The use of emergency department electronic health data for syndromic surveillance to enhance public health surveillance programmes in England

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy by Helen Elizabeth Hughes.

March 2021

Abstract

The use of emergency department electronic health data for syndromic surveillance to enhance public health surveillance programmes in England.

Helen E Hughes

Public health surveillance allows for the identification and monitoring of trends in human health. Syndromic surveillance is a relatively recent addition to these activities, offering the potential to monitor trends on a (near) real-time basis and is often more timely than may be possible through other, traditional, surveillance routes.

Emergency department (ED) syndromic surveillance systems have been developed and successfully operated worldwide. The Public Health England Emergency Department Syndromic Surveillance System (EDSSS) was developed in preparation for the London 2012 Olympic and Paralympic Games and remains as a public health legacy of the Games.

This thesis aimed to describe and provide evidence of how emergency department syndromic surveillance (as performed by EDSSS) provides additional benefit to public health surveillance and added value to emergency care services in England. Additionally the potential for further development and future improvements to public health surveillance is described.

The EDSSS is shown here to have been successfully used to describe the impact of the rotavirus vaccine, indicating that EDSSS has the potential to be used for future rapid, stand alone, investigation of impact of vaccines in England. In the first cross-national study of its kind, the EDSSS (alongside OSCOUR, its counterpart in France) was successfully used to describe the changes in human health indicators during periods of poor air quality.

In addition to reporting on both infectious and non-infectious disease, emergency department syndromic surveillance also successfully described the impacts of human behaviour on ED attendances. During the EURO 2016 football tournament ED attendances were found to differ from the expected during match periods, not only in France the host country, but also in the UK home nations where fans followed team progress from home.

The EDSSS is also the first example of a syndromic surveillance system having input into the development of a standardised national dataset, which has been mandated across EDs in England. Primarily aimed to improve patient care and the wider workings of EDs, this improved data collection has resulted in improvements in the EDSSS itself, which was subsequently expanded from a small sentinel to truly national surveillance system.

The standardisation of ED data collection and reporting, alongside improved geographical coverage and near real-time surveillance reporting, enabled rapid feedback on the impact of the COVID-19 pandemic on ED attendances in England. EDSSS described general trends in ED attendances, encompassing both infectious and non-infectious indicators, prompting the refinement of public health messaging, encouraging continued use of emergency care as required by the general public.

The evidence presented in this thesis has demonstrated where the ED syndromic surveillance has added value for public health surveillance in England, utilising the system flexibility and timeliness of reporting. Successful collaborative working has provided the potential for future cross-system learning for further system development, as well as the ability to work at local, national and potentially international scales.

Acknowledgements

Firstly, thank you to my academic supervisors, Sarah, Alex and Roberto, for the support and guidance they have given me throughout this process. The beast has well and truly been fed, for the last time.

Thank you to the Real-time Syndromic Surveillance Team. Without them there would be no ED system.

Thank you to all of my co-authors on each individual pieces of research included here. I count myself lucky to have collaborated with such a wide range of people, on such a variety of projects and I look forward to continuing with this way of working in future.

Thank you to all of my family, friends and colleagues who have provided so many words of encouragement over the years.

Thank you to Helen for the unenviable task of the proof read, burgers are still owed.

And finally to A, my #1 supporter. Thank you for the support and encouragement that have kept me going while sat at this desk for hours on end. Thank you for also reminding me to get away from the screen, go outside and have some fun every once in a while!

PhDing done.

Contents

Chapter 1 Background and introduction

1.1 Public health surveillance

Public health surveillance is "*…the continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public health practice*".[1] These surveillance activities cover all health conditions, from infectious disease, to obesity, to cancer, amongst many others. The information and intelligence gathered through surveillance activities aim to; identify and warn of future public health issues, provide detail and monitoring of ongoing, known, situations, as well aid in the determination of need for, and confirm and quantify the effect of, any public health interventions.

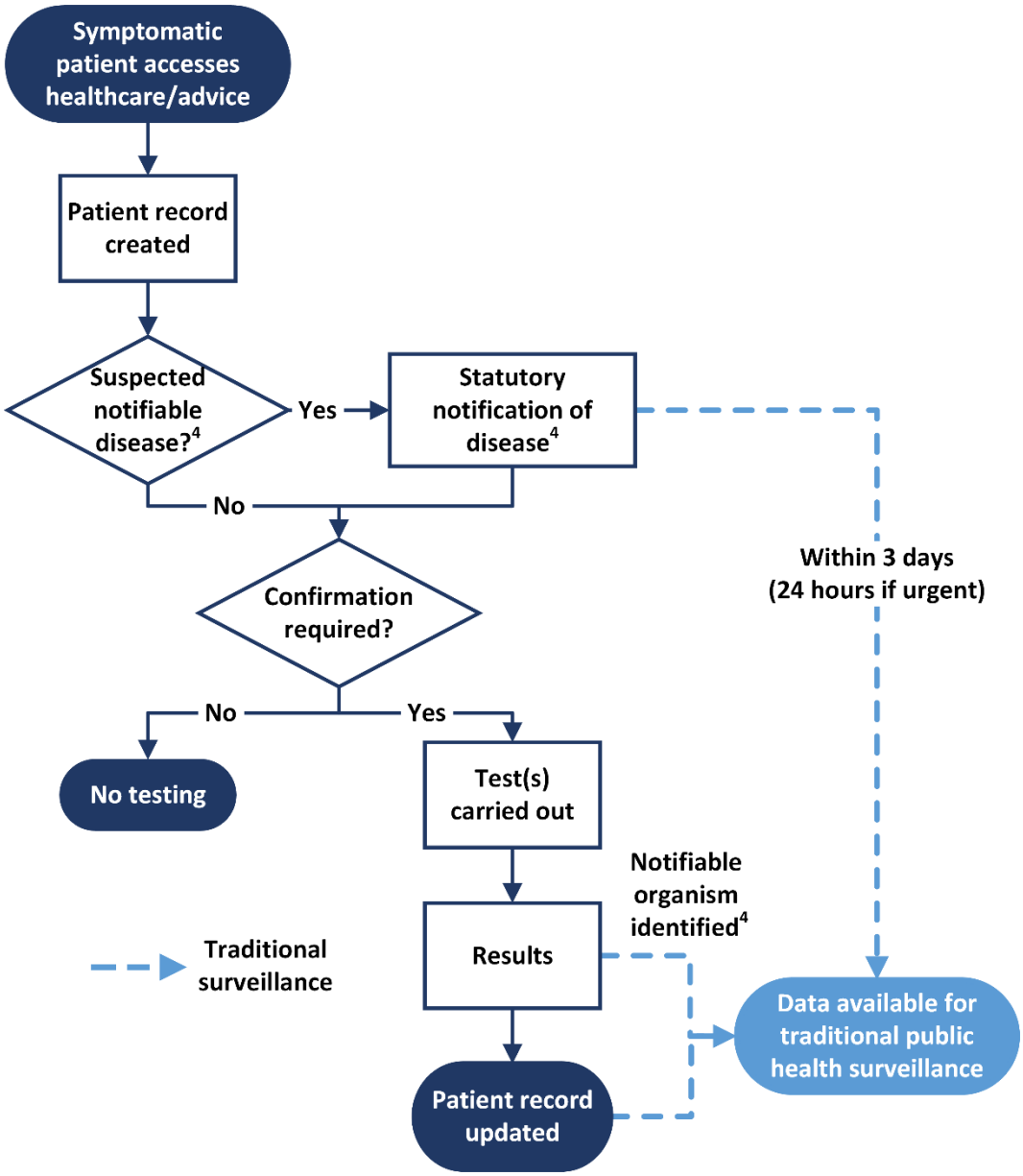
This information can then be acted upon by public health authorities, including immediate actions (such as outbreak investigation and control) or the development of interventions and public health strategies and policies (such as vaccination programmes). Additionally, public health surveillance can also provide reassurance during a known event (such as periods of poor air quality), where no impact on human health has been detected.

Traditional public health surveillance methods

Traditional public health surveillance activities generally rely on either the active reporting of individual cases of illness by a health professional, or the passive reporting of laboratory confirmations of specified diseases and conditions. Both active and passive reporting of illness require a clinical diagnosis to have been made by a health care professional. This is true for the surveillance of both infectious and non-infectious disease of public health concern (information flow for infectious disease surveillance shown in **Figure 1-1**).

In England there is a legal requirement[2,3] for registered medical practitioners to report selected communicable diseases, and for laboratories to report results to Public Health England (PHE) when specified organisms are isolated.[4] This statutory notification of infectious disease is primarily for outbreak detection to allow for rapid public health response. Information is also collected by PHE for cases of specified non-communicable diseases and conditions, with surveillance activities carried out in a wide range of areas including the National Cancer Registration and Analysis Service[5] and National Congenital Anomaly and Rare Disease Registration Service.[6] The routine reporting of disease to PHE results in the provision of public health advice, support or action, as appropriate.

Figure 1-1: Information flow for traditional public health surveillance of infectious disease in England.



Public health surveillance also allows long term monitoring and investigation at a population level, forming the basis for the identification and monitoring of risk. Again these longer term surveillance activities are carried out for both communicable and non-communicable diseases such as; investigation into vaccine effectiveness[7] and surveillance of levels of cancer diagnoses in specified geographical areas, for the detection of clusters.[8]

Traditional public health surveillance methods rely on a degree of certainty being reached in a diagnosis before public health authorities are informed. Where diagnosis requires investigations to be carried out there may be a delay before testing is performed, followed by a necessary wait for results to be confirmed and communicated to the treating

physician, who may then report a case to the relevant public health authorities (**Figure 1-1**). Even where a statutory notifiable disease is suspected there is no immediate requirement for reporting to public health authorities, with a 3-day delay permitted (24 hours if considered 'urgent'). These factors can result in a lag between the initial patient presentation and eventual inclusion in surveillance analysis and reporting.

Furthermore, in cases of self-limiting illness, or where treatment does not require a confirmation of pathogen (e.g. diarrhoea due to unknown cause may be successfully treated without laboratory confirmation of the organism involved), a final or confirmed diagnosis may not be reached, meaning no report is made to public health authorities.

Syndromic surveillance

Traditional surveillance activities have been augmented by the relatively recent developments of syndromic surveillance systems, which are able to detect and report on trends in public health in near real-time. First developed in the late 1990s,[9] this type of public health surveillance is termed *syndromic* surveillance as it relies on the grouping of patient presenting symptoms/complaints into 'syndromic indicators'.[10] These indicators can be based on patient reported (or observed) symptoms, which are often recorded by healthcare providers from the first patient contact, alongside preliminary/working diagnosis, in the absence of confirmatory testing.

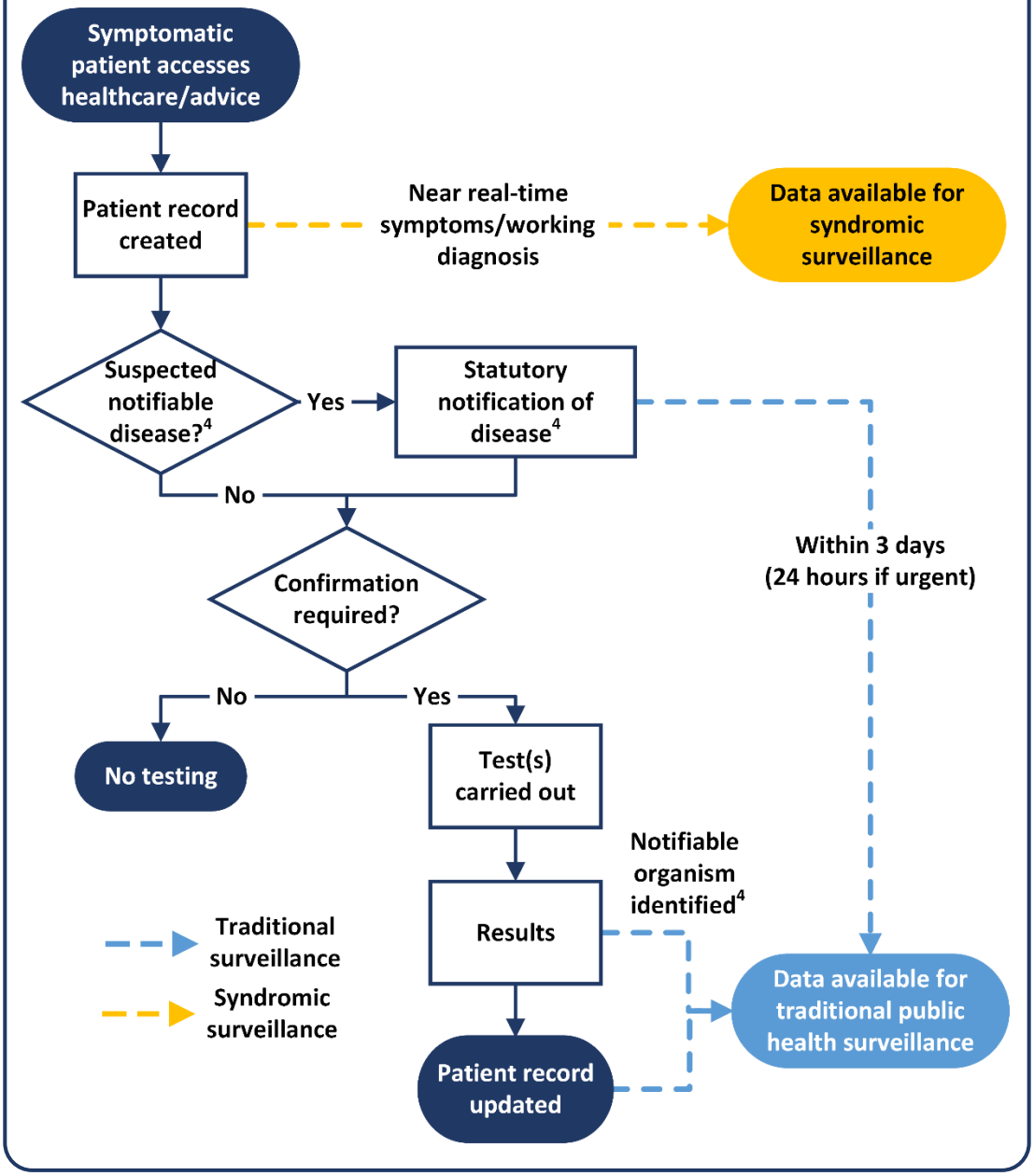
Syndromic indicators may be a very generic capture all grouping, such as 'all respiratory conditions' which may be anything from very non-specific symptoms such as 'cough' or 'shortness of breath', through to more detailed diagnoses such as 'pneumonia' or 'asthma'.

Generic, 'all conditions', indicators give an indication of the levels of all broad groupings of illness (such as all respiratory) identified within the syndromic surveillance system. Where the patient care record allows for the entry/selection of more detailed options, more specific groupings can be created for syndromic indicators such as 'acute respiratory infection'. If the level of information recorded is even more detailed, the granularity of the indicator grouping can be taken a step further, identifying conditions such as 'bronchiolitis' or 'influenza-like illness'. The limitation of these more detailed syndromic indicators is that they are likely to include a much smaller number of patient contacts: many patients attend for respiratory conditions; a subset can be classified as acute respiratory infection; a smaller number may be diagnosed with influenza-like illness.

Syndromic surveillance has the potential to include cases of symptomatic illness not identified by traditional public health surveillance. Where a patient has presented with self-

limiting illness and laboratory confirmation is not required for effective treatment, they are unlikely to be reported through traditional surveillance methods (**Figure 1-2**). Traditional surveillance methods may therefore under-estimate disease burden and are often biased towards certain groups e.g. the elderly and severely ill hospitalised patients. However, the ability to monitor levels of illness in the community remains an important factor in public health surveillance. Although the individuals may be less severely ill there are likely to be large numbers affected with notable social and economic impacts, such as time taken from work/education or even caring for others.

Figure 1-2: Information flow for public health surveillance of infectious disease in England, comparing traditional and syndromic surveillance.



Though the level of detail available may be limited, the use of syndromic surveillance allows the identification of trends (increases, decreases or even stable in the absence of change over time) in indicator levels in more timely way than may be possible through other surveillance routes. Syndromic surveillance systems offer the ability to monitor these trends on a (near) real time basis i.e. daily, or more frequent.

(Near) real-time syndromic surveillance

The provision of health care has developed in the digital age. Contemporaneous recording of information during each patient contact has become the norm, be that a telephone call (e.g. NHS 111), a patient consultation in primary care (e.g. with a general practitioner; GP) or treatment in an emergency department (ED). Electronically recorded information gathered during a patient contact with a health care provider provides detail on symptom presentations and initial diagnoses. The storage of this information in databases may then potentially be made available quickly for public health surveillance purposes, presenting opportunities for syndromic surveillance.

The use of automated processes for the identification, batching and transfer of data can make this a passive process. No extra work is required from the health care provider. These factors mean that there can be minimal delay between a patient contact with health care and that information being used for surveillance purposes (**Figure 1-2**).

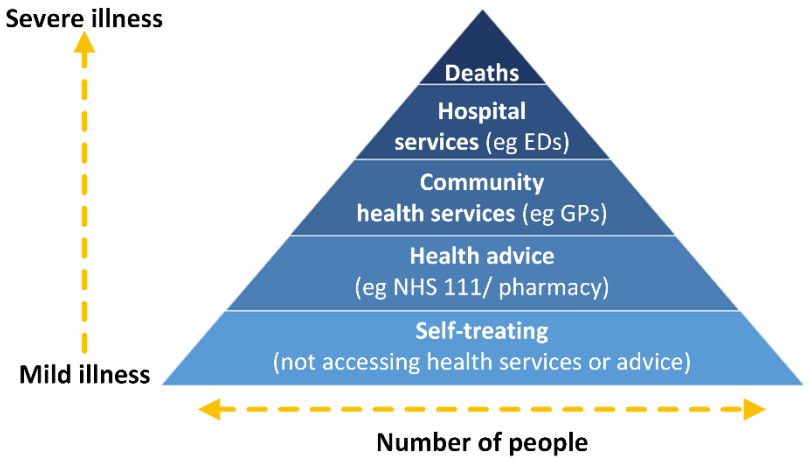
1.2 Syndromic surveillance in England

Those people experiencing periods of ill health may access health care or advice from different types of health care provider in England. This may range from large numbers of people with relatively mild illness who may, at most, seek advice on self-care, to a smaller number who are severely ill requiring emergency hospital level care and even fewer dying from their condition (**Figure 1-3**). The PHE Real-time Syndromic Surveillance Team (ReSST) has developed and maintains a suite of national syndromic surveillance systems, providing a daily service monitoring and identifying trends in patients making contact with several of the different levels of health care/advice providers across England.[9]

Initially the ReSST syndromic surveillance service was focussed on infectious disease monitoring, particularly the surveillance of influenza-like illness as part of the national monitoring of influenza through each winter period. The first PHE syndromic surveillance system was established in 1999, based on the data gathered from calls made to a newly launched NHS telephone helpline (NHS Direct, which transitioned into NHS 111).[11-13] Following a successful pilot in the West Midlands, England-wide roll-out established the

NHS 111 syndromic surveillance system as one of the first national syndromic systems to be created and integrated into a public health system.[12] NHS 111 call records include the selected 'pathway' for each call providing a record of the symptoms reported, chosen from a limited number of non-specific options e.g. cold/flu or sore throat. The NHS 111 syndromic surveillance system uses anonymised information from those generally seeking health advice, rather than treatment; those at the less severe end of the surveillance pyramid (**Figure 1-3**).

