIWATCH® internal dataset, a stakeholder survey, and an internal document review, as summarised in Figure 1

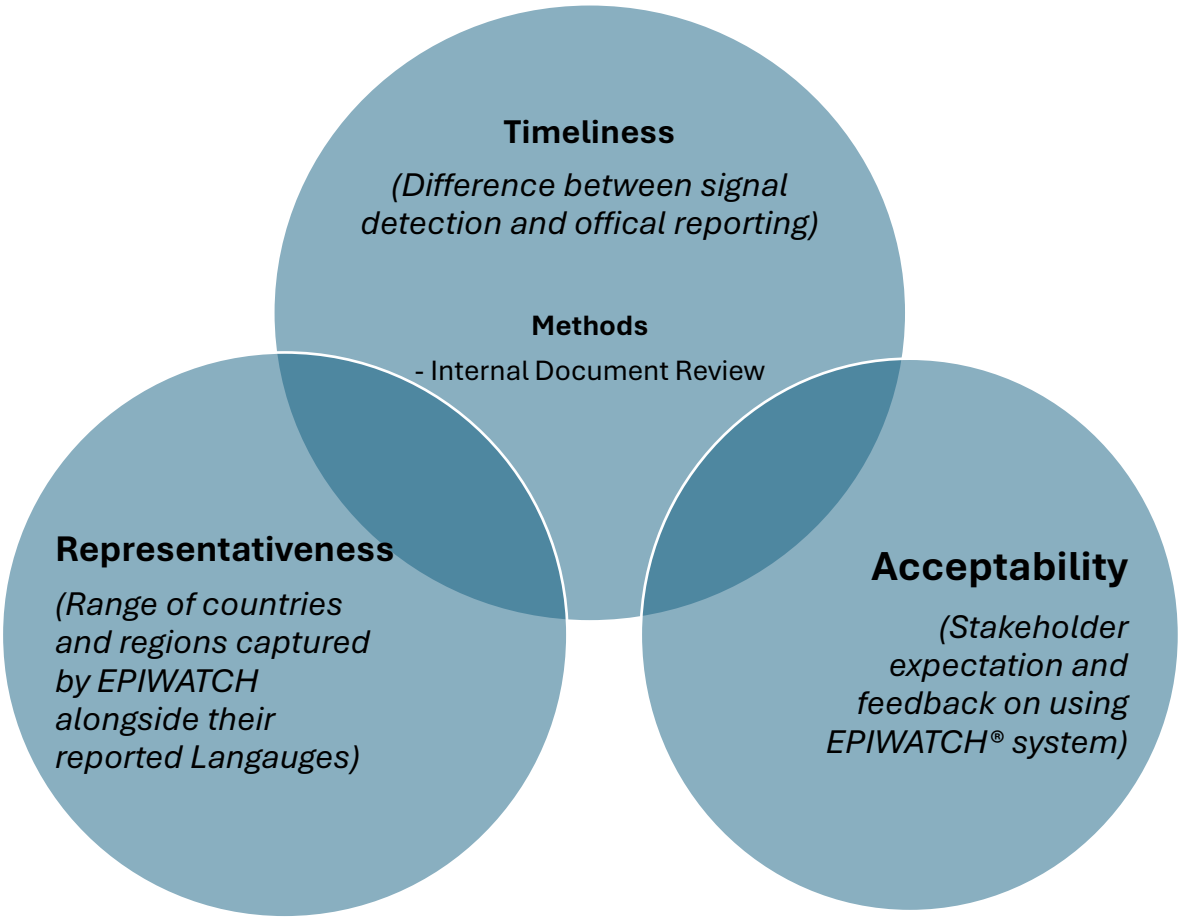

Figure 1: Summary of the methods used to determine the surveillance characteristics of the syndromic respiratory component of EPIWATCH® compared to the evaluation objectives.

Timeliness

Timeliness was assessed by tracking the time between EPIWATCH®'s detection of a syndromic signal and the subsequent reporting of the official diagnosis of the disease. However, as previously noted, syndromic surveillance produces very few linked official outbreak diagnoses; previous investigations by EPIWATCH® determined that only 12.9% of human syndromic outbreaks were associated with later disease diagnoses, limiting the scope of this component of the assessment.

Stakeholders' opinions on EPIWATCH®'s timeliness were also assessed. A short questionnaire was distributed to organisations subscribed to the weekly digest, EPISCOPE. The survey, designed using Qualtrics, included 32 questions that gathered both qualitative and quantitative data on stakeholder experiences, particularly related to the syndromic surveillance component. A range of questions were crafted to explore stakeholder consumption patterns, their use of the syndromic component, the quality of information provided, and the value of the syndromes captured. One such question was focused on the perceived timeliness of EPIWATCH® to

effectively meet their needs and to rate the system from not being timely to always being timely enough for their needs.

The questionnaire was initially distributed to a select group of nine stakeholder departmental email addresses. This included government organisations, research institutes, and non-government agencies. These organisations would then forward it within their networks, ensuring broad engagement from public health professionals, policymakers, and international partners.

Representativeness

Given EPIWATCH®'s goal of capturing global signals, we assessed its ability to report on influenza-like illness (ILI) and pneumonia of unknown cause cases across various countries and regions, descriptively categorising the frequency of countries by number of reports, the number of outbreaks, and the frequency of languages appearing in the EPIWATCH® dataset.

The period of analysis was between March 2021 and March 2023. This period was chosen to be after the beginning of the COVID-19 pandemic in 2020 for two main reasons. The system had become automated in its data collection rather than a manual process, which led to a rapid increase in signals from global sources as well as in multiple languages. The second reason is to reduce the possibility of interference from unintentional data quality interactions. The most common interference was misreported or unreported COVID-19 signals; therefore, these signals may have been unintentionally associated with ILI or pneumonia of unknown cause due to the lack of ability to adequately report COVID-19 in the early days of the pandemic. This data was categorised, and the results were visualised to highlight the top countries and languages contributing to EPIWATCH®'s internal dataset. A detailed list of countries and languages is provided in Supplemental 1.

Case Study: The Argentina Signal of Pneumonia of Unknown Cause

For a deeper analysis of both timeliness and representativeness, we selected the Argentina PUC outbreak that occurred in 2022 as a case study. This outbreak was chosen due to its severity and the opportunity to assess the system's performance from initial syndromic detection to official disease confirmation (Legionella). Data from September 2022 to October 22 was extracted from EPIWATCH®'s internal database and analysed to determine the country and language of the reports. A timeline was created by collating key dates, such as the syndromic signal's detection, official confirmation of the outbreak, and the completion of the outbreak. This case study provided a concrete example of how the system performs during significant events and allowed for a detailed evaluation of both timeliness and representativeness.

Data Analysis Definitions

Two respiratory syndromes were focused on specifically during the data analysis for both representativeness and timeliness: ILI and pneumonia of unknown cause. These were chosen because they may indicate the emergence of a new respiratory pathogen with pandemic potential, given the higher likelihood of such PPPs being respiratory in their transmission method.

All articles collected from the EPIWATCH® internal database and used in the analysis of either timeliness or representativeness must have met the following criteria outlined in this section, including, firstly, a location is mentioned at least at the country level, if not higher. Secondly, ILI or pneumonia of unknown cause is mentioned, case numbers are mentioned, and the outbreak must be human. Articles were removed from analysis if they identified a known respiratory illness, did not have an associated time, collated country statistics over a period of time, or were routine surveillance reports. Articles that were duplicated, could not be accessed due to dead links or required subscriptions were also removed.

Articles focusing on ILI were defined as ILI if they followed the WHO definition of ILI, that being a fever of 38° Celsius or above, having a cough, and onset within the last ten days[32]. Articles focusing on pneumonia of unknown cause were defined as pneumonia of unknown cause if they matched the WHO definition of having a combination of the following symptoms: shortness of breath, fever, sweating or shaking, chills, fatigue, chest pain, nausea, vomiting or diarrhea or confusion[33].

Acceptability

“To assess acceptability, a specific subset of questions from the stakeholder questionnaire was created to understand the utilisation of the syndromic component within the EPISCOPE digest, identifying syndromes of particular concern to external stakeholders and the quality of information EPISCOPE provides.

Short answer responses were analysed using a thematic analysis approach. Responses were read in their entirety and then grouped into broader themes, such as information overload, relevance of content, and visual presentation, which are reported in the results section. Where responses were sufficiently similar in nature, they were quantified by frequency to indicate how commonly a particular view was expressed across the respondent group. It should be noted that given the small sample size of nine respondents, these frequencies are intended to provide descriptive context only and should not be interpreted as statistically representative of the broader stakeholder population.

Ethical Considerations

This study did not require ethical approval due to being created entirely from publicly available sources of data and was created using the private research program EPIWATCH®. No persons were required to be contacted, and no interventions were applied to any persons.

Results

Summary of Results

A summary of the results of this evaluation is presented in Table 3 below, providing an overview of the key findings across the three assessed attributes of timeliness, representativeness, and acceptability. In terms of timeliness, the evaluation demonstrated that EPIWATCH® effectively detected syndromic signals before official diagnoses were publicly available. The finding highlighted the representativeness of the system, as 87% of signals detected were not in English, indicating a broad degree of linguistic and geographic diversity in signal capture. Overall acceptability was generally satisfactory among the stakeholders surveyed, with most respondents finding EPISCOPE to be at least somewhat valuable in meeting their organisational needs. Detailed findings for each attribute are presented in the sections below.

Table 1: Summary of results of EPISCOPE evaluation, separated by characteristic evaluated, tool that was used and the major findings.

Characteristics	Tool Used	Major Findings
Timeliness	• Surveillance system Data • Argentina case Study • EPISCOPE Survey	• Over 90% of syndromic signals did not have an associated diagnosable condition detected, thus correctly classifying them as syndromes. • Those that did have a subsequent diagnosis, EPIWATCH® was able to capture them on average 24 hours before the official diagnosis was publicly reported. • A majority of those who responded to the external stakeholder survey found EPIWATCH® satisfactory in its timeliness. • Detecting signals in the native language leads to earlier detection of syndrome reports.
Representativeness	• Surveillance system Data • Argentina case Study	• 89% of reports were not in English. • Five languages made up 53% of reports detected. • There were fewer reports from the African and Middle Eastern Regions than in Southeast Asia or European regions.

Acceptability	• EPISCOPE Survey	• Most of those surveyed found EPIWATCH® to be acceptable in its current state. • Seven of eight respondents were using the syndromic component of the EPIWATCH® system • Of the three subjects that did not recommend the system, information overload was cited. • Only nine respondents were surveyed, leading to lower power in conclusions that can be drawn

Analysis of a surveillance system data

During the data collection period, a total of 693 reports were gathered, corresponding to 219 unique outbreaks. Among these, 292 reports were linked to pneumonia of unknown cause, representing 167 unique outbreaks with a median of approximately two. Similarly, 400 reports were associated with ILI, comprising 249 unique outbreaks, also with a median of approximately two reports per outbreak.

The median duration of outbreak reporting was effectively a single day, as most outbreaks were documented in only one article. For outbreaks with multiple reports, the median reporting duration remained one day, reflecting the brevity of media coverage of most disease events.

Timelessness

Data Analysis

Of the 219 outbreak signals detected during the data extraction period, only six outbreaks had an associated later disease diagnosis confirmed through an independent investigation of syndromic events. In all cases, the time difference between syndromic signal detection and disease diagnosis was one day earlier.

Internal Documentation and Internal Stakeholder Engagement

An investigation into the internal documentation revealed that the time between detection of an article by the EPIWATCH® system and its review to upload to the internal database ranged from instantaneous to eight hours, depending on when the article was detected. As scanning shifts were based on a nine to five schedule, reports detected after 5 pm were not scanned and uploaded until the following day.

Dissemination of outbreak signals depended on severity. For high-consequence outbreaks, dissemination could occur almost instantaneously via EPIWATCH® X account (formerly Twitter), bypassing the regular methods. If not immediately released, signals would be included in the weekly EPISCOPE digest, with dissemination ranging from two to eight days post-detection. The cut-off for signals is Tuesday afternoon, meaning any signals detected after this

time may not appear until the next week's digest, unless considered urgent by executive privilege. However, subscribers who access the real-time dashboard have access to all data in real time.

Argentinian Case Study

Due to the lack of confirmed outbreaks, we decided to focus on the timeliness of EPWATCH®'s ability to identify a pneumonia outbreak. An outbreak that occurred on the 30th of August 2022 at 12:45 pm, reported bilateral pneumonia of unknown cause in healthcare workers and patients in the city of San Miguel de Tucuman, Argentina. This outbreak was specifically selected because it would allow us to collect data from the length of the outbreak, from the first cases reported, to reported deaths and finally to disease confirmation.

The first cases of bilateral pneumonia were reported among a cluster of hospitalised patients in San Miguel de Tucumán City, Tucumán Province, Argentina, with early cases occurring among healthcare workers resulting in intensive care unit admissions. On August 29, 2022, the Argentine Ministry of Health of Tucumán Province notified the World Health Organization (WHO) of a cluster of six cases of bilateral pneumonia of unknown cause. One patient died on August 30, 2022. EPIWATCH® first detected a signal of pneumonia of unknown cause on September 1, 2022, which is reflected as day one in Figure 5. The official diagnosis of Legionella was confirmed on September 3, 2022, represented as day three in Figure 5. All reports captured in Figure 5 represent articles detected by the EPIWATCH® system during this period, with the day of first EPIWATCH® detection used as the reference point for the timeline[33]. The highest number of reports occurred on the day of the official diagnosis, and subsequent reports shifted focus to the confirmed diagnosis of Legionnaires' disease.

The EPIWATCH® system detected the outbreak before the official diagnosis. Additional passive collection continued through EPIWATCH® data methods, while active surveillance provided further context. This culminated in a detailed watching brief, published after the initial syndromic outbreak detection and included in the weekly EPISCOPE digest.

Stakeholder Engagement

Nine external stakeholders responded to the survey. Of these, two respondents indicated that EPISCOPE could report sometimes in a timely manner, while others stated that it could not report in a timely manner. Only one respondent affirmed that they believe that EPISCOPE was always able to report on time.

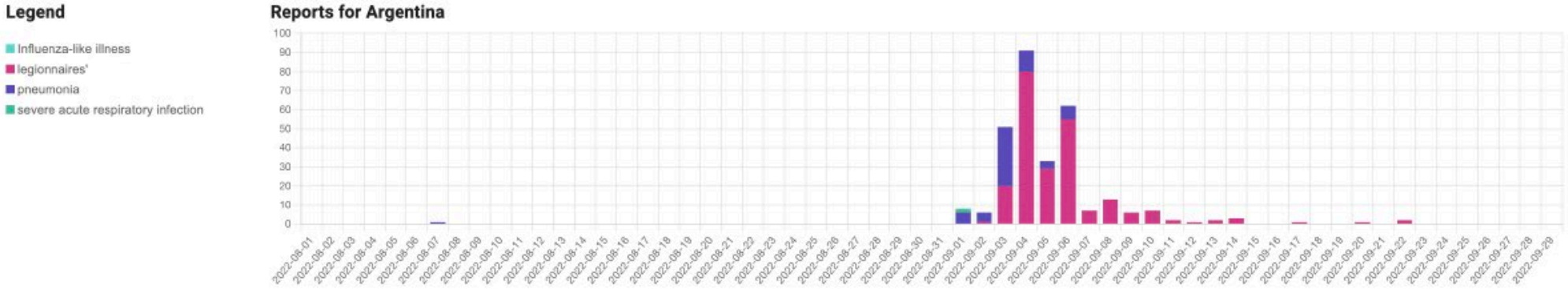

Figure 2: Timeline of reports of pneumonia and other key events captured by EPIWATCH® on the Argentinian Pneumonia of Unknown Cause Outbreak that occurred in August 2022 in Tucumán ®

Representativeness

Data Analysis

A total of 56 countries had related reports during the data collection period. The most reported country was India with 139 reports, followed by Argentina with 55 and the Democratic People's Republic of Korea with 45 reports. These three countries, along with Bangladesh and the Czech Republic, accounted for 52% of all signals detected by the system (Table 2). A full country breakdown can be seen in Supplementary 1. When collated by number of outbreaks, India remained the most reported, with 104 unique outbreak signals detected, accounting for 32.4% of all outbreaks detected by the system. All but three outbreaks in India and Bangladesh for both ILI and pneumonia of unknown cause contained only a single report, with no other linked report being able to be connected. Bangladesh ranked second in the number of unique outbreaks at 22 (6.9%). All other countries detected had small percentages, ranging from 1-5%. The top five countries alone accounted for 52.4% of all detected countries.

EPIWATCH® collected information conveyed in a total of 94 languages during the data collection period. In terms of report totals, English was the most frequent (80/595 reports, 13%), followed closely by Hindi (78) and Spanish (54). Non-English languages comprised most reports, with 515/595 (87%) being in languages other than English. Hindi had the highest number of related outbreaks, with 57 unique outbreaks being reported in Hindi, compared to English, which had 42 unique outbreaks. Bengali and Czech were then the fourth and fifth most reported. These five languages comprised close to 54% of all outbreaks detected by the system in the collection period. A higher number of outbreaks reported in languages was seen than those by country. This is because, in the case of major outbreaks, the outbreak has been reported on by multiple news agencies in different languages. A breakdown can be seen below in Tables 2 and 3. A higher number of outbreaks were detected in different languages than by country, due to major outbreaks reported by multiple news agencies in different languages. A breakdown can be seen in Tables 2 and 3. When separated by WHO region, fewer reports were detected in Africa during the reporting period, while South-East Asia had the highest number of reports. This trend remained consistent when represented by outbreaks (Figures 3 and 4).

Pneumonia of Unknown Cause

Reports associated with pneumonia of unknown cause came from 36 separate countries. Argentina had the highest with 78, followed by India at 60 and Bangladesh at 33. When collated into unique outbreaks, India contained the highest number of unique outbreaks at 36, followed by Bangladesh at 22 and Romania at 8. These countries accounted for 59% of all country-based outbreaks detected.

By language, Spanish reports were the most common at 57, closely followed by Hindi with 49. Bengali was the third most common language with 39 (Table 2). When collated into unique outbreaks, Bengali and Hindi tied for first with 29 unique outbreaks each, followed by Spanish with 18, as seen in Table 1. All other languages contributed to one-third of the reports.

ILI

The most common country for ILI-related reports was India with 103 reports (Table 2), followed by the Democratic People's Republic of Korea at 47 and the Czech Republic at 35 separate reports. However, when collated into unique outbreaks, India remained the highest country with 103 reports, as no outbreak contained more than one associated article. The second most common country was Russia with 13 unique outbreaks, with the United States ranked third at 12 unique outbreaks, accounting for 45% of all ILI outbreaks detected. The top five country breakdown can be seen in Table 2. English was the most detected language in ILI-related reports with 82, followed by Hindi with 45, and Czech with 36 (Table 2). When collated, English remained the most common language with 40 unique outbreaks, while Hindi was close behind with 34. Ukrainian, Mandarin, and Russian all tied for third place with 15 related unique outbreaks each, with the top five languages accounting for 59% of all ILI outbreaks detected. This can be seen in Table 2.

Table 2: Number of reports captured by the EPIWATCH® system between March 2021 and March 2023.By total, Pneumonia of Unknown Cause and ILI stratified by Country and Language.

Number of reports per Country					
Total Top five Countries detected		**Top five Countries detected from Outbreaks assigned "Pneumonia of unknown cause"**		**Top five Countries detected from Outbreaks assigned "Influenza Like Illness"**	
India	139 (23.4%)	**Argentina**	55 (21.8%)	**India**	84 (24.5%)
Argentina	55 (9.2%)	**India**	55 (21.8%)	**Democratic People's Republic of Korea**	44 (12.8%)
Democratic People's Republic of Korea	45 (7.6%)	**Bangladesh**	30 (11.9%)	**Czech Republic**	34 (9.9%)
Bangladesh	36 (6.1%)	**El Salvador**	13 (5.2%)	**United States**	31 (9.0%)
Czech Republic	36 (6.1%)	**Afghanistan**	12 (4.8%)	**Ukraine**	18 (5.2%)
Other	284 (47.7%)	**Other**	165 (50%)	**Other**	235 (52.6%)

Total	595 (100%)	**Total**	330 (100%)	**Total**	446(100%)
Number of reports per Language					
Top five languages detected from total reports captured		**Top five languages detected from reports assigned "Pneumonia of unknown cause"**		**Top five languages detected from reports assigned "Influenza Like Illness"**	
English	80 (13.4%)	**Spanish**	48(19.0%)	**English**	61 (17.8%)
Hindi	78 (13.1%)	**Hindi**	45(17.9%)	**Czech**	35 (10.2%)
Spanish	54 (9.1%)	**Bengali**	35(13.9%)	**Hindi**	33 (9.6%)
Bengali	46(7.7%)	**English**	19(7.5%)	**Ukrainian**	21 (6.1%)
Czech	37 (6.2%)	**Romanian**	13(5.2%)	**Mandarin**	19 (5.5%)
Other	300 (50.4%)	**Other**	92 (36.5%)	**Other**	174 (50.8%)
Total	595 (100%)	**Total**	252 (100%)	**Total**	343 (100%)

Table 3: Number of Outbreaks captured by the EPIWATCH® system between March 2021- March 2023 by total, Pneumonia of Unknown Cause and ILI stratified by Country and Language.

Number of Outbreaks per Country					
Total Top five Countries detected		**Top five Countries detected from Outbreaks assigned "Pneumonia of unknown cause"**		**Top five Countries detected from Outbreaks assigned "Influenza-like illness"**	
India	104 (32.4%)	**India**	35 (27.6%)	**India**	69 (35.6%)
Bangladesh	22 (6.9%)	**Bangladesh**	20 (15.7%)	**Ukraine**	13 (6.7%)
Russian Federation	17 (5.3%)	**Romania**	8 (6.3%)	**Russian Federation**	12 (6.2%)
Ukraine	13 (4.0%)	**Peru**	6 (4.7%)	**United States**	10 (5.2%)
China	12 (3.7%)	**Kazahkstan**	5 (3.9%)	**Bulgaria**	8 (4.1%)
Other	153 (47.6%)	**Other**	53 (41.7%)	**Other**	82 (42.2%)
Total	321	**Total**	127 (100%)	**Total**	194 (100%)

Number of Outbreaks per Language					
Total Top five Languages detected		**Top five Languages detected from Outbreaks assigned "Pneumonia of unknown cause"**		**Top five Languages detected from Outbreaks assigned "Influenza-like illness"**	
Hindi	57 (15%)	**Hindi**	28(18.4%)	**English**	32 (14.0%)
English	42 (11%)	**Bengali**	25 (16.4%)	**Hindi**	29 (12.7%)
Bengali	31 (8.1%)	**Spanish**	17 (11.2%)	**Ukrainian**	16 (7.0%)
Russian	23 (6.0%)	**English**	10 (6.6%)	**Mandarin**	15 (6.6%)
Spanish	23 (6.0%)	**Romanian**	9 (5.9%)	**Russian**	15 (6.6%)
Other	205 (53.8%)	**Other**	63(41.4%)	**Other**	122 (53.2%)
Total*	381 (100%)	**Total***	152 (100%)	**Total***	229

*Number of outbreaks per language is higher than per country as some outbreaks were reported in multiple languages from multiple sources, inflating the number of outbreaks per language.

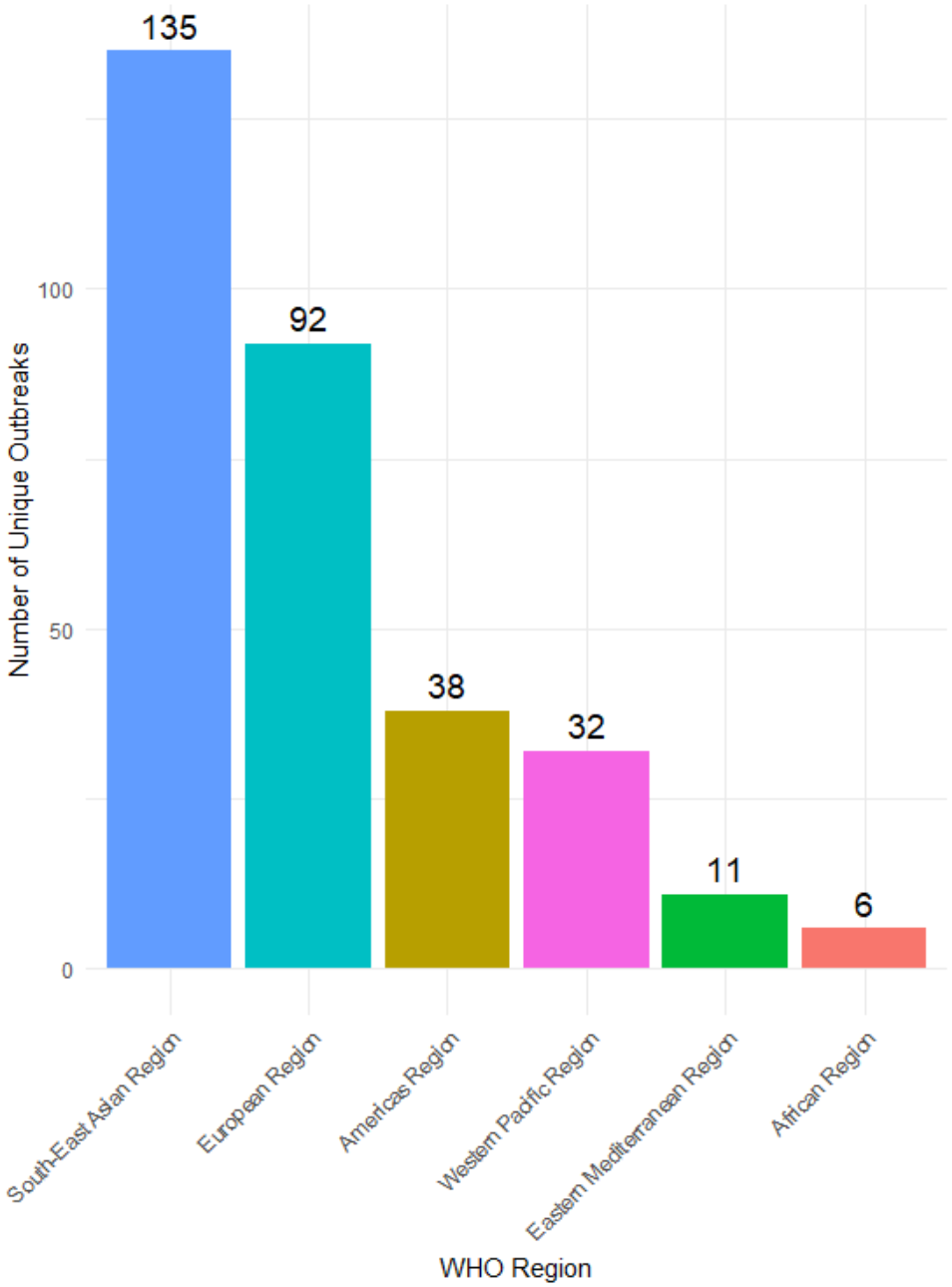

Figure 3: Total number of unique outbreaks captured by the EPIWATCH® system between March 2021 and March 2023 summarised by WHO Region

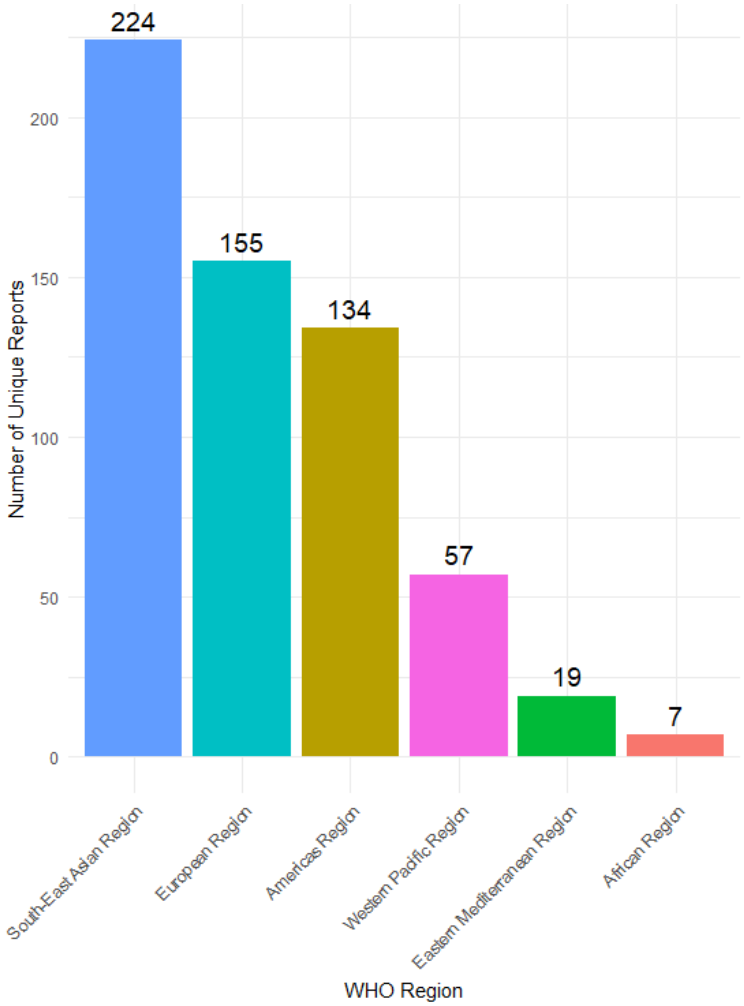

Figure 4: Total number of unique reports captured by the EPIWATCH® system between March 2021- March 2023 summarised by WHO Region

Argentinian Case Study

We investigated an event in Argentina in 2022 of an outbreak of pneumonia of unknown cause. For the first two days, on the first of September and the second of September, articles were labelled as pneumonia of unknown cause and were predominantly in Spanish. By the third day, 42 reports were detected, with a shift to including reports written in English (Figure 5). On the third day of reporting, an official diagnosis of Legionnaires disease was made. As a result, by the fourth day, most news sources began reporting the outbreak as Legionnaires disease rather than pneumonia of unknown cause. This led to a decline in reports, with only a small number of single reports published nine days following the initial alert.

Due to this outbreak's international attention, global news sites began covering the unfolding situation, leading to 16 languages and countries reporting on the outbreak. Figure 5 shows the breakdown by language per date. Most languages were reported on the third day after the initial detection. No English articles were detected on the first day, with Spanish, German, and French being the first three languages detected.

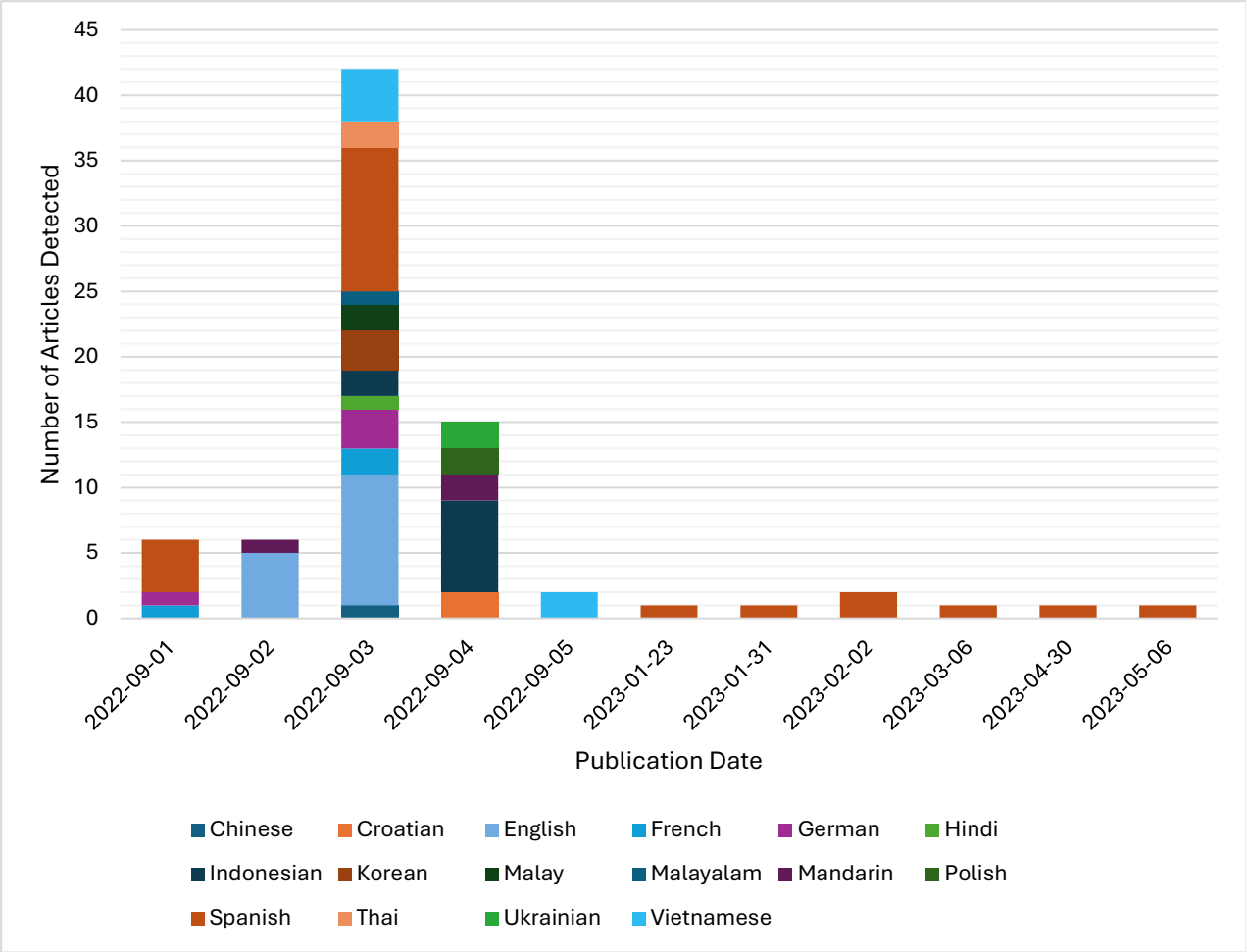

Figure 5: Language breakdown of EPIWATCH®-detected reports of the 2022 Argentina pneumonia of unknown cause event, presented by day relative to the first signal detected by EPIWATCH® on September 1, 2022. All reports shown represent articles captured within the EPIWATCH® system. Day three corresponds to the official diagnosis of Legionnaires' disease on September 3, 2022.

Acceptability

The results of the external stakeholder survey from 9 respondents indicate that the EPISCOPE digest is generally considered acceptable. The survey was distributed to nine EPISCOPE stakeholders' departments, yielding nine responses. This low response rate should be considered when interpreting the findings presented in this section, as discussed further in the limitations. All responses collected were from locations within Australia in either New South Wales or the Australian Capital Territory. Of these, eight respondents completed the survey in its entirety, while one partially completed 60% of the survey; this respondent's input was still included in the analysis. Importantly, eight respondents said they found EPISCOPE to be a useful or somewhat valuable tool, while one indicated that it was not. Responding to the question "What Sections are the most valuable to your work?" among the nine survey participants, six respondents identified the "Avian Influenza Bulletin" as the most valuable

component of the EPISCOPE digest. This was followed by the “Outbreaks in Focus” and “New Animal Outbreak” sections, each highlighted by five respondents. In contrast, only one respondent considered the “Unknown illness and Syndromic Surveillance” component the most valuable for their work. While four respondents read the "Unknown Illness and Syndromic Surveillance" section, only one reported reading the "COVID-19 Local and International Updates" section.

Seven respondents indicated that they consume the syndromic surveillance component of EPISCOPE, with respiratory syndromes being the most followed section; three respondents identified it as the most useful. However, engagement with this component varied; four respondents reported using it regularly, while three stated they use it only occasionally. Two respondents who did not actively use the syndromic surveillance component cited its limited relevance to their work, describing it as more of an interesting resource than a critical tool. Additionally, three respondents expressed concerns about EPISCOPE's overall usability and clarity. These concerns included difficulties in identifying significant information amidst the volume of reports, with one respondent specifically noting that irrelevant events made it harder to focus on important content. Two respondents highlighted issues with the visual presentation, describing the charts and maps as difficult to read and suggesting improvements to make them more accessible, including colourblind-friendly design options.

Their reasons aligned with earlier feedback, emphasising challenges in filtering relevant information, difficulties understanding the significance of reports, and the need for more streamlined and concise content. Suggestions for improvement included condensing the information to reduce perceived "noise" and enhancing the visual formatting for better clarity and usability.

Seven respondents reported engaging with the syndromic surveillance component of EPISCOPE, with respiratory syndromes identified as the most useful section by three respondents. Four used the component regularly, while three only used it occasionally. Two respondents who did not actively use the syndromic component cited limited relevance to their work. One described it as "not relevant to daily work but interesting to briefly peruse," while the other stated, "It isn't so relevant for me."

Three of nine respondents indicated they would not recommend EPISCOPE to others. Their feedback highlighted key areas of concern, such as difficulty identifying significant information due to an overwhelming volume of reports and irrelevant event inclusions. One noted that the reports were "a lot of noise," making it hard to determine what was significant. Another commented that "too many irrelevant event inclusions" hindered the identification of critical issues. The formatting and visual presentation of EPISCOPE were also raised as challenges.

One respondent suggested improving the readability of charts and maps, recommending the involvement of a graphic designer to create a more user-friendly and colour-blind-accessible layout.

Discussion

This study aimed to evaluate EPIWATCH® in terms of timeliness, representativeness and acceptability by assessing these factors against the United States CDC guidelines for the evaluation of a surveillance system. This discussion demonstrates how the tools employed provided these insights. The evaluation reveals that overall, EPIWATCH®'s syndromic surveillance component effectively meets its objective of identifying syndromic signals before official disease diagnosis. EPIWATCH® is sufficiently developed to monitor, detect, and inform stakeholders, enhancing public health response. As of the time of writing, ongoing developments are expected to address several of the weaknesses identified in this report.

Timeliness

The primary goal of the EPIWATCH® system is to prevent the next pandemic, making the timely capture of syndromic signals its most critical component. Therefore, assessing the system's timeliness should be this evaluation's primary focus. The project planned to assess timeliness first by determining the difference in time between syndrome detection and official disease diagnosis and by assessing the time difference between detection and dissemination. However, only the second was assessable during this project. The first part was not possible, as it relied on linking disease diagnoses to specific syndrome events; this could not work because only six outbreaks were identified by the disease.

The EPIWATCH® system effectively detected syndromic events within a timeframe acceptable to the eight stakeholders who responded to the external stakeholder survey. This capability is enabled by the system's flexibility, which allows it to prioritise information and bypass steps that may introduce lag time. The current system can detect and present reports to analysts typically within 12 – 24 hours of the report being publicly available. The primary factor influencing this time range is the availability of analysts to review and upload reports to the EPIWATCH® database or flag for senior review. If a signal is detected during unmonitored hours, such as at night, the manual review will not be conducted until the following morning. Once detected, senior analysts can expedite signals determined to be of high priority through the system pipeline for rapid dissemination via the EPIWATCH® X handle or direct email correspondence to known stakeholders.

However, this reporting timeline relies on analysts' ability to understand a signal's context and recognise its priority, which can lead to delays in identifying signals that analysts may not view

as urgent but are important to certain stakeholders, which would only be detected through the usual pipeline timeline. The typical dissemination timeline can take two to seven days, depending on when the report is detected during the surveillance week and when the weekly surveillance digest, EPISCOPE, is released to stakeholders.

This variability is worth acknowledging, as in the context of a rapidly evolving outbreak, the difference between two and seven days could have implications for the speed of public health response. A broader consideration emerging from this evaluation is what constitutes timely detection in the context of syndromic surveillance for pandemic pathogens. In this evaluation, EPIWATCH® detected syndromic signals approximately 24 hours before official disease diagnosis in those outbreaks where a subsequent diagnosis was confirmed. While this window is relatively modest, it nonetheless provides public health officials with an opportunity to initiate preliminary investigations and early communications ahead of formal confirmation. Future evaluations would benefit from a more explicitly defined benchmark for timeliness, ideally informed by consultation with public health response agencies, to better contextualise such findings. It should also be noted that this finding is derived from a small number of confirmed outbreak diagnoses and should be interpreted accordingly.

Assessing the EPIWATCH® system's ability to detect syndromes promptly before the lack of global surveillance for undiagnosed syndromes limits official disease diagnosis. Mainstream surveillance systems require a formal diagnosis, making direct comparisons difficult. However, when a syndrome is later diagnosed and captured by formal surveillance, the evaluation showed that syndromic reports typically precede official disease diagnosis by 24 to 48 hours, which can be crucial for responding to PPPs. This 24–48-hour lag time can be explained by initial media releases, raising awareness. At the same time, laboratory testing is conducted on the first cases, with results for viral infections usually available 24 to 72 hours after sample collection. This timeline of events can take multiple days or weeks for bacterial infections due to the need for environmental sampling and culturing of patient samples.

This phenomenon is exemplified in the Argentinian case study, which demonstrated that although initial syndromic events were reported on August 18th, the outbreak did not become public knowledge for over a week after the Argentinian authorities initiated their investigation (Figure 5). This led to a five-day lag time between the pneumonia of unknown cause outbreak and its detection by the system. Since the EPIWATCH® system relies heavily on mainstream media reports, this lag time is unlikely to be eliminated until additional alternative data sources are incorporated. By including sources such as social media or other alternative data collection methods, the lag time between syndrome onset and system detection could be reduced, thereby improving timeliness.

Disease diagnosis results may never be publicly available; as discussed in existing literature, media, both social and traditional, has a vested interest in covering topics perceived to generate higher engagement. This often leads to reporting on events that are seen as sensational, such as severe pneumonia of unknown cause. In contrast, events that do not remain of high interest may not be reported, or may be reported past their initial article.

Representativeness

Representativeness refers to the system's ability to accurately capture a true reflection of the populations it aims to survey; in this case, that population is the entire globe, including its 195 recognised countries and hundreds of languages and dialects. In evaluating this, the ability to detect signals in proportion to the population and geographical density is key.

EPIWATCH® captured signals from 56 countries within the two-year evaluation period. However, a notable concentration of reports from a few countries, particularly India, accounted for 23.4% of all reports (Table 1) and 32.4% of all outbreaks (Table 2), with Argentina at 9.2% and Bangladesh at 6.9% of outbreaks. This high prevalence in India can be partially attributed to the large number of undiagnosed conditions reported in media outlets and the country's large population size; this suggests that the system's data is broadly representative. Countries with highly developed healthcare systems are less likely to have undiagnosed syndromic events, as they rely on active IBS systems to diagnose and treat diseases before they become public outbreaks. In contrast, countries like the Democratic People's Republic of Korea (DPRK), which ranked third in the number of reports (Table 2), showed a high prevalence of undiagnosed respiratory disease outbreaks, largely due to censorship, as the reported events were never officially confirmed by DPRK sources.

Additionally, there are culturally and ethnically diverse populations within countries, and a system must ensure that signals are not biased towards specific populations. The most effective method of assessing this in the current version of EPIWATCH® is through the languages used in the reports. This is a critical factor for both representativeness and timeliness. For instance, during the Argentinian outbreak, media outlets translated reports into multiple languages, which led to a 24-48 hour lag, as seen in Figure 4. This is a crucial period in detecting and preventing PPPs. By capturing Spanish, French and German reports, the system is ahead of English-based news articles by 24 hours. Notably, only 11% of EPIWATCH® reports were in English, highlighting its ability to represent a broader portion of global reports.

However, certain regions, including sub-Saharan Africa and the Middle East, still face underreporting in EPIWATCH®. This issue stems from factors such as reporting biases, terminology differences, and language nuances. To address this, efforts are underway to enhance the system's capabilities. During the evaluation, languages like Hindi and Portuguese

underwent rigorous validation and translation processes, leading to increased detection rates for these languages; however, the data for this report was collected before they were validated and added as languages. By employing region-specific teams and leveraging professional contacts, EPIWATCH® has been able to increase its representativeness by capturing regional terminology and improving contextual awareness. This approach has led to a noticeable increase in the number of reports captured while writing this thesis.

Acceptability

The evaluation of the EPIWATCH® system found that the acceptability of the system was generally satisfactory among external stakeholders. Specifically, eight out of nine respondents indicated that EPISCOPE was, at the least, somewhat valuable in meeting their needs, and seven out of nine respondents were actively using the syndromic surveillance component.

Themes emerging from stakeholder feedback included information overload, difficulty identifying significant signals within the volume of reports, and challenges with visual presentation. These reflect a broader tension inherent in EBS system design between maximising sensitivity through broad signal capture and presenting information in a way that is accessible and actionable for stakeholders. The finding that the most valued sections of EPISCOPE were those featuring curated analysis, such as the avian influenza bulletin and the Outbreaks in Focus section, suggests that stakeholders benefit from synthesised and contextualised information alongside raw signal reporting. Consideration of how the syndromic surveillance component could be presented in a more curated format may therefore be a productive avenue for future development.

Engagement with the Unknown Illness and Syndromic Surveillance section was relatively low compared to other components of EPISCOPE, though those who did engage with it reported finding it valuable. This discrepancy between engagement and perceived value suggests that improvements to the accessibility and presentation of this section could increase both its readership and its utility among stakeholders.

It should be noted, however, that the conclusions of this evaluation are limited by the low number of survey respondents, which restricts the generalisability of the findings. There could be bias in those who chose to respond (of nine organisational email addresses that received the survey), which may skew the results. Larger surveys will be needed to properly inform development of EPIWATCH®.

Strengths and Limitations

The inherent nature of EBS systems relying on unverified reports of events rather than laboratory-confirmed diagnoses or other clinical methods leads to inherent vagueness and

uncertainty. This causes syndromic reports to often lack the specificity needed to establish direct, verifiable links between reported events and disease diagnoses. This led to a major limitation within the data analysis, as many potentially linkable articles were removed due to either a lack of detail to meet the criteria required to be definitive or because they may have been included when not actually associated with an ILI or pneumonia of unknown cause outbreak.

Another major limitation was the low response rate to the stakeholder survey. Only nine respondents provided feedback despite the survey being distributed to over nine stakeholders' email addresses with expectations of being forwarded on to multiple personnel within each organisation over a month, representing a response rate of approximately 13%. This low response rate has meaningful implications for the findings reported in this evaluation and warrants careful consideration when interpreting the acceptability results specifically. With only nine respondents, the statistical power of any conclusions drawn from the survey data is severely limited. For context, a single respondent in this sample represents approximately 11% of all responses, meaning that the addition or removal of even one respondent could meaningfully shift the reported findings in either direction. This is particularly relevant to the acceptability findings, where the margin between positive and negative responses was narrow in several instances. For example, the finding that three of nine respondents would not recommend EPISCOPE to others represents 33% of survey respondents; however, this conclusion is drawn from only three individuals and should therefore be interpreted with considerable caution. This may also lead to potential responder bias. Voluntary surveys are prone to attracting individuals with strong opinions, either highly positive or negative, leading to polarised responses that may not represent the broader stakeholder population. The limited sample size also reduces the generalisability of findings, making it difficult to draw robust conclusions about stakeholder satisfaction and acceptability. While the survey provided valuable insights into the strengths and weaknesses of the system, addressing these limitations in future evaluations will be crucial. Future evaluations should consider setting a minimum required sample size before analysis. If that threshold is not met, the acceptability component should either be deferred or reported solely as preliminary and exploratory in nature. Expanding respondent pools, employing alternative survey methods, or incorporating qualitative interviews could provide more representative and nuanced feedback.