Figure 1-3: Disease severity pyramid: where (and how many) people access health service or advice, dependent on severity of illness



The development of a GP in hours syndromic surveillance system in 2006[14] further extended the PHE surveillance capability for monitoring levels of illness in the community across England. The GP in hours syndromic surveillance system initially monitored weekly consultations within a network of GPs across the UK.[14] The healthcare treatment and advice provided by GP services constitute the next level in terms of disease severity, those symptomatic and seeking treatment for their illness or condition (**Figure 1-3**). The electronic record of each GP consultation collects symptoms as well as diagnoses, including a greater degree of clinical detail than a NHS 111 call record. Items such as cough/cold may still be selected, but more detailed diagnoses such as acute respiratory infection or even influenza-like illness may also be recorded.

In preparation for the London 2012 Olympic and Paralympic Games (London 2012) the national syndromic service was reviewed in light of the enhanced surveillance requirements for the Games. This review highlighted that although near real-time (daily) systematic surveillance of less severe types of illness in the community could be carried out as standard, the same was not possible for the more severe presentations of illness. As a

result, two new syndromic surveillance systems were developed and implemented ahead of London 2012. These new systems focussed on the more severe end of the disease severity pyramid, those people seeking unscheduled urgent care and treatment (**Figure 1-3**).

First, a new syndromic surveillance system focussed solely on GP contacts outside of usual office hours (GP out-of-hours)[15] was developed, complementing and extended the pre-existing GP in hours surveillance system. The GP out-of-hours syndromic surveillance system filled in the gaps in the surveillance picture; providing the ability to monitor trends in disease presentation during evenings and weekends, by those unable to wait for a week-day, day time, appointment for medical care.

A second new syndromic surveillance system was developed to monitor trends in disease presentation by those most severely ill and requiring urgent, potentially lifesaving care in EDs.[16] At that time the UK did not have an ED surveillance system, despite ED syndromic surveillance being relatively common internationally. Syndromic surveillance systems using ED data and the use of ED syndromic surveillance globally are systematically reviewed and described in **Chapter 2**. The development of the ED syndromic surveillance system in England is described in **Chapter 3**.

1.3 References

1. World Health Organisation. Public Health Surveillance. [Available from: https://www.who.int/emergencies/surveillance Accessed: 20 Feb 2021].
2. Public Health (Control of Disease) Act 1984. [Available from: http://www.legislation.gov.uk/ukpga/1984/22 Accessed: 20 Feb 2021].
3. The Health Protection (Notification) Regulations 2010. [Available from: http://www.legislation.gov.uk/uksi/2010/659/contents/made Accessed: 20 Feb 2021].
4. Public Health England. Notifiable diseases and causative organisms: how to report. [Available from: https://www.gov.uk/guidance/notifiable-diseases-and-causative-organisms-how-to-report Accessed: 20 Feb 2021].
5. Public Health England. National Cancer Registration and Analysis Service. [Available from: https://www.gov.uk/guidance/national-cancer-registration-and-analysis-service-ncras Accessed: 20 Feb 2021].
6. Public Health England. National Congenital Anomaly and Rare Disease Registration Service. [Available from: https://www.gov.uk/guidance/the-national-congenital-anomaly-and-rare-disease-registration-service-ncardrs Accessed: 20 Feb 2021].
7. Public Health England. National enhanced surveillance of vaccination programmes targeting invasive meningococcal disease in England. [Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/484661/MeningoEnhancedSurveillancePlan_Final_Dec15.pdf Accessed: 20 Feb 2021].
8. Public Health England. Public Health England: approach to surveillance. [Available from: https://www.gov.uk/government/publications/public-health-england-approach-to-surveillance/public-health-england-approach-to-surveillance Accessed: 20 Feb 2021].
9. Smith GE, Elliot AJ, Lake I, et al. Syndromic surveillance: two decades experience of sustainable systems - its people not just data! *Epidemiology and Infection* 2019;147:e101. doi: 10.1017/S0950268819000074
10. Triple S Project. Assessment of syndromic surveillance in Europe. *Lancet* 2011;378(9806):1833-34. doi: 10.1016/S0140-6736(11)60834-9
11. Cooper DL, Smith GE, Hollyoak VA, et al. Use of NHS Direct calls for surveillance of influenza--a second year's experience. *Communicable disease and public health / PHLS* 2002;5(2):127-31.
12. Harcourt SE, Smith GE, Hollyoak V, et al. Can calls to NHS Direct be used for syndromic surveillance? *Communicable disease and public health / PHLS* 2001;4(3):178-82.
13. Harcourt SE, Morbey RA, Loveridge P, et al. Developing and validating a new national remote health advice syndromic surveillance system in England. *Journal of Public Health* 2017;39(1):184-92. doi: 10.1093/pubmed/fdw013
14. Hippisley-Cox J, Smith S, Smith G, et al. QFLU: new influenza monitoring in UK primary care to support pandemic influenza planning. *Euro Surveillance* 2006;11(6):E060622 4.
15. Harcourt SE, Fletcher J, Loveridge P, et al. Developing a new syndromic surveillance system for the London 2012 Olympic and Paralympic Games. *Epidemiology and Infection* 2012;140(12):2152-6. doi: 10.1017/S0950268812001781
16. Elliot AJ, Hughes HE, Hughes TC, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. *Emergency medicine journal : EMJ* 2012;29(12):954-60. doi: 10.1136/emermed-2011-200684

Chapter 2 Emergency department syndromic surveillance systems: a systematic review

Helen E. Hughes
Obaghe Edeghere
Sarah J. O'Brien
Roberto Vivancos
Alex J. Elliot

BMC Public Health. 2020;20(1):1891. Crown Copyright.
DOI: 10.1186/s12889-020-09949-y

Syndromic surveillance is a relatively new addition to the public health surveillance arsenal, providing opportunities for timely monitoring of disease at a population level. Though primary care provision and access may vary greatly from country to county, emergency care is generally a universal provision, available and accessible to all as and when required.

This systematic review describes the evolution and development of emergency department syndromic surveillance globally, from small local surveillance systems requiring active participation, often used for a short time period, to full national systems making use of technological advancements for the passive and rapid transfer of data from individual patient records for (near) real-time analysis and surveillance outputs. Variation in system structures is discussed, along with potential for further developments and improvements, as well as possible collaborations and learning between systems in future.

2.1 Abstract

Background

Syndromic surveillance provides public health intelligence to aid in early warning and monitoring of public health impacts (e.g. seasonal influenza), or reassurance when an impact has not occurred. Using information collected during routine patient care, syndromic surveillance can be based on signs/symptoms/preliminary diagnoses. This approach makes syndromic surveillance much timelier than surveillance requiring laboratory confirmed diagnoses.

The provision of healthcare services and patient access to them varies globally. However, emergency departments (EDs) exist worldwide, providing unscheduled urgent care to people in acute need. This provision of care makes ED syndromic surveillance (EDSyS) a potentially valuable tool for public health surveillance internationally.

The objective of this study was to identify and describe the key characteristics of EDSyS systems that have been established and used globally.

Methods

We systematically reviewed studies published in peer review journals and presented at International Society of Infectious Disease Surveillance conferences (up to and including 2017) to identify EDSyS systems which have been created and used for public health purposes. Search criteria developed to identify "emergency department" and "syndromic surveillance" were applied to *NICE healthcare, Global Health* and *Scopus* databases.

Results

In total, 559 studies were identified as eligible for inclusion in the review, comprising 136 journal articles and 423 conference abstracts/papers. From these studies we identified 115 EDSyS systems in 15 different countries/territories across North America, Europe, Asia and Australasia. Systems ranged from local surveillance based on a single ED, to comprehensive national systems. National EDSyS systems were identified in 8 countries/territories: 2 reported inclusion of ≥85% of ED visits nationally (France and Taiwan).

Conclusions

EDSyS provides a valuable tool for the identification and monitoring of trends in severe illness. Technological advances, particularly in the emergency care patient record, have enabled the evolution of EDSyS over time. EDSyS reporting has become closer to 'real-

time', with automated, secure electronic extraction and analysis possible on a daily, or more frequent basis.

The dissemination of methods employed and evidence of successful application to public health practice should be encouraged to support learning from best practice, enabling future improvement, harmonisation and collaboration between systems in future.

Prospero number CRD42017069150

2.2 Background

Syndromic surveillance is a relatively recent addition to the public health surveillance toolbox, with the earliest reported systems established during the mid-1990s.[1] Syndromic surveillance uses symptom and/or preliminary diagnosis information and rapid data collection methods to provide information for public heath action. Syndromic surveillance is more timely than other more traditional options for public health surveillance, such as statutory notifications of disease or laboratory reporting.[2] The non-specific nature of syndromic surveillance and its rapid data collection also makes it sensitive and flexible enough to respond to different situations/scenarios including infectious outbreaks and non-infectious disease events. The data used for syndromic surveillance are primarily gathered from patient contacts with a health care service, although increasingly non-health care syndromic surveillance data are being explored e.g. social media[3] or internet search data.[4,5]

The sources of patient health information used for syndromic surveillance are as varied as the different types of health care provision that exist. Examples of syndromic surveillance data range from calls from those who are ill in the community to telehealth advice phone lines,[6,7] to patients attending in person in primary care (family doctors)[8,9] or in emergency care situations including emergency departments (ED).

Patients seen in the ED are generally expected to be presenting with severe illness requiring immediate, often lifesaving, medical attention and treatment. This severe level of acute illness is of particular interest to public health surveillance to enable the identification and monitoring of public health issues requiring an acute response. Conversely, this surveillance may also provide reassurance, confirming that there is no public health impact from an incident already identified.

Healthcare systems vary, however, EDs are commonly found worldwide, providing unscheduled emergency care to patients as required. The global presence of EDs has facilitated the increasing use of ED clinical data for syndromic surveillance purposes. To date there has not been a review of the ED systems developed worldwide, with only one systematic review on the use of ED syndromic surveillance (EDSyS) for influenza.[10]

Here, we systematically review the available literature to identify and describe the range of EDSyS systems reported to have been developed for public health use globally. We describe the different models developed to collect and analyse ED data, and the public health uses of EDSyS. Additionally, we discuss the changes and development of these systems over time and the potential for future development.

2.3 Methods

This systematic review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[11] and was registered on Prospero,[12] reference number: CRD42017069150.

Identification of studies

Searches were carried out using the NICE healthcare database (HDAS, accessing PubMed, MedLine, EmBase, Health Business Elite, Health Management Information Consortium, PsycINFO, British Nursing Index, and Cumulative Index to Nursing and Allied Health Literature), in addition to the Global Health (accessed through EBSCO) and Scopus online databases.

Search terms were developed to identify published papers demonstrating an operational EDSyS system collecting, analysing and reporting in near real-time for public health purposes. These papers required inclusion of terms related to both syndromic surveillance AND to ED, in the title and/or abstract. The electronic HDAS search string was:

("emergency department" OR "emergency room" OR "emergency care" OR "emergency medical" OR "chief complaint" OR "presenting complaint" OR "triage") AND ("syndromic surveillance" OR "real-time surveillance" OR "real time surveillance" OR "syndrome surveillance").ti,ab

Where review-type studies were identified, the references from each were searched to identify any primary research studies describing an eligible system not identified elsewhere during the search.

The restriction to English language peer reviewed publications was recognised as a possible bias against ED systems established in non-English speaking countries/territories, or smaller systems which may not be written up for formal publication. In order to counteract this potential selection bias, all available abstracts/papers for the International Society for Disease Surveillance (ISDS) annual conferences up to 2016 were also included in the search (including predecessor conferences, beginning 2002: no conference was held in 2017). ISDS conference abstracts which included the eligible search terms were identified through searching of conference abstract archives available in online journals.[13-26] Abstracts for the 2009 conference were obtained through personal communication with ISDS as an online archive was not available.

Included studies

We included all studies which included reference to an operational EDSyS system, defined as an EDSyS which collected, analysed and reported on ED data in real time, for public health purposes. The search was limited to studies published up to and including 31 December 2017, with no limitation on the search start date.

Excluded studies

We excluded studies reporting on the use of retrospectively accessed ED data from a source other than an operational EDSyS system (e.g. directly from an ED information system or other database). These retrospective studies generally investigated the potential use and/or benefits of ED data for syndromic surveillance purposes. Non-English language journal articles were excluded, as were book chapters, non ISDS conference abstracts/papers, dissertations and reports.

Screening

The selection of studies for inclusion was carried out independently by two reviewers (HEH and OE) using Covidence.[27] All titles and abstracts were initially screened to identify only those which reported on, or appeared to report on, an operational EDSyS system. Full text screening was carried out by both reviewers selecting studies that met the inclusion criteria. Any conflicts were resolved by HEH.

Data extraction

Following full text screening, studies meeting selection criteria were then subjected to qualitative data extraction. The data extracted included: EDSyS location; motivation for system creation; system start date; coverage; and the dates and coverage of any research project reported. Where available, information was also extracted describing the technical details of the system (timings, frequency and methods of data collection and transfer of data from the ED to the syndromic surveillance database). Qualitative data details included: the syndromic indicators used (data source, format and syndromes of interest); the analytical techniques used; and public health actions carried out in response to the surveillance findings.

Data extraction from all studies was carried out by the primary reviewer (HEH). The secondary reviewer (OE) undertook a quality control check by extracting information from a random 10% sample of studies.

2.4 Results

In total 1,273 journal articles were identified, with publication dates from 2002-2017. Duplicate (n=892) and articles not eligible for inclusion (n=111) were removed. Additionally, 795 ISDS conference abstracts were identified for inclusion. Of these the full conference papers were available for conferences held in 2003 and 2004 (**Figure 2-1**).

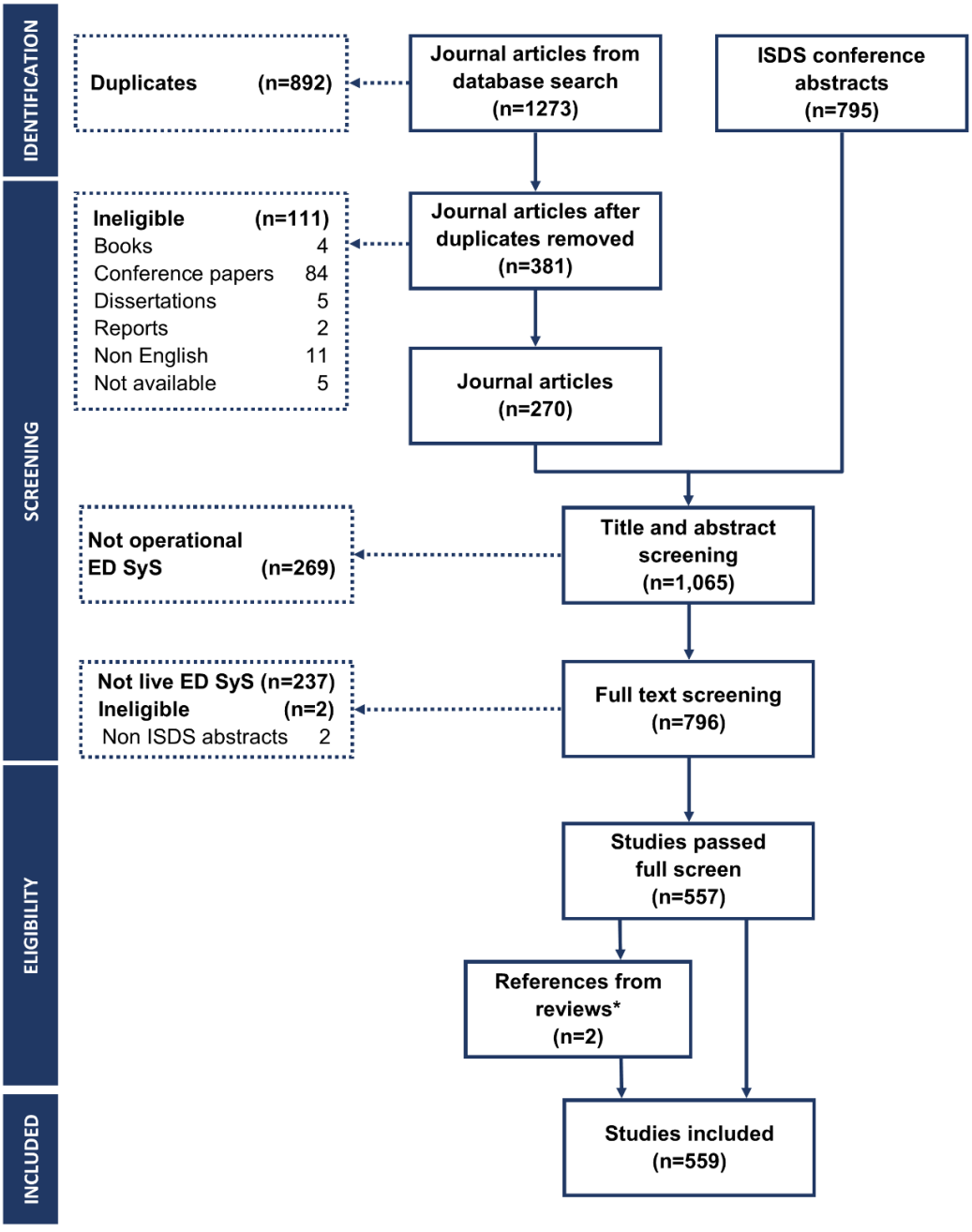
Title and abstract screening of the resulting 1,065 studies (270 journal articles and 795 ISDS conference abstracts/papers) excluded 237 studies that did not clearly describe an operational EDSyS system (or the use of data from one) and two studies that were identified as non-ISDS conference abstracts. The resulting 796 studies were included for full text screening (**Figure 2-1**).

The full text screen identified one systematic review,[10] one case study of three separate EDSyS systems[28] and one review of automated outbreak detection in syndromic surveillance systems (not limited to EDSyS).[29] These three manuscripts included description of multiple EDSyS systems, two of which had not been identified by the original search. These two additional EDSyS systems had primary references, which were added to the full data extraction (**Figure 2-1**).

In total 559 studies were identified as eligible for inclusion in the review comprising 136 journal articles and 423 ISDS conference abstracts/papers. A full list of all references is included in this review are available in **Appendix A**, which includes a detailed summary of all EDSyS systems identified, by country/territory, with sub national breakdown where appropriate.

The eligibility criteria allowed for individual EDSyS systems to be described in multiple references. The quality control check with the second reviewer extracting did not reveal any errors.

Figure 2-1: PRISMA flow diagram of the screening process and numbers of articles identified



Summary of global EDSyS

Each EDSyS included in the review had a single underlying aim to provide information for public health action. This aim encompassed the use of EDSyS in the monitoring of seasonal and sporadic, infectious and non-infectious disease activity, as well as the detection and the monitoring of the impact of unusual/unanticipated events (including natural disasters and bioterrorism).