Conclusion and recommendations

The evaluation of the EPIWATCH® syndromic surveillance component found that the system demonstrates a reasonable capacity to detect and disseminate syndromic signals ahead of official disease diagnoses. Where a subsequent diagnosis was confirmed, syndromic signals

were detected approximately 24 hours in advance, which provides some operational advantage. However, the significance of this margin will depend on the nature and pace of the outbreak in question. It should be acknowledged that this finding is based on a small number of confirmed diagnoses and should therefore be interpreted with caution.

The system's multilingual capability is a notable strength, with 87% of detected signals captured in languages other than English, contributing positively to both the representativeness and timeliness of signal detection. However, the evaluation also identified meaningful gaps in geographic coverage, particularly in sub-Saharan Africa and the Middle East. Stakeholder acceptability was broadly satisfactory, with the majority of respondents finding EPISCOPE to be of value. However, recurring themes around information overload and presentation challenges suggest that there remains meaningful work to be done to ensure the system meets the needs of its full stakeholder base. The low survey response rate also limits the confidence with which conclusions about acceptability can be generalised.

Overall, EPIWATCH® shows promise as an early warning tool and a valuable adjunct to traditional indicator-based surveillance systems. The system is continuing to develop, with ongoing efforts to increase automation and address gaps in representativeness. While the findings of this evaluation are broadly encouraging, they also highlight several areas where further development and more rigorous evaluation will be needed before stronger conclusions about the system's effectiveness in preventing the next pandemic can be drawn.

Recommendations

- Suggest the creation of a weekly or monthly “follow-up” procedure to actively investigate select syndromic events that were seen as high priority.
- Consider establishing a weekly or fortnightly “Events to Watch” dataset that is easily accessible to increase information exchange within a team of syndromic events to increase the potential of capturing an associated disease event.
- Implement further automation of scanning procedures to reduce analyst workload and increase turnaround time from detection to dissemination.
- Establish a dataset of languages for each signal, preferably during the scanning phase. This would then be used for a monthly language audit to determine gaps in languages.
- Undertake biyearly or yearly stakeholder surveys to determine stakeholder satisfaction over development of the EPIWATCH® system.
- Establish a dedicated competency-based assessment that includes continuously updated procedures that require recertification every 6-12 months.
- Undertake biyearly or yearly stakeholder surveys to determine stakeholder satisfaction with the development of the EPIWATCH® system.

- Establish a dedicated competency-based assessment that includes continuously updated procedures that require recertification every 6-12 months.
- Formal evaluation of sensitivity, flexibility, and other remaining CDC guideline attributes is recommended in future evaluation cycles to provide a more comprehensive assessment of the EPIWATCH® system
- Future research could explore the drivers of regional signal concentration identified in this evaluation, including whether these patterns reflect true epidemiological differences, reporting biases, or characteristics of the system's current source and language capabilities

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Supplementary Materials

Supplemental 1

Supplemental 1.1: Total number of Reports, ILI and Pneumonia of unknown Cause separated by topic of country and ordered by frequency of articles from highest reported to lowest.

Total Number of Reports			Reports detected as ILI			Reports detected as Pneumonia of Unknown Cause		
Country	Articles	%	Country	Articles	%	Country	Articles	%
India	139	23.4	India	84	24.5	Argentina	55	21.8
Argentina	55	9.2	Korea, Dem. People Rep.	44	12.8	India	55	21.8
Korea, Dem. People Rep.	45	7.6	Czech Republic	34	9.9	Bangladesh	30	11.9
Bangladesh	36	6.1	United States	31	9	El Salvador	13	5.2
Czech Republic	36	6.1	Ukraine	18	5.2	Afghanistan	12	4.8
United States	31	5.2	Russian Federation	16	4.7	Peru	12	4.8
Russian Federation	22	3.7	China	13	3.8	Romania	12	4.8
China	19	3.2	Malaysia	12	3.5	Italy	8	3.2
Italy	18	3	Italy	10	2.9	China	6	2.4
Ukraine	18	3	Bulgaria	9	2.6	Russian Federation	6	2.4
Afghanistan	14	2.4	Bangladesh	6	1.7	Brazil	5	2
El Salvador	13	2.2	Brazil	6	1.7	Kazakhstan	5	2
Malaysia	12	2	Korea, Rep.	6	1.7	Germany	3	1.2
Peru	12	2	Germany	5	1.5	Belarus	2	0.8
Romania	12	2	Canada	4	1.2	Bosnia and Herzegovina	2	0.8
Brazil	11	1.8	Japan	4	1.2	Czech Republic	2	0.8
Bulgaria	10	1.7	Belarus	3	0.9	Indonesia	2	0.8
Germany	8	1.3	Bosnia and Herzegovina	3	0.9	Mexico	2	0.8
Kazakhstan	7	1.2	Congo, Dem. Rep.	3	0.9	Pakistan	2	0.8
Korea, Rep.	7	1.2	Macao SAR, China	3	0.9	Vietnam	2	0.8
Belarus	5	0.8	Vietnam	3	0.9	Austria	1	0.4
Bosnia and Herzegovina	5	0.8	Afghanistan	2	0.6	Belgium	1	0.4
Japan	5	0.8	Belgium	2	0.6	Bolivia	1	0.4
Vietnam	5	0.8	Hong Kong SAR, China	2	0.6	Bulgaria	1	0.4
Canada	4	0.7	Indonesia	2	0.6	Ecuador	1	0.4
Indonesia	4	0.7	Kazakhstan	2	0.6	Egypt, Arab Rep.	1	0.4
Belgium	3	0.5	Kiribati	2	0.6	France	1	0.4
Congo, Dem. Rep.	3	0.5	Kyrgyz Republic	2	0.6	Ireland	1	0.4
Macao SAR, China	3	0.5	Algeria	1	0.3	Israel	1	0.4
Mexico	3	0.5	Australia	1	0.3	Japan	1	0.4

Bolivia	2	0.3	**Bolivia**	1	0.3	**Korea, Dem. People Rep.**	1	0.4
Egypt, Arab Rep.	2	0.3	**Colombia**	1	0.3	**Korea, Rep.**	1	0.4
Hong Kong SAR, China	2	0.3	**Croatia**	1	0.3	**Latvia**	1	0.4
Kiribati	2	0.3	**Egypt, Arab Rep.**	1	0.3	**Madagascar**	1	0.4
Kyrgyz Republic	2	0.3	**Fiji**	1	0.3	**Nicaragua**	1	0.4
Pakistan	2	0.3	**Finland**	1	0.3	**Nigeria**	1	0.4
Algeria	1	0.2	**Greece**	1	0.3			
Australia	1	0.2	**Hungary**	1	0.3			
Austria	1	0.2	**Kenya**	1	0.3			
Colombia	1	0.2	**Mexico**	1	0.3			
Croatia	1	0.2						
Ecuador	1	0.2						
Fiji	1	0.2						
Finland	1	0.2						
France	1	0.2						
Greece	1	0.2						
Hungary	1	0.2						
Ireland	1	0.2						
Israel	1	0.2						
Kenya	1	0.2						
Latvia	1	0.2						
Madagascar	1	0.2						
Nicaragua	1	0.2						
Nigeria	1	0.2						

Supplemental 1.2 Total number of Outbreaks, ILI and Pneumonia of Unknown Cause separated by topic of country and ordered by frequency of outbreaks from highest reported to lowest.

Total number of Outbreaks collated from Reports			Outbreaks reported as ILI			Outbreak Reported as Pneumonia of unknown cause		
Country	Outbreak	%	Country	Outbreak	%	Country	Outbreak	%
India	104	33.2	India	70	35.9	India	35	26.9
Bangladesh	23	7.3	Ukraine	13	6.7	Bangladesh	22	16.9
Russian Federation	14	4.5	Russian Federation	12	6.2	Romania	8	6.2
Ukraine	13	4.2	United States	11	5.6	Peru	6	4.6
China	12	3.8	Bulgaria	8	4.1	Afghanistan	5	3.8
Italy	11	3.5	China	8	4.1	Kazakhstan	5	3.8
United States	11	3.5	Italy	8	4.1	Russian Federation	5	3.8
Bulgaria	8	2.6	Brazil	4	2.1	China	4	3.1
Romania	8	2.6	Czech Republic	4	2.1	Brazil	3	2.3
Brazil	7	2.2	Germany	4	2.1	Germany	3	2.3
Kazakhstan	7	2.2	Korea, Dem. People Rep.	4	2.1	Italy	3	2.3
Afghanistan	6	1.9	Malaysia	4	2.1	Argentina	2	1.5
Germany	6	1.9	Bosnia and Herzegovina	3	1.5	Belarus	2	1.5
Peru	6	1.9	Canada	3	1.5	Czech Republic	2	1.5
Czech Republic	5	1.6	Japan	3	1.5	Indonesia	2	1.5
Belarus	4	1.3	Macao SAR, China	3	1.5	Mexico	2	1.5
Bosnia and Herzegovina	4	1.3	Afghanistan	2	1	Pakistan	2	1.5
Indonesia	4	1.3	Bangladesh	2	1	Austria	1	0.8
Japan	4	1.3	Belarus	2	1	Belgium	1	0.8
Korea, Dem. People Rep.	4	1.3	Congo, Dem. Rep.	2	1	Bolivia	1	0.8
Malaysia	4	1.3	Indonesia	2	1	Bosnia and Herzegovin a	1	0.8
Canada	3	1	Kazakhstan	2	1	Bulgaria	1	0.8
Macao SAR, China	3	1	Kiribati	2	1	Ecuador	1	0.8
Mexico	3	1	Kyrgyz Republic	2	1	Egypt, Arab Rep.	1	0.8
Vietnam	3	1	Vietnam	2	1	El Salvador	1	0.8
Argentina	2	0.6	Algeria	1	0.5	France	1	0.8
Bolivia	2	0.6	Australia	1	0.5	Ireland	1	0.8
Congo, Dem. Rep.	2	0.6	Belgium	1	0.5	Israel	1	0.8
Egypt, Arab Rep.	2	0.6	Bolivia	1	0.5	Japan	1	0.8
Kiribati	2	0.6	Colombia	1	0.5	Korea, Dem. People Rep.	1	0.8
Kyrgyz Republic	2	0.6	Croatia	1	0.5	Korea, Rep.	1	0.8
Pakistan	2	0.6	Egypt, Arab Rep.	1	0.5	Latvia	1	0.8
Algeria	1	0.3	Fiji	1	0.5	Madagascar	1	0.8

Australia	1	0.3	**Finland**	1	0.5	**Nicaragua**	1	0.8
Austria	1	0.3	**Greece**	1	0.5	**Nigeria**	1	0.8
Belgium	1	0.3	**Hong Kong SAR, China**	1	0.5	**Vietnam**	1	0.8
Colombia	1	0.3	**Hungary**	1	0.5			
Croatia	1	0.3	**Kenya**	1	0.5			
Ecuador	1	0.3	**Korea, Rep.**	1	0.5			
El Salvador	1	0.3	**Mexico**	1	0.5			
Fiji	1	0.3						
Finland	1	0.3						
France	1	0.3						
Greece	1	0.3						
Hong Kong SAR, China	1	0.3						
Hungary	1	0.3						
Ireland	1	0.3						
Israel	1	0.3						
Kenya	1	0.3						
Korea, Rep.	1	0.3						
Latvia	1	0.3						
Madagascar	1	0.3						
Nicaragua	1	0.3						
Nigeria	1	0.3						

Supplemental 1.3 Total number of Reports, ILI and Pneumonia of Unknown Cause separated by topic of language and ordered by frequency of articles from highest reported to lowest.

Total Number of Reports			Reports detected as ILI			Reports detected as Pneumonia of Unknown Cause		
Language	Reports	%	Language	Reports	%	Language	Reports	%
English	80	13.4	English	61	17.8	Spanish	48	19
Hindi	78	13.1	Czech	35	10.2	Hindi	45	17.9
Spanish	54	9.1	Hindi	33	9.6	Bengali	35	13.9
Bengali	46	7.7	Ukrainian	21	6.1	English	19	7.5
Czech	37	6.2	Mandarin	19	5.5	Romanian	13	5.2
Mandarin	29	4.9	Russian	19	5.5	Arabic	10	4
Russian	28	4.7	Italian	12	3.5	Mandarin	10	4
Ukrainian	23	3.9	Malay	12	3.5	Indonesian	9	3.6
Italian	20	3.4	Bengali	11	3.2	Russian	9	3.6
Indonesian	16	2.7	Gujarati	11	3.2	Italian	8	3.2
Malay	15	2.5	Bulgarian	9	2.6	German	6	2.4
Arabic	14	2.4	Korean	9	2.6	Vietnamese	5	2
Romanian	14	2.4	Marathi	8	2.3	French	4	1.6
Korean	12	2	Indonesian	7	2	Bosnian	3	1.2
German	11	1.8	French	6	1.7	Korean	3	1.2
Gujarati	11	1.8	Portuguese	6	1.7	Malay	3	1.2
Bulgarian	10	1.7	Spanish	6	1.7	Malayalam	3	1.2
French	10	1.7	German	5	1.5	Czech	2	0.8
Vietnamese	10	1.7	Japanese	5	1.5	Kazakh	2	0.8
Marathi	9	1.5	Kannada	5	1.5	Serbian	2	0.8
Bosnian	7	1.2	Vietnamese	5	1.5	Ukrainian	2	0.8
Japanese	6	1	Arabic	4	1.2	Belgian	1	0.4
Portuguese	6	1	Bosnian	4	1.2	Bosian	1	0.4
Kannada	5	0.8	Tamil	4	1.2	Bulgarian	1	0.4
Malayalam	5	0.8	Macedonian	3	0.9	Chinese	1	0.4
Tamil	5	0.8	Odia	3	0.9	Croatian	1	0.4
Macedonian	3	0.5	Telugu	3	0.9	Japanese	1	0.4
Odia	3	0.5	Gurjarati	2	0.6	Marathi	1	0.4
Telugu	3	0.5	Malayalam	2	0.6	Nepali	1	0.4
Chinese	2	0.3	Persian	2	0.6	Polish	1	0.4
Croatian	2	0.3	Chinese	1	0.3	Tamil	1	0.4
Gurjarati	2	0.3	Croatian	1	0.3	Thai	1	0.4
Kazakh	2	0.3	Hebrew	1	0.3			
Persian	2	0.3	Hungarian	1	0.3			
Serbian	2	0.3	Kyrgyz	1	0.3			
Thai	2	0.3	Pashto	1	0.3			
Belgian	1	0.2	Punjabi	1	0.3			
Bosian	1	0.2	Romanian	1	0.3			
Hebrew	1	0.2	Swedish	1	0.3			

Hungarian	1	0.2	**Thai**	1	0.3
Kyrgyz	1	0.2	**Vietnam**	1	0.3
Nepali	1	0.2			
Pashto	1	0.2			
Polish	1	0.2			
Punjabi	1	0.2			
Swedish	1	0.2			
Vietnam	1	0.2			

Supplemental 1.4 Total number of Outbreaks, ILI and Pneumonia of Unknown Cause separated by topic of languages and ordered by frequency of outbreaks from highest reported to lowest.

Total number of Outbreaks			Total number of outbreaks reported as ILI			Total number of outbreaks reported as pneumonia of unknown cause		
Language	Outbreak	%	country	Outbreak	%	Language	Outbreak	%
Hindi	57	15.1	India	70	35.9	Hindi	28	18.1
English	43	11.4	Ukraine	13	6.7	Bengali	27	17.4
Bengali	32	8.5	Russian Federation	12	6.2	Spanish	17	11
Spanish	22	5.8	United States	11	5.6	English	10	6.5
Mandarin	21	5.6	Bulgaria	8	4.1	Romanian	9	5.8
Russian	20	5.3	China	8	4.1	Russian	8	5.2
Ukrainian	18	4.8	Italy	8	4.1	Arabic	7	4.5
Italian	12	3.2	Brazil	4	2.1	Mandarin	6	3.9
Gujarati	11	2.9	Czech Republic	4	2.1	German	4	2.6
Arabic	10	2.6	Germany	4	2.1	Indonesian	4	2.6
Indonesian	10	2.6	Korea, Dem. Peoples Rep.	4	2.1	Italian	3	1.9
Romanian	10	2.6	Malaysia	4	2.1	Malayalam	3	1.9
German	9	2.4	Bosnia and Herzegovina	3	1.5	Bosnian	2	1.3
Marathi	9	2.4	Canada	3	1.5	Czech	2	1.3
Bulgarian	8	2.1	Japan	3	1.5	French	2	1.3
Bosnian	6	1.6	Macao SAR, China	3	1.5	Kazakh	2	1.3
Czech	6	1.6	Afghanistan	2	1	Korean	2	1.3
Malay	6	1.6	Bangladesh	2	1	Malay	2	1.3
Japanese	5	1.3	Belarus	2	1	Serbian	2	1.3
Kannada	5	1.3	Congo, Dem. Rep.	2	1	Ukrainian	2	1.3
Malayalam	5	1.3	Indonesia	2	1	Vietnamese	2	1.3
Tamil	5	1.3	Kazakhstan	2	1	Belgian	1	0.6
Vietnamese	5	1.3	Kiribati	2	1	Bosian	1	0.6
French	4	1.1	Kyrgyz Republic	2	1	Bulgarian	1	0.6
Korean	4	1.1	Vietnam	2	1	Chinese	1	0.6
Portuguese	4	1.1	Algeria	1	0.5	Croatian	1	0.6
Telugu	3	0.8	Australia	1	0.5	Japanese	1	0.6
Chinese	2	0.5	Belgium	1	0.5	Marathi	1	0.6
Croatian	2	0.5	Bolivia	1	0.5	Nepali	1	0.6
Kazakh	2	0.5	Colombia	1	0.5	Polish	1	0.6
Macedonian	2	0.5	Croatia	1	0.5	Tamil	1	0.6
Odia	2	0.5	Egypt, Arab Rep.	1	0.5	Thai	1	0.6
Persian	2	0.5	Fiji	1	0.5			
Serbian	2	0.5	Finland	1	0.5			
Thai	2	0.5	Greece	1	0.5			
Belgian	1	0.3	Hong Kong SAR, China	1	0.5			

Bosian	1	0.3	**Hungary**	1	0.5	
Gurjarati	1	0.3	**Kenya**	1	0.5	
Hebrew	1	0.3	**Korea, Rep.**	1	0.5	
Hungarian	1	0.3	**Mexico**	1	0.5	
Kyrgyz	1	0.3				
Nepali	1	0.3				
Pashto	1	0.3				
Polish	1	0.3				
Punjabi	1	0.3				
Swedish	1	0.3				
Vietnam	1	0.3				

Chapter 3: Adult Australian attitudes and behaviours related to COVID-19 government public health measures implemented in 2022

List of Abbreviations

ANU	Australian National University
BREATHE	Bushfire, Respiratory protection, Emphysema, bronchitis and Asthma Triggering Health Effects
CI	Confidence Interval
CO2	Carbon Dioxide
COVID-19	Coronavirus Disease 2019
GVIF	Generalised Variance Inflation Factor
HEPA	High-Efficiency Particulate Air
UNSW	University of New South Wales
AR-UVC	Far-Ultraviolet C

Prologue

This chapter focuses on my data analysis project, using a cross-sectional analysis of survey data on the attitudes, abilities, and government practices in relation to non-pharmaceutical mitigation measures for COVID-19, such as avoiding crowds, social distancing, and environmental risk factors, among a sampling of Australian adults in 2023. Examples of such measures include avoiding crowds and increasing ventilation. It also contains a further analysis of the views of Australian adults on the removal of mandatory isolation for COVID-19, as well as other potential predictors of approval or disapproval of the various state governments' decisions to remove these COVID-19 isolation requirements.

During the early stages of a severe health threat, where information is scarce and knowledge is rapidly evolving, having a clear understanding of how a population would respond to non-pharmaceutical measures is necessary to prevent the further escalation of the health threat. Past experiences, current knowledge and socio-economic factors create the public's predicted responses. By determining these factors that cause an increase in disapproval of the removal of isolation requirements, it is hoped that a greater understanding of how the opinions and beliefs of the Australian population during the COVID-19 pandemic were shaped, potentially aiding future policies that are implemented more quickly and efficiently, and with greater satisfaction from the public.

In the early period of the COVID-19 pandemic in Australia, several non-pharmaceutical measures were enacted, some of which were legal requirements. These included mandatory mask wearing in public, mandatory isolation of those with either confirmed or suspected infection for a variable amount of time depending on the state, and limiting crowd sizes and reducing or removing methods of moving between locations. Other recommendations were optional, such as using CO2 filters, opening windows in a home to increase airflow, staying home while sick, and avoiding crowded spaces. Understanding how the Australian public responded and what they thought of these measures could help future health crisis planning and execution be better received, understood, and followed by the Australian public.

My study is a component of a larger research project from the Bushfire, Respiratory protection, Emphysema, bronchitis and Asthma Triggering Health Effects (BREATHE) NHMRC Centre for Research Excellence at UNSW investigating a multitude of attitudes from the adult Australian public, including attitudes associated with mask wearing, vaccines, hygiene practices and communication. My cross-sectional study aimed to answer the following questions about non-pharmaceutical mitigation measures for COVID-19:

- What demographic or socio-economic factors affect the Australian adult population's attitudes and beliefs around non-pharmaceutical mitigation measures for COVID-19?
- What were the opinions about the removal of mandatory isolation for COVID-19?
- What demographic or behavioural factors affected the agreement with the government's decision to reduce government-mandated isolation requirements?

This chapter fulfils the following MAE competencies

1. Analyse a public health data set
2. Conduct a literature review
3. Conduct an epidemiological study

My role

I joined the project after the completion of the survey responses by participants. I worked closely with those involved in creating the survey to define the research questions that would form the focus of my project. I consulted with both my field and academic supervisors. Therefore, I decided that the questions both met my competencies for the MAE and were feasible for the degree timeline. Based on this, I decided to focus on a subset of the study questions rather than investigating all survey question responses. I designed a cross-sectional analysis study to answer my study questions and contribute to the body of work being undertaken by the larger research team.

I then conducted an audit of the raw dataset, with support from others on the research team, to understand the definitions, weaknesses, and areas of missing data, as well as further guidance on running and troubleshooting the logistic regression. I then collated and analysed the data in RStudio and determined the findings, accounting for the limitations of the dataset as well as the data collection method.

Key reflections

This project provided several key lessons. First, I gained a great appreciation of how ensuring the study design is high quality before data collection can lead to fewer problems during and after data collection. Second, this led to me learning how to, ifit is feasible to do so, conduct large scale population surveys by engaging with a professional survey collection company, such as Dynata. This provided the wider team and me with a dataset that was of high calibre in both its quality and its validity.

Thirdly, learned the importance of reviewing raw data, data cleaning, and preparing data for analysis. I learnt that sometimes less is more when it comes to undergoing data analysis. In addition, I have come to understand that choosing which data to focus on is an incredibly difficult undertaking when provided with large amounts of quality data to draw upon. How to

concentrate on what is achievable within your time constraints to ensure effective allocation of effort is an ongoing learning experience. However, I have gained a better understanding of what those limitations are for myself and for a research team with multiple goals and deadlines.

Finally, I was also able to meet the data analysis competency by conducting basic descriptive statistics, visualising data, and then learning the complexities of logistic regression, and troubleshooting to ensure its validity as a model. I learned how respondent opinions sometimes don't make sense from a logical standpoint, but still must be accounted for when undergoing more advanced statistics. Exploring the multiple diagnostic tests and weighing up their pros and cons provided an excellent learning experience and gave me greater insight into being able to understand the mechanisms behind statistical testing.

Public health implications

This study contributes to the growing body of literature on public responses to government public health decisions during a health crisis. By identifying the demographic and behavioural factors associated with disapproval of mandatory isolation removal, the findings provide context that could assist governments and public health institutions in designing more targeted and effective communication strategies during future health events. Understanding which population groups are most likely to disengage from or disapprove of government public health decisions allows for proactive and tailored engagement with those communities, to improve adherence and maintain public trust. The findings also highlight the central role of perceived personal risk in shaping public opinion on government mandates, suggesting that future public health communication strategies would benefit from directly addressing the concerns of those with higher perceived risk, rather than relying solely on broad population-wide messaging.

Acknowledgements

I want to thank the BREATHE research team at the Kirby Biosecurity team, specifically Essa Tawfiq, for his statistical help and review of the statistical methods and results, as well as Mohana Kunasekaran for helping me understand the ins and outs of the research project. I would also like to thank those who undertook the survey when it was disseminated, whose valuable insights helped in the pursuit of knowledge. I would also like to thank Paul Young for his support, guidance, and encouragement throughout the process.

Abstract

Background: During a health crisis, non-pharmaceutical measures (such as masks, isolation, contact tracing) are one of the earliest available methods to prevent further transmission. In the earliest stages of a health event, it can in some cases be the only method available, as seen during the COVID-19 pandemic. Understanding what the Australian public's knowledge and opinions of these measures can help inform future health crisis planning. This study aimed to determine what these opinions were, as well as possible predictors of the public's opinion on the removal of mandated isolation for those infected with COVID-19.

Methods: A cross-sectional survey of Australians adults was conducted in January 2023 (n = 2616). Participants were asked questions about demographics, behaviours, and opinions related to COVID-19, such as non-pharmaceutical measures and media consumption. Univariate chi-square analysis and logistic regression were conducted to determine factors associated with disapproval of the government's removal of mandatory isolation for those infected with COVID-19.

Results: Of the respondents, 58% were female, 47% were aged 51 or older, 70% had tertiary accreditation, 60% were in paid employment, and 59% had a chronic disease. Only 5% identified as Aboriginal or Torres Strait Islander. Most could use basic non-pharmaceutical measures, such as opening windows (93%), while fewer had access to CO2 monitors (10%) or HEPA filters (15%). Men were 59% less likely than women to disagree with the removal of government-mandated isolation requirements. Those aged 51–64 were 51% more likely to disagree than those aged 18–50. Respondents without a chronic disease were 27% less likely to disagree than those with a chronic disease. Those not using a CO2 monitor had 3.94 times higher odds of disagreeing. Those who did not avoid indoor places or large gatherings had 0.45 times lower odds of disagreement**.**

Conclusion: Most Australian adults have the knowledge and ability to use basic non-pharmaceutical measures to mitigate COVID-19. The results suggested that women where more likely to disagree with the removal of mandatory isolation requirements compared to men, and those with lower risk of severe disease were more likely to agree with the removal of government mandated isolation.

Introduction

In January 2020, the first wave of COVID-19 appeared on Australia's shores, leading to a nationally enforced lockdown[2]. Whilst the experience of the pandemic varied considerably across Australian states and territories, the Victorian experience has been widely documented due to the severity and duration of its restrictions. By June 2020, a second, more localised, wave occurred in Melbourne, Victoria, which contained higher community spread and death rates than the first nationwide lockdown. It was during this secondary lockdown that several public health measures were mandated by the Victorian government, including mandatory mask wearing, a curfew from 9 pm to 5 am, travel restrictions, no visitors to homes, no visits to aged care homes, and mandatory isolation of the infected. [2, 3,4, 5]. Other states and territories enacted varying degrees of restriction during this period, with notable outbreaks also occurring elsewhere in Australia, such as the northern beaches outbreak in Sydney in 2020, reflecting the nationally distributed nature of the pandemic response[6].

In times of crisis, swift and effective action is required to succeed. When dealing with a public health crisis such as the scale of the Melbourne outbreak, this concept requires not only swift reaction from institutions but also quick and strict adherence from the public[7, 8]. Without compliance from the population, transmission can still occur at increased rates[3, 9, 10]. An individual's decision to comply with government health guidelines and mandates is reliant on a host of factors that are both external and internal. This includes a person's perceived risk, whether they have the capacity and resources to comply, as well as confidence in their government's decisions [9, 11, 12]. Understanding people's perceptions, abilities and capabilities and how they relate to their opinions on the government's decisions, as well as their own behaviours during the COVID-19 pandemic, would then allow for better communication, more effective targeted interventions as well as increased public trust in government decisions [7, 13].

Understanding the public's attitudes and beliefs towards government's public health actions and decisions and how their socio-economic and demographic characteristics interact with these beliefs can help inform future pandemic and health event planning. It can also provide avenues for further communication and targeted interventions in groups that were most dissatisfied with government mandates.

This study aimed to examine the relationship between socio-demographic characteristics and levels of agreement with government public health measures implemented during the Victorian second wave of the COVID-19 pandemic. By identifying population groups with differing perceptions of these public health measures, this analysis aims to inform future pandemic preparedness, public health communication strategies, and targeted interventions designed to improve community engagement and compliance during future public health emergencies."

Methods

Research design and sampling

This study was my data analysis project and will contribute to a more comprehensive study that aims to understand the Australian adult population's opinions of the Australian Government's public health actions and decisions in response to the COVID-19 pandemic. For my data analysis project, I analysed selected variables from a large survey.

A cross-sectional online, anonymous survey of Australian residents aged ≥ 18 years was conducted between 9th and 25th of January 2023. A global marketing research company, Dynata, recruited participants. During this period, Australia had lifted most restrictions. It had now become completely open to global travel, and vaccination had reached the intended two-dose target in the general Australian population.[14]

Dynata's consumer research panel includes people from 30 different countries, including Australia, with information on both demographic and health attributes being collected[15]. Members undergo a verification process to ensure reliability and accuracy of responses as well as to avoid duplicate participants. These members also undergo quality checks such as ensuring participation limits, screening questions, digital fingerprinting and the detection and removal of participants who provide illogical responses or do not spend enough time on surveys.

People who met the eligibility criteria were identified through Dynata, a global market research company with expertise in medical research in over 30 countries, including Australia. Dynata randomly distributed the survey link to geographically targeted sample populations that met both Dynata's and our own project's eligibility requirements. Eligibility criteria were that they were 18 or over, were currently residents of Australia, gave their permission for their data to be used by 3rd parties and agreed to provide truthful information. Dynata provided a geographically representative sample. The link was distributed through email as well as on their online platform. Once opened participants were directed to the survey page on Qualtrics where a verification of their age and state of residence was conducted, as well as to give their consent[16]

Dynata operates a structured incentive scheme for survey participation, whereby panellists are rewarded upon completion of a survey. The incentive amount is determined by factors including the length and content of the survey, the type of data being collected, the nature of the task, and sample characteristics. Incentives are awarded only once the survey has been completed, and panellists may redeem their rewards from a range of options including gift cards, points programs, charitable contributions, and partner products or services. People aged ≥ 18 years

living in Australia at the time of the survey were eligible to participate in the study. These incentives were provided and administered by Dynata and were not funded by the research project[16].

Data Collection

Participants were asked to respond to a total of 218 questions for the larger BREATHE study. This included 33 questions on demographic characteristics such as age, gender, education or Indigenous status. For the aim of this study, I focused on perceived risks and attitudes in personal prevention of COVID-19 transmission; as such, this analysis focused on a total of 27 questions, 21 related to their opinions on attitudes, abilities and practices in relation to avoiding crowds, social distancing and environmental risk factors. And six demographic questions. These questions were written as multiple-choice questions with the possibility of a written short answer response if the provided answers were not adequate. Attitude questions were then separated into topics such as COVID-19 communication, attitudes and practices in relation to COVID-19, mask wearing and avoiding crowds, social distancing and ventilation. These 21 questions related to their attitudes, abilities and practices in relation to avoiding crowds, social distancing, and environmental risk factors such as ventilation. Participants responded with a binary choice of “Agree” or “Disagree”.

Data Analysis

For my data analysis competency, descriptive and univariate analysis was first conducted on the study participants’ responses to selected questions. This was followed by logistic regression analysis, as described below. The frequencies and proportions of the study participants’ responses were calculated for the categorical variables. Some continuous variables were converted to categorical variables for analysis, including age, which was replaced with age brackets of 18-50, 51-64, and 65+. These categories were chosen to reduce confounding with questions related to education, employment, and health. The 18-50 age group was selected as the reference category for the logistic regression, meaning that comparisons were made between the 51-64 and 65+ groups relative to the youngest age group.

Those who preferred not to disclose their gender or identified as non-binary were removed from the analysis due to low numbers. The category of tertiary education was created by combining all certifications obtained after completion of high school to be classed as a tertiary education. Those who only completed a high school or lower accreditation were classed as not having a tertiary education. If a participant responded with having any chronic disease, they were collated under identifying a chronic disease. Employment was also simplified into

whether a participant received a paid wage of any kind; they were classified as employed. Survey responses were then represented visually using Excel.

All analysis was conducted in R version 4.2.216, using the Tidyverse package for data processing; ggplot was used for visualisation; and the MASS, car, ResourceSelection and caret packages were used for logistic regression, assumption checking and residual analysis [17 - 21]. The association of the categorical demographic variables with the attitudes and beliefs on COVID-19, mask wearing, avoiding crowds, social distancing and ventilation was tested using a chi-squared test. The question of "I am happy with the government's decision to remove (COVID-19) isolation requirements" was chosen for further analysis. This was chosen as it represents the overall public opinion on the government's response to COVID-19. This question encapsulates both the public's opinion on the current progress of the control of the pandemic, as well as an opinion on the severity of the COVID-19 outcomes. Some variables were removed from further chi-square analysis due to the overlap with other questions, causing potential for high confounding. For example, the questions "I open windows to reduce my risk of COVID-19" and "I can open the windows where I live". Variables that returned a p-value of less than 0.3 were included in the multivariable logistic regression as a risk factor/exposure. This was chosen rather than 0.05 to reduce the possibility for relevant variables to not be prematurely excluded from the model due to minimising type 2 errors. It also greatly increases the ability to detect complex relationships that may not have strong associations but could still act as confounders.

Afterwards, it was confirmed that the regression model fit all required assumptions of a logistic regression, such as no collinearity being observed, and all variables contained a variance inflation factor (GVIF) of close to 1, as well as no continuous predictors being included,. All predictors had the necessary large sample size. Then, the logistic regression was conducted with a backwards stepwise elimination method with McFadden's r2 and the Hosmer-Lemeshow test for determining goodness of fit. A determination of the residual deviance was also conducted using a Cook's distance calculation. Those residuals that were over a factor of four of the Cook's distance caused a failure of the Hosmer-Lemeshow test. An investigation of the residuals to determine if any pattern of significant outliers was discovered revealed a pattern of contradictory opinions being given. Most commonly, 82 participants agreed with the statement "I am happy to be in public spaces among people who are infectious with COVID-19" while also disagreeing with the statement "I am happy with the government's decision to remove isolation requirements". Effectively stating that they were happy for COVID-19 in the community but disagreed with the government allowing those with COVID-19 to be in the community. These responses, as well as the other 38 responses, were then removed from the dataset, and the methodology reapplied with the now updated dataset. This led to low numbers

for the cells of the statement “I am happy to be in public spaces among people who are infectious with COVID-19”. As such, the question was removed for later logistic regression.

Statistical significance for adjusted ORs in the multivariable logistic regression was determined to be a p-value of less than 0.05 and where the 95% confidence interval (CI) did not contain 1.

Ethical Considerations

The study was approved by the UNSW Human Research Ethics Committee. The survey was anonymous, and data were stored in secure, password-protected computers at UNSW. Ethics approval was also gained through ANU, H/2024/1190.

Results

The survey was completed by 2616 eligible participants. Approximately 58% of respondents were female, 53% were aged between 18 and 50, and 70% had a tertiary education. Only 5% of respondents identified as an Aboriginal or Torres Strait Islander. There were 59% of participants who reported having a chronic disease, and 60% were employed.

Table 1: Sociodemographic characteristics of study participants

Characteristics		Number	Percentage
Gender	Female	1492	58%
	Male	1093	42%
Age Group	18-50	1391	53%
	51-64	646	25%
	65+	577	22%
Education	Tertiary Accreditation	1827	70%
	No Tertiary Accreditation	789	30%
Indigenous Status	Identifies as Aboriginal or Torres Strait Islander	131	5%
	Does not identify as Aboriginal or Torres strait islander	2476	95%
Chronic Disease	Identifies as having a chronic disease	1534	59%
	Does not identify as having a chronic disease.	1082	41%
Employment	Employed	1577	60%
	Not Employed	1039	40%

Figure 1 shows the range of responses to the selected 21 questions. A majority of Australian adults (59%) disagreed with the government’s decision to remove mandatory isolation for those with COVID-19, with 41% agreeing. The least utilised mitigation measures were FAR-UVC, CO2 monitoring and HEPA filters. 21% of respondents reported working from home as much as possible to reduce their risk of COVID-19. This showed a low overall response rate compared to other responses. (Figure 1).

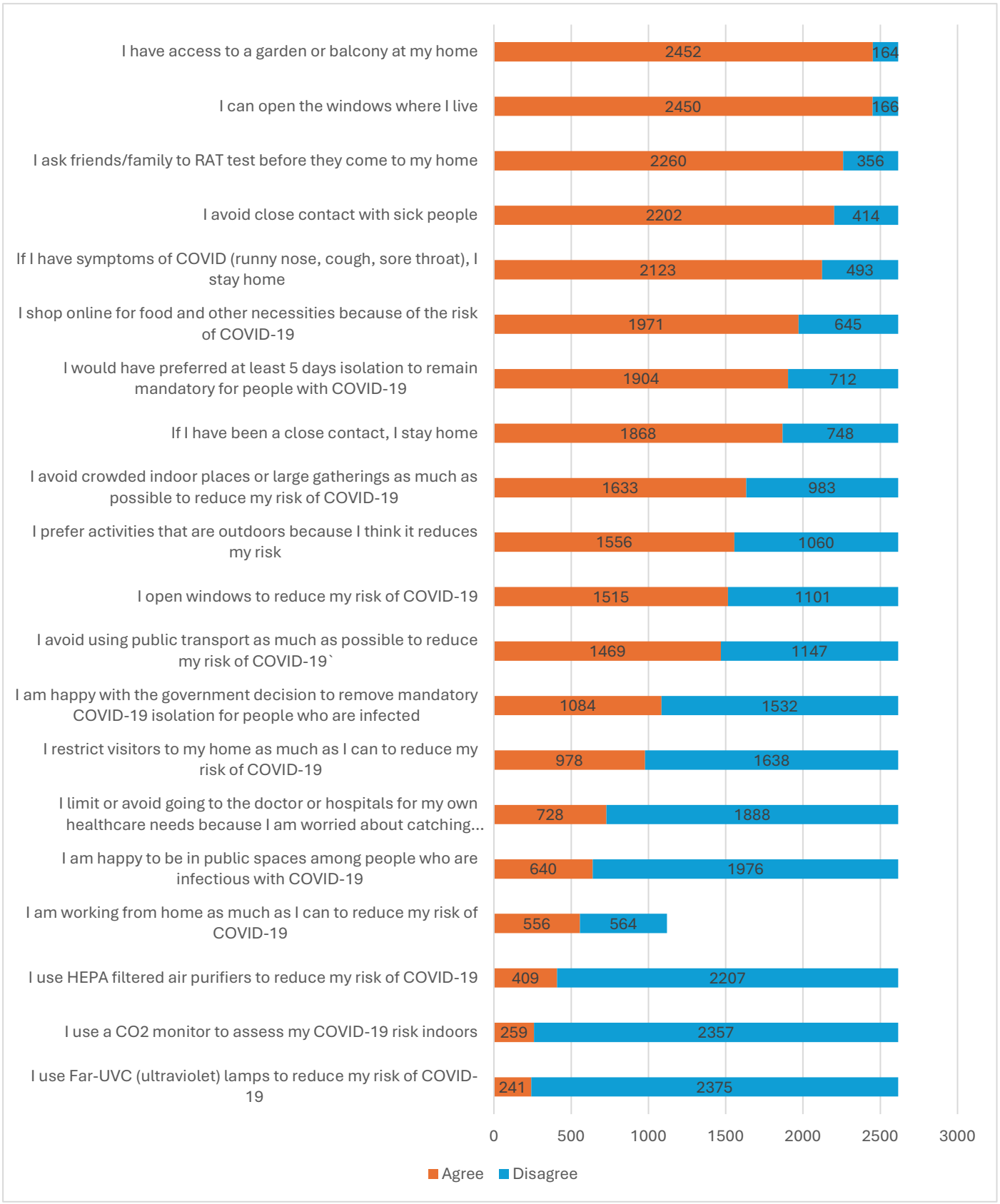

Figure 1: Frequency of respondents agreeing and disagreeing to questions on attitudes, abilities and practices in relation to avoiding crowds, social distancing and environmental risk factors.

Age, gender, chronic disease, Indigenous status and a range of attitudes were significant in predicting views about the removal of COVID-19 isolation. A higher percentage of female participants (61.3%) compared with males (51.1%) disagreed with the removal of isolation requirements. The highest percentage of disagreement was observed among those aged 65 and older (65.2%). Those who did not identify as indigenous and those who had a chronic disease disagreed more with the removal of isolation requirements than those who were Indigenous or did not have a chronic disease. (Table 2)

Table 2: Chi-square analysis of demographic and personal behaviours and agreeing or disagreeing with the statement "I am happy with the government's decision to remove isolation requirements"

		"I am happy with the government's decision to remove isolation requirements"		p-value
		Agree	Disagree	
Gender	Female	552 (38.7%)	876 (61.3%)	<0.001
	Male	507 (48.9%)	530 (51.1%)	
Age Group	18-50	641 (49.8%)	647 (50.2%)	<0.001
	51-64	225 (36.2%)	397 (63.8%)	
	65+	193 (34.8%)	362 (65.2%)	
Education	Tertiary Accreditation	324 (41.6%)	454 (65.2%)	0.918
	No Tertiary Accreditation	751 (41.6%)	1056 (58.4%)	
Indigenous Status	Identifies as Aboriginal or Torres Strait Islander	66 (52.8%)	59 (47.2%)	0.012
	Does not identify as Aboriginal or Torres strait islander	1009 (41.0%)	1451 (59.0%)	
Chronic Disease	Identify as having a chronic disease	560 (38.3%)	903 (61.7%)	<0.001
	Does not identify as having chronic disease.	499 (49.8%)	503 (50.2%)	
Employment	Employed	696 (7.3%)	8775 (92.7%)	<0.001
	Unemployed	363 (36.5%)	631 (63.5%)	
"I can open windows where I live"	Agree	573 (40.0%)	860 (60.0%)	<0.001
	Disagree	486 (47.1%)	546 (52.9%)	
"I use a CO2 monitor to assess my COVID-19 risk"	Agree	182 (86.7%)	28 (13.3%)	<0.001
	Disagree	877 (38.9%)	1378 (61.1%)	
"I avoid crowded indoor places or large gatherings as much as possible to reduce my risk of COVID-19"	Agree	528 (33.8%)	1033 (66.2%)	<0.001
	Disagree	531 (58.7%)	373 (41.3%)	
"I restrict visitors to my home as much as I can to reduce my risk of COVID-19"	Agree	357 (38.6%)	568 (61.4%)	<0.001
	Disagree	702 (45.6%)	838 (54.4%)	
"I am happy to be in public spaces among people who are infectious with COVID-19"	Agree	535 (99.8%)	1 (0.02%)	<0.001
	Disagree	524 (27.2%)	1405 (72.8%)	
	Agree	560 (37.7%)	927 (61.6%)	<0.001

“I prefer activities that are outdoors because I think it reduces my risk”	Disagree	499 (51.0%)	479 (49.0%)	
“If I have been a close contact, I stay home”	Agree	678 (38.4%)	1089 (61.6%)	<0.001
	Disagree	381 (54.6%)	317 (45.4%)	

All variables except for education were included in the logistic regression. The logistic regression model results are shown in Table 3. Of the 2465 total participants, 120 were removed as outliers, accounting for 4.6% of the total participant population. The 120 removed 120 were investigated for potential commonalities and were found to give contradictory answers and were removed. The low cell count in the question “I am happy to be in public spaces among people who are infectious with COVID-19” led to its removal from the model as well. Based on the Mcfaddens R2 of best fit, the model explains 38.9% of the variation in the data. A non-significant Hosmer-Lemeshow goodness of fit result of 0.440 indicates that there is no significant difference in the observed frequencies of the outcome to the frequencies predicted.

The odds of disagreement with the statement of “I am happy with the government’s decision to remove isolation requirements” among males were 0.41 times less than those among females (aOR: 0.59, 95% CI:0.47-0.74). Those aged 51-64 had 51% (aOR: 1.51, 95% CI:1.16-1.99) higher odds of disagreeing with the same statement than those aged 18-50 years. While those aged 65+ had no statistically significant difference compared to those aged 18-50. Those who did not report a chronic disease had 27% lower odds (aOR: 0.73, 95% CI: 0.59 –0.91) of disagreeing with the government decision compared to those who did. Those who did not use a CO2 monitor to assess their COVID-19 risk had 3.94 higher odds of disagreeing (aOR:3.94, 95% CI : 2.36 – 6.63) compared to those who did use a CO2 monitor. Those who disagreed with avoiding indoor places or large gatherings had 0.45 lower odds to disagree (aOR: 0.45, 95% CI:0.36-0.55) with the government decisions compared to those who did agree to try and avoid crowds.

Table 3: Binomial logistic regression model of predictors of disagreeing with the statement "I am happy with the government's decision to remove isolation requirements"

Characteristic		Unadjusted odds ratio (OR)	95% CI	p-value	Adjusted odds ratio (aOR)	95% CI	P Value
Gender	Female	REF	-	-	-	-	-
	Male	0.66	0.56-0.77	<0.001	0.59	0.47-0.74	<0.001
Age Group	18-50	REF	-	-	-	-	-
	51-64	1.75	1.44-2.13	<0.001	1.51	1.16-1.99	<0.001
	65+	1.86	1.51-2.29	<0.001	1.30	0.98-1.74	0.08
Chronic Disease	Identify as having a chronic disease	REF	-	-	-	-	-
	Does not identify as having chronic disease.	0.63	0.53-0.75	<0.001	0.73	0.59-0.91	0.01
"I use a CO2 monitor to assess my COVID-19 risk"	Agree	REF	-	-	-	-	-
	Disagree	10.21	6.92-15.65	<0.001	3.94	2.36 – 6.63	<0.001
"I avoid crowded indoor places or large gatherings as much as possible to reduce my risk of COVID-19"	Agree	REF	-	-	-	-	-
	Disagree	0.36	0.30-0.42	<0.001	0.45	0.36-0.55	<0.001

Discussion

This data analysis project enabled me to conduct univariate and multivariate logistic regression analysis on survey data, as well as use different data visualisation methods. The findings will contribute to a broader study. I gained experience in cleaning, preparing, and analysing a dataset for research. My findings confirm that those who favoured more risk-reducing strategies had higher disapproval of efforts to remove isolation requirements. In this study, it was determined that while Australians were aware of and availed themselves of many non-pharmaceutical measures to mitigate COVID-19 in early 2023, most adult Australians disagreed with the government's response to remove isolation requirements for those infected with COVID-19. Specific population demographics and behaviours affected this opinion, such as women being more likely to disagree than men and Australians aged between 51 and 64 being more likely to disagree compared to the younger populations. Finally, those with chronic diseases were more likely to disagree with the government's decision to remove isolation requirements than those who didn't have a chronic disease.