The descriptions of EDSyS systems identified in the review were grouped by country/territory in order to summarise the reporting of the large number of systems. The following description of findings is based on this grouping, with individual examples highlighted as appropriate. A full list of EDSyS systems identified in the review is provided in **Appendix A**.

The 559 studies included from the full screen comprised 115 EDSyS systems, in 15 countries and territories, across North America, Europe, Asia and Australasia (**Table 2-1**). The first EDSyS systems identified were all in the United States of America (USA), with four reported to have started data collection in 1999[30-33] and a fifth reported in a study using data from 1999.[34]

EDSyS systems in four countries were identified solely from journal articles (Albania, Italy, New Zealand, Spain), whereas systems from three countries (Greece, Jamaica and Singapore) were identified only in ISDS conference abstracts/papers, (**Figure 2-2**, **Table 2-1**). Although the number of conference abstracts greatly outnumbered the journal articles, the number of journal articles published each year increased over time, from one in 2002, to 26 in 2017 (the only year during which there was no ISDS conference).

Figure 2-2: Number of journal articles and International Society for Disease Surveillance (ISDS) conference abstracts identified, by year of publication/conference and country/territory

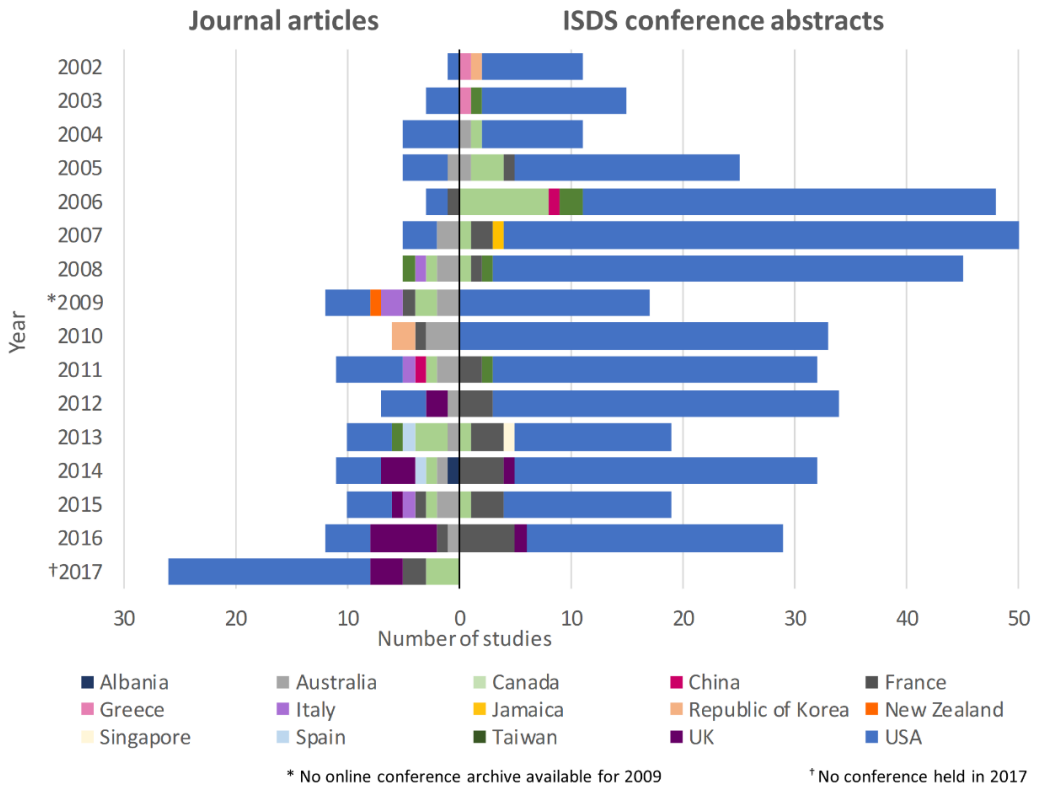


Table 2-1: Summary of Emergency Department Syndromic Surveillance (EDSyS) systems by country/territory, detailing the number of systems, start date, coverage, initial design aim and the number (and type) of studies identified in this review.

Country / territory	Number of systems	Earliest start year*	Coverage of individual system(s)		Initial design of system(s)		Number of studies identified**	
			National	Sub-national	Aim	Event type	Journal papers	ISDS abstracts
Albania	1	2013*	✓	-	Standard surveillance	No specific event	1	0
Australia	3	2003	-	✓	Preparation	Mass gathering (sport)	18	2
					Standard surveillance	No specific event		
Canada	19	2002	-	✓	Preparation	Mass gathering (religious)	14	18
					Standard surveillance	No specific event		
China	2	2004*	-	✓	Response	Outbreak (SARS)	0	2
France	1	2004	✓	-	Response	Natural disaster (heatwave)	7	25
Greece	1	2002	-	✓	Preparation	Mass gathering (sport)	0	2
Italy	2	2000	-	✓	Standard surveillance	No specific event	5	0
Jamaica	1	2007	✓	-	Preparation	Mass gathering (sport)	0	1
Republic of Korea	1	2002	✓	-	Preparation	Mass gathering (sport)	2	1
					Standard surveillance	No specific event		
New Zealand	1	2008	-	✓	Standard surveillance	No specific event	2	0

Country / territory	Number of systems	Earliest start year*	Coverage of individual system(s)		Initial design of system(s)		Number of studies identified**	
			National	Sub-national	Aim	Event type	Journal papers	ISDS abstracts
Singapore	1	2013*	✓	-	-	-	0	1
Spain	1	2010*	-	✓	Standard surveillance	No specific event	2	0
Taiwan	2	2003	✓	✓	Response	Outbreak (SARS)	3	5
UK***	1	2010	✓	-	Preparation	Mass gathering (sport)	15	3
USA	78	1999	✓	✓	Preparation	Mass gathering (sport)	67	365
						Mass gathering (political)		
						Natural disaster (hurricane)		
					Response	Terrorism		
						Outbreak (SARS)		
					Standard surveillance	Health surveillance requirements		
						No specific event		

* Start date not specified in all systems, so estimated from data used/ text ** excluding reviews *** UK: England & Northern Ireland

✓ EDSyS system in this category identified - no EDSyS system in this category/no information identified

Geographical coverage

ED services are a globally recognisable type of healthcare provision but access to these services and the administrative/organisational structures vary greatly. There is also variation in the organisation and delivery of public health services (delivered at national and sub-national levels), both between and within countries/territories. Each of these factors are likely to have impacted on the geographical and population coverage of EDSyS systems, which ranged from very local (including a single ED), to national systems, with many levels in between.

Six countries described having EDSyS systems developed with national coverage (Albania, France, Jamaica, Republic of Korea, Singapore, United Kingdom (UK): **Table 2-1**, **Appendix A**). 'National' coverage varied in geographical (and consequently population) terms, with most being sentinel (**Appendix A**). Where national ED systems had been developed, they were not solely used for national level investigation and reporting, with sub-national and localised geographical analyses also undertaken (e.g. overseas territories reported separately from France,[35] and London reported from the UK[36]).

Seven countries had EDSyS systems working solely on a sub-national basis. Single, locally run systems were identified in Greece, New Zealand and Spain, whereas multiple stand-alone systems were identified in Australia, Canada, China and Italy (**Table 2-1**, **Appendix A**).

EDSyS systems which had been separately developed at both national and sub-national levels were identified in Taiwan and USA (**Table 2-1**). The USA national system developments have been built upon (and subsequently extending) pre-existing local, sub-national EDSyS systems. Population-based systems were also identified in the USA, with dedicated military (including veteran) EDSyS operated at both state (North Carolina, in addition to a civilian EDSyS system) and national (potentially global) level (**Appendix A**).

Descriptions of the EDSyS systems in both France and Taiwan reported ED participation to be 'required' (Taiwan)[37] and 'mandatory' (France),[38] with both reportedly receiving data from 85% or more of all ED visits (**Appendix A**).

The rationale for the development of EDSyS systems

This review identified three broad themes for EDSyS development and implementation. Firstly, EDSyS systems developed in preparation for an expected event (mass gathering or predictable natural disaster); secondly, those developed in response to an unanticipated event (natural disaster, outbreak or terrorism); or finally, EDSyS systems developed as a new standard surveillance format that was generally aimed to supplement and

complement existing public health surveillance, adding resilience should any of the above events occur in future, including bioterrorism (**Table 2-1**).

In seven countries/territories, EDSyS systems were reportedly introduced in preparation for a mass gathering event (e.g. politics/religion/sport related), or even in advance of a predicted natural disaster (e.g. hurricane). A number of these systems were designed and run as short term, event-based systems, created shortly before and intended to be disbanded shortly after the event.[30,39-43] Some of these short-lived event-based systems were subsequently redeveloped into ongoing operational EDSyS systems.[30] EDSyS systems created in preparation for a specific event have also been intentionally designed from the outset to remain in place as standard surveillance capability, continuing as a legacy of the event.[36,44]

EDSyS systems developed in response to events of public health importance were implemented in response to infectious disease outbreaks (namely SARS[45-47]), terrorist events (September 2001[48-51]) and natural disasters (heat wave[52]). The speed at which these systems were implemented was dependent on the level of immediate threat. Again, the design and structure of these systems may have been optimised for short lived surveillance (particularly when created quickly), but then further developed to become a routine surveillance system (e.g. New York City[53,54]). Those responding to a non-immediate threat were created less rapidly as an ongoing, routine surveillance system (e.g. France[55]).

The creation of EDSyS systems solely to augment standard public health surveillance (including for the identification of bioterrorist threats) was identified as the primary purpose for the set-up of some systems, particularly small systems operating at a local level across the USA as well as others in New Zealand[56] and Republic of Korea.[57]

Data analysis

Real-time data collection and analysis on a more frequent than daily basis were described in systems from Australia,[58] Canada[59] and the USA.[60-62] The analysis of EDSyS data was, however, most commonly reported to be conducted on a daily basis, even where data collection occurred more frequently.[63-65]

The methods by which syndromic EDSyS data were analysed for exceedances or temporal spikes were often not clearly presented in the studies. The specific statistical methods applied to operational syndromic surveillance data in some studies were simply described as the use of ‘statistical algorithms’ or ‘aberration detection’. Statistical algorithms using or based on commonly used syndromic surveillance tools were reported in several EDSyS

systems. This included reporting: the surveillance system used e.g. the Electronic Surveillance System for the Early Notification of Community-Based Epidemics (ESSENCE II)[66] or Real-time Outbreak and Disease Surveillance (RODS);[67] the algorithm used e.g. Early Aberration Reporting System (EARS);[68] or the tool used e.g. SatScan[69] for statistical analyses carried out. A bespoke statistical analysis method (Rising Activity, Multi-level Mixed effects, Indicator Emphasis, RAMMIE) was reported as a standard statistical method used for EDSyS in the UK.[70]

Studies describing the development of statistical/analytical methods for use on syndromic data (rather than the application in day-to-day practice) were common. These studies focussed largely on the range of statistical methods and techniques that were available, proposals for potential statistical approaches and future developments.[40,71-87]

Indicators monitored in EDSyS systems

Syndromic indicators were often-described for detecting 'bioterrorist' events.[54,88,89] Syndromic indicators were also identified for a wide range of infectious and non-infectious diseases, particularly for the identification and monitoring of seasonal trends in illness. Indicators used to monitor infectious diseases were reported in all 15 countries/territories. Respiratory infection indicators were described in all 15 countries/territories (influenza surveillance was specifically mentioned in 13/15 countries/territories) and infectious gastrointestinal illness indicators were described in 13/15 countries/territories (**Table 2-2**).

The development and application of non-infectious syndromic indicators was also reported, particularly for the impact of weather events (storms/hurricanes – chiefly in the USA and hot (6/15) and cold (5/15) weather); injury surveillance (4/15); impact of alcohol (4/15) and drugs (2/15; **Table 2-2**).

Table 2-2: Summary of emergency department syndromic surveillance systems (EDSyS) included in the review, by country/territory, with source and format of information used to define syndromic indicators and of areas of public health surveillance supported the EDSyS.

Country/ territory	Syndromic indicator		Infectious diseases			Extreme weather		Other non-infectious		
	Source*	Format	Respiratory	Influenza	Gastrointestinal	Heat	Cold	Injury/trauma	alcohol	drug
Albania	diagnosis	coded	✓	✓	✓	-	-	-	-	-
Australia	diagnosis	coded	✓	✓	✓	✓	✓	✓	✓	✓
Canada	chief complaint	text	✓	✓	✓	✓	✓	✓	-	-
China	chief complaint	coded	✓	✓	-	-	-	-	-	-
France	diagnosis	coded	✓	✓	✓	✓	✓	✓	✓	-
Greece	chief complaint	pick list	✓	-	✓	-	-	-	-	-
Italy	chief complaint	text/ coded	✓	✓	✓	-	-	-	-	-
Jamaica	"daily analysed data"		✓	-	✓	✓	-	-	-	-
Republic of Korea	diagnosis	coded	✓	✓	✓	-	-	-	-	-
New Zealand	diagnosis	coded	✓	✓	-	-	-	-	-	-
Singapore	unknown	coded	✓	✓	✓	-	-	-	-	-
Spain	chief complaint	coded	✓	✓	✓	-	-	-	-	-
Taiwan	chief complaint	text/ coded	✓	✓	✓	-	-	-	-	-
UK**	diagnosis	coded	✓	✓	✓	✓	✓	-	✓	-
USA	chief complaint	text	✓	✓	✓	✓	✓	✓	✓	✓

* EDSyS may collect more than one data item for syndromic indicators, but each reported a primary field used as standard
** UK: England & Northern Ireland ✓ relevant EDSyS indicators identified - no relevant EDSyS indicators identified

Indicator mapping

For methods used in the mapping of ED data to syndromic indicators there was an apparent divergence between EDSyS systems based in (or using a surveillance tool developed in) North America and other countries. Non-North American systems primarily use coded diagnosis information (most commonly International Classification of Diseases (ICD) and Snomed CT code sets; **Table 2-2**). Over the time period included in this review there was increasing provision of coding lists adding detail of which diagnoses were selected for the various indicators used in EDSyS systems using coded diagnostic information.

Conversely, EDSyS systems and surveillance tool solutions developed in North America primarily used chief complaints or triage/signs/symptoms collected as text, which is then mapped to syndromic indicators. These fields are cited as being available more closely to real-time than diagnostic coded information, which is often also collected at a later point in time (in ICD code format).[90-96]

The complexity of indicator recognition in a (free) text-based system is much greater than in a coded system. Text-based chief complaint EDSyS systems regularly provided case definitions,[97-101] keywords used (including negations),[99,102-104] or simply described the use of an algorithm (either bespoke,[54] or 'CoCo'[67,76]). Although free text chief complaint data was the primary source of information for the identification of a syndromic indicator, diagnosis data was collected where available and also used to supplement indicator development.[90,104]

Information for public health action

All systems reported the use of EDSyS data to identify and monitor incidents of public health importance. Effective communication is necessary between those administering the surveillance and those responsible for public health action in order for the EDSyS system to enable swift public health action.

EDSyS systems which collected data at a patient level (i.e. not aggregated) were mostly designed and run to collect patient identifiable information (PII; defined here as patient name, date of birth, full postal/zip code or any ID number not unique to the EDSyS system). The use of PII supported local health protection functions through the identification of individual cases or contacts of infectious disease (e.g. gastrointestinal outbreaks,[105-107] measles contact tracing,[108] TB case follow-up[109]). One EDSyS was reported to have the facility to include PII if required, however the use of PII was not routine.[44]

A small number of systems, working at both national (France[110] and UK[111]) and sub-national levels (Canada,[67] Australia[112] and USA[66,112,113]) were specifically stated to be restricted to the collection of non PII data only. The methods for this anonymisation included the use of patient age in years (rather than date of birth) and partial postal/zip codes. The surveillance outputs from these EDSyS systems were reportedly communicated to public health protection colleagues, similar to the non-anonymised systems, although individuals could not be directly identified and followed up from this data source alone.

The methods used to communicate the findings of EDSyS to local public health colleagues ranged from the provision of summary reports[114] to the sharing of line listings of cases.[93,115] In some instances, direct online access to the ED surveillance database or bespoke surveillance dashboards was described as being available to those working in public health.[116-118] The EDSyS systems in France and the UK reported the regular publication of national surveillance findings on publicly available platforms.[111,119]

Cross-system working

EDSyS systems have been developed and implemented separately in multiple locations, however, collaborations between systems for public health risk assessment and investigation purposes have been reported. Within the USA, cross-system collaboration crossing multiple health/government jurisdictions was identified for particular events,[120,121] for increased coverage across sub-national borders[122,123] and in response to an outbreak/incident.[45,124]

These collaborations developed further over time with the move to a single National Syndromic Surveillance Program (NSSP) across the USA (building upon the earlier DiSTRiBute and BioSense systems).[125] The consolidation into NSSP has aided in collaborative working across larger areas of the USA as well as introducing EDSyS where it had not previously been available.[126] This collaboration demonstrated the evolution of locally developed EDSyS systems into a national network.

Examples of public health process research (rather than data combining/sharing) were found across EDSyS in Canada.[127-129] Collaborative working across international borders was identified less often. The Real-time Outbreak Disease Surveillance (RODS) tool had been reported to be used for EDSyS in Canada, Taiwan and USA, however, outside of the USA no international cross-border use of the tool was identified.[130]

A single report of an international cross-EDSyS system collaboration was identified where the impact of poor air quality was examined using EDSyS data from EDSyS systems in France

and the UK.[131] One other instance of potential cross border working was identified, however it relied on a comparison with a bespoke ED data collection, rather than a second syndromic surveillance system.[132]

Evolution

The evolution of EDSyS was a recurring theme of the studies identified. Expanding coverage, improved data quality/completeness and more real-time surveillance have become the norm. Several of the earliest ED systems utilised a 'drop in' surveillance format, requiring relatively labour-intensive manual data collection processes, before the manual transfer of information to a central surveillance point.[30,45]

Developments in technology have facilitated improvements in data collection in EDs and accessibility of the data from the ED clinical patient record. These changes have provided opportunities for EDSyS, allowing extraction of data from EDs with secure and automated processes transferring data to EDSyS databases. These processes in turn require no extra work from data providers. The frequency of collection in these systems varies from 'near real-time' (i.e. the collation and transfer of data on a daily basis[133-135] or more frequently[63,65]), to truly 'real-time' (i.e. data available as entered in the ED system, or very soon after).[67,77,136]

Furthermore, the availability of ED data has further improved as the working practice in the ED has changed to collect electronic clinical information. This change has removed the need to wait for a data entry clerk to enter billing information or even paper-based diagnosis records several days later. These factors increase the potential for diagnosis information to be made available, along with other details such as clinical measurements carried out in the ED.

2.5 Discussion

With the relatively common provision of ED services globally it is therefore unsurprising that EDSyS systems were identified in 15 countries and territories, on four different continents. The earliest EDSyS systems identified in this review were created in 1999 and are some of the first examples of syndromic surveillance in general. However, the references describing these systems (or their use) were not published until several years later. The earliest EDSyS paper identified was published during September 2002,[53] two weeks before the first ISDS conference (which was the US National Syndromic Surveillance Conference at that time).[14]

Historically the threat from bioterrorism provided much impetus as well as funding for the early development of syndromic surveillance, and in particular EDSyS systems.[54,88,89,137,138] The bioterrorism threat has also influenced the need for more timely public health reporting and action, necessitating rapid surveillance activities. Though some EDSyS systems were identified to collect truly real-time data, the majority of EDSyS activities appear to have settled to a daily rhythm of analysis and reporting. The daily time frame is in most instances both necessary and appropriate (simplifying the transfer and storage of data by allowing time for records to be completed during the patient journey through the ED and sent at a time when the local network is less busy, rather than continually updated/refreshing/transmitting) whilst also enabling provision of easily understood and actionable information in a suitable timeframe for action by public health authorities, which do not generally work on a minute-by-minute basis.

EDSyS has been shown to be an effective form of public health surveillance, providing information for action (or even reassurance of no public health impact) across a wide range of situations, both infectious and non-infectious conditions, during seasonal and sporadic events. Although initially largely focused on infectious diseases (particularly influenza) EDSyS has developed to encompass many of the different types of conditions seen and treated in EDs, providing information for public health action. This valuable source of data augments laboratory surveillance of infectious diseases (providing information more quickly than laboratory systems and on those conditions for which a confirmatory test may not be carried out) and extends the ability of public health to identify and respond to non-infectious diseases in a timelier manner than would be possible without EDSyS.

An important feature of the early examples of EDSyS was rapid system establishment to provide valuable public health information for action in preparation for known mass gatherings and/or in response to an outbreak/unanticipated events. These early versions provided the first evidence of the value of EDSyS, whilst highlighting the limitations in terms of the workload and sustainability, particularly of drop-in systems. Technological and working practice developments within EDs, which have occurred for patient care purposes (particularly the immediate collection and storage of electronic patient records), have enabled developments in the automation of secure data collection and transfer for EDSyS purposes. The greater opportunity for secure automated data collection has made EDSyS data collection easier and more sustainable.

As a result, EDSyS systems are developing rapidly and largely in the same direction: utilising electronic patient ED records which are completed immediately and can be made available for public health surveillance rapidly. The observed dichotomy between systems utilising either chief complaint or coded diagnosis data may become less distinct in future. EDSyS systems may base their indicators primarily on either diagnosis codes or chief complaints, however, in practice they generally collect both data fields when they are available. With coded diagnosis data being made available more quickly and methods for working with text based chief complaint data becoming more mainstream, the use of both chief complaint and coded diagnosis data to group clinical encounters/episodes into syndromic indicators is likely to become standard. Additional detail may also be added as appropriate, such as clinical measurements e.g. body temperature.

It is important to acknowledge that while EDSyS systems comprise some of the earliest examples of syndromic surveillance systems, there are examples of other morbidity sentinel surveillance networks that were operational decades before EDSyS. Sentinel surveillance systems such as the Royal College of General Practitioners Weekly Returns Service (England) and the French 'Réseau Sentinelles' physician network have been collecting weekly returns of community-based morbidity data using semi-automated methods since 1966 and 1984 respectively.[139,140]

Strengths and limitations of this review

Through the identification and interrogation of both journal articles and abstracts/papers from syndromic surveillance themed conferences, we were able to identify a large number of EDSyS systems, in more countries/territories than would have been possible from journal articles alone. The exclusion of non-English language publications may still have limited the findings of this review. Other novel descriptions of EDSyS systems, such as websites and reports are also likely to have added further detail, though may not be searchable in a systematic manner.

As the terminology for healthcare provision is not globally standardised this review relied on the identification of studies including the term 'emergency' (while allowing for global variation with the addition of room/department/care) or an indication of data collected during unscheduled emergency hospital care (such as triage) in the title and/or abstract. In the absence of these terms any other EDSyS that is described as 'hospital' based syndromic surveillance systems will have been excluded. Furthermore, the description of EDSyS in the literature is occasionally obscured by the use of names of syndromic surveillance systems

and tools in titles and abstracts, rather than explicitly describing the use of data from an ED source. These difficulties may be due to the surveillance system being reported collecting data from a range of sources. Several syndromic surveillance systems collect data from multiple data sources (e.g. ambulance call outs, poison centre calls, and/or over the counter sales), with analysis and interpretation on a whole system basis, rather than a single data source. We are aware that a number of references excluded during the identification phase of this review were indeed related to EDSyS, but did not include any term related to the ED in the title or abstract, instead relying on the reader being familiar with the system name (e.g. ESSENCE or RODS both of which were described elsewhere in references used in this review).

The level of information available in conference abstracts in particular was minimal in some cases, providing little detail other than an EDSyS system existed. These references instead focused on a research question (such as a natural language processing algorithm, or a statistical technique). Discussion of research in both conferences and the published literature is important, however the day-to-day working and the value added to public health by EDSyS was less obvious. The inclusion of multiple information sources for each EDSyS when found (both research papers and conference abstracts), allowed the available information to be pieced together, filling in gaps where possible.

In those countries with large numbers of standalone EDSyS systems, e.g. Canada and USA, there is potential for this review to have incorrectly estimated the number of EDSyS systems, as not all have been described individually. The evolution of systems over time with occasional overlap/merging of once separate systems, or addition of new national surveillance layers above what may still remain as stand-alone systems locally is, however an encouraging sign that EDSyS continues to be used and developed. Geographical (and population) coverage is increasing, aiding in both the developments of systems themselves, but importantly increasing the potential to achieve the primary aim of providing information for public health action.

Finally, it is inevitable that between the execution of this review and the peer review publishing of results there will have been further developments or significant events in the field that the review does not capture, for example the COVID-19 pandemic. Whilst this can't be avoided, we acknowledge that the EDSyS systems included in this systematic review will not capture all systems in operation at the time of publication. Reviews of this kind require continual updating to remain timely and representative.

Future work and developments

This review provides a pragmatic exploration and description of international EDSyS, giving some insight into where, and how, it has been used and how systems have evolved over time. A previous review focussed solely on the use of EDSyS for influenza surveillance.[10] Similar detailed reviews may be useful for the description of other syndromic indicators or even the statistical methods in use or even those proposed for or discounted from use in future.

Increased sharing of indicator detail (diagnosis coding lists/algorithms for free text processing) will enable syndromic surveillance systems to learn from each other. Further developments in the standardisation of, and increased breadth of, information available from electronic patient records and real-time entry of data into the ED patient record are allowing for additional, more granular detail to be made available in (near) real-time for surveillance purposes. The collection of patient observation details, particularly temperature, has been discussed for the more reliable identification of patients attending ED with a clinical fever (rather than self-reported).[141] Future exploration into the use of combinations of data fields from the ED patient care record (e.g. diagnosis/chief complaint/tests and measurements) for the identification of syndromic indicators should be carried out to utilise and expand on the experience gained through the past 20 years of EDSyS globally.

Artificial intelligence (AI) and deep machine learning are exciting areas of development within syndromic surveillance. These methods have the potential to improve analysis tools, detection algorithms and syndromic surveillance activities in general. However, because of the relatively recent advent of these technologies they have not been included in this systematic review. A further review of the application of AI and deep machine learning in syndromic surveillance would be an interesting and relevant addition to this field. Furthermore, the timing of this review has precluded the COVID-19 pandemic, which has further highlighted the importance of EDSyS.[142,143] It will be important to undertake a future systematic review of EDSyS in the aftermath of COVID-19 to assess changes to EDSyS globally and how systems were used in response to the pandemic.[144]

The monitoring of syndromic indicators of public health importance is effective and, in some situations, provides the only real-time method for monitoring rapidly evolving events. The identification of similarities between EDSyS systems presents opportunities for harmonisation and collaboration in future. The USA has developed NSSP,[125] there has been

an investigation of cross-border working in Europe with the Triple S project[145] and the first examples of multi country, multi EDSyS analysis in France and the UK.[146,147]

Infectious and of non-infectious disease events of public health importance do not respect geopolitical borders. Additionally, patients may cross these borders when seeking/receiving health care. Countries with linked and unified health information systems have a major advantage for EDSyS system development, but unified systems are rarely applied across borders. Therefore, cross-border cooperation is a vital and necessary development for EDSyS and wider syndromic surveillance. International cooperation and collaborations to oversee a coordinated syndromic surveillance approach would strengthen public health surveillance. The ISDS developed such a model providing a much-needed international forum for sharing and discussing ED syndromic surveillance, as evidenced by the number of EDSyS identified from conference abstracts (including several not identifiable elsewhere in the literature). However, during 2019 a loss of funding resulted in the dissolution of ISDS: the field of syndromic surveillance has since missed the leadership of ISDS, particularly during the COVID-19 pandemic. The 'Triple-S' program also sought a programme of syndromic surveillance standardisation across Europe, however, without ongoing funding this initiative was not sustained. However, the trans-European system EUROMOMO demonstrates a positive example of sustained cross-border surveillance of mortality data across Europe illustrating the benefits of such networks.[148] The field of syndromic surveillance would benefit again from such international collaborative programmes.

2.6 Conclusions

This systematic review included 559 studies describing 115 EDSyS systems across 15 countries/territories. EDSyS was found to provide a valuable tool for the identification and monitoring of trends in those seeking care within the ED setting, for both infectious and non-infectious disease. Although individual EDSyS systems have been developed independently across various geographies in multiple countries/territories, many similarities were identified with opportunities for cross-system learning. There is potential for further system developments, collaborative working and even harmonisation between systems in future. This review provides the first description of EDSyS globally and reveals how ED clinical system evolution has provided the potential for future growth of EDSyS, both geographically and in the development and refinement of surveillance tools for new and existing areas of public health concern.

2.7 Declarations

Ethics approval and consent to participate

Not required

Consent for publication

Not required

Availability of data and materials

Data sharing is not applicable to this article, however the full list of 558 studies included in this review (presented by individual system, detailing the geography, coverage, timing and reference type for each) is given in **Appendix A**.

Competing interests

None reported

Funding

HEH, OE, RV and AJE receive support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Gastrointestinal Infections. AJE receives support from the NIHR HPRU in Emergency Preparedness and Response. The views expressed are those of the author(s) and not necessarily those of the NIHR, Public Health England or the Department of Health and Social Care.

The funding body was not involved in the design of the study, the collection, analysis or interpretation of data, or the writing of the manuscript.

Authors' contributions

HEH: study design, data preparation, drafted the manuscript, critical revision and final approval of the manuscript

OE: study design, data preparation, critical revision and final approval of the manuscript

AJE: study design, critical revision and final approval of the manuscript

RV: Study design, critical revision and final approval of the manuscript

SJOB: Study design, critical revision and final approval of the manuscript

All authors have read and approved the manuscript.

Acknowledgements

We thank Catherine Tong (International Society for Disease Surveillance) for providing conference abstracts from the 2009 ISDS conference, for which no online archive was

available. HEH, RV and AJE receive support from the National Institute for Health Research (NIHR) Health Protection Research Unit (HPRU) in Gastrointestinal Infections.

2.8 References

1. Heffernan R, Mostashari F, Das D, et al. New York City Syndromic Surveillance Systems. MMWR: Morbidity & Mortality Weekly Report, 2003:25-27.

2. Henning KJ. What is Syndromic Surveillance? MMWR: Morbidity & Mortality Weekly Report: Centers for Disease Control & Prevention (CDC), 2003:7-11.

3. Charles-Smith LE, Reynolds TL, Cameron MA, et al. Using Social Media for Actionable Disease Surveillance and Outbreak Management: A Systematic Literature Review. *PLOS ONE* 2015;10(10):e0139701. doi: 10.1371/journal.pone.0139701

4. Polgreen PM, Chen Y, Pennock DM, et al. Using Internet Searches for Influenza Surveillance. *Clinical Infectious Diseases* 2008;47(11):1443-48. doi: 10.1086/593098 %J Clinical Infectious Diseases

5. Ginsberg J, Mohebbi MH, Patel RS, et al. Detecting influenza epidemics using search engine query data. *Nature* 2009;457(7232):1012-14. doi: 10.1038/nature07634

6. Harcourt SE, Smith GE, Hollyoak V, et al. Can calls to NHS Direct be used for syndromic surveillance? *Communicable disease and public health / PHLS* 2001;4(3):178-82.

7. Ma T, Englund H, Bjelkmar P, et al. Syndromic surveillance of influenza activity in Sweden: an evaluation of three tools. *Epidemiology and infection* 2015;143(11):2390-98. doi: 10.1017/S0950268814003240

8. Smith G, Hippisley-Cox J, Harcourt S, et al. Developing a national primary care-based early warning system for health protection--a surveillance tool for the future? Analysis of routinely collected data. *Journal of Public Health (Oxford)* 2007;29(1):75-82. doi: 10.1093/pubmed/fdl078

9. Gault G, Larrieu S, Durand C, et al. Performance of a syndromic system for influenza based on the activity of general practitioners, France. *Journal of Public Health* 2009;31(2):286-92. doi: 10.1093/pubmed/fdp020 %J Journal of Public Health

10. Hiller KM, Stoneking L, Min A, et al. Syndromic surveillance for influenza in the emergency department - a systematic review. *PLoS ONE* 2013;8(9):e73832.

11. Moher D, Liberati A, Tetzlaff J, et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLOS Medicine* 2009;6(7):e1000097. doi: 10.1371/journal.pmed.1000097

12. PROSPERO. Centre for Reviews and Dissemination, University of York.[Available from: https://www.crd.york.ac.uk/PROSPERO/ Accessed: Access Date 11 Feb 2020].

13. International Society for Disease Surveillance Conference 2010. Emerging Health Threats Journal; 2010 2011; Park City, Utah Accessed: 11 Feb 2020].

14. National Syndromic Surveillance Conference 2002. Journal of Urban Health; 2002; New York, New York. Journal of Urban Health.[Available from: https://link.springer.com/journal/11524/80/1/suppl/page/1 Accessed: 11 Feb 2020].

15. National Syndromic Surveillance Conference 2003. MMWR; 2003; New York, New York. MMWR.[Available from: https://www.cdc.gov/mmwr/preview/ind2004_su.html Accessed: 11 Feb 2020].

16. Syndromic Surveillance Conference 2004. MMWR; 2004; Boston, Massachusetts. MMWR.[Available from: https://www.cdc.gov/mmwr/preview/ind2005_su.html Accessed: 11 Feb 2020].

17. Syndromic Surveillance Conference 2005. Advances in Disease Surveillance; 2005 2006; Seattle, Washington.[Available from: http://faculty.washington.edu/lober/www.isdsjournal.org/htdocs/volume1.php Accessed: 11 Feb 2020].

18. Conference of the International Society for Disease Surveillance 2006. Advances in Disease Surveillance; 2006.[Available from: http://faculty.washington.edu/lober/www.isdsjournal.org/htdocs/archives.php Accessed: 11 Feb 2020].

19. Conference of the International Society for Disease Surveillance 2007. Advances in Disease Surveillance; 2007; Indianapolis, Indiana.[Available from: http://faculty.washington.edu/lober/www.isdsjournal.org/htdocs/archives.php Accessed: 11 Feb 2020].

20. Conference of the International Society for Disease Surveillance 2008. Advances in Disease Surveillance; 2008; Raleigh, North Carolina.[Available from: http://faculty.washington.edu/lober/www.isdsjournal.org/htdocs/archives.php Accessed: 11 Feb 2020].

21. International Society for Disease Surveillance 10th Annual Conference 2011. Emerging Health Threats; 2011; Atlanta, Georgia.[Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3261719/ Accessed: 11 Feb 2020].

22. 2012 ISDS Conference. Online Journal of Public Health Informatics; 2012; San Diego, California.[Available from: https://ojphi.org/ojs/index.php/ojphi/issue/view/382 Accessed: 11 Feb 2020].

23. 2013 ISDS Conference. Online Journal of Public Health Informatics; 2013; New Orleans, Louisiana.[Available from: https://ojphi.org/ojs/index.php/ojphi/issue/view/413 Accessed: 11 Feb 2020].

24. 2014 ISDS Conference. Online Journal of Public Health Informatics; 2014; Philadelphia, Pennsylvania.[Available from: https://ojphi.org/ojs/index.php/ojphi/issue/view/438 Accessed: 11 Feb 2020].

25. 2015 International Society for Disease Surveillance Conference. Online Journal of Public Health Informatics; 2015; Denver, Colorado.[Available from: https://ojphi.org/ojs/index.php/ojphi/issue/view/471 Accessed: 11 Feb 2020].

26. 2016 International Society for Disease Surveillance Conference. Online Journal of Public Health Informatics; 2016; Atlanta, Georgia.[Available from: https://ojphi.org/ojs/index.php/ojphi/issue/view/7791 Accessed: 11 Feb 2020].

27. Covidence [program]: Covidence, Melbourne, Australia.

28. Kaydos-Daniels SC, Rojas Smith L, Farris TR. Biosurveillance in outbreak investigations. *Biosecurity and bioterrorism : biodefense strategy, practice, and science* 2013;11(1):20-28. doi: 10.1089/bsp.2011.0109

29. Buckeridge DL. Outbreak detection through automated surveillance: a review of the determinants of detection. *Journal of Biomedical Informatics* 2007;40(4):370-79.

30. Lober WB, Baer A, Karras BT, et al. Collection and integration of clinical data for surveillance. *Medinfo MEDINFO* 2004;11:1211-15.

31. Chapman WW, Christensen LM, Wagner MM, et al. Classifying free-text triage chief complaints into syndromic categories with natural language processing. *Artificial intelligence in medicine* 2005;33(1):31-40. doi: 10.1016/j.artmed.2004.04.001

32. Johnson J, McClean C, Poggemeyer K, et al. Application of bioterrorism surveillance methods in San Diego County. Journal of Urban Health, 2002:i137.

33. Vaughan-Batten H, Deyneka L, Ising A, et al. Data requests for research: best practices based on the North Carolina DETECT experience. Emerging Health Threats Journal, 2011:153.

34. Betancourt JA, Hakre S, Polyak CS, et al. Evaluation of ICD-9 codes for syndromic surveillance in the Electronic Surveillance System for the Early Notification of Community-based Epidemics. *Military Medicine* 2007;172(4):346-52.

35. Vilain P, Larrieu S, Mougin-Damour K, et al. Emergency department syndromic surveillance to investigate the health impact and factors associated with alcohol intoxication in Reunion Island. *Emergency medicine journal : EMJ* 2017;34(6):386-90. doi: 10.1136/emermed-2015-204987

36. Morbey RA, Elliot AJ, Charlett A, et al. Using public health scenarios to predict the utility of a national syndromic surveillance programme during the 2012 London Olympic and Paralympic Games. *Epidemiology and Infection* 2014;142(5):984-93.

37. Wu T-SJ, Shih F-YF, Yen M-Y, et al. Establishing a nationwide emergency department-based syndromic surveillance system for better public health responses in Taiwan. *BMC public health* 2008;8:18. doi: 10.1186/1471-2458-8-18

38. Pontais I, Bousquet V, Ruello M, et al. Factors Influencing the Stability and Quality of the French ED Surveillance System. Online Journal of Public Health Informatics 2016; Vol 8, No 1, 2015:e153.

39. Aung M. Syndromic Surveillance In Major Sporting Event - Jamaican Experience. Advances in Disease Surveillance 2007:144.