Those with a chronic disease were more likely to disagree with the removal of isolation requirements than those without. This is consistent with findings from other studies, which have identified chronic disease as a factor associated with greater caution towards public health policy relaxation, likely reflecting the objectively greater clinical vulnerability of this group to severe COVID-19 outcomes. Chronic disease sufferers belong to one of the major demographics that have had a historical connection to favouring more risk-reducing strategies . This has been due to the very real possibility of poor outcomes when infected with COVID-19[22, 23]. Although this study does not explore additional causes, other studies have suggested that increased health literacy among those with high potential risk and poorer outcomes may be a potential cause for this difference [22, 23]. Those with a greater understanding of the potential negative outcomes when infected may be less inclined to increase their potential exposure risk. This would be consistent with the 27% higher likelihood of disagreement observed among those with a chronic disease compared to those without.

Gender has also been found to be a major demographic with historical differences in perceived risk [24, 25]. As such, it has also been found to be a characteristic associated with a difference in disagreeing with the government's removal of isolation requirements, with men being 41% more likely to agree with the government's decisions than women. There are multiple causes for this change; however, one phenomenon that has been well documented on this subject has been that women are consistently determined to have a higher likelihood of having a greater self-perceived concern for their health and that of those around them. Men were, in contrast, more likely to partake in risk-taking behaviour. This has been documented in both domestic

studies within Australia, but also in Europe and North America [22, 24, 25, 26]. This suggests that the gender difference is caused by issues that are not only specific to Australia and are independent of a government's individual public health actions. The gender difference may instead be driven by a complex combination of demographic and personal experiences that are specific to each gender.

Those within the age range of 51-64 were less likely to agree with the isolation removal than those aged 18-50. Historically, those who are younger are more likely to be unsure of health responses and have higher risky behaviours. At the same time, those who are older are more likely to be negatively affected by disease than younger populations[22]. In other studies, higher ages were associated with an increased risk aversion [23, 27]. This would usually show a decrease in agreement with isolation removal in older age brackets compared to the youngest age brackets. However, those aged 65 and older showed no statistically significant difference compared to those under 50, which was an unexpected finding. One possible explanation is that those aged 65 and older may have been more accepting of the removal of isolation requirements due to higher rates of vaccination and booster uptake in this age group at the time of the survey, potentially reducing their perceived personal risk. Alternatively, factors such as increased social isolation and the psychological burden of prolonged restrictions may have contributed to a greater willingness among the oldest age group to accept the relaxation of mandates.

Only two behavioural questions were found to significantly affect the likelihood of disagreeing with the government response. Those who stated they agreed to avoid crowds to reduce their risk were more likely to disagree with the government's response to remove isolation requirements. This reasoning can be explained through the increased perceived risk of additional COVID-19 infected persons being present post removal of isolation requirements. Those already avoiding crowds due to the perceived risk would be unlikely to agree to increasing this perceived potential risk.

Those that used a CO2 monitoring device to reduce their risk were found to have a statistically significant difference compared to those that did not. CO2 monitoring device to reduce their risk were found to have a statistically significant difference compared to those who did not use a CO2 device. Those that used a monitor were four times more likely to agree with the removal of isolation requirements than those that did not use one. The potential cause of this is unknown, however other unmeasured factors may be leading to this increase. By controlling for age, gender, and chronic disease, the disagreement decreased substantially. Potential explanations could be due to increased knowledge of COVID-19 leading to a higher

understanding of the removal of government required isolation, however more exploration of other behaviours is required to determine this effectively.

From this study, demographic and behavioural characteristics were found to be more strongly associated with disagreement with the government's decision to remove isolation requirements than factors such as education, Indigenous status, or employment. The cause for these associations is likely due to specific chronic diseases, the method of information consumption leading to potential misinformation, or past lived experiences when being exposed to government authorities. Determining the cause for these associations and then tailoring specific messaging and information to address the underlying concerns may lead to their alleviation, reducing disagreement and increasing approval of government action. From this study, one of the main factors determined someone's likelihood to agree with the government's decision to remove isolation requirements was favouring risk-reducing strategies . This is more relevant than any specific demographic response such as education, Indigenous status or employment. The cause for these perceived risks is highly individualistic; however, it may be due to specific chronic diseases, the method of information consumption leading to potential misinformation or past lived experiences when being exposed to government authorities [23, 26, 28].

Determining the cause for these increased perceived risks and then tailoring specific messaging and information to address the underlying concerns may lead to their alleviation. Reducing perceived risk and increasing approval of government action [25, 26, 28, 29, 30, 31]. A government's response to a public health event is multifaceted and requires consultation from multiple stakeholders and the weighing of risks for various populations [7]. This will always lead to both those who will be happy with the decision and those who will not be. However, continual disaffection with a government's response may lead to a reduction in trust in government expertise over time and may lead to an increase in misinformation or disinformation and to lower adherence to future actions [13]. In times where rapid action is required, trust and agreement with government decisions are highly important[7, 13]. Designing communication and policies that will engage with those who disagree with government responses is highly critical to ensure long-term engagement and adherence to health recommendations. By focusing on communicating with those who have a higher perceived risk, acknowledging their concerns, and providing targeted explanations for the removal of isolation requirements rather than keeping explanations broad, may increase the likelihood of agreeing with the government's decision. Investigating further causes for this perceived risk is a potential avenue of further research to determine specific methods of communication.

Strengths and Limitations

This investigation adds to the important literature to understand the Australian adult population's behaviours and beliefs related to COVID-19 public health measures. The questionnaire was created with professional input from a third-party data gathering agency. However, the questionnaire was only presented in English, which creates a barrier to communication. As such, households that spoke no or limited English were under-represented within the study. The study was also given to those already associated and who volunteered to receive surveys from the 3rd-party agency and was entirely online. This also leads to a limitation of participants who do not use digital services, or do not engage with surveys. These factors may have introduced selection bias and could reduce representativeness of the general population.

The survey also relied entirely on self-reported data, which introduces the possibility of social desirability bias, whereby respondents may have reported behaviours or opinions that they perceived to be more socially acceptable rather than reflecting their true views. This is particularly relevant for questions regarding compliance with government health mandates. Additionally, the survey captured responses from a sample that skewed towards older age groups and those with tertiary education, which may limit the generalisability of the findings to the broader Australian adult population. In later studies, potentially specific population-targeted methods should be employed to try and capture a larger portion of those that are under-represented in this data.

A further limitation relates to the design of several survey questions. Some questions measured agreement with the use of specific mitigation measures, such as the statement "I use a CO_2 monitor to assess my COVID-19 risk". Responses to these questions may reflect more than participants' attitudes or behaviours, as disagreement could arise because participants lacked awareness of the technology, did not have access to it, or could not afford it, rather than because they actively chose not to use it. Consequently, these questions may partially capture differences in opportunity, knowledge or resources in addition to individual beliefs and behaviours, and this should be considered when interpreting the findings.

Also, the study was cross-sectional in nature the study does have a limited ability to give a causal relationship in the interpretation of the findings. As the time of collection was close to a year after the removal of isolation restrictions, this may affect people’s current opinions compared to their opinions at the time of the restriction removal. People’s opinions would also be coloured by their geographical location, as the survey was disseminated nationally; those in cities such as Melbourne would have more negative experiences of mandatory isolation than others in areas with fewer isolation requirements. Additional questions may have increased the

predictive capabilities of the regression while also helping to explain associations or identify confounders. Due to time constraints, additional questions could not be analysed; if additional resources were to be given in the future, other questions could be analysed and interpreted.

Conclusion

In this data analysis and interpretation, it was determined that being female, aged 51-64, and having a chronic disease were characteristics most strongly associated with disagreement with the government's decision to remove isolation requirements. These findings highlight the importance of targeted public health communication strategies that engage with those most likely to disengage from government health decisions during future health events.

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Chapter 4: Investigation of epidemic signals of two laboratory incidents in the United States in 2018 and 2019 using open-source intelligence

List of abbreviations

AFP	Acute Flaccid Paralysis
AI	Artificial Intelligence
BSL	Biosafety Level
EEE	Eastern Equine Encephalitis
EV	Enterovirus
LAI	Laboratory Acquired Infections
NIAID	National Institute of Allergy and Infectious Diseases
NLP	Natural Language Processing
US	United States
USAMRIID	United States Army Medical Research Institute of Infectious Diseases
WNV	West Nile Virus

Prologue

Laboratory-acquired infections and accidental releases of infectious agents from high-containment laboratories remain an important, although uncommon, public health concern. Despite stringent biosafety protocols within biosafety level 3 (BSL-3) and biosafety level 4 (BSL-4) laboratories, laboratory incidents continue to occur internationally, most commonly because of human error, equipment failure or deficiencies in biosafety systems. Although many incidents are contained without consequence, accidental releases have the potential to expose laboratory workers, contaminate the surrounding environment, or initiate disease transmission within nearby communities. Consequently, the ability to rapidly identify and investigate any unusual disease activity following a biosafety incident is an important component of public health preparedness and biosecurity.

Traditional indicator-based surveillance systems rely on laboratory-confirmed diagnoses and formal reporting pathways to detect outbreaks. While these systems provide highly specific and validated information, they depend on recognised disease, healthcare presentation, and laboratory confirmation. Event-based surveillance (EBS) systems complement traditional surveillance by monitoring informal sources of information, including media reports and publicly available information, allowing earlier identification of unusual disease events before they are formally recognised. The emergence of artificial intelligence (AI) has further strengthened EBS systems by automating the collection, filtering and classification of large volumes of information, increasing their usefulness as early warning tools during emerging health threats.

The United States Army Medical Research Institute of Infectious Diseases (USAMRIID) at Fort Detrick, Maryland, is one of the world's leading biodefence research facilities and conducts research on numerous high-consequence pathogens. In 2018 and 2019, two separate wastewater containment failures were reported at the facility, resulting in the release of laboratory wastewater into the surrounding environment. Although no evidence has demonstrated that either incident resulted in community transmission of infectious disease, these events generated considerable public interest regarding their potential public health implications. Open-source epidemic intelligence provides an opportunity to retrospectively examine whether unusual disease activity occurred following such incidents and to explore the potential value of AI-supported surveillance systems in investigating biosafety events.

This chapter describes a retrospective analysis of outbreak signals detected by the EPIWATCH® event-based surveillance system before and after the two reported wastewater incidents at USAMRIID. The investigation compared outbreak reports during defined control and incident periods, using descriptive epidemiology and geospatial analysis to identify any

changes in disease activity that may have warranted further public health investigation. Particular attention was given to pathogens reported to have been present within the laboratory, as well as unexplained clinical syndromes that could represent emerging infectious threats.

This chapter demonstrates the application of event-based surveillance and geospatial epidemiology to investigate potential public health consequences following laboratory biosafety incidents. It also explores the strengths and limitations of open-source epidemic intelligence as a complementary surveillance tool for biosecurity investigations. It contributes to the growing evidence supporting the use of artificial intelligence in modern public health surveillance.

This chapter satisfies the requirements for the following competencies of the MAE program:

1- Analyse a public health data set
2- Conduct an epidemiological study
3- Prepare a manuscript for publication
4- Conduct a literature review

My Role

I undertook this project while completing my placement with the University of New South Wales (UNSW) Kirby Institute's Biosecurity Program (BSP), where I had been involved in the routine operational use of the EPIWATCH® event-based surveillance system. Building on this experience, I worked closely with my academic and field supervisors to develop a research question that investigated the potential application of open-source epidemic intelligence in assessing laboratory biosafety incidents. Following discussions with the research team, I designed a retrospective observational study that examined disease signals before and after the reported wastewater incidents at the United States Army Medical Research Institute of Infectious Diseases (USAMRIID).

To undertake the investigation, I first reviewed the available literature surrounding the laboratory incidents to establish the chronology of events and identify the pathogens reportedly being researched at the facility during the relevant period. I then developed a customised EPIWATCH® search strategy targeting these pathogens, together with syndromes of unknown infectious aetiology that may represent emerging diseases. I extracted outbreak signals from the EPIWATCH® database, defined the control and incident periods, and collated the data for descriptive epidemiological analysis.

I independently conducted the statistical summaries and geospatial analyses using RStudio and ArcGIS Pro, producing maps and temporal visualisations to compare disease signals before and after each laboratory incident. I reviewed the identified signals against the published literature and formal surveillance reports to determine whether plausible epidemiological explanations existed for the observed trends. Throughout the project, I regularly consulted with my supervisors and members of the Biosecurity Program to discuss the interpretation of findings and the methodological challenges and limitations of the analysis, ensuring that the conclusions drawn were supported by the available evidence. This project allowed me to integrate epidemiological investigation, event-based surveillance, literature review and geospatial analysis into a single research study. It also strengthened my ability to critically interpret surveillance data, communicate complex findings and contribute to the ongoing development and evaluation of AI-supported surveillance systems within the Biosecurity Program. This then culminated into preparing a manuscript for publication.

Key Reflections

This project provided valuable insight into the strengths and limitations of using event-based surveillance (EBS) to investigate biosecurity incidents where little official information is available. Unlike traditional epidemiological investigations, there was no confirmed outbreak, no case interviews and no access to internal laboratory information. Instead, the investigation relied on analysing patterns of disease signals from open-source intelligence and determining whether any observed changes could reasonably be associated with the reported laboratory incidents. This required me to think critically about the difference between identifying an epidemiological signal and demonstrating causation.

Throughout the project I gained a greater appreciation for the importance of considering alternative explanations for observed disease patterns. Although increases in several diseases and syndromes were detected following the two laboratory incidents, reviewing the literature, seasonal trends and epidemiological characteristics demonstrated that each had plausible explanations unrelated to the wastewater leaks. This reinforced the importance of avoiding confirmation bias and ensuring that investigations remain objective, particularly when examining events that have generated considerable public and media interest.

Public Health Implications

Although this investigation found no evidence that the reported wastewater incidents at USAMRIID resulted in identifiable community outbreaks, it demonstrates the potential value of artificial intelligence-assisted event-based surveillance as an additional tool for investigating laboratory biosafety incidents. Open-source epidemic intelligence can rapidly identify unusual

disease activity and provide independent situational awareness while formal public health investigations are underway, particularly when official information is limited or unavailable.

The methodology described in this chapter also provides a framework for future investigations of laboratory accidents and other biosecurity events. Combining AI-supported surveillance with geospatial analysis allows epidemiologists to rapidly identify areas requiring further investigation and generate hypotheses that can subsequently be explored through formal surveillance systems, laboratory investigations and environmental monitoring. As the number of high-containment laboratories and emerging infectious disease research programs continues to increase globally, complementary surveillance approaches such as these may become increasingly valuable in strengthening biosecurity preparedness.

More broadly, this project highlights the importance of integrating multiple surveillance systems to improve public health preparedness. Event-based surveillance is most effective when used alongside indicator-based surveillance rather than as a replacement. Continued development of artificial intelligence, automation and multilingual data collection has the potential to improve further the timeliness, sensitivity and global reach of these systems. Such improvements would enhance the capacity of public health agencies to detect and assess unusual disease events before they develop into larger public health threats.

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Abstract

Introduction: The United States of America Army Medical Research Institute of Infectious Diseases (USAMRIID) laboratories had environmental leakages from wastewater tanks in June 2018 and July 2019. This study aimed to investigate the effects of these leakages on the incidence of infectious disease outbreaks using an open-source artificial intelligence event-based surveillance system.

Methods: United States of America data of open-source signals were used to detect signals. This included media reports of disease detections by state media, official government announcements of epidemiological events, as well as social media posts associated with diseases and outbreaks. Signals from six months before and after the two laboratory incidents were collected by EPIWATCH®, an open-source artificial intelligence event-based surveillance system. This data was then analysed using geospatial analysis in ArcGIS to determine differences in signal incidence before and after the lab incidents and represented graphically.

Results: After the first incident, there was an increased signal for West Nile Virus in the states of Massachusetts and New Jersey compared to before the laboratory incident. After the second incident, there was an increased signal for Eastern Equine Encephalitis in states surrounding the lab location in the states of Connecticut, Massachusetts, Michigan, and New Hampshire compared to before the laboratory incident. Accounting for expected seasonal incidence and known climate events, no detected signals were feasibly associated with the lab incidents.

Conclusion: We could not find any apparent epidemic signal associated with either lab incident. We demonstrated the utility of open-source epidemic intelligence to monitor epidemics independently of official internal government surveillance systems and to separate and analyse signals of disease at the state level. This showcases that event-based open-source intelligence can enhance and supplement traditional, validated surveillance systems.

Introduction

Laboratory-acquired infections (LAIs) and accidents in laboratories are common, with over 300 such incidents described globally in the past 20 years alone. Despite stringent safety protocols and containment measures at biosafety level 3 (BSL-3) and biosafety level 4 (BSL-4) laboratories, incidents involving the accidental release of these pathogens occur regularly, usually due to human error or inadequate biosafety[1].

The United States Army Medical Research Institute of Infectious Diseases (USAMRIID), located at Fort Detrick in Frederick, Maryland, plays a pivotal role in safeguarding United States national security by conducting cutting-edge research on infectious diseases, biodefense, and emerging pathogens[2]. As a key component of America's biodefense efforts, USAMRIID remains highly classified in both its operations and research. However, investigative journalism uncovered two biosecurity incidents that occurred at the laboratory in 2018 and 2019, both involving the laboratory's wastewater tanks, which were poorly maintained[3,4,5,6,7].

During the period of the lab incidents, it was reported that the lab was working with pathogens *Bacillus anthracis*, Ebola, Eastern Equine Encephalitis virus, Lassa Fever, West Nile, Crimean Congo Haemorrhagic Fever, Nipah virus and other emerging pathogens[3]. The first incident was a pressurised leak of the laboratory's wastewater tanks in May 2018, which led to an estimated amount of 2,000 to 3,000 gallons of bleached wastewater entering the local Carroll Creek by storm drains in the area, with another smaller pressurised leak occurring in June 2019 of approximately 100 gallons of inadequately sterilised wastewater[3,4,7].

Leakage of possible contaminants from a wastewater tank may result in contamination of the soil, the waterways or aerosolisation during the pressurised leak, which may in turn lead to transmission of pathogens to animals and/or humans[3,4].

This study aimed to analyse open-source outbreak data in the United States before and after these incidents to determine if there was an increase in the incidence of signals of diseases that were associated with the infectious agents known to be present within the laboratory at the time of the wastewater leaks.

Methodology

We used EPIWATCH®, an open-source Artificial Intelligence (AI) driven system that generates early warnings for epidemics worldwide. The system collects data using pre-specified search terms in 46 languages for diseases and clinical syndromes from open-source news reports and other sources[8]. The EPIWATCH® system has two AI-sub systems: system one

incorporates contemporary natural language processing (NLP) and named entity recognition algorithms to automatically detect data points within retrieved data and a second AI sub-system where classification and prioritisation are empowered by bidirectional encoder representations derived from transformers[8]. The system automatically removes irrelevant data and creates outbreak reports, which are then verified by a team of trained and experienced epidemiologists that further validate the information. These collated information points of data are then labelled a "signal" of disease. These signals are then uploaded onto an internal database and visualised in the EPIWATCH® dashboard. As such, a signal is used to represent a rise in outbreak reports above the expected baseline of such signals. A report may include multiple cases in a single outbreak[8,9].

We developed a customised search strategy to extract outbreak reports of potential relevance to the Fort Detrick incidents in 2018 and 2019. This included signals associated with the pathogens known to be present at the laboratory or on the National Institute of Allergy and Infectious Diseases (NIAID) Emerging Pathogens list[10].

We defined an incident period and control period for each lab incident to examine the effects of the two incidents. The incident periods were defined as 25/05/2018 to 31/12/2018 for the incident in May 2018 and 01/06/2019 to 31/12/2019 for the incident in June 2019. These periods were selected to allow for epidemic growth for infections with long incubation periods. A control period was defined as six months before each incident, 25/12/ 2017 to 24/05/18 for the first incident and 01/12/2018 to 31/05/2019 for the second one. The system was still in development in 2017, so six months were used to avoid ascertainment bias that may have occurred for longer historical periods.

Due to the high mobility of people in the United States, we included reports in Maryland and the Eastern States closest to USAMRIID, such as Pennsylvania, Virginia and West Virginia, and the wider mainland United States[11]. This widened criterion is because an outbreak or signal associated with the laboratory may not necessarily occur within close geographical proximity to the laboratory and may occur anywhere that a potential case may be able to travel to other parts of the country within the disease's incubation period. EPIWATCH® data for all diseases and syndromes during the relevant periods in the US were analysed using descriptive epidemiology. We looked for the following:

Signals from pathogens that were reported as being present at USAMRIID or on the NIAID Emerging Pathogens List.

Any clinical syndromes consistent with infectious aetiology but of unknown cause. This included pneumonia, severe acute respiratory infection, encephalitis, acute flaccid paralysis, rash with fever, and other syndromes captured by EPIWATCH®.

Any other outbreak signals that increased during the test periods.

Geospatial bivariate analysis was conducted using ArcGIS Pro[12] to determine differences in signal incidence between the time periods. Bivariate analysis is a method to quantify the relationship between two variables. A set of graduated colours for one variable and another set of graduated colours for the other variable can represent each variable's statistics, and the product of the two sets of graduated colours shows the relationship between the two variables. In our case, we selected graduated pink colours to represent signal frequencies in the period of six months before the lab leak, and graduated blue colours to represent signal frequencies in the period of six months after the lab leak. The product of pinks and blues shows the temporal trends of the signal frequencies. The bivariate analysis compares the geographical origin of EPIWATCH® signals during 2018 and 2019, with pink representing high frequencies of signals in six months before the incident and blue representing high frequencies of signals in six months after the incident. States with light blue represent locations that had low signal incidence before the incident and high incidence afterwards, denoting states of highest interest. States with dark blue denote high incidence both before and after the incident. This informed the visual representation that was used to showcase the relationship before and after the laboratory incidents, and then diseases of increased interest were described descriptively using R 4.2.3 and Rstudios.[13]

Ethical Considerations

This study did not require ethical approval due to being created entirely from publicly available sources of data and was created using the private research program EPIWATCH®. No persons were required to be contacted, and no interventions were applied to any persons.

Results

A total of 537 outbreak reports were identified in 2018 and 628 in 2019. In the six months leading to the first laboratory incident on May 25, 2018, a low number of outbreak reports was detected across the continental United States, as seen in Figure 1. After the first incident, there was an increase in West Nile Virus, cyclosporiasis, and adenovirus reports (See Supplementary Table 1). The West Nile Virus signal in August was from New Jersey as well as Philadelphia, reporting 11 cases by August; there were also reports from Massachusetts (38 cases and two deaths), Leon County, Florida (three cases), and Kentucky (one case). Outbreak reports across the mainland of the United States after the first incident can be seen in Figure 2. Figure 3 shows the appearance of West Nile Virus after the 2018 incident. These signals were found in the states of Tennessee, Minnesota, North Carolina, Vermont and New

Hampshire. Figure 4 shows the relationship using a bivariate analysis of outbreak reports between the control and the incident period.

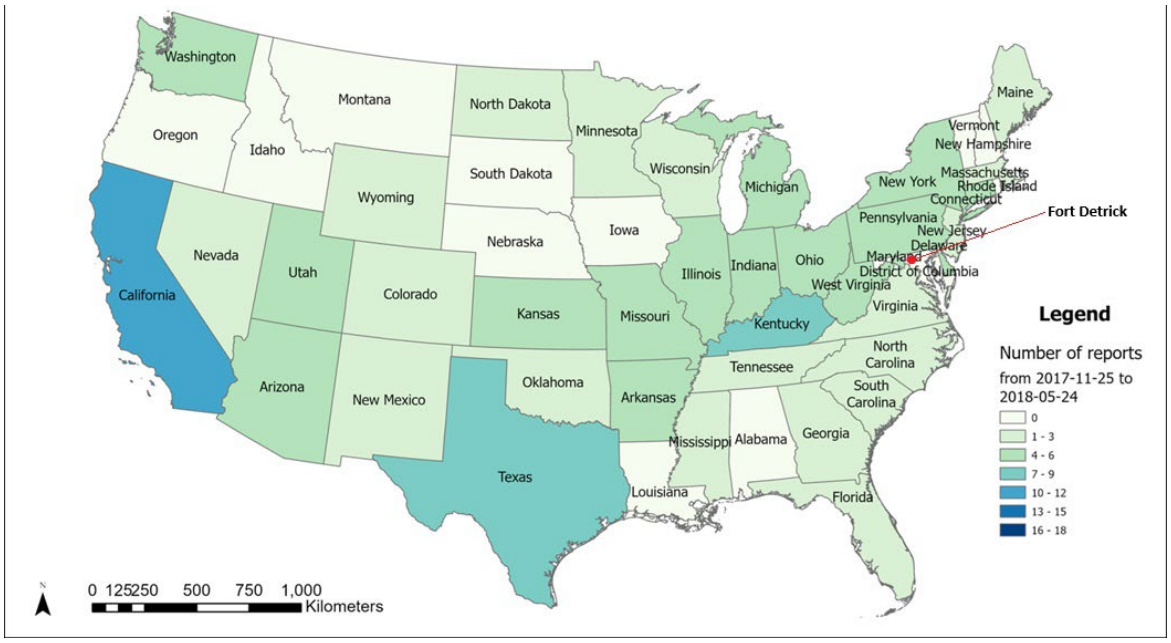

Figure 1: Number of all outbreak reports for the control period of the first lab incident from 25/11/2017 to 24/05/2018 within the Mainland United States.

**Dark blue areas had the highest number of outbreak reports.*

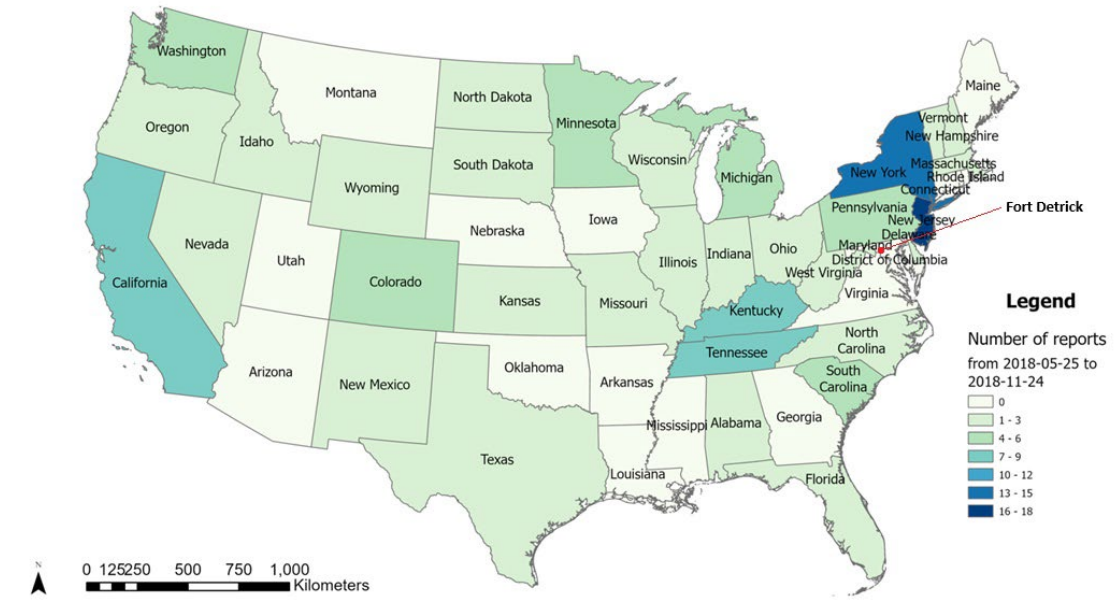

Figure 2: Number of all outbreak reports for the incident period after the first lab incident from 25/05/2018 to 24/11/2018 within the Mainland United States.
**Dark blue areas had the highest number of outbreak reports.*

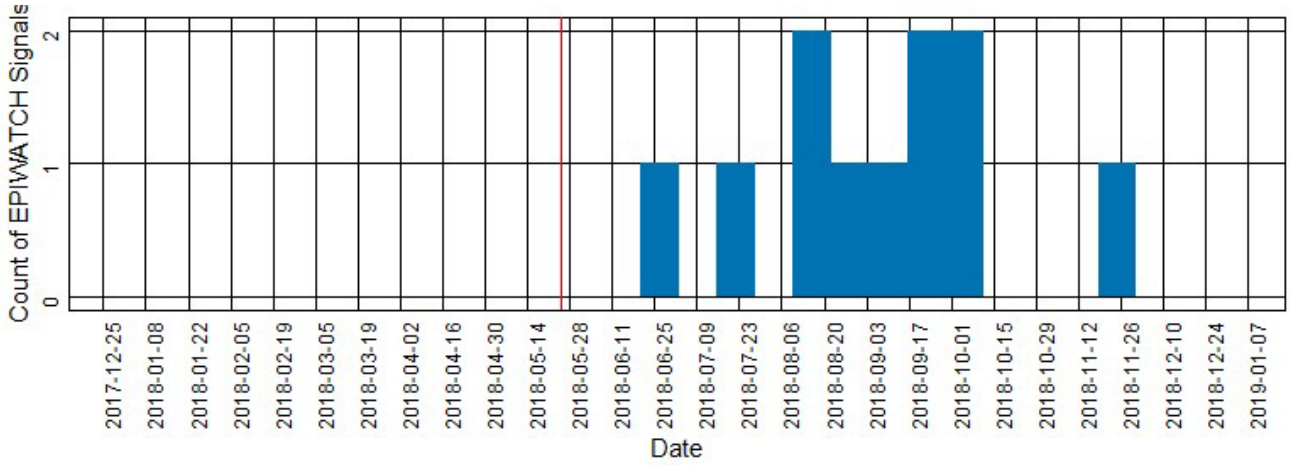

Figure 3. Total count of EPIWATCH® outbreak reports of West Nile Virus before and after the 2018 laboratory incident within the United States from 25/11/2017 to 24/11/2018.

**The red line represents the date of the lab incident.*

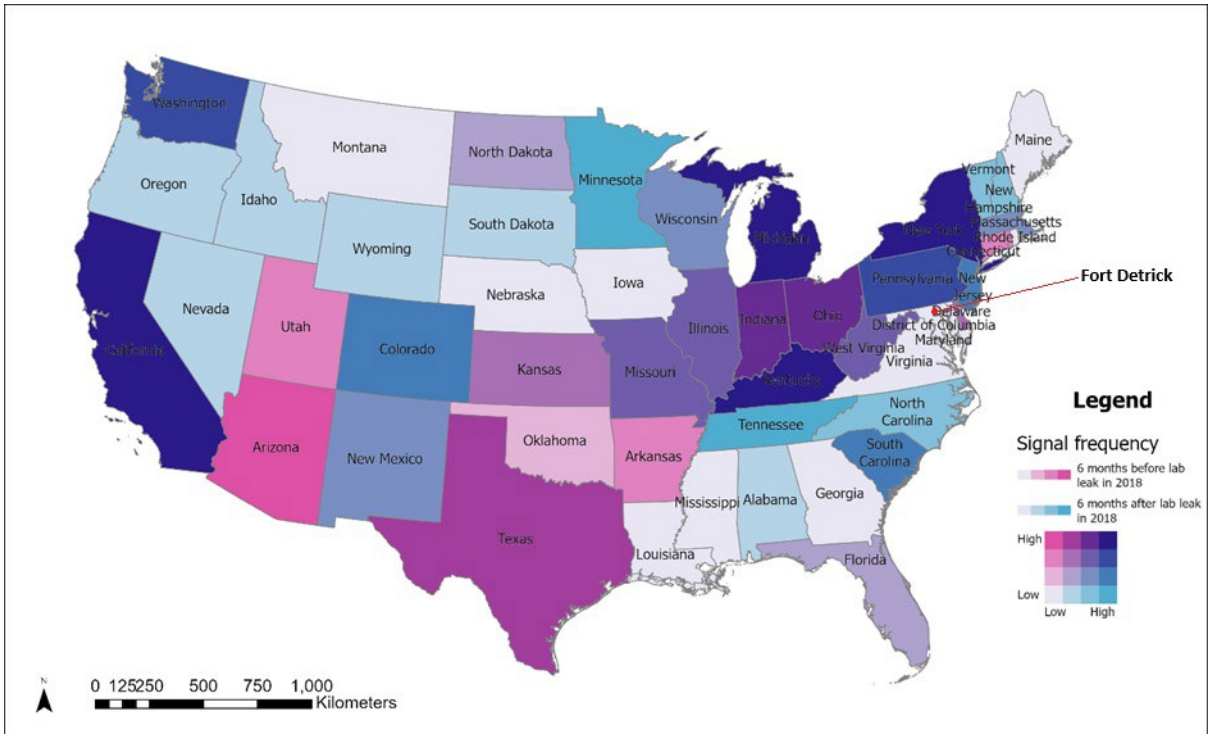

Figure 4. Bivariate analysis comparing the geographical origin of signals from the control period of 25/11/2017 to 24/05/2018 and the incident period of 25/05/2018 to 24/11/2018. **The states with light blue represent states with low signal frequency before the incident and high signal frequency after the incident, whereas pink represents a higher signal prior to the incident. The locations of Tennessee, Minnesota, North Carolina, Vermont and New Hampshire showed the most increase between the control and incident periods.*

Figure 5 shows the outbreak reports in the six months prior to the second laboratory incident on 01 June 2019. Signals were detected in some states, such as California, Washington, New York and Pennsylvania. Figure 6 shows signals six months after the incident in the states of Connecticut, Massachusetts, Michigan, and New Hampshire. These were associated with an

increase in Eastern Equine Encephalitis within the region, as seen in Figure 7. A signal for West Nile Virus was also apparent again, as shown in Figure 8. In the bivariate analysis (Figure 9), there is an increase in signals in Nevada compared to before the incident. Unknown syndromes increased in 2018, mainly attributed to an increase in Acute Flaccid Paralysis (AFP) signals detected from 9/10/2018, with 233 confirmed cases of AFP being detected in 2018 alone in the United States. Bronchiolitis obliterans of unknown cause also increased during the later period of 2019. However, the first reports were not made until 28/09/2018. The signals from Maryland in the post-incident periods included salmonellosis, adenovirus, and rabies. These can be seen in the supplemental materials section.

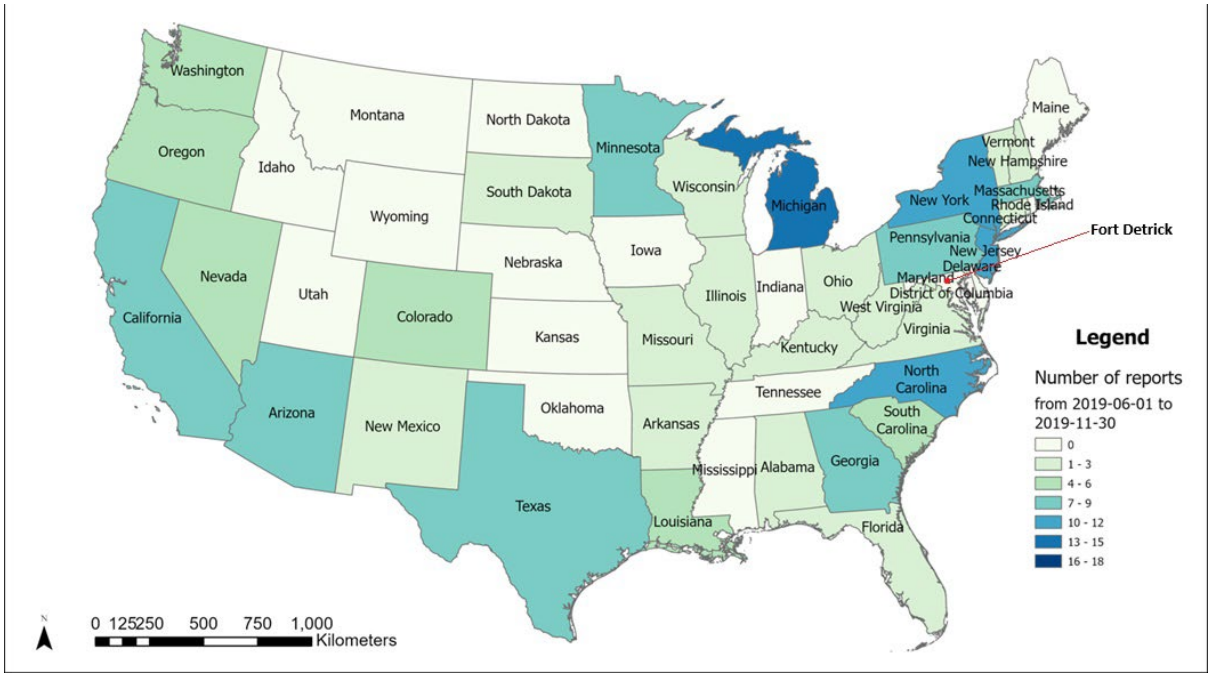

Figure 5: Number of all outbreak reports for the control period of the second lab incident from 01/12/2018 to 01/06/2019 within the Mainland United States

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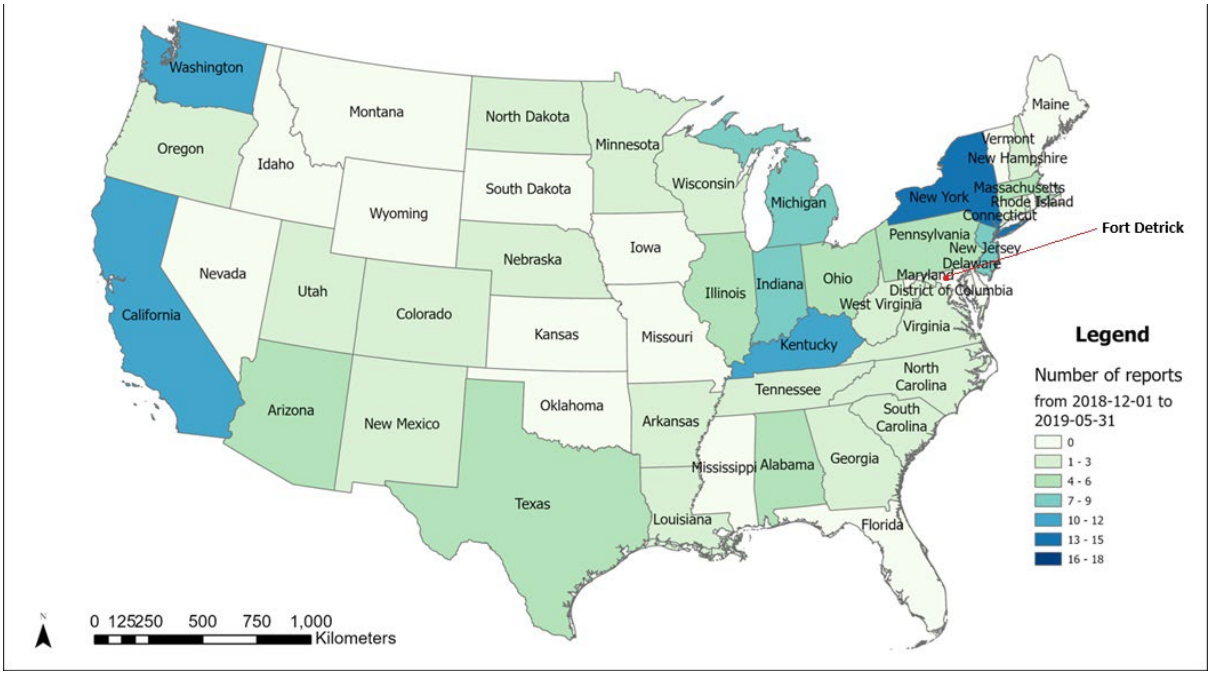

Figure 6: Number of all outbreak reports for the incident period, six months after the second lab incident from 01/06/2019 to 30/11/2019 in the Mainland United States.

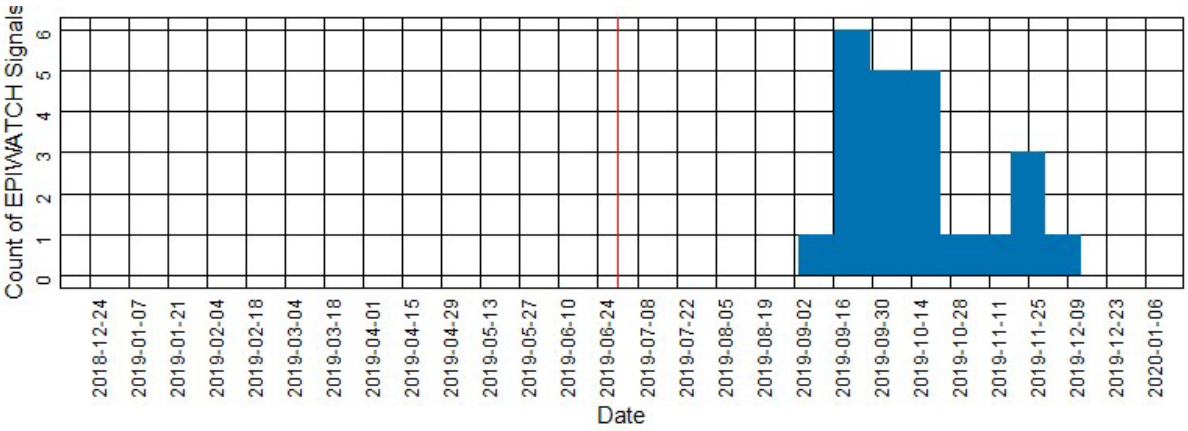

Figure 7: Total count of EPIWATCH® outbreak reports of Eastern Equine Encephalitis before and after the 2019 laboratory incident within the United States from 24/12/2018 to 24/01/2020. **The red line represents the date of the lab incident.*

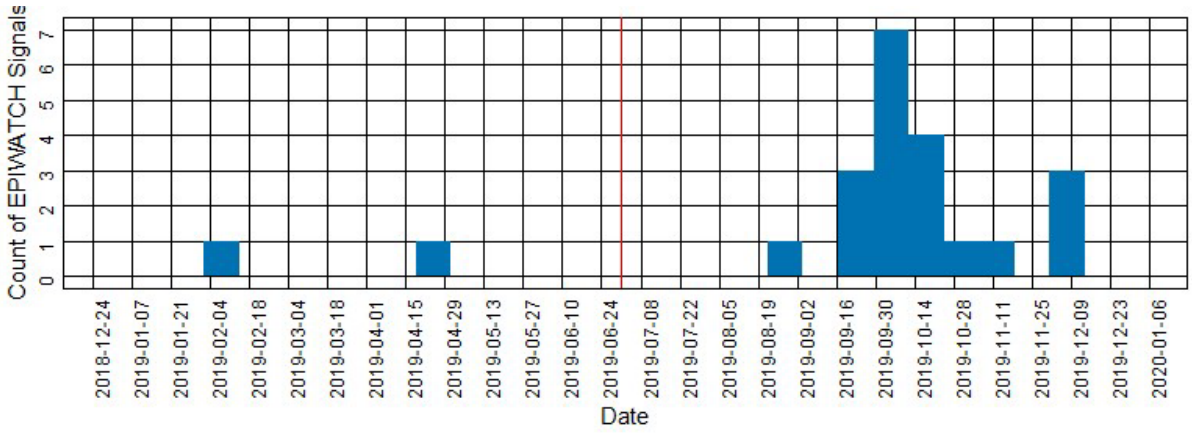

Figure 8: Total count of EPIWATCH® outbreak reports of West Nile Virus before and after the 2019 laboratory incident within the United States from 24/12/2018 to 24/01/2020. **The red line represents the date of the lab incident.*

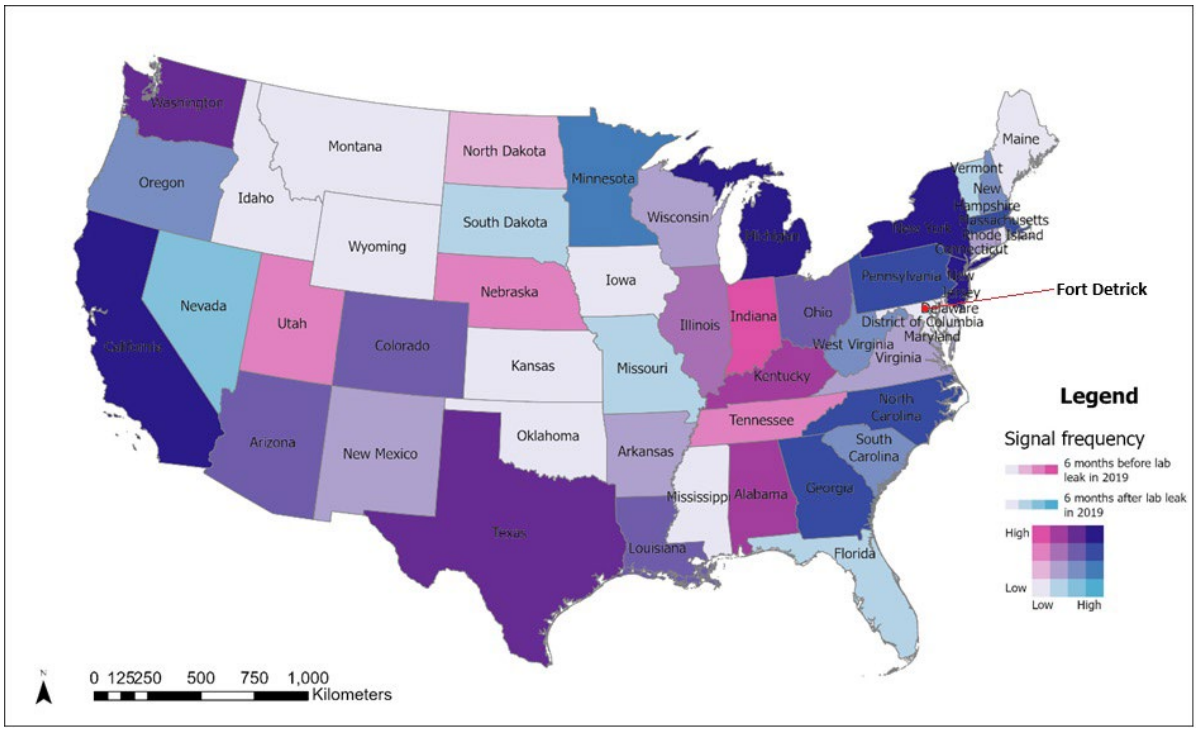

Figure 9: Bivariate analysis comparing the geographical origin of EPIWATCH® signals from the control period of 01/12/2018 to 01/06/2019 and the incident period 01/06/2019 to 30/11/2019

*The *states with light blue represent states with low signal frequency before the incident and high signal frequency after the incident, whereas pink represents a higher signal prior to the incident. The states of Nevada saw the largest increase in signals from the control period to the incident period.*

Discussion

The EPIWATCH® system can detect and investigate epidemic signals retrospectively after biosafety incidents and has the potential for real-time application. However, due to the limitations of such a system, open-source intelligence is not a replacement for formal surveillance but can enhance surveillance by providing rapid and more timely early warnings when used in real time.