40. Dafni UG, Tsiodras S, Panagiotakos D, et al. Algorithm for statistical detection of peaks--syndromic surveillance system for the Athens 2004 Olympic Games. MMWR Morbidity and mortality weekly report, 2003:86-94.

41. Fleischauer AT, Silk BJ, Schumacher M, et al. The validity of chief complaint and discharge diagnosis in emergency department-based syndromic surveillance. *Academic Emergency Medicine* 2004;11(12):1262-67.

42. Goss L, Carrico R, Hall C, et al. A day at the races: Communitywide syndromic surveillance during the 2002 Kentucky Derby Festival. Journal of Urban Health, 2002:i124-i24.

43. Cookson ST, Buehler JW, Lance SE. Georgia's Strategy for Targeting Syndromic Surveillance. Advances in Disease Surveillance 2005:16.

44. Muscatello DJ, Churches T, Kaldor J, et al. An automated, broad-based, near real-time public health surveillance system using presentations to hospital Emergency Departments in New South Wales, Australia. *BMC Public Health* 2005;5(141) doi: https://doi.org/10.1186/1471-2458-5-141

45. Foldy SL, Barthell E, Silva J, et al. SARS Surveillance Project -- Internet-Enabled Multiregion Surveillance for Rapidly Emerging Disease. MMWR: Morbidity & Mortality Weekly Report, 2003:215-20.

46. King C-C, Shih F-Y, Yen M-Y, et al. Syndromic Surveillance of Infectious Diseases in Taiwan — Before and After the Challenges of Severe Acute Respiratory Syndrome (SARS). MMWR: Morbidity & Mortality Weekly Report, 2003:245.

47. Qian YH, Su J, Shi P, et al. Attempted early detection of influenza A (H1N1) pandemic with surveillance data of influenza-like illness and unexplained pneumonia. *Influenza Other Respir Viruses* 2011;5(6):e479-86. doi: 10.1111/j.1750-2659.2011.00248.x

48. Das D, Weiss D, Mostashari F, et al. Enhanced drop-in syndromic surveillance in New York City following September 11, 2001. *Journal of Urban Health* 2003;80:i76-i88.

49. Stoto MA, Jain A, Griffin BA, et al. Evaluation of the DC Department of Health's Syndromic Surveillance System. Advances in Disease Surveillance 2006:213.

50. Hamby T, Tsai S, McHugh L. Surveillance in New Jersey*from anthrax to automation. Emerging Health Threats Journal, 2011:70.

51. Swenson D, Zhang X, Miller S, et al. Ten years of syndromic surveillance in New Hampshire: innovation, experience and outcomes. Emerging Health Threats Journal, 2011:148.

52. Josseran L, Gailhard I, Eboumbou B, et al. Syndromic Surveillance, The First French Experience. Advances in Disease Surveillance 2005:37.

53. Syndromic Surveillance for Bioterrorism Following the Attacks on the World Trade Center -- New York City, 2001. *MMWR: Morbidity & Mortality Weekly Report* 2002;51:13-15.

54. Heffernan R, Mostashari F, Das D, et al. Syndromic surveillance in public health practice, New York City. *Emerging Infectious Diseases* 2004;10(5):858-64.

55. Fouillet A, Bousquet V, Pontais I, et al. The French Emergency Department OSCOUR Network: Evaluation After a 10-year Existence. Online Journal of Public Health Informatics 2015; Vol 7, No 1.

56. McLeod M, White P, Read D, et al. The 2005 Wellington influenza outbreak: Syndromic surveillance of Wellington Hospital Emergency Department activity may have provided early warning. *Australian and New Zealand Journal of Public Health* 2009;33(3):289-94. doi: 10.1111/j.1753-6405.2009.00391.x

57. Ahn S, Lee JH, Kim W, et al. Analysis of the korean emergency department syndromic surveillance system: mass type acute diarrheal syndrome. *Healthcare informatics research* 2010;16(3):177-84. doi: 10.4258/hir.2010.16.3.177

58. Hope K, Merritt T, Eastwood K, et al. The public health value of emergency department syndromic surveillance following a natural disaster. *Communicable diseases intelligence* 2008;32(1):92-94.

59. Sheline KD. Evaluation of the Michigan Emergency Department Syndromic Surveillance System Advances in Disease Surveillance 2007:265.

60. Wade M, Gibson J, Dearth S, et al. Operational Considerations and Early Successes with a Statewide Public Health Surveillance System. Advances in Disease Surveillance 2006:123.

61. Purviance KM, Siniscalchi AJ, Hadler JL. Use of the Connecticut Emergency Department Syndromic Surveillance System for Situational Awareness During Public Health Events. Advances in Disease Surveillance 2008:125.

62. Hamby T, Tsai S, Genese C, et al. Paralysis Analysis: Investigating Paralysis Visit Anomalies in New Jersey. Online Journal of Public Health Informatics 2013; Vol 5, No 1, 2012:e126.

63. Hope KG, Merritt TD, Durrheim DN, et al. Evaluating the utility of Emergency Department syndromic surveillance for a regional public health service. *Communicable Diseases Intelligence* 2010;34(3):310-18.

64. Borjan M, Lumia M. Evaluation of a state based syndromic surveillance system for the classification and capture of non-fatal occupational injuries and illnesses in New Jersey. *American journal of industrial medicine* 2017;60(7):621-26. doi: 10.1002/ajim.22734

65. Hibler E, Trepanier D, Wade M. Expanding the Functionality of Syndromic Surveillance Systems: Data Mining and Query Development Advances in Disease Surveillance 2006:106.

66. Lombardo J, Burkom H, Elbert E, et al. A systems overview of the electronic surveillance system for the Early Notification of Community-Based Epidemics (ESSENCE II). *Journal of Urban Health* 2003;80:i32-i42.

67. Moore KM, Edgar BL, McGuinness D. Implementation of an automated, real-time public health surveillance system linking emergency departments and health units: rationale and methodology. *CJEM: Canadian Journal of Emergency Medicine* 2008;10(2):114-19.

68. Hutwagner L, Thompson W, Seeman GM, et al. The bioterrorism preparedness and response Early Aberration Reporting System (EARS). Journal of Urban Health, 2002:i89-i96.

69. SaTScan [program]: SaTScan, Boston, USA.

70. Morbey RA, Elliot AJ, Charlett A, et al. The application of a novel 'rising activity, multi-level mixed effects, indicator emphasis' (RAMMIE) method for syndromic surveillance in England. *Bioinformatics* 2015;31(22):3660-65. doi: 10.1093/bioinformatics/btv418

71. Mathes RW, Lall R, Levin-Rector A, et al. Evaluating and implementing temporal, spatial, and spatio-temporal methods for outbreak detection in a local syndromic surveillance system. *PLoS ONE* 2017;12(9):e0184419.

72. Xing J, Burkom H, Tokars J. Method selection and adaptation for distributed monitoring of infectious diseases for syndromic surveillance. *Journal of Biomedical Informatics* 2011;44(6):1093-101.

73. VanStone N, van Dijk A, Chisamore T, et al. Characterizing the Effects of Extreme Cold Using Real-time Syndromic Surveillance, Ontario, Canada, 2010-2016. *Public Health Reports* 2017;132:48S. doi: 10.1177/0033354917708354

74. Kass-Hout TA, Xu Z, McMurray P, et al. Application of change point analysis to daily influenza-like illness emergency department visits. *Journal of the American Medical Informatics Association* 2012;19(6):1075-81. doi: 10.1136/amiajnl-2011-000793

75. Griffin BA, Jain AK, Davies-Cole J, et al. Early detection of influenza outbreaks using the DC Department of Health's syndromic surveillance system. *BMC public health* 2009;9:483.

76. Hafen RP, Anderson DE, Cleveland WS, et al. Syndromic surveillance: STL for modeling, visualizing, and monitoring disease counts. *BMC medical informatics and decision making* 2009;9:21. doi: 10.1186/1472-6947-9-21

77. Zou J, Karr AF, Datta G, et al. A Bayesian spatio-temporal approach for real-time detection of disease outbreaks: A case study. *BMC Medical Informatics and Decision Making* 2014;14(1) doi: 10.1186/s12911-014-0108-4

78. Sparks R, Carter C, Graham P, et al. Understanding sources of variation in syndromic surveillance for early warning of natural or intentional disease outbreaks. *IIE Transactions (Institute of Industrial Engineers)* 2010;42(9):613-31. doi: 10.1080/07408170902942667

79. McClean C, Johnson J, Colanter B, et al. Too Many Signals? Frequency and Quantitative Descriptions of Detected Events Advances in Disease Surveillance 2005:49.

80. Zhang G, O'Connell E, Leguen F, et al. Use of Epidemiological Knowledge to Create Syndromic Surveillance Reports. Advances in Disease Surveillance 2007:211.

81. Goranson C, K T, T T, et al. Cluster Detection Comparison in Syndromic Surveillance Advances in Disease Surveillance 2008:33.

82. Xing J, Burkom H, Tokars J. Comparison of Regression Models with Modified Time Series Methods for BioSurveillance. Advances in Disease Surveillance 2008:72.

83. Mathes R, Sell J, Tam AW, et al. Building a Better Syndromic Surveillance System: the New York City Experience. Online Journal of Public Health Informatics 2015; Vol 7, No 1, 2014:e39.

84. Sharip A, Monroe J, Croker C, et al. Preliminary Analysis of SaTScan's Effectiveness to Detect Known Disease Outbreaks Using Emergency Department Syndromic Data in Los Angeles County. Advances in Disease Surveillance 2005:83.

85. Chang H-G, Chen J-H, Cochrane DG, et al. A Pilot Study of Aberration Detection Algorithms with Simulated Data. Advances in Disease Surveillance 2007:240.

86. Konty K, Olson D. The spatial-temporal pattern of excess influenza visits at the (sub-)urban scale. Emerging Health Threats Journal, 2010:**s35**.

87. Green K, Miller B, Hadidi M, et al. Dual-Model Approach to Syndromic Surveillance Using Hospital Emergency Department Data. MMWR: Morbidity & Mortality Weekly Report, 2003:242.

88. Ayala A, Berisha V, Goodin K, et al. Public health surveillance strategies for mass gatherings: Super Bowl XLIX and related events, Maricopa County, Arizona, 2015. *Health Security* 2016;14(3):173-84.

89. Kajita E, Luarca MZ, Wu H, et al. Harnessing Syndromic Surveillance Emergency Department Data to Monitor Health Impacts During the 2015 Special Olympics World Games. *Public Health Reports* 2017;132(1):99s-105s. doi: 10.1177/0033354917706956

90. Ising A, Proescholdbell S, Harmon KJ, et al. Use of syndromic surveillance data to monitor poisonings and drug overdoses in state and local public health agencies. *Injury Prevention (1353-8047)* 2016;22:i43–i49. doi: 10.1136/injuryprev-2015-041821

91. Williams KA, Buechner JS. Evaluation of the Rhode Island Real-time Outbreak and Disease Surveillance (RI RODS) System: Disparate Data. Advances in Disease Surveillance 2006:219.

92. Ratcliffe A, Barnett C, Ising A, et al. Evaluating the Validity of ED Visit Data for Biosurveillance Advances in Disease Surveillance 2008:57.

93. Harduar Morano L, Waller AE. Evaluation of the Components of the North Carolina Syndromic Surveillance System Heat Syndrome Case Definition. *Public Health Reports* 2017;132(1):40S-47S. doi: 10.1177/0033354917710946

94. MacFarquhar J, Sickbert-Bennett E, Waller A, et al. Evolution of a Syndromic Surveillance Case Definition. Advances in Disease Surveillance 2005:46.

95. Martin C, Tokars J, Fowlkes A, et al. Use of Final Diagnosis Data for Surveillance of Respiratory Syncytial Virus Advances in Disease Surveillance 2007:176.

96. Podgornik MN, English R, Tokars JI. Correlation between Real-Time BioSense Influenza Indicators and Data from the U.S. Influenza Sentinel Physicians Surveillance Network Advances in Disease Surveillance 2007:109.

97. Simaku A, Ulqinaku D, Hatibi I, et al. Syndromic surveillance for detection of influenza in Albania. *Albanian Journal of Agricultural Sciences* 2014;13(1):16-21.

98. Ansaldi F, Orsi A, Altomonte F, et al. Syndrome surveillance and molecular epidemiology for early detection and tracing of an outbreak of measles in Liguria, Italy. *Journal of Medical Virology* 2009;81(10):1807-13.

99. Guasticchi G, Giorgi Rossi P, Lori G, et al. Syndromic surveillance: Sensitivity and positive predictive value of the case definitions. *Epidemiology and Infection* 2009;137(5):662-71. doi: 10.1017/S0950268808001374

100. Schrell S, Ziemann A, Garcia-Castrillo Riesgo L, et al. Local implementation of a syndromic influenza surveillance system using emergency department data in Santander, Spain. *Journal of public health (Oxford, England)* 2013;35(3):397-403. doi: 10.1093/pubmed/fdt043

101. Savard N, Bédard L, Allard R, et al. Using age, triage score, and disposition data from emergency department electronic records to improve Influenza-like illness surveillance. *Journal of the American Medical Informatics Association : JAMIA* 2015;22(3):688-96. doi: 10.1093/jamia/ocu002

102. Seil K, Marcum J, Lall R, et al. Utility of a near real-time emergency department syndromic surveillance system to track injuries in New York City. *Injury epidemiology* 2015;2(1):11.

103. Ansaldi F, Orsi A, Altomonte F, et al. Emergency department syndromic surveillance system for early detection of 5 syndromes: a pilot project in a reference teaching hospital in Genoa, Italy. *Journal of preventive medicine and hygiene* 2008;49(4):131-35.

104. Tsai S, Hamby T, Chu A, et al. Development and Application of Syndromic Surveillance for Severe Weather Events Following Hurricane Sandy. *Disaster medicine and public health preparedness* 2016;10(3):463-71. doi: 10.1017/dmp.2016.74

105. Hines JZ, Bancroft J, Powell M, et al. Case Finding Using Syndromic Surveillance Data During an Outbreak of Shiga Toxin--Producing Escherichia coli O26 Infections, Oregon, 2015. *Public Health Reports* 2017;132(4):448-50. doi: 10.1177/0033354917708994

106. Murray EL, Heffernan R, Yeung A, et al. Use of Syndromic Surveillance in the Investigation of Salmonella wandsworth Outbreak. Advances in Disease Surveillance 2007:180.

107. Brown H, Romanosky A, Aslam S, et al. Early Identification of Salmonella Cases Using Syndromic Surveillance Advances in Disease Surveillance 2008:94.

108. Sikora C, Fournier K, Usman H, et al. Rapid Measles Exposure Assessment in an Urban Emergency Department Using a Syndromic Surveillance System. Online Journal of Public Health Informatics 2014; Vol 6, No 1, 2013:e161.

109. Wiese M, Atrubin D, McDougle W, et al. Effectiveness of Using a Chief Complaint and Discharge Diagnosis Query in ESSENCE-FL to Identify Possible Tuberculosis Patients and Contacts in Hillsborough County, Florida. Online Journal of Public Health Informatics 2014; Vol 6, No 1, 2013:e36.

110. Noel G, Viudes G, Laporte R, et al. Evaluation of the impact of pneumococcal conjugate vaccine on pediatric community-acquired pneumonia using an emergency database system. *Journal of the Pediatric Infectious Diseases Society* 2017;6(2):129-33. doi: 10.1093/jpids/piw019

111. Elliot AJ, Hughes HE, Hughes TC, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic

Games. *Emergency medicine journal : EMJ* 2012;29(12):954-60. doi: 10.1136/emermed-2011-200684

112. Mohlenbrock WC, Rogers RF. Multi-Agency and Hospital, Syndromic Surveillance System in Montana Advances in Disease Surveillance 2008:46.

113. Kniss K, Benoit S, McIntyre A, et al. Comparison of Distribute and ILINet for national influenza surveillance. Emerging Health Threats Journal, 2010:s135.

114. Viola R, Luarca MZ, Kajita E, et al. Monitoring the 2016 LA County Sand Fire with Multiple Early Detection Systems. Online Journal of Public Health Informatics 2017; Vol 9, No 1, 2016:e135.

115. Lall R, Abdelnabi J, Ngai S, et al. Advancing the Use of Emergency Department Syndromic Surveillance Data, New York City, 2012-2016. *Public Health Reports* 2017;132(1) doi: 10.1177/0033354917711183

116. Ising A, Li M, Deyneka L, et al. Improving syndromic surveillance for nonpower users: NC DETECT dashboards. Emerging Health Threats Journal, 2011:75.

117. Foldy SL, Biedrzycki PA, Baker BK, et al. The Public Health Dashboard: a surveillance model for bioterrorism preparedness. *Journal of Public Health Management & Practice* 2004;10(3):234-40.

118. Kite-Powell A, Hamilton J, Wojcik R, et al. Florida's ESSENCE systemFfrom syndromic surveillance to routine epidemiologic analysis across syndromic and non-syndromic data sources. Emerging Health Threats Journal, 2010:s89.

119. Josseran L, Fouillet A, Caillère N, et al. Assessment of a syndromic surveillance system based on morbidity data: results from the Oscour network during a heat wave. *PLoS ONE* 2010;5(8):e11984. doi: 10.1371/journal.pone.0011984

120. Sniegoski C, Loschen W, Dearth S, et al. Super Bowl Surveillance: A Practical Exercise in Inter-Jurisdictional Public Health Information Sharing. Advances in Disease Surveillance 2007:195.

121. Jagger MA, Jaramillo S, Boyd L, et al. Mass Gathering Surveillance: New ESSENCE Report and Collaboration Win Gold in OR. Online Journal of Public Health Informatics 2017; Vol 9, No 1, 2016:e133.

122. Fowler BE, Wade ME, Campbell RJ, et al. Enhancing Syndromic Surveillance through Cross-border Data Sharing. Advances in Disease Surveillance 2008:31.

123. Marsden-Haug N, Baer A, Metcalf H, et al. Syndromic Surveillance for Influenza in Washington State: A Local and Regional Perspective. Advances in Disease Surveillance 2007:256.

124. Richardson D, Paladini M, Azarian T, et al. Increased emergency department presentations for head trauma following media coverage of a fatal epidural hematoma. Emerging Health Threats Journal, 2010:s51.

125. Gould DW, Walker D, Yoon PW. The Evolution of BioSense: Lessons Learned and Future Directions. *Public Health Reports* 2017;132(1) doi: 10.1177/0033354917706954

126. Stein ZM. Creation of a Kansas Spring Extreme Weather Syndrome Definition and Unique Records. Online Journal of Public Health Informatics 2017; Vol 9, No 1, 2016:e128.

127. Rivera LA, Li Y, Savage RD, et al. Evaluation of the ability of standardized supports to improve public health response to syndromic surveillance for respiratory diseases in Canada. *BMC public health* 2017;17(1):199. doi: 10.1186/s12889-017-4073-6

128. Chu A, Savage R, Whelan M, et al. Assessing the Relative Timeliness of Ontario's Syndromic Surveillance Systems for Early Detection of the 2009 Influenza H1N1 Pandemic Waves. *Canadian Journal of Public Health* 2013;104(4):340-47.