After the 2018 incident, we found an increase in West Nile Virus and adenovirus signals. However, these signals could not be reasonably linked to the lab incident. The increase in adenoviruses was beyond a reasonable time frame for possible incubation periods, and cyclosporiasis was not reported to be present at the laboratory[14]. West Nile Virus typically occurs predominantly in Arizona and the central United States, whereas the signals detected following the 2018 incident were concentrated along the east coast[15]. However, east coast transmission of West Nile Virus is not without precedent, and the signal increase is consistent with the seasonal nature of the virus in the United States, which sees a rise in cases during the summer and autumn months coinciding with peak mosquito activity[15]. To more definitively characterise whether the east coast distribution of West Nile Virus signals in 2018 was statistically abnormal relative to historical patterns, a formal comparison against multi-year baseline data would be required. Such an analysis was beyond the scope of this project but represents a valuable avenue for future investigation, particularly given the proximity of some affected states to Fort Detrick and the downstream waterways associated with the leak. An increase in AFP was also detected and may be due to neuroinvasive enteroviruses EV-D68 and EV-A71, which have shown periodic epidemic activity since 2018[18]. However, no known outbreaks were detected using EPIWATCH®. The EPIWATCH® system was able to detect the seasonal trends of West Nile Virus (WNV) and AFP independently from formal surveillance. However, due to the location and seasonal, recurring nature of such outbreaks, they are unlikely linked to the laboratory incident. The most likely explanation for the lack of clear signals is that the lab incident did not result in any epidemics in the community.

After the 2019 incident, increased signals of Eastern Equine Encephalitis(EEE), which was present at USAMRIID, were detected in the following months following the incident[17]. A large epidemic occurred in 2019 along the Northeastern Coast of the United States in Massachusetts, Michigan, and New Hampshire[17]. These states occasionally have EEE, with Massachusetts having the second highest incidence in the nation behind Florida due to its wide range of wetlands providing excellent breeding sites for the host mosquito C*uliseta melanura*[18]. Maine, New Hampshire and Vermont have been more recently affected[19]. However, the EEE outbreak from June 18 to September 20, 2019, was unprecedented, being

the largest epidemic of EEE in 50 years, with a combined count of 34 cases by October 15th[19]. The cause for this epidemic has not been definitively established, but phylogenetic mapping suggests multiple introductions into the Northeastern United States of the host mosquito C*uliseta melanura* in 2019 due to higher-than-average rainfall and warm temperatures in Florida[17,19]. This suggests that the outbreak is not associated with the laboratory incident at Fort Detrick.

Strengths and Limitations

There are several limitations, including a lack of validation of open-source data. However, the value of such data is in identifying trends and deviations from a baseline of signals. It is used as an indicative rather than a definitive approach, which is why EPIWATCH® should be used as one of the many tools in investigating laboratory incidents. Further, the ability of open-source data from EPIWATCH® to provide insights into outbreaks has been shown in another research. Open-source data may not have identified smaller scale disease outbreaks or individual cases.[8,9]

There was no available data from USAMRIID, nor were there any specific pathogens disclosed in the wastewater tanks, making it difficult to ascertain any definitive link. As such, any potential signals that could be detected within a reasonable time and location would require additional investigation through other methods. The lack of a longer control period in 2017 is a limitation, as this limits analysis of seasonal trends. Additionally, we did not analyse signals captured within animal populations, which may be affected by environmental contamination. A further limitation of this analysis is that signal detection was not specifically weighted by geographic proximity to Carroll Creek or the downstream waterways into which the wastewater was reported to have entered. Future analyses could benefit from a more geographically targeted approach, focusing signal detection on communities and regions situated downstream from the leak site, where environmental contamination would be most likely to have occurred. The incorporation of environmental and agricultural surveillance data, such as veterinary disease reports, crop contamination records, and water quality monitoring, alongside open-source human disease signals, could also provide a more comprehensive picture of any potential ecological impact of the incidents. Such a multi-source approach would strengthen the ability to detect or rule out any downstream effects and represents a valuable direction for future investigation.

Conclusions

We demonstrate the utility of an AI-based epidemic observatory, EPIWATCH®, in combination with geo-spatial analysis, to independently evaluate outbreak signals within specific geographic locations after notable biosafety incidents. We detected some signals after each period, including seasonal West Nile Virus and the EEE outbreak in the eastern mainland United States. However, plausible explanations were identified, and none appear to be linked to the laboratory

The signals identified during both incident periods had plausible alternative explanations, and several areas identified throughout this chapter, including downstream geographic analysis and the incorporation of environmental surveillance data, represent important directions for future investigation. Open-source epidemic intelligence demonstrates utility as an adjunct to formal surveillance in the context of biosafety incidents, and its application in this area would benefit from further methodological development.

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Supplemental Materials

Supplemental 1: All signals collected by EPIWATCH® during the investigation period.

Disease signals captured by EPIWATCH®	EPIWATCH® signals captured six months pre 25/05/2018	EPIWATCH® signals captured six months post 25/05/2018	EPIWATCH® signals captured six months pre 01/06/2019	EPIWATCH® signals captured six months post 01/06/2019
Adenovirus	0	16	0	0
Anthrax/unspecified	0	1	0	3
Botulism	4	0	1	5
Brucellosis	0	0	0	1
Campylobacteriosis	1	1	0	3
Candida auris	2	0	0	3
Chikungunya	1	0	0	0
Cryptosporidiosis	1	1	0	4
Cyclosporiasis	0	15	0	1
Dengue	0	0	0	4
e coli	24	15	10	27
Eastern equine encephalitis	1	2	0	23
Ebola haemorrhagic fever	0	1	3	0
Encephalitis	0	0	0	1
Enterovirus d68	0	4	0	0
Hand, foot and mouth disease	0	1	0	4
Hantavirus	2	4	0	2
Heartland virus	0	1	0	0
Hepatitis a	35	37	29	64
Hepatitis b	0	1	0	0
Hepatitis c	2	1	0	0
Histoplasmosis	0	0	0	1
HIV/AIDS	1	1	1	1
Influenza	45	5	5	16
Influenza a/h1n1	0	2	2	0
Influenza a/h3n2	3	0	0	2
Jamestown Canyon virus infection	0	1	0	1
Legionnaires	5	18	5	29
Leptospirosis	0	1	0	0
Listeriosis	0	3	5	8
Lyme disease	1	0	0	1
Malaria	1	1	0	0
Measles	25	25	52	34

Meningococcal	3	0	4	1
MERS	0	0	0	1
Mumps	16	2	20	34
Newcastle disease	1	1	0	0
Norovirus	11	5	6	12
Other	17	24	9	46
Parvovirus	0	0	1	0
Pertussis	2	7	3	27
Plague	2	2	0	1
Pneumococcus pneumonia	0	1	1	0
Pneumonia of unknown origin	0	1	0	2
Powassan virus infection	0	1	0	2
Pseudomonas aeruginosa	0	0	0	1
Psittacosis	0	1	0	0
Rabies	3	2	1	10
Rocky Mountain spotted fever	0	1	0	0
Salmonellosis	29	31	16	35
Scabies	0	1	0	1
Shigellosis	0	1	1	6
Smallpox	1	0	0	2
St. Louis encephalitis	1	2	0	0
Staphylococcus	0	0	1	6
Syphilis	2	0	0	1
Tuberculosis	4	1	0	6
Tularemia	0	4	0	0
Typhoid fever	1	3	3	0
Unknown*	3	12	1	17
Varicella	0	5	0	2
Vibriosis	0	3	0	0
West Nile virus	0	11	2	20
Zika	1	2	1	0

*Unknowns represent a mixture of diseases of suspected origin, such as bronchiolitis obliterans, known as “Popcorn Lung”, syndromic events of acute flaccid paralysis with no known disease, meningitis with no known origin and acute gastroenteritis of unknown origin.

Chapter 5: Public Health Investigation and Response to an Imported Measles Case in Southeast Sydney, 2024

List of Abbreviations

AIR	Australian Immunisation Register
ANU	Australian National University
ELR	Electronic Laboratory Record
IT	Information Technology
LHDs	Local Health Districts
MAE	Master of Applied Epidemiology
NAAT	Nucleic Acid Amplification Test
NIP	National Immunisation Program
NCIMS	Notifiable Conditions Information Management System
NSLHD	Northern Sydney Local Health District
NSW	New South Wales
PCR	Polymerase Chain Reaction
PHU	Public Health Unit
QLD	Queensland
SESLHD	South Eastern Sydney Local Health District
SOPs	Standard Operating Procedures
SoNG	Series of National Guidelines
UNSW	University of New South Wales
WHO	World Health Organization

Prologue

Measles is eliminated in Australia, but occasional travel-imported outbreaks occur. During the COVID-19 pandemic, the severe reduction in international travel to Australia substantially decreased the risk of measles importation. However, after the resumption of travel, imported cases have begun to reappear. Due to the high transmissibility of measles, each individual confirmed case requires a quick and effective response from local public health units (PHUs). This chapter describes a public health response to a measles investigation, including clinical presentation, public health follow-up and laboratory investigations following a highly mobile confirmed case.

This chapter fulfils the following MAE competencies

1. Conduct an outbreak investigation or investigate an acute public health threat
2. Conduct an epidemiological study
3. Analyse a public health data set
4. Conduct a literature review

My Role

While operating at the University of New South Wales (UNSW) Kirby Institute's Biosecurity Program (BSP), I was alerted via the Southeast Sydney Local Public Health Unit (SESPHU) that a case of suspected measles had been detected. I then transferred to the PHU for the length of the health threat. I took a central role in the response, including conducting interviews with the index case and potential contacts, creating a timeline of events, liaising with laboratory staff, creating public health alerts to the public of potential sources of exposure and following up with the index case and contacts. I worked alongside a multi-disciplinary public health team that included four public health nurses, two epidemiologists, as well as advice from both the director of the public health unit and scientific advice from laboratory staff. Together, over the course of the four days, we were able to both collect the needed information smoothly and methodically and effectively contain and respond to prevent a larger health crisis.

Public health implications

The lack of transmission from this investigation demonstrates the strength of herd immunity within the Sydney area, based on the high level of vaccination coverage within the community. It also reflects the effectiveness of the prevention activities implemented during the response, including the rapid post-exposure vaccination campaign, which served to further reduce the pool of susceptible individuals following the exposure events. the effectiveness of the

coordinated response and prevention activities undertaken by SESLHD and its partners. However, the low level of known vaccination history available to public health responders during this investigation created additional workload during a rapidly unfolding event. Requiring potentially exposed individuals to retrieve medical records from home countries, family members, or government agencies was not always viable, with most opting instead to receive an additional MMR vaccine at the health clinic, placing additional demand on clinic staff and the state vaccine stockpile

Key Reflections

The high level of transmissibility of measles requires urgent response and effective management and control. It was during my role in this response that I learned of the need for a highly experienced and open team environment, where members have assigned roles and responsibilities but also the understanding of each other's needs and responsibilities. This allows for fast dissemination of information, before even being prompted, while also providing a calm and professional environment. I also learned of the importance of collectively reviewing case evidence from both cases and potential cases. This allowed for a collaborative approach that uncovered previously undetected exposure events. Through collating the clinical and public health follow-up information, it made me intimately familiar with the national guidelines for the public health management of measles, as well as the routine activities that PHU and state organisations undertake during follow-up. I gained a greater understanding of measles as well as its public health history and current impact by reviewing the literature for measles within Australia, as well as in conversations with epidemiologists, laboratory staff and public health nurses.

Acknowledgements

This public health response to a measles notification would not have been possible without the team at Southeast Sydney Local Public Health Unit, and their director Vicky Sheppeard. Without their guidance and patience during my time with them both during the response, and in previous weeks where I had planted myself with them full time for a week to learn their systems. I would also need to acknowledge my team at the Biosecurity Program who provided guidance in helping me understand the context of measles in Australia while also covering my regular operational responsibilities while I was away enjoying myself with the response.

Abstract

Background: Measles is one of the most infective viruses currently circulating globally. Its high mortality and morbidity in the very young have led to a global elimination campaign that in recent years has begun to decrease in effectiveness. In Australia, measles is an overseas acquired infection due to the lack of local transmission sources. We investigated a measles notification that occurred in an overseas traveller to New South Wales who had travelled to multiple locations within the state and interstate to Queensland. We traced two visits that occurred in a high-risk setting of a general practice and gave vaccinations to those exposed.

Methods: All 49 potential contacts were monitored for symptoms, and a determination of their age, gender, vaccination status and other high-risk characteristics such as pregnancy was conducted. Other exposure sites were contacted to educate and disseminate necessary information on the disease, exposure risk, and vaccination methods.

Results: Only the initial index case was determined to be positive for measles during this investigation. No other measles cases presented themselves within the two-week incubation timeframe within the Sydney area. Of those potential contacts without known vaccination, 19 received the MMR vaccination as prophylaxis.

Conclusion: Immediate response to outbreaks of disease with high infectivity is required to prevent rapid transmission within the community. However, this requires close communication with both the responding public health experts, the local community and those potentially exposed. During this response, although there were initial language difficulties, a rapid response was achieved. These findings reinforce the need for rapid response to infectious disease outbreaks and the role of public health measures such as rapid vaccination campaigns to reduce the risk of further infection.

Introduction

Measles is a highly contagious viral infection that is associated with possible severe outcomes in children.[1] The incubation period of measles is approximately 10 days, with a range of 7 to 18 days, but has been known to have an incubation period up to 23 days.[2, 3, 4] The basic reproductive number (R0) range for measles is 12 to 18 average secondary cases caused by a typical case.[2]

Before 2016, measles incidence had been reducing globally, with a milestone of less than 100,000 measles-related deaths globally for the first time.[5] In the Southeast Asia region, an annual decrease of 92% from 94,598 cases in 2003 to 9,389 cases in 2020 was reported.[6] However, this trend began to reverse in 2019, with the WHO reporting that more measles had been reported globally in 2019 than in any year since 2006.[7] Such examples of this were the United States in 2019 having its largest outbreak since 2000, leading to a near loss of elimination status as over 1200 confirmed cases across 31 states were reported.[8]By the first half of 2019, Europe had reported approximately 90,000 cases, compared to 84,000 cases that were reported in all of 2018.[9]

In 2014, WHO declared measles eliminated in Australia.[7] Achievement of measles elimination is based on three main criteria. These are: firstly, the documented cessation of endemic measles transmission for a period of at least 36 months from the last known endemic case, supported by genotyping evidence; secondly, the achievement and maintenance of at least 95% vaccination coverage with two doses of a measles-containing vaccine across all districts; and thirdly, the presence of a sensitive surveillance system capable of detecting and investigating all suspected measles cases, supported by adequate laboratory capacity for confirmation.[10] This reflects the success of the National Immunisation Program (NIP), where a two-dose measles-containing vaccine is given to children aged 12 or more months. While not funded under the NIP, the Australian Immunisation Handbook recommends that infants aged six months and older travelling to high-risk locations may receive a one-dose measles-containing vaccine prior to travel, though this dose is not counted towards the standard two-dose schedules.[11] However, before the COVID-19 pandemic, Australia had begun to follow the global trend of rapidly increasing incidence, with 286 cases being reported in 2019, a threefold increase compared to 2018.[7] In that year, 47% of cases were in NSW, with 66% of those unvaccinated or had an unknown vaccination history and 11% were inadequately vaccinated.[7] Imported cases made up 58% of the acquired infections in Australia; however, locally acquired transmission was increasing[7].

During the COVID-19 pandemic, a combination of a reduction of international and domestic travel and increased public health measures such as mask wearing, social distancing and

lockdowns led to the incidence of measles reducing dramatically both domestically and overseas.[12] However, it also led to a reduction in vaccination and an increase in anti-vaccine and anti-government sentiment.13, 14 Once countries began to open borders for international travel and reduced their public health measures, measles incidence began to increase rapidly.[1, 15] In February 2024, WHO published a statement that more than half of the globe could expect significant measles outbreaks during 2024.[16] In the United States, nearly one third of measles cases since 2020 were reported in 2024.[17] In the United Kingdom, although regaining their measles elimination status in 2021, there had been 300 confirmed cases since October 2023 alone, leading to the possibility of losing their status once more.[18] Although WHO in April 2023 announced a campaign named the "The Big Catch-Up" to lift vaccination rates to the pre-pandemic period, there were still over 320,000 cases of measles globally in 2023, an 88% increase in cases over 2022.[19, 20]

Australia, although also suffering from a reduction in vaccinations due to interrupted schedules, still meets the targeted 95% vaccination target in children over 60 months, with 96.3% of all children in 2022 being fully vaccinated on the MMR vaccination schedule.[21] Although a dip to 92.7% was seen at 24 months of age. Remote regions such as Northern Queensland and central Australia having coverages in the mid 80%.[21] Australia removed COVID-19-related international travel restrictions from the 21st of February 2022, and since this time has once again begun to have imported measles outbreaks. In 2022, six of the seven measles outbreaks in Australia occurred within Victoria and were all from return travellers from other countries, with no secondary transmissions occurring within Australia[15].

On the 12th of February 2024, South East Sydney Local Health District was notified of a suspected measles case in a young female. The suspected case had been notified to the unit by the case's general practitioner (GP) after presenting with fever, rash and prodrome. This prompted an immediate public health response from SESLHD. On the 13th of February, a urinary analysis testing confirmed a measles diagnosis through PCR. This chapter presents the acute public health threat investigation that occurred and the public health actions that were implemented.

Literature Review

A focused review of the published literature on measles outbreaks in Australia was conducted in preparation for this study on the search database PubMed. Search terms were created by including keywords that were separated by OR and AND statements to capture initial publications. A full search history and methodology can be found in Supplemental 2.

The initial search yielded 317 records after filters for English language, human studies, and publications between 2014 and 2024 were applied. Given the volume of results, further refinement of the included literature was necessary. Title and abstract screening was conducted to assess relevance to the specific focus of this review, which centred on measles epidemiology, transmission, and public health response within the Australian context. Studies were excluded at this stage if they did not specifically address measles within Australia, focused solely on clinical management without a public health component, or were case reports or series that did not contribute to broader epidemiological trends as outlined in the exclusion criteria. Following this screening process, a final set of peer-reviewed publications was selected for inclusion. Where peer-reviewed publications were unavailable for specific data points, such as national surveillance figures and immunisation coverage statistics, grey literature including government reports and WHO publications were incorporated to ensure the review remained current and contextually relevant. It is acknowledged that the relatively high proportion of grey literature in the final reference list reflects the nature of public health surveillance data, which is more commonly reported through official channels than peer-reviewed journals

Studies conducted in the last 10 years have shown a significant public health concern with increasing cases from overseas arrivals as well as increasing vaccination hesitancy despite the elimination status of measles within Australia. Imported cases from overseas continue to spark outbreaks, predominantly affecting younger adults, the under-vaccinated population, and individuals with unknown immunisation histories. Studies have shown that Australia has experienced a recurring outbreak linked to international travel.[22, 23, 24, 25, 26, 27] Between 2009 and 2023, an average of 167 cases per year were reported. [22]This is an increase from the previous five-year period of 51 cases per year.[28] In Victoria, 75% of all outbreaks were associated with overseas travel. [29]The largest outbreak, occurring in 2012 in New South Wales, resulting in 168 infections, was caused by an imported case from Thailand. [30]

Risk factors associated with measles infection were identified. Young adults were found to exhibit lower seropositivity due to gaps in vaccine coverage, with Victoria having 84.2% in 2020.[27] Whereas the very young, especially those in under-vaccinated regions, have been shown to transmit the disease at higher rates.[28] Travellers who were found to be visiting friends or family were at a higher risk of exposure in endemic regions and were less likely to seek pre-travel vaccinations.[27] Migrant populations, specifically Australian-born individuals with migrant parents, were more likely to face immunisation barriers due to healthcare access, as well as record-keeping issues. [27]

Delayed measles diagnosis was also found to be a significant challenge in measles elimination[31]. Infections in healthcare settings caused up to 50% of cases in developed countries[32]. Modified measles, a milder presentation of wild measles that has been seen to occur in vaccinated individuals, has caused complications in clinical recognition, causing delay in diagnosis and contact tracing[31]. Although Polymerase chain reaction (PCR) cycle threshold values do offer a method to gain additional insights, the test relies on sample timing and quality of collection. [31]

Although Australia maintains high immunisation rates overall, several gaps identified in the literature have direct implications for measles elimination. These include declining seropositivity among young adults, barriers to immunisation among migrant and overseas-born populations, delays in diagnosis associated with modified measles presentations in vaccinated individuals, sub-optimal coverage in specific jurisdictions such as New South Wales, and incomplete capture of adult vaccination histories within the Australian Immunisation Register[22, 24, 27, 31]. Together, these gaps highlight the continued vulnerability of the Australian population to measles importation and local transmission, and provide important context for the public health investigation described in this chapter. The findings of this literature were used to inform the context of this report for both international trends before and after COVID-19 as well as Australian-specific trends.

Methods

This public health response to an acute public health threat documents the response and prevention activities undertaken following the identification of a widely travelled confirmed measles case. In this report we describe the investigation, the epidemiological characteristics of the case, the response activities undertaken by SESLHD including case and contact management and exposure site notification, and the prevention activities implemented to reduce the risk of further transmission, including post-exposure vaccination. A review of the Australian measles literature contextualising the investigation is also provided.

Case and contact definitions

Three classifications were used for this investigation to describe cases as defined in the Series of National Guidelines (SoNG) guidelines. A probable case requires laboratory suggestive evidence such as the detection of measles specific IgM antibodies, except if the case has a measles containing vaccine eight days to eight weeks before laboratory test as well as the clinical evidence of a generalised maculopapular rash lasting three or more days, a fever of at least 38 degrees Celsius at the time of rash onset and a combination of either a cough, coryza, conjunctivitis, Koplik spots.[3]

A confirmed case is confirmed by laboratory definitive evidence such as the isolation of a measles virus, the detection of measles virus via nucleic acid test, the detection of the measles virus antigen or a fourfold increase in titer of measles virus in IgG, except when receiving a measles-containing vaccine eight days to eight weeks prior to specimen collection. [3]

An epidemiologically linked case is established as per the NSW Measles control guidelines. This requires contact between two people through a plausible mode of transmission during the infectious period, defined as 24 hours before prodromal symptom onset or four days before to four days after rash onset. The subsequent suspected case must develop illness within seven to 18 days of contact, and at least one case in the chain must have laboratory-confirmed measles.[3] During this investigation, laboratory testing was conducted on all suspected measles cases and consisted of a first-catch urine collection, throat swab and a blood collection for blood nucleic acid amplification test (NAAT) and serology.