129. Rivera L, Savage R, Crowcroft N, et al. Characterizing Public Health Actions in Response to Syndromic Surveillance Alerts. Online Journal of Public Health Informatics 2016; Vol 8, No 1, 2015:e34.

130. Krenzelok E, MacPherson E, Mrvos R. Disease surveillance and nonprescription medication sales can predict increases in poison exposure. *Journal of medical toxicology : official journal of the American College of Medical Toxicology* 2008;4(1):7-10. doi: 10.1007/BF03160942

131. Hughes H, Dobney A, Fouillet A, et al. Syndromic surveillance of air pollution incidents across international borders. Online Journal of Public Health Informatics 2017; Vol 9, No 1, 2016:e139.

132. Hoen A, Buckeridge D, Charland K, et al. Effect of expanded recommendations for pediatric seasonal influenza vaccination: an international comparison. Emerging Health Threats Journal, 2010:s85.

133. Mathes RW, Ito K, Lane K, et al. Real-time surveillance of heat-related morbidity: relation to excess mortality associated with extreme heat. *PLoS ONE* 2017;12(9):e0184364.

134. Todkill D, Hughes HE, Elliot AJ, et al. An observational study using English syndromic surveillance data collected during the 2012 London Olympics - what did syndromic surveillance show and what can we learn for future mass-gathering events? *Prehospital and Disaster Medicine* 2016;31(6):628-34. doi: 10.1017/S1049023X16000923

135. Josseran L, Nicolau J, Caillere N, et al. Syndromic surveillance based on emergency department activity and crude mortality: two examples. *Euro surveillance : bulletin europeen sur les maladies transmissibles = European communicable disease bulletin* 2006;11(12):225-29.

136. Fan S, Brown A, Honish L, et al. Enhancing Public Health Surveillance by Using Multiple Data Sources for Syndromic Surveillance: The Alberta Real Time Syndromic Surveillance Net. Advances in Disease Surveillance 2007:161.

137. Franz DR, Jahrling PB, Friedlander AM, et al. Clinical recognition and management of patients exposed to biological warfare agents. *Journal of the American Medical Association* 1997;278(5):399-411. doi: 10.1001/jama.278.5.399

138. Buehler JW, Berkelman RL, Hartley DM, et al. Syndromic surveillance and bioterrorism-related epidemics. *Emerging Infectious Diseases* 2003;9(10):1197-204. doi: 10.3201/eid0910.030231

139. Elliot AJ, Fleming DM. Surveillance of influenza-like illness in England and Wales during 1966-2006. *Euro Surveill* 2006;11(10):249-50.

140. Flahault A, Blanchon T, Dorleans Y, et al. Virtual surveillance of communicable diseases: a 20-year experience in France. *Stat Methods Med Res* 2006;15(5):413-21. doi: 10.1177/0962280206071639

141. Kass-Hout TA, Buckeridge D, Brownstein J, et al. Self-reported fever and measured temperature in emergency department records used for syndromic surveillance. *Journal of the American Medical Informatics Association* 2012;19(5):775-76. doi: 10.1136/amiajnl-2012-000847

142. Hartnett KP, Kite-Powell A, DeVies J, et al. Impact of the COVID-19 Pandemic on Emergency Department Visits - United States, January 1, 2019-May 30, 2020. *MMWR Morb Mortal Wkly Rep* 2020;69(23):699-704. doi: 10.15585/mmwr.mm6923e1

143. Hughes HE, Hughes TC, Morbey R, et al. Emergency department use during COVID-19 as described by syndromic surveillance. *Emergency Medicine Journal* 2020;37(10):600-04. doi: 10.1136/emermed-2020-209980

144. Elliot AJ, Harcourt SE, Hughes HE, et al. The COVID-19 pandemic: a new challenge for syndromic surveillance. *Epidemiol Infect* 2020;148:e122. doi: 10.1017/S0950268820001314

145. Triple S Project. Assessment of syndromic surveillance in Europe. *Lancet* 2011;378(9806):1833-34. doi: 10.1016/S0140-6736(11)60834-9

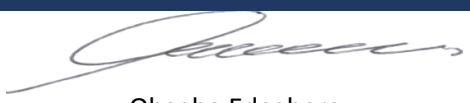
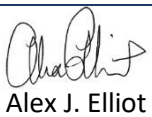
146. Hughes HE, Colon-Gonzalez FJ, Fouillet A, et al. The influence of a major sporting event upon emergency department attendances; A retrospective cross-national European study. *PLoS ONE* 2018;13(6):e0198665. doi: 10.1371/journal.pone.0198665

147. Hughes HE, Morbey R, Fouillet A, et al. Retrospective observational study of emergency department syndromic surveillance data during air pollution episodes across London and Paris in 2014. *BMJ Open* 2018;8:e018732.

148. EuroMOMO. European monitoring of excess mortality for public health action. [Available from: http://www.euromomo.eu/index.html Accessed: 30/03/2017].

2.9 Co-author declaration

I confirm the specific contribution of **Helen Hughes** to this publication is as described in the Authors' contributions statement and give my permission for this paper to be appear in her thesis.

 Obaghe Edeghere	*12/02/2020* Date
 Sarah J. O'Brien	*26/10/2020* Date
 Roberto Vivancos	*12/02/2020* Date
 Alex J. Elliot	*12/02/2020* Date

Chapter 3 Establishing ED syndromic surveillance in England

3.1 Background

As described in **Chapter 2**, ED syndromic surveillance systems had previously been successfully developed outside of the UK, on local, regional and national levels, often in preparation for mass gathering events. The London 2012 Olympic and Paralympic Games (London 2012) involved over 10,000 athletes from 204 countries, a workforce of over 200,000 and media presence of over 21,000 broadcasting to a global audience of 4 billion people. With 8.8 million spectator tickets, along with further non-ticketed events (including marathon and road cycling), London 2012 was a mass gathering on a major scale.[1]

In addition to the delivery of the Games, London 2012 required the provision of an enhanced public health surveillance programme capable of meeting the specialist health needs of a major mass gathering directly involving potentially millions of people, across several months in multiple locations. As discussed in **Chapter 1**, a shortfall in surveillance capability around monitoring severe health outcomes during London 2012 was identified as a potential risk for public health authorities. The Health Protection Agency (now PHE) was tasked with developing a national ED surveillance system to mitigate this risk.

The PHE ED Syndromic Surveillance System (EDSSS) was therefore designed and built as the first national ED surveillance system in the UK, to provide near real-time public health surveillance of patient presentations to EDs. The EDSSS was considered a vital component of the enhanced public health surveillance programme which had to be delivered for London 2012.[2,3]

Emergency care service provision in the United Kingdom

Healthcare in the United Kingdom (UK) has been publicly funded since the 1940s, with control devolved to each individual nation through the National Health Service (NHS) in England, Scotland and Wales,[4,5] and Health and Social Care in Northern Ireland.[6] The general principle for this healthcare provision is the same in each nation: a single payer system, funded through taxation and free at the point of care for all residents. Across the UK all primary care (GP) and hospital services, as well as some dental and ophthalmic services, are provided to residents without fee.[7]

The provision of free health care is extended further in emergency departments (EDs). Emergency care in EDs is available without cost to all those in need, irrespective of residency status. EDs provide a range of services available from different types of department:[8]

- Type 01 EDs are commonly associated with the term 'Emergency Department', a facility led by consultant level medical doctors, available 24 hours a day, 365 days a year, with the facilities and skills to see and treat the most urgent/complex emergencies, including full resuscitation facilities;
- Type 02 EDs are single specialty units (e.g. ophthalmology/dental);
- Type 03 and 04 EDs are equipped to treat less severe illness than a Type 01 ED and may be doctor or nurse led (i.e. walk in and minor injury units).

At the time of the initial development of EDSSS there was no central England (or UK) wide standardisation of ED data collection or storage: different data items were collected and stored in different ways in different EDs. There was a requirement for the central reporting of some ED data for monitoring and payment purposes (in the form of a Commissioning Data Set[9], specifically the now retired CDS 010[10]), made publicly available as monthly total attendances and waiting times reports[11] and annual activity level reports.[12]

No central dataset existed collecting ED data in sufficient detail, or the near real-time timeframe, required for syndromic surveillance. This absence necessitated the development of a new national ED syndromic surveillance network.

3.2 ED surveillance system development

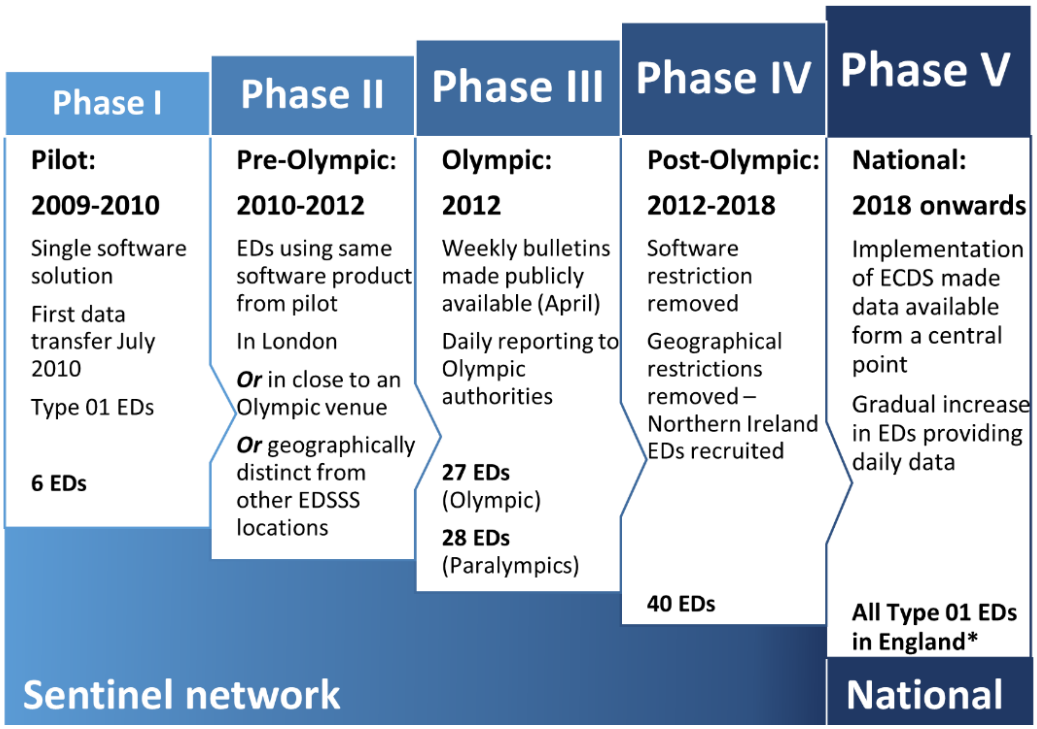
To ensure the successful delivery of EDSSS, meeting the London 2012 deadline, system development was undertaken in a series of phases, over several years (**Figure 3-1**).

An initial pilot provided crucial proof of concept that ED attendance data could be collected from EDs in England, in near real-time, and used for public health surveillance purposes. The first EDs recruited to EDSSS began transmitting daily data in July 2010, 2 years ahead of the 2012 Olympic opening ceremony.

The network was expanded during phase II, specifically targeting EDs using the same patient care record software as the pilot sites and located in London/close to Olympic venues. By the Olympic opening ceremony in July 2012, 27 EDs were reporting to EDSSS on a daily basis. During the Paralympic Games (September 2012) 28 EDs were reporting to

EDSSS. This achievement exceeded the target number of EDs that had been agreed in the project plan for delivering EDSSS for the Games.

Figure 3-1: The five phases of EDSSS development, from initial pilot to national system



*Not all EDs providing daily data as of 28 February 2021

Remaining as an Olympic legacy, EDSSS coverage continued to grow during phase IV. ED recruitment was expanded to include EDs using alternative software solutions and from a wider geographical area. EDs located in Northern Ireland were recruited during phase IV in preparation for large mass gatherings in both Belfast and Londonderry during 2013 (the World police and fire games[13] and the Fleadh Cheoil festival[14]).[2] A total of 40 EDs were recruited to the sentinel EDSSS.

Phase V, the development of a truly national EDSSS, became possible with the introduction of the Emergency Care Data Set (ECDS). This newly developed standard for data collection, storage and daily transfer from all EDs in England to a central repository is described further in **Chapter 8**.

EDSSS technical development

EDs were recruited individually to the sentinel EDSSS (phases I-IV). Each site required formal approval for recruitment and data sharing agreements prior to the technical preparation for the automated transfer of anonymised data each day. These processes

involved up to five different organisations: individual NHS Trusts (the EDs and the hospital system in which they operate), PHE (overall EDSSS management), Royal College of Emergency Medicine (RCEM[15]: initial approach to each ED inviting them to join EDSSS), an external IT service provider (providing secure, automated data extraction across the NHS N3 network) and where appropriate the ED software supplier (for the preparation of data in EDSSS format).

The recruitment of EDs took a varying amount of time. The shortest period between an ED agreeing to participate in EDSSS and data beginning to flow was 56 days. The longest period to successful recruitment was 486 days. The recruitment process was not always successful. A small number of EDs declined the invitation to join EDSSS, while recruitment stalled and was never completed at some EDs.

The introduction of ECDS in EDs in England included provision of data to EDSSS for public health surveillance purposes.[16] Phase V therefore required a single data sharing agreement between PHE and NHS Digital (which is responsible for the receipt and storage of ECDS data centrally), for the secure, automated, daily transfer of anonymised data.

EDSSS Data format and quality

The items identified to be of potential value for sentinel EDSSS, and likely to be entered into the electronic patient record and available for extraction on a daily frequency, included:

- the basic demographics of the patient (age in years, sex and place of residence approximated by postcode district);
- administrative information about the attendance (ED attended, date/time of arrival, date/time of departure);
- the patient journey to the ED (transport used, who referred them to the ED);
- the journey through the ED (acuity of illness on arrival, presenting complaint, investigations carried out, diagnoses, treatments);
- the discharge from the ED (if admitted to hospital including ward type e.g. ICU/HDU, sent home including any referral for GP/outpatient care, or died).

All EDSSS fields were requested (and provided) in coded format. In the absence of a nationally agreed standard for ED data collection and storage the sentinel EDSSS required the creation of the EDSSS codeset, based on the RCEM minimum dataset.[17] The use of standardised coding simplified the subsequent data analysis required (i.e. no need for free text analysis for syndromic indicator recognition and mapping) and prevented the inclusion of any potential patient identifiable information (PII) in free text fields.

The national EDSSS expanded on this list of data items, with the addition of a range of newly standardised injury related fields and inclusion of self-declared patient ethnicity. All ECDS data is collected in Snomed CT format.

As with all PHE syndromic surveillance systems, the EDSSS (both sentinel and national) does not require data fields to be complete or validated. Data collection allows for only a single 'snapshot' of the data as it was recorded at the time of the automated extraction. Therefore, records of any patient with incomplete/incorrect information (e.g. not yet discharged or awaiting test results) at the time of data extraction for EDSSS are not updated at a later date.

Data collection and transfer

Sentinel EDSSS was designed to complement other PHE syndromic surveillance systems, providing a next day service, reporting on what happened in EDs across England up to midnight the night before. This reporting time frame enabled daily surveillance activities to be carried out on the day following each patient arrival.

At approximately 4am each morning, records of patient arrivals that had occurred from 00:00 – 23:59 on the previous calendar day were selected and prepared for transfer to EDSSS. Automated routines within the NHS Trust IT systems processed the local ED data into the EDSSS codeset. The secure transmission of this data to PHE each day across the NHS N3 network was automated and maintained by a specialist IT service provider. Data from all EDs was batched into a single file and arrived at ReSST by 9am on the calendar day following the patient arrival.

The national EDSSS is reliant on data submission through the ECDS processes. Though 'daily' data transfer is required, at the time of writing this has not yet been achieved by all EDs in England. National EDSSS currently receives all new data by 12:00 each day, and surveillance is carried out with a two day delay i.e. based on attendances arriving up to midnight two calendar days earlier.

Development of public health outputs

In addition to the technical architecture development, the creation of EDSSS required the establishment of a network of stakeholders and specialists, who formed the EDSSS steering group. This group provided oversight of the strategic development of the EDSSS and included membership from a range of different stakeholders in EDSSS including: ReSST; ED consultants from pilot EDs; RCEM representation; and specialists from other areas in PHE (including subject area leads, e.g. influenza surveillance, statistical leads and mass gathering

experts working specifically on London 2012). The steering group provided strategic support and direction for all areas of EDSSS from the development of syndromic indicators of public health interest, to public health outputs designed to inform on the system and the surveillance findings.

Syndromic surveillance indicators

Syndromic surveillance groups together patient diagnoses/symptoms/presenting complaints into indicators of public health importance. As described in **Chapter 2**, ED syndromic surveillance systems to date have generally used either presenting/chief complaint *or* diagnoses for the identification of syndromic attendances. During phase I of EDSSS development the real-time entry of diagnoses was found to be common. The high levels of diagnosis code completion made this the preferred field for indicator development in EDSSS, negating the need for free text analysis of the triage presentation.

Using the experience gained from the ReSST GP in-hours and NHS Direct syndromic surveillance systems, alongside the WHO mass gathering guidelines,[18] new syndromic surveillance indicators were developed for the EDSSS. These focused initially on indicators for infectious diseases (i.e. to identify influenza-like illnesses/gastrointestinal outbreaks). With RCEM input and the experience gained from phase I, other, non-infectious indicators of illness were also developed (particularly for the impact of environmental events, such as hot or cold weather).

As far as possible EDSSS indicators are constructed in a hierarchical format. G*eneric* overarching groupings of diagnoses (e.g. respiratory/gastrointestinal conditions) are followed where possible by more detailed *specific* indicators (e.g. gastroenteritis/acute respiratory infections) and even further to a *2nd specific* level (e.g. diarrhoea/influenza-like illness; Table **3-1**).

The *generic* indicators were required during sentinel EDSSS due to the types of diagnosis codes received: three different diagnosis codesets were in use locally: Accident and Emergency Diagnosis Tables[19], used for the basic reporting at a national level as required in the Commissioning Data Set (CDS)[10]; International Statistical Classification of Diseases (ICD-10)[20]; and Snomed CT[21]). The *specific* coding level provided the highest level of detail across the largest number of EDs (those using ICD-10[20] or Snomed CT[21]). In many cases, however, the *2nd specific* level indicators were more detailed than was possible from the diagnosis pick lists available locally; i.e. all EDs could report 'respiratory' attendances, all EDs using

ICD-10 or Snomed CT could report 'acute respiratory infections', but only a small number had 'influenza' type diagnoses available in their local diagnosis pick list.

Table 3-1: Hierarchical format of EDSSS indicators (based on sentinel EDSSS indicators*)

Generic	Specific	2nd Specific
Gastrointestinal	Gastroenteritis	Diarrhoea*
		Vomiting*
		-
	-	
Respiratory	Acute Respiratory Infection	Influenza-like Illness
		Pneumonia
		Acute Bronchitis/Bronchiolitis
		-
	Asthma/Wheeze/ Difficulty Breathing	Asthma
		-
	-	
Cardiac	Myocardial Ischaemia	-
	-	

* Sentinel EDSSS allowed for entry of symptoms as diagnoses. National EDSSS is based the ECDS data specification which does not allow for symptoms such as diarrhoea/vomiting in the diagnosis field

Surveillance information for action

EDSSS daily surveillance feeds into wider public health surveillance activities, providing early warning of and situational analysis during (or reassurance of an absence of impact of) incidents/outbreaks; including local and national incidents. The ability to monitor and report on public health impacts in near real-time, aids in planning, public health action and messaging to the public.

Bespoke statistical analyses (rising activity, multi-level mixed effects, indicator emphasis, RAMMIE, method)[22] and a formal risk assessment process,[23] were developed for syndromic surveillance in England and are applied to EDSSS. Daily data from EDs are received, analysed and where indicated full risk assessment carried out every day. Using system specific statistical analysis, in combination with multi-system risk assessment of all syndromic systems, EDSSS has become a valued information source, reporting key intelligence within PHE. The daily risk assessment process flags changes in ED attendances of potential public health concern, and even provides further intelligence during known incidents/outbreaks, which can then be communicated to local PHE teams and specialist teams nationally.

In addition to the daily surveillance activities, weekly EDSSS bulletins describing trends in ED attendances for a range of indicators are made publicly available. Each publication provides a national overview of ED attendances for respiratory, gastrointestinal and cardiac indicators, with the addition of seasonally relevant cold and heat/sun reporting during the NHS cold and health watch periods each year. The first EDSSS bulletin was made publicly available on 11 April 2012[24] and continues to be made available on a weekly basis.[25]

Evaluation of public health interventions

In addition to the contribution that EDSSS makes to the day to day surveillance activities, EDSSS has also played a role in the investigation and evaluation of the impact of two new childhood vaccination programmes. This research has been carried out alongside other public health surveillance information streams:

- piloting, and subsequent monitoring following the introduction of live attenuated influenza vaccination in school children;[26-28]
- early investigation into the impact of rotavirus vaccination of infants in England.[29,30]

ED syndromic indicator utility

An important feature of the continued development of EDSSS has been the validation of indicators against other public health surveillance data to assess/establish their added benefit for public health surveillance. This has supported and strengthened the public health utility of the EDSSS, determining the sensitivity of indicators for detecting public health incidents in the community and how they compare to other surveillance systems and local intelligence in terms of the trends observed and the timeliness with which changes in trend can be identified.

Infectious diseases

The surveillance of acute respiratory infections, particularly influenza, is a common (often primary) objective for many public health surveillance systems. The majority of these infections are self-limiting and of low severity (not requiring healthcare advice), however, the significant impact and burden of circulating respiratory pathogens has been monitored in EDSSS. Acute respiratory infection attendances in EDs, particularly in young children was found to be highly sensitive to respiratory syncytial virus (RSV) circulation in the community, as confirmed by statistical correlation with RSV laboratory surveillance. EDSSS was also found to have provided advance warning of increases in acute respiratory infections in young children, ahead of the standard laboratory surveillance in England.[31]

Environmental incidents

The impact of environmental incidents on human health is often difficult to monitor and quantify, particularly during and immediately after the incident. Short term health effects of environmental incidents are often acute, with rapid onset of severe symptoms requiring emergency treatment. EDSSS has therefore, unsurprisingly, been successful in showing potential in the detection and monitoring of these kinds of events, including:

- increased asthma type attendances around the timing of thunderstorms (based on both day and hour of patient arrival/storm activity);[32]
- increased ED attendances for the 'cold' indicator (based largely on a select group of cold related fractures, particularly in females), has been shown to be associated with periods of extreme cold weather;[33]
- EDSSS heatstroke/sunstroke indicator attendances have been shown to increase during heat waves;[34]
- EDSSS added evidence and support to other syndromic surveillance systems in England in the identification and monitoring the impact of poor air quality incidents on human health.[35]

3.3 References

1. The International Olympic Committee. London 2012. [Available from: https://www.olympic.org/london-2012 Accessed: 20 Feb 2021].
2. Elliot AJ, Morbey RA, Hughes HE, et al. Syndromic surveillance - a public health legacy of the London 2012 Olympic and Paralympic Games. *Public health* 2013;127(8):777-81. doi: 10.1016/j.puhe.2013.05.007
3. Elliot AJ, Hughes HE, Hughes TC, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. *Emergency medicine journal : EMJ* 2012;29(12):954-60. doi: 10.1136/emermed-2011-200684
4. National Health Service Act 1946.1946 [Available from: http://www.legislation.gov.uk/ukpga/Geo6/9-10/81/contents/enacted Accessed: 20 Feb 2021].
5. National Health Service (Scotland) Act 1947 1947 [Available from: http://www.legislation.gov.uk/ukpga/Geo6/10-11/27/contents/enacted Accessed: 20 Feb 2021].
6. Elder AT. Health Services of Northern Ireland. *British Journal of Preventive & Social Medicine* 1953;7(3):105-11.
7. The NHS Constitution for England. [Available from: https://www.gov.uk/government/publications/the-nhs-constitution-for-england Accessed: 20 Feb 2021].
8. NHS. EMERGENCY CARE DEPARTMENT TYPE. [Available from: https://www.datadictionary.nhs.uk/data_dictionary/attributes/e/emergency_care_department_type_de.asp?shownav=1 Accessed: 20 Feb 2021].
9. NHS Digital. Commissioning Data Sets Introduction. [Available from: https://datadictionary.nhs.uk/supporting_information/commissioning_data_sets_introduction.html Accessed: 20 Feb 2021].
10. NHS Digital. CDS V6-2 Type 010 - Accident and Emergency CDS. [Available from: https://datadictionary.nhs.uk/data_sets/retired/cds_v6-2/cds_v6-2_type_010_-_accident_and_emergency_cds.html?hl=cds%2Cv6-2%2Ctype%2C010%2Caccident%2Cemergency Accessed: 20 Feb 2021].
11. NHS England. A&E Attendances and Emergency Admissions. [Available from: https://www.england.nhs.uk/statistics/statistical-work-areas/ae-waiting-times-and-activity/ Accessed: 20 Feb 2021].
12. NHS England. Hospital Accident & Emergency Activity. [Available from: https://digital.nhs.uk/data-and-information/publications/statistical/hospital-accident--emergency-activity Accessed: 20 February 2021].
13. British Embassy Dublin. World Police and Fire Games, Belfast, Northern Ireland. [Available from: https://www.gov.uk/government/news/world-police-and-fire-games-belfast-northern-ireland Accessed: 20 Feb 2021].
14. McLaughlin D. Fleadh to be a 'spectacular weekend' in Londonderry. [Available from: https://www.bbc.co.uk/news/uk-northern-ireland-foyle-west-23723191 Accessed: 20 Feb 2021].
15. Royal College of Emergency Medicine. History of Emergency Medicine and the College: 2010s. [Available from:

https://www.rcem.ac.uk/RCEM/About/History/RCEM/About_Us/History/History.aspx?hkey=bd0643ab-7966-47a6-b15d-5324bbd70649 Accessed: 20 Feb 2021].

16. NHS Digital. Commissioning Data Set v6.2.1: Introduction of CDS Type 011 Emergency Care Data Set: Requirements Specification. [Available from: https://digital.nhs.uk/binaries/content/assets/legacy/pdf/0/j/0092-2062172015reqspec.pdf].
17. College of Emergency Medicine Emergency Care Minimum Dataset. In: College of Emergency Medicine, ed. v4.1 ed, 2014.
18. World Health Organisation. Communicable disease alert and response for mass gatherings. [Available from: http://www.who.int/csr/mass_gathering/en/ Accessed: 20 Feb 2021].
19. NHS Digital. Supporting Information: Accident and Emergency Diagnosis Tables. [Available from: https://datadictionary.nhs.uk/data_elements/retired/accident_and_emergency_diagnosis_-_second.html?hl=accident%2Cemergency%2Cdiagnosis Accessed: 20 Feb 2021].
20. World Health Organisation. International Classification of Disease (ICD). [Available from: https://icd.who.int/browse10/2010/en Accessed: 20 Feb 2021].
21. International Health Terminology Standards Development Organisation. SNOMED CT. [Available from: http://www.ihtsdo.org/snomed-ct/ Accessed: 20 Feb 2021].
22. Morbey RA, Elliot AJ, Charlett A, et al. The application of a novel 'rising activity, multi-level mixed effects, indicator emphasis' (RAMMIE) method for syndromic surveillance in England. *Bioinformatics* 2015;31(22):3660-65. doi: 10.1093/bioinformatics/btv418
23. Smith GE, Elliot AJ, Ibbotson S, et al. Novel public health risk assessment process developed to support syndromic surveillance for the 2012 Olympic and Paralympic Games. *Journal of Public Health (Oxford)* 2017;39(3):e111-e17. doi: 10.1093/pubmed/fdw054
24. Health Protection Agency. Emergency Department Syndromic Surveillance System. [Available from: https://webarchive.nationalarchives.gov.uk/20140722223619/http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317133540747 Accessed: 20 Feb 2021].
25. Public Health England. Syndromic surveillance: systems and analyses. [Available from: https://www.gov.uk/government/collections/syndromic-surveillance-systems-and-analyses Accessed: 20 Feb 2021].
26. Pebody R, Green H, Andrews N, et al. Uptake and impact of a new live attenuated influenza vaccine programme in England: early results of a pilot in primary school-age children, 2013/14 influenza season. *Euro Surveillance* 2014;19(22):pii=20823.
27. Pebody RG, Green HK, Andrews N, et al. Uptake and impact of vaccinating school age children against influenza during a season with circulation of drifted influenza A and B strains, England, 2014/15. *Euro Surveillance* 2015;20(39):pii=30029. doi: 10.2807/1560-7917.ES.2015.20.39.30029
28. Pebody RG, Sinnathamby MA, Warburton F, et al. Uptake and impact of vaccinating primary school-age children against influenza: experiences of a live attenuated influenza vaccine programme, England, 2015/16. *Eurosurveillance* 2018;23(25):pii=1700496. doi: 10.2807/1560-7917.ES.2018.23.25.1700496
29. Bawa Z, Elliot AJ, Morbey RA, et al. Assessing the likely impact of a rotavirus vaccination programme in England; the contribution of syndromic surveillance. *Clinical infectious*

diseases : an official publication of the Infectious Diseases Society of America 2015;61(1):77-85. doi: 10.1093/cid/civ264

30. Thomas SL, Walker JL, Fenty J, et al. Impact of the national rotavirus vaccination programme on acute gastroenteritis in England and associated costs averted. *Vaccine* 2017;35(4):680-86. doi: 10.1016/j.vaccine.2016.11.057

31. Hughes HE, Morbey R, Hughes TC, et al. Emergency department syndromic surveillance providing early warning of seasonal respiratory activity in England. *Epidemiology and Infection* 2016;144(5):1052-64. doi: 10.1017/S0950268815002125

32. Elliot AJ, Hughes HE, Hughes TC, et al. The impact of thunderstorm asthma on emergency department attendances across London during July 2013. *Emergency medicine journal : EMJ* 2014;31(8):675-78. doi: doi 10.1136/emermed-2013-203122

33. Hughes HE, Morbey R, Hughes TC, et al. Using an emergency department syndromic surveillance system to investigate the impact of extreme cold weather events. *Public health* 2014;128(7):628-35. doi: 10.1016/j.puhe.2014.05.007

34. Elliot AJ, Bone A, Morbey R, et al. Using real-time syndromic surveillance to assess the health impact of the 2013 heatwave in England. *Environmental research* 2014;135C:31-36. doi: 10.1016/j.envres.2014.08.031

35. Smith GE, Bawa Z, Macklin Y, et al. Using real-time syndromic surveillance systems to help explore the acute impact of the air pollution incident of March/April 2014 in England. *Environmental research* 2015;136:500-04. doi: 10.1016/j.envres.2014.09.028

Chapter 4 Research questions

A series of manuscripts are presented which address the questions raised in this thesis:

4.1 Does near real-time emergency department syndromic surveillance provide additional benefit to public health surveillance in England?

A wide range of well established, traditional, public health surveillance systems existed prior to the establishment of ED syndromic surveillance in England. Each of these generally focus on a particular area of human health, both infectious diseases (pathogen specific) and non-infectious disease (either grouped by outcome e.g. cancer, or by exposure e.g. chemical/radiological/environmental). Syndromic surveillance approaches surveillance from a different starting point, by establishing what information is available, before then identifying what can (or cannot) be monitored. Syndromic surveillance systems also existed in England prior to the creation, with the monitoring call levels to the NHS Direct and GP consultations.

The implementation of EDSSS (described in **Chapter 3**) resulted in a surveillance system focussed on the more severe end of the disease spectrum, with the flexibility to provide valuable public health intelligence across a wide range of factors of public health importance: infectious diseases (**Chapter 5**), health effects of environmental events (**Chapter 6**) and even human behaviour (**Chapter 7**).

ED syndromic surveillance, with data collection, analysis and feedback in near real-time, is also more timely than traditional surveillance techniques. Rather than waiting weeks, months or even years for fully validated ED data to be made available, syndromic surveillance can provide early warning of issues and enhanced monitoring of situations allowing for the identification of changes in the basic tenements of epidemiology i.e. time, person and place. The potential for this during periods of poor air quality is described in **Chapter 6** and during mass gatherings/sporting events in **Chapter 7** as well as actual use for near real-time reporting during a global pandemic, as shown in **Chapter 9**.

Additionally ED syndromic surveillance has the potential to provide quick, early feedback on the implementation of public health interventions in future as evidenced by the impact of rotavirus vaccination described in **Chapter 5** and again shown in near real-time following

large scale public health measures (shielding and social distancing) during a pandemic in **Chapter 9**.

Rapid identification of changes in demographic or geographic presentations of illness can aid in better management of incidents and targeting of interventions, including public health messaging. The first example of EDSSS standard outputs impacting on public health policy and messaging is highlighted in **Chapter 9**. The indirect impacts of the COVID-19 pandemic, and public health interventions, in England were clearly visible in the routine reporting of ED attendances in the national EDSSS.

Furthermore, as described in **Chapter 2**, the presence of ED syndromic surveillance systems offers the potential for collaborative working. Collaboration between ED syndromic systems across international borders has, so far, been limited. Cross-border collaboration is, however, appropriate as factors which have an adverse impact on human health, or causing changes in health seeking behaviour, do not only occur on a local basis. As described in **Chapter 6**, air quality incidents do not respect political borders, and as seen in **Chapter 7** population level changes in behaviour in response to international sporting events can be seen in geographically distinct locations. The effect of these stimuli on the local population may not be nation specific, and the ability to draw comparisons within collaborative studies is a valuable feature of ED syndromic surveillance.

4.2 What value can ED syndromic surveillance add to emergency care services in England?

Public health surveillance can often appear to be a one-way flow of information: from the data provider(s) to the surveillance system. Data gathered by public health surveillance systems provides information on the health of the population, which may then be used for public health action. This data held within and analysis outputs from the surveillance system are not necessarily used to provide feedback to the system from which the data was originally gathered.

As detailed in **Chapter 3**, the original sentinel EDSSS network was restricted by the limited availability of data and lack of standardisation of coding from EDs across England. Collaborative working was an essential part of EDSSS from the outset. **Chapter 8** describes how the collaboration with RCEM developed beyond the creation of a surveillance system. The experience gained from developing and maintaining the sentinel EDSSS provided input

into the development and implementation of the new Emergency Care Data Set (ECDS), by RCEM, NHS Digital and NHS England.

The ECDS mandates a new standard for the collection and formatting of data within the electronic patient care record in all EDs in England; including the requirement for daily data transmission to a central point (NHS Digital) on a national basis. The lessons learned from EDSSS in the successful creation of a sentinel ED syndromic surveillance network, collecting disparate data, in an EDSSS specific codeset, on a daily basis, were directly applicable to the development of ECDS. In this instance syndromic surveillance was able to provide feedback for a project which had a primary focus on the improvement of patient care through better record keeping.

4.3 How can ED syndromic surveillance in England be further developed for improved public health surveillance?

Each individual piece of work described in **Chapter 5**, **Chapter 6**, **Chapter 7**,**Chapter 8** and **Chapter 9** has revealed multiple areas for future development. Opportunities exist for the learning from past experience and future collaboration with other ED systems. There is also the need to develop a better understanding of how the new national EDSSS can improve further, making full use of the improved data quality and provision afforded by the introduction of ECDS.

The findings presented within this thesis are underpinning further work programmes driving the expansion and continued development of the national EDSSS coordinated by PHE, as discussed in **Chapter 3**.

Chapter 5 Using emergency department syndromic surveillance to investigate the impact of a national vaccination program: a retrospective observational study

Helen E. Hughes
Alex J. Elliot
Thomas C. Hughes
Daniel Hungerford
Roger A. Morbey
Gillian E. Smith
Roberto Vivancos
Sarah J. O'Brien

PLoS ONE. 2020;15(10):e0240021. Crown Copyright.
DOI: 10.1371/journal.pone.

The real-time nature of ED syndromic surveillance provides the opportunity for the identification and monitoring of changing trends in demand from those severely ill and requiring emergency care and/or treatment. Intuitively the standard use for this information is for the identification of increases in trend. However, ED syndromic surveillance may also be used for the quick investigation and evaluation of the impact of public health interventions by identifying and monitoring changes (possible decreases) in disease outcomes presenting within EDs.

Rotavirus vaccination was introduced into the UK childhood vaccination schedule in July 2013. Similar to other countries, the introduction of rotavirus vaccination was reportedly followed by reduced the levels of childhood gastroenteritis in the community, as identified by laboratory and syndromic surveillance. ED syndromic surveillance has previously provided additional support in wider investigation of vaccine impact across multiple levels of healthcare provision. Here we demonstrate the potential for ED syndromic surveillance to be used for rapid, stand alone, investigation of vaccine impact.

5.1 Abstract

Background

Rotavirus infection is a common cause of gastroenteritis in children worldwide, with a high mortality burden in developing countries, particularly during the first two years of life. Rotavirus vaccination was introduced into the United Kingdom childhood vaccination schedule in July 2013, with high coverage (>90%) achieved by June 2016. We used an emergency department (ED) syndromic surveillance system to assess the impact of the rotavirus vaccination programme, specifically through the demonstration of any immediate and continuing impact on ED gastroenteritis visits in England.

Methods

This retrospective, observational study used syndromic surveillance data collected from 3 EDs in the two years before (July 2011 - June 2013) and 3 years post (July 2013 - June 2016) introduction of rotavirus vaccination. The weekly levels of ED visits for gastroenteritis (by age group and in total) during the period before rotavirus vaccination was first described alongside the findings of laboratory surveillance of rotavirus during the same period. An interrupted time-series analysis was then performed to demonstrate the impact of rotavirus vaccination introduction on gastroenteritis ED visit levels.

Results

During the two years before vaccine introduction ED visits for gastroenteritis in total and for the 0-4 years age group were seen to rise and fall in line with the seasonal rotavirus increases reported by laboratory surveillance. ED gastroenteritis visits by young children were lower in the three years following introduction of rotavirus vaccination (reduced from 8% of visits to 6% of visits). These attendance levels in young children (0-4years) remained higher than in older age groups, however the previously large seasonal increases in children were greatly reduced, from peaks of 16% to 3-10% of ED visits per week.