A potential contact was defined as a person who was either a household contact of the index case or spent significant time in proximity during the period from 6th of February 2024 to 14th of February 2024. Those who attended the GP clinic, work colleagues or were in proximity to the index case were classified as potential contacts. All potential contacts were interviewed to determine their potential exposure, their vaccination status, and any possible symptomology.

A vaccination window was determined to be up to 72 hours post-exposure event. This is due to one dose of MMR vaccination having a 93% effectiveness post-exposure in preventing measles infection if given within this period[3,11].

Study design and data collection

A public health investigation was conducted to identify and follow up all potential contacts of the confirmed index case. The investigation comprised two main components: a cohort study of contacts at the two GP clinic visits, one of which included a pathology visitation, and broader contact tracing of known close contacts.

Exposure and outcome definitions for the GP clinic cohort were as follows. Exposure was defined as being present within the waiting room, pathology collection clinic, or the GP's private room for any length of time while the index case was present, or within 45 minutes of the index case having left, to account for potential airborne transmission. Outcome was defined as laboratory confirmation of measles.

Contact tracing was conducted for all known contacts of the index case, including close contacts who had travelled with the index case to Queensland, work colleagues at the massage clinic, and all attendees at the two GP clinic visits during the exposure windows of 12 and 13 February 2024. All identified potential contacts were followed up with daily phone

calls until completion of the maximum incubation period of 18 days or confirmation of MMR vaccination. During follow-up, contacts were assessed for immunocompromised status or pregnancy, in which case alternative methods of prophylaxis were considered.

Data were collected using a standardised questionnaire adapted from the NSW Health measles questionnaire for this specific investigation. The questionnaire was designed to be completed in under 10 minutes and captured key information on demographic characteristics, exposure risk factors, vaccination status, and travel history. It was administered by telephone by SESLHD staff, with responses recorded in a secure online Excel document hosted on the NSW Health Teams network. All persons interviewed provided verbal consent prior to participation, or consent was obtained from a parent or guardian for those under 18 years of age. Data were collated and managed using Microsoft Excel and Microsoft Word.

Ethical Considerations:

The Ethical aspects of this project were covered by the Australian National University Human Research Ethics Committee (Protocol 2023/909) standing approval for outbreak investigations for the Master of Philosophy in Applied Epidemiology program.

Results

The index case and movement history

Only one confirmed measles case was determined from this investigation, a young adult unvaccinated female born overseas in Southeast Asia. The laboratory diagnosis was confirmed on the 13th of February 2024 from urine NAAT 24 hours after initial collection, this delay in confirmation was due to the sample becoming lost within the laboratory.

Arriving from Southeast Asia two weeks prior to being detected, the index case showed no symptoms of infection for the first several days, developing symptoms on the 7th of February. The index case took a trip to Queensland between the dates of the 6th to the 9th of February 2024, during the trip the index case caught seven rideshares between locations and visited a total of ten locations including a hotel, and several cafes and restaurants. When returning to NSW on the 9th, the index case travelled through a domestic airport after returning on a flight from the Gold Coast while infectious.

On the 10th of February, the index case worked as a massage therapist and had six clients. After work, she then attended a restaurant with a work colleague where she was present for one hour from 9 pm to 10 pm. Throughout this timeline, the index case used public transport to go between locations, as well as walking and catching a bus to go from home to work.

Potential contacts:

Potential contacts were separated into three main exposure events. The two friends and the partner of the index case travelled with her for five days to Queensland, the first GP clinic visit, and the second GP clinic visit. As well as the work colleague at the massage clinic, however the massage clinic was not able to identify the clients that were present during the infectious period. As such, they were included in the public release statement as a potential exposure location.

The index case had visited a GP clinic twice over two days while infectious on 12/02/2024 and on 13/02/2024. The clinic contained a pathology collection centre. The cause for the return visit has been explained to SESLHD staff by the index case as a lack of understanding by the index case of her urgent, potentially dangerous condition after the original diagnosis on her first visit. As such, the index case thought that a return visit the next day was required to complete her diagnosis, instead of staying home and monitoring symptoms. During the first visit on the 12th of February 2024, the index case stayed in the GP waiting room from 13:50 to 15:45, which resulted in a total of 27 people potentially exposed. The second visit to the GP occurred on the 13th of February 2024 from the time of 10:30 to 11:30 and had a total of 19 potential exposures.

A cohort study was designed to investigate the vaccination status and measles infectious status after exposure. The cohort included the partner and the two friends and potential contacts at the GP clinic. There were 33 females (67%) and 16 males (33%). A majority were over the age of 20 (61%), while for nine individuals (18%) age could not be obtained. Of the 49 potential contacts, 33 (67%) had either unknown or unvaccinated status, and 17 (35%) had received two doses of the MMR vaccine, with four (8%) having received only one dose. A majority of those with unknown or unvaccinated status were those over 20 years old, while among those aged six months to 20 years (n: 12), eight (67%) were fully vaccinated. None of those with unknown or unvaccinated status developed symptoms during the incubation period.

Of those who were either unvaccinated or had unknown vaccination history, 27 of 33 (82%) received MMR vaccination within the 72-hour post-exposure window. Of the six who did not receive the vaccine, two (33%) were uncontactable during the investigation, one (17%) refused vaccination, one (17%) was born before 1966 and therefore considered immune through prior exposure, and one (17%) was outside of the vaccination window by the time communication was made.

Table 1: Gender, age and vaccination status data of those exposed on the 12th and 13th of February 2024 at the GP clinic as well as the three close exposure travel companions.

Vaccination Status					
	People who received Two Doses	**People who received only One Dose**	**Total unvaccinated or susceptible persons**	**Total persons present at the clinic**	**Persons who received an MMR vaccine after being judged susceptible**
	Gender				
Male	4	-	12	16	6 (50%)
Female	13	4	18	35	13 (72%)
Total	17	4	30	51	19 (63%)
	Age in Years				
6 months – 3 years	1	1	1	3	1 (100%)
3-9 Years	4	-	-	4	-
10 – 20 Years	3	-	2	5	2 (100%)
20+ Years	4	5	21	30	20 (70%)
Unknown	-	-	9	9	7 (77.7%)

Public health response

The public health response necessitated a multi-jurisdictional approach due to the large amount of travel that occurred during the infectious period. Communication with the affected airlines was completed by senior investigators to both inform the cabin crew and to inform

passengers, this required communication with the dedicated health and safety officer present at the Sydney domestic airport. An information sheet was given for dispersal to all affected staff and personnel. Due to the sheer number of casual contacts, however, it was determined that no further dedicated contact tracing would be feasible.

Queensland Health was also informed of the travel route of the index case, including her itinerary that was collected and collated while within the state. This included accommodation, travel arrangements and visited locations. This was then disseminated to Gold Coast Public Health Unit to complete their own outbreak investigation and contact tracing; however no known infections were reported within Gold Coast that were associated with the Index case.

Within New South Wales, two health units were involved in this investigation, South East Sydney Local Health District and Northern Sydney Local Health District. This required communication between senior investigators to share information on potential exposure sites as well as case information. A Sydney-wide health alert was created, detailing exposure sites, and requesting any potential contacts to get tested if symptoms appear and to obtain an MMR vaccine if they had not already received two doses of MMR vaccine or measles-specific vaccine. Those exposed at the health clinic and had not already received full vaccine coverage were advised to return to the same clinic to obtain MMR vaccine. This was reasoned due to the familiarity of patients with the clinic, as well as the now closer relationship between the PHU and the health clinic during the investigation period. Regardless of vaccination status, all potentially exposed persons at either the GP clinics or the potential contacts were given an information pamphlet; this pamphlet included information on measles disease and the MMR vaccine. All potential contacts were directed to either provide documented proof of MMR vaccine or obtain an MMR vaccination as soon as possible. Those with proof of a completed MMR vaccine schedule that was recorded either through AIR, hospital records or other authorised medical records were not required to vaccinate as they were determined to be immune.

Discussion

That the index case had travelled extensively and unintentionally exposed potentially at-risk populations for a significant time on multiple occasions and that no further cases were detected is a testament to the effectiveness of both the rapid public health response activities, including case identification, contact tracing and exposure site notification, and the prevention activities implemented, including the rapid post-exposure vaccination campaign conducted within the 72-hour window.

Within the South East Sydney area, the overall vaccination rate of MMR is expected to be 93.53% in children aged 2 years old in 2023, which is slightly below the 95% threshold for measles.[33, 34] This falls slightly below the 95% vaccination coverage threshold recommended by the WHO as the minimum required to achieve herd immunity against measles. Herd immunity refers to the indirect protection afforded to unvaccinated individuals when a sufficiently high proportion of the population is immune, thereby interrupting transmission chains. Given the high transmissibility of measles, with an R0 of 12 to 18, a higher vaccination threshold is required compared to less transmissible diseases. When coverage falls below 95%, the proportion of susceptible individuals in the community may be sufficient to sustain transmission following the introduction of a case, increasing the risk of local spread.[3] However, this investigation does suggest that although vaccination rates may be high in childhood vaccinations, adult vaccination is difficult to determine due to incomplete vaccination documentation. In this investigation, vaccination status was found to be indeterminate in more than half of the persons surveyed, and thus these persons were defined as susceptible, as it cannot be assumed that vaccination was conducted or completed. As without known documentation, vaccination history is based effectively on memory. Following up this documentation becomes extra difficult when investigating overseas-born populations that either do not have access to their medical records while in Australia, or that the delay in obtaining them would make it unviable in such a time-sensitive setting as an outbreak investigation.

However, due to the ability to undertake a post-exposure MMR vaccine that is still 99% effective if taken within 48 hours of exposure, the consequences of an unknown vaccination are minimised, as when in doubt exposed individuals are recommended to complete a course of vaccination regardless of previous vaccination. [3, 21]

Strengths and Limitations

The findings of this investigation are subject to some limitations. Only potential contacts were actively followed. Casual contacts at the airport, rideshare groups, public transport and within

the various tourist locations in QLD were not actively managed. This may have resulted in under-ascertainment of confirmed cases, there is a possibility that some cases remained hidden from public health institutions. Secondly, while all potential contacts were interviewed within 48 hours of exposure, due to the casualness of the exposure, there may have been persons exposed during the index case's infectious period that either do not remember or were not aware of being in the same airspace as the index case, forming a recall bias on the number of the potentially exposed. Despite these limitations, no further measles cases were reported in the Sydney area during the infectious period of the initial case or within two incubation periods after the initial isolation of the infected case.

Although the Australian government does not currently require evidence of measles vaccination status to travel to Australia or obtain a visa, the findings of this investigation highlight the potential value of more strongly encouraging proof of vaccination for those travelling from endemic regions or seeking to work in high-risk settings such as childcare or aged care. Similar requirements exist for other vaccine-preventable diseases of public health concern, including tuberculosis, yellow fever, and polio. During this investigation, the need for educational materials in languages other than English was also highlighted, as initial communication difficulties were encountered with the index case. Providing public health materials in multiple languages may improve community awareness and adherence to public health measures during future cases. Domestic residents planning to travel overseas should additionally be made aware of the current resurgence of measles internationally and encouraged to ensure their vaccination status is current prior to departure.

Conclusion

This public health response should be seen as a victory for the continued elimination of measles from Australia. However, the slowly reducing vaccination rates in Australia should not be taken lightly. Continued primary prevention through promotion of vaccination amongst eligible populations, alongside targeted health education for at-risk populations in multiple languages, remains essential to maintaining Australia's measles elimination status. These primary prevention activities are distinct from but complementary to the response and secondary prevention activities, such as post-exposure vaccination and contact tracing, that are required once a case is identified.

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Supplementals

Supplemental 1: Public Health Alert for Measles Exposure Event.

NSW HEALTH
Media Release

Wednesday, 14 February 2024

Measles alert for Sydney

NSW Health is advising people to be alert for signs and symptoms of measles after being notified of another confirmed case of measles in Sydney.

The case is an adult who recently returned from south-east Asia where there have been ongoing outbreaks of measles in several countries. This case is not linked to another case reported in northern NSW earlier this week.

People who may have been exposed to the virus in the following locations should monitor for symptoms:

Wednesday 7 February

- Flight JQ427 from Gold Coast, arriving in Sydney 10:15pm
- Sydney Airport Domestic Terminal 2 between 10:15pm and 11:00pm

Saturday 10 February

- Bus Route 288 from Sussex St at Erskine St to Lane Cove Interchange Stand C from 9:30am to 10:00 am
- Thai Chiva Therapeutic Massage, Lane Cove between 10:00am and 7pm
- Satang Thai Take Away Restaurant, Haymarket between 9:00pm and 11pm

There are further exposure sites in Queensland, with further information available via **Queensland Health**.

South Eastern Sydney Local Health District Director of Public Health Dr Vicky Sheppeard, said while these locations pose no ongoing risk, if you, or someone you know, visited the above locations at those times it is important to be on the lookout for symptoms.

"Symptoms of measles include fever, runny nose, sore eyes and a cough, usually followed three or four days later by a red, blotchy rash that spreads from the head to the rest of the body," Dr Sheppeard said.

Measles is a vaccine preventable disease that is spread through the air when someone who is infectious coughs or sneezes.

"Symptoms may appear between 7 and 18 days after an exposure, so it's important for people to stay vigilant if they've been exposed, and if they develop symptoms, to please call ahead to their GP or emergency department to ensure they do not spend time in the waiting room with other patients," Dr Sheppeard said.

"This should be a reminder for everyone to check that they are protected against measles, which is very infectious.

NSW HEALTH Media
Tel. 02 9391 9121 A/Hours. 02 9962 9890 Web. www.health.nsw.gov.au

healthdirect AUSTRALIA – providing expert health advice 24 hours a day to NSW residents – Tel. 1800 022 222

"Anyone born during or after 1966 needs to ensure they have received two doses of measles vaccine, this is particularly important prior to overseas travel, as measles outbreaks are occurring in several regions of the world at the moment."

The measles-mumps-rubella (MMR) vaccine is safe and effective against measles and is included on the National Immunisation Program (NIP) for children at 12 and 18 months of age. It is also free in NSW for anyone born during or after 1966 who hasn't already had two doses.

Children aged 6 to 12 months can have their MMR vaccine schedule adjusted to receive their first dose earlier if they are travelling to areas considered high risk for measles following consultation with their GP.

People who are unsure of whether they have had two doses should get a vaccine, as additional doses are safe. This is particularly important prior to travel. MMR vaccine is available from GPs (all ages) and pharmacies (people over 5 years of age).

For more information on measles, view the **measles factsheet**.

If you, or a loved one, is experiencing measles symptoms, or have questions about measles, please call your GP or Healthdirect on 1800 022 222.

Supplemental 2: Literature Review Search Strategy History for PubMed

Keyword search

"Measles/epidemiology"[Mesh:NoExp] OR "Measles/prevention and control"[Mesh:NoExp] OR "Measles/transmission"[Mesh:NoExp] OR Measle*[tw] OR "Measles Virus"[tw] AND "Australia/epidemiology"[Mesh] OR Australi*

Inclusion Criteria:

- Published between 2014 and 2024
- Peer Reviewed

Exclusion Criteria:

- Written in languages other than English
- Used Animal Models
- Clinical trials
- Case reports or series with insufficient data on broader trends

Query	Sort By	Filters	Search Details	Results
#15 AND #14		English, Humans, from 2014 - 2024	(("australia/epidemiology"[MeSH Terms] OR "australi*"[All Fields]) AND ("measles/epidemiology"[MeSH Terms:noexp] OR "measles/prevention and control"[MeSH Terms:noexp] OR "measles/transmission"[MeSH Terms:noexp] OR "measle*"[Text Word] OR "Measles Virus"[Text Word])) AND ((humans[Filter]) AND (english[Filter]) AND (2014:2024[pdat]))	317
#15 AND #14		English, from 2014 - 2024	(("australia/epidemiology"[MeSH Terms] OR "australi*"[All Fields]) AND ("measles/epidemiology"[MeSH Terms:noexp] OR "measles/prevention and control"[MeSH Terms:noexp] OR "measles/transmission"[MeSH Terms:noexp] OR "measle*"[Text Word] OR "Measles Virus"[Text Word])) AND ((english[Filter]) AND (2014:2024[pdat]))	370

#15 AND #14	from 2014 - 2024	(("australia/epidemiology"[MeSH Terms] OR "australi*"[All Fields]) AND ("measles/epidemiology"[MeSH Terms:noexp] OR "measles/prevention and control"[MeSH Terms:noexp] OR "measles/transmission"[MeSH Terms:noexp] OR "measle*"[Text Word] OR "Measles Virus"[Text Word])) AND (2014:2024[pdat])	372
#15 AND #14		("australia/epidemiology"[MeSH Terms] OR "australi*"[All Fields]) AND ("measles/epidemiology"[MeSH Terms:noexp] OR "measles/prevention and control"[MeSH Terms:noexp] OR "measles/transmission"[MeSH Terms:noexp] OR "measle*"[Text Word] OR "Measles Virus"[Text Word])	805
"Australia/epidemiology"[Mesh] OR Australi*		"australia/epidemiology"[MeSH Terms] OR "australi*"[All Fields]	896,080
"Measles/epidemiology"[Mesh:NoExp] OR "Measles/prevention and control"[Mesh:NoExp] OR "Measles/transmission"[Mesh:NoExp] OR Measle*[tw] OR "Measles Virus"[tw]		"measles/epidemiology"[MeSH Terms:noexp] OR "measles/prevention and control"[MeSH Terms:noexp] OR "measles/transmission"[MeSH Terms:noexp] OR "measle*"[Text Word] OR "Measles Virus"[Text Word]	31,154

Chapter 6: Teaching Epidemiology

Prologue

Background

Epidemiology and public health in general require constant development and collaboration to effectively respond to emerging public health issues and threats. This is even more important to those in field epidemiologist roles who work closely with a wide range of stakeholders from multiple career pathways. As such being able to communicate and effectively educate peers is a competency requirement of the Master of Philosophy in Applied Epidemiology (MAE) program. The program separates this competency into two components, teaching peers in a peer-to-peer environment in a public health concept and creating and presenting a lecture in a classroom environment as part of a team. Peer-to-peer education occurred throughout the two years of the placement by online Zoom meetings, whereas the classroom learning occurred during course block whilst at the Australian National University in Canberra.

Lessons Learnt

Although I had previously been trained to educate adult learners through prior certifications in adult education, those were associated with vocational training and those who were in a subordinate role. Teaching fellow peers is a much different teaching environment than the one I was familiar with. During my peer-to-peer learning, I realised I tended to go off on tangents away from the core teaching objectives being taught. Although somewhat relevant, it would cause me to both lose track of time and track of where I was in the flow of pre-prepared materials. However, I was still able to complete both teaching events on time with no unsatisfied students.

Acknowledgements

I want to acknowledge Davoud Pourmarzi for giving clear guidance while undertaking the classroom teaching task. I would also like to thank my fellow collaborators of the classroom task, Malize Mhango and especially Paul Young, for their help in both developing these lessons and refining the materials.

Teaching Activities

Lessons from the field

My lessons from the Field (LFF) task was on developing a Situational Report (SITREP) based on event-based intelligence. This includes scanning, filtering and analysing a series of signals and then being able to effectively collate and communicate their information to external stakeholders. This task was chosen due to its rarity in the wider public health community, and exposure to an event-based surveillance system within Australia. It also exercises alternative epidemiological skills than what is regularly used due to its unique nature of being based on events and reports rather than cases and incidences.

The activity consisted of a dummy dataset of two dozen signals of events that were pulled from the EPIWATCH®, an artificial intelligence (AI) driven global event-based surveillance system, internal database. These signals included both relevant and non-relevant articles as well as dead links, incorrect dates and other raw data characteristics. This was done to replicate the real-world experience of working with event-based data. The participants were then required to read the articles within one hour and create a basic synopsis in a SITREP format for a fictional department lead and team. This was done to test the participants' ability to use scanning techniques to quickly identify important information through skimming and data cleaning techniques, like those employed at EPIWATCH® by its trained analysts.

After completing the training exercise, participants were prompted to complete an online anonymous feedback survey on the activity using Qualtrics. The feedback provided was positive, with 60% stating the information was extremely useful in their role in field epidemiology, 20% stating it was very useful, and 20% stating it was moderately useful. 60% also stated that the exercise was clearly explained and easy to follow, while 40% somewhat agreed. Two comments expressed gratitude for covering an event-based surveillance system.

Classroom Teaching of First Year MAE Students

The topic of the classroom teaching exercise was collaboration with laboratories during an outbreak investigation. This was chosen due to the necessity of laboratories in diagnosing and detecting disease, and how their context and capabilities dictate the ability of an outbreak response. The topic was also chosen due to all my group members for this topic having laboratory backgrounds themselves, either in human, animal or environmental laboratories.

The teaching was separated into two components. The first was a presentation of information on both the capabilities of a human medical laboratory and the hierarchy of laboratories in Australia regarding the location and capabilities, as well as an education into associated factors such as cold chain travel distances, testing capacity and effective test requesting. For this exercise, I covered rural laboratories and their strengths and weaknesses for laboratory testing and their associated limitations in determining outbreak definitions. The second component of the activity was to break into smaller groups of four to five and create a case definition depending on the capabilities and capacities of the assigned laboratories. Each group was given a unique scenario and unique variables such as remote laboratories, specialist testing requirements and capacity shortfalls. Each group then presented their case definitions to the wider group and was asked to justify their responses.

After the completion of the session, the class was then requested to provide anonymous feedback through an online survey. The responses were well received. However, two respondents did mention that more prior knowledge would be required to be able to fully

understand and respond to the activity. These comments I believe are accurate, due in part to all team members having a background in laboratories, assumed knowledge was most likely unreasonably higher than what realistically should have been expected. In future, further collaboration with non-technically advised personnel would be appropriate to ensure that the level of previous knowledge is reasonable.

Demonstrator Teaching

While at my placement at the University of New South Wales, Kirby Institute's Biosecurity Program, I had the opportunity to gain paid employment in the first year of my placement as a casual demonstrator of graduate-level introductory statistics with the School of Public Health at the University of New South Wales. During this time, I presented weekly 2-hour tutorials to graduate students using predetermined statistical exercises in the R programming language. Students were expected to have completed their exercise before class, where I, as the demonstrator, would then go through the answers and provide context and clarification if needed. This provided me with my first experience teaching university students regularly in a classroom setting. I had been a private tutor in statistics previously, but this was an entirely new experience for me. I learned the necessity of prior planning in providing key information to ensure effective digestion of technical knowledge, as well as how to read a classroom to discover those who may be struggling and provide further context.

As part of the overall university doctrine, students were given the opportunity to provide end-of-semester feedback on their tutors and lecturers. I received 50% of participants stating that they strongly agree with the quality of my teaching, and 50% stated I provided helpful feedback. Comments also included taking the time to clearly explain concepts, being familiar with the software and troubleshooting, as well as being able to simplify the biostatistics and address all queries.

Conclusion

Due to the wide range of backgrounds of most field epidemiologists, there exists a highly diverse pool of past experiences and knowledge within the field. Teaching represents the best method to successfully impart this knowledge, however learning the best way to convey your message and knowledge is difficult. The method of teaching changes dynamically with the cohort being taught, whether it's in a formal learning environment, at a workplace in peer-to-peer training, or even informally between two colleagues. Learning and gaining experience in these different environments has taught me the best ways to teach to meet the occasion and will no doubt form a core part of my field epidemiology career in the years to come.