Conclusions

ED syndromic surveillance demonstrated a reduction in gastroenteritis visits following rotavirus vaccine introduction. This work establishes ED syndromic surveillance as a platform for rapid impact assessment of future vaccine programmes.

5.2 Introduction

Rotavirus infection is a common cause of gastroenteritis in children worldwide, particularly during the first two years of life. Clinical presentation ranges from mild, self-limited diarrhoea, to more serious cases requiring medical interventions, and deaths.[1] Although deaths are less likely in developed countries, illness due to rotavirus in the youngest children in the community results in high numbers of contacts with health care. In the United Kingdom (UK), rotavirus was estimated to account for much of the National Health Service (NHS) health care contacts made for acute gastroenteritis in children under 5 years: 27% of calls for advice (e.g. to the NHS 111 health advice line), 25% of visits to general practitioners (GPs), 20% of visits to emergency departments (ED) and 45% of hospital admissions.[2] Rotavirus is known to follow a seasonal pattern, with activity in the UK largely seen between January and June, usually reaching a peak in February/March (similar seasonal patterns are seen throughout Europe[3]).

Rotavirus vaccination (RV) with the live attenuated monovalent vaccine (Rotarix®: GlaxoSmithKline Biologicals)[4] was introduced into the UK childhood vaccination schedule in July 2013[5] as a two dose course targeted at infants 8-15 weeks (second dose before 24 weeks).[6] High coverage was achieved with >85% coverage for both doses by February 2014,[6] a level which increased to >90% by June 2016.[7] Immediately following introduction of the RV programme reductions in the levels of gastroenteritis were reported in young children (0-4 years) in England, as estimated through laboratory confirmations, GP consultations and ED visits,[8-12] with the costs avoided resulting in economic savings estimated at £12.5 million per year.[13] Similar results were reported in other countries including Australia,[14] Brazil,[15] Canada[16] and across sub-Saharan Africa[17] and Europe,[18] although reductions were also reported in the Netherlands, where vaccination had not been introduced.[19]

Syndromic surveillance involves the near real-time collection, analysis and reporting on health related data[20] which has been applied to a wide variety of contemporaneously collected patient data sources. This type of surveillance provides the potential to monitor and identify trends, across a wide variety of conditions and within shortened timescales compared to more traditional surveillance based on formal notifications and laboratory reporting. ED syndromic surveillance has previously demonstrated to be a valuable component in vaccine impact investigations alongside other data sources.[9, 13, 21] Here we

demonstrate the utility of ED syndromic surveillance for a stand-alone investigation of a public health intervention: the introduction of rotavirus vaccination in England.

The principle aim of this study was to use a national ED syndromic surveillance system to assess the continued impact of the UK national RV programme. We first describe trends in ED visits for gastroenteritis during the two years prior to the introduction of the RV programme (2011-2013), compared to the weekly number of rotavirus confirmations identified in laboratory surveillance. We then explored the use of ED syndromic surveillance data for England to demonstrate the immediate impact of RV on young children attending EDs for gastroenteritis, to identify if previously reported reductions in rotavirus associated disease have continued. Our investigation also investigated possible changes in gastroenteritis ED visits across older age groups outside of the vaccination target groups, including any changes in seasonality.

5.3 Methods

Emergency department visits

The Emergency Department Syndromic Surveillance System (EDSSS) is part of the Public Health England (PHE) suite of real-time syndromic surveillance systems.[22] EDSSS was set up as a voluntary sentinel system prior to the 2012 London Olympic and Paralympic Games.[23] This system has provided an opportunity to investigate the ongoing impact of RV on ED visits, with surveillance data available from a number of English EDs, both prior to and following RV introduction.

The EDSSS collects an anonymised record for every visit at a participating ED on a daily basis, including: simple non-identifiable demographic data (sex and age), and any diagnoses selected. Clinical diagnoses are received in the coded format used within each ED; different diagnostic coding systems reveal different levels of clinical detail, requiring the development and use of a range of EDSSS syndromic indicators (three coding systems used in the sentinel EDSSS: NHS Accident and Emergency Diagnosis Tables,[24] ICD-10[25] and Snomed CT[26]). A detailed 'gastroenteritis' indicator (diagnosis codes considered to indicate an infectious gastrointestinal disease) was used here and was only available from those EDs reporting sufficiently detailed diagnostic codes (ICD-10 or Snomed CT: codes included in the gastroenteritis indicator, as reported by EDs included in this study, are detailed in **Appendix B**).

Only EDs able to report diagnosis codes mapped to the gastroenteritis indicator (gastrointestinal diagnoses considered due to infection), which reported throughout the time period and with no known changes in diagnosis coding practices or gaps in data, were eligible for inclusion.

The pre-RV period used for the description of gastroenteritis before RV programme introduction included data from July 2011 to June 2013. The post-RV period used for the investigation of vaccine impact included data from July 2013 to June 2016. Only EDs which were capable of reporting gastroenteritis throughout the pre-RV and post-RV time periods were eligible for inclusion in this study.

Laboratory reports

Anonymised laboratory reports of rotavirus detection were accessed from the PHE Second Generation Surveillance System (SGSS), which contains data on isolates from diagnostic laboratories in England, using a range of diagnostic tests.[27] These data were used as an indicator of the community circulation of rotavirus during the two years prior to RV introduction available from EDSSS (4/7/11-30/6/13), ending the day before national RV implementation on 1/7/2013. Each laboratory report included the specimen date, patient age, organism identified and specimen type. Analyses were restricted to faecal specimens to exclude instances of invasive disease, which would not be comparable to the gastroenteritis ED visits. No restriction was included on specimen location (e.g. hospital/community) or patient age, as laboratory confirmation was used here to indicate pathogen activity in the community, not disease severity or age group affected. Episode based de-duplication is built into the SGSS,[27] and therefore no further patient-based de-duplication was required.

Descriptive analysis

Both ED syndromic surveillance and laboratory data for the two-year pre-RV period were grouped into weekly totals in order to remove any day of the week effects (04/7/11 – 03/07/16; International Organisation for Standardisation (ISO) weeks 2011 week 27 to 2013 week 26). The total weekly number of rotavirus isolates (as an indicator of community circulation) was compared to the weekly ED gastroenteritis visits in total and individual age group (0-4 years, 5-14 years, 15-44years, 45-64 years and 65+ years).

Statistical analysis of vaccine impact on gastroenteritis ED visits

ED visit data, for number of visits with a gastroenteritis diagnosis and number of visits with a diagnosis code, were stratified by age group (as above) and by week. The number of total

visits which included a diagnosis code each week was used as a denominator to calculate the percentage of visits due to gastroenteritis.

Time-series were constructed for the weekly percentage of visits reported as gastroenteritis for each age group and in total. An interrupted time-series analysis method was used to estimate the impact of the introduction of RV on gastroenteritis ED visits in each age group and for all ages. A negative binomial regression model, selected due to over dispersion, was fitted to the pre-vaccination period, to calculate estimated weekly visits, and an estimation of the trend and seasonality in the absence of vaccination, with the weekly gastroenteritis visits as the dependent variable. The total number of ED visits was included as an offset variable, to allow for changes in total ED visits over time and a seasonal harmonic (sine/cosine) Fourier pair of terms to model seasonality. These models were then projected forward to predict the expected visit levels had RV not been implemented. These 'no change', counterfactual models were then compared with models that included terms to account for a change following the vaccine introduction and a change in seasonality post-vaccine.

Interrupted time-series analysis was carried out using the statistical software R[28] (MASS, tsModel and epi packages[29-31]).

Ethics

This surveillance is undertaken as part of the national surveillance functions of PHE and so ethical approval for this work was not required. The anonymised health data used in this study were routinely collected as part of the public health function of PHE.

5.4 Results

Three EDs were eligible for inclusion in the study. They were based in two cities in England (one Northern, one Southern), included adult and paediatric services and reported consistently to EDSSS throughout both the pre-RV and post-RV periods. During the two years pre-RV, 596,122 visits (in the 3 study EDs) were reported to EDSSS, of which 71.5% included a diagnosis code (**Table 5-1**). In total, 2.2% of these coded visits were identified as due to gastroenteritis. The highest number of attendances for gastroenteritis were recorded in young children 0-4 years, despite this group accounting for only 10.2% of all ED visits (**Table 5-1**). Consequently, the percentage of attendances attributable to gastroenteritis was highest in children aged 0-4 years (8.0% of coded visits), whereas in age

groups 5 years and over gastroenteritis was identified in less than 2.0% of ED visits (**Table 5-1**).

Table 5-1: ED visits, those including diagnosis coding and those identified as gastroenteritis, by age group during the pre-RV period from 4 July 2011 to 30 June 2013

Age group (years)	**ED visits** (% total visits)		**Diagnosis included** (% age group visits)		**Gastroenteritis visits** (% age group visits with diagnosis)	
0-4	60,531	(10.2%)	43,354	(71.6%)	3,470	(8.0%)
5-14	49,623	(8.3%)	34,219	(69.0%)	655	(1.9%)
15-44	266,010	(44.6%)	189,907	(71.4%)	2,946	(1.6%)
45-64	104,615	(17.5%)	75,731	(72.4%)	909	(1.2%)
65+	114,672	(19.2%)	82,839	(72.2%)	1,431	(1.7%)
unknown	671	(0.1%)	308	(45.9%)	0	(0.0%)
Total	596,122	(100.0%)	426,358	(71.5%)	9,411	(2.2%)

A seasonal pattern was observed in gastroenteritis visits for children under 5 years during the 2-year pre-RV period, with increased ED attendances from week 1-17 each calendar year (**Figure 5-1**). This increase mirrored increases in rotavirus reported through laboratory surveillance during the same period. ED visits for gastroenteritis in all other age groups showed less seasonal variation (**Figure 5-1**).

A separate period of increased gastroenteritis visits was also observed during the summer of 2012 (week 39-45), particularly in children 0-4 years.

During the three years following the introduction of the rotavirus vaccine, 914,725 ED visits were reported by the three eligible EDs (**Table 5-2**). Diagnosis codes were received for 71.8% of visits (very similar to the levels identified during the pre-RV period), with 2.1% of these identified as due to gastroenteritis. The numbers and levels of gastroenteritis were highest in the youngest age group, 0-4 years though lower than identified during the pre-RV period (6.1% of visits with diagnosis information, compared to 8.0% before RV).

Figure 5-1: Weekly emergency department (ED) gastroenteritis visits (as a percentage of visits with a diagnosis), by age group and in total and weekly number of rotavirus laboratory isolations (England) during the two years pre-rotavirus vaccine introduction (2011 week 27 - 2013 week 26)

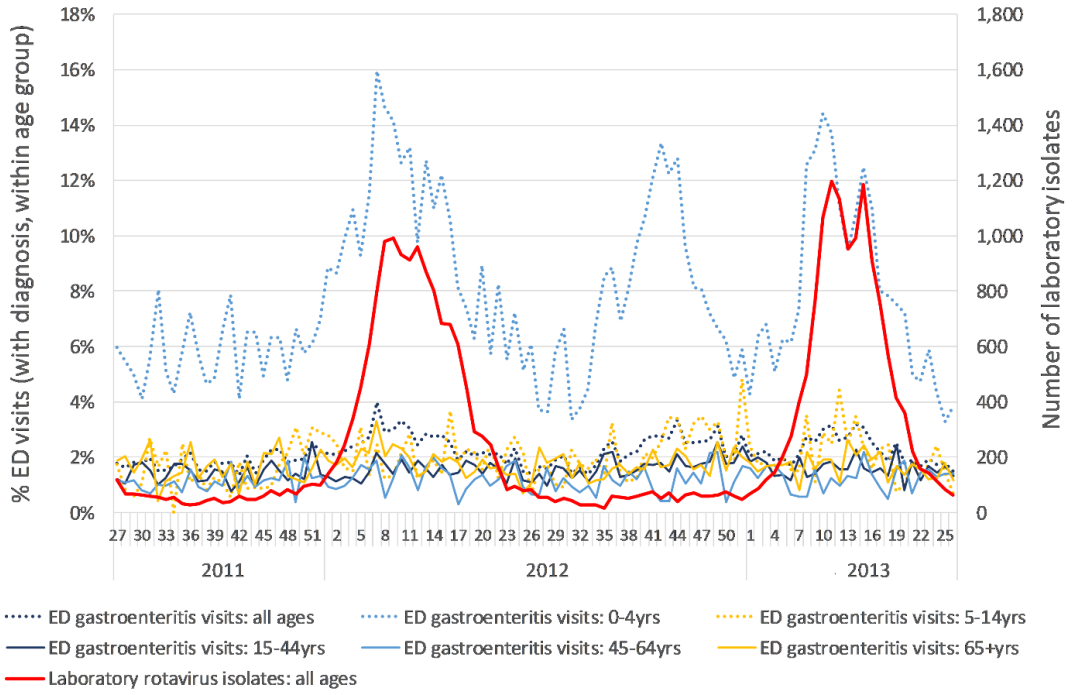


Table 5-2 Emergency department (ED) visits, those including diagnosis coding and those identified as gastroenteritis, by age group during the post-RV period from 1 July2013 to 3 July 2016)

Age group (years)	**ED visits** (% total visits)		**Diagnosis included** (% age group visits)		**Gastroenteritis visits** (% age group visits with diagnosis)	
0-4	84,673	(9.3%)	63,411	(74.9%)	3,860	(6.1%)
5-14	74,595	(8.2%)	52,385	(70.2%)	1,126	(2.1%)
15-44	401,187	(43.9%)	282,915	(70.5%)	4,863	(1.7%)
45-64	165,511	(18.1%)	119,562	(72.2%)	1,497	(1.3%)
65+	187,808	(20.5%)	137,815	(73.4%)	2,256	(1.6%)
unknown	951	(0.1%)	507	(53.3%)	0	(0.0%)
Total	914,725	(100.0%)	656,595	(71.8%)	13,602	(2.1%)

Vaccine impact

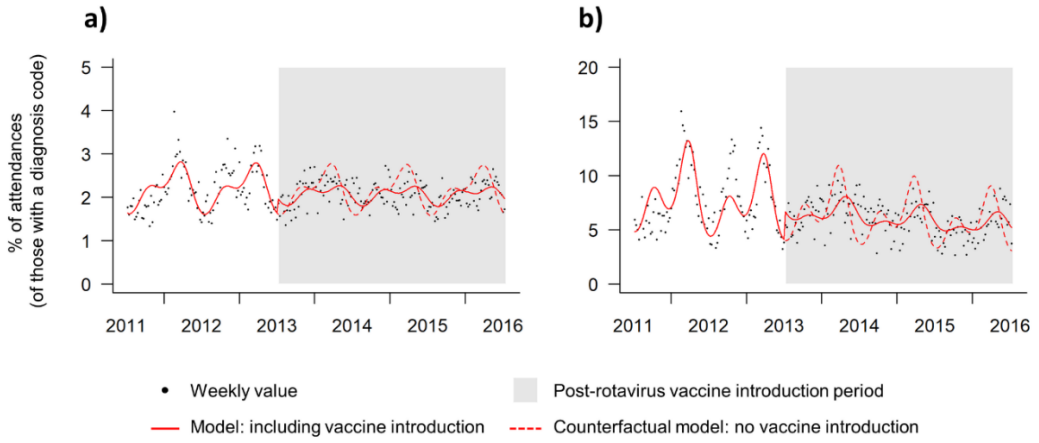
The time-series constructed for gastroenteritis visits for all ages in total showed differences in both visit levels and seasonality between the pre-RV and post-RV time periods (**Figure 5-2a**). During the pre-RV period the weekly gastroenteritis levels ranged from 1.3-4.0% of

all weekly visits. Post-RV slightly lower peaks were seen, ranging from 1.4-2.7% of all weekly visits (**Figure 5-2a**). As observed in the descriptive analysis, levels of gastroenteritis were much higher in young children (0-4 years; **Figure 5-2b**).

A more pronounced seasonal pattern was identified in ED visits present in young children (0-4 years: **Figure 5-2b**). The highest peaks in weekly visits levels were identified in this youngest age group (pre-RV max 15.9; post-RV max 9.6%: **Figure 5-2b**).

The interrupted time series models for all ages in total and for the 0-4years age group separately, demonstrated a clear divergence between the model fit to actual data and the counterfactual model (estimated trends had no vaccine been introduced). For the all age and 0-4 years group modelling the counterfactual models predicted large seasonal variation, as seen pre-RV. This degree of seasonality was not, however, seen in the post-RV period (**Figure 5-2**).

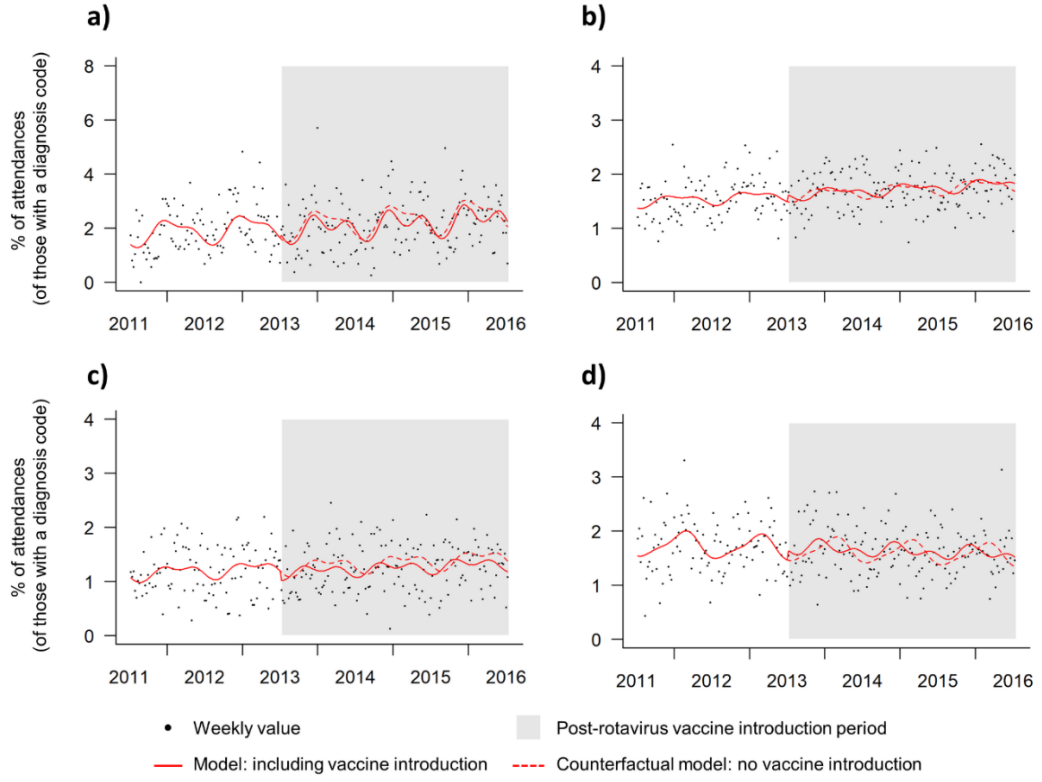
Figure 5-2: Weekly emergency department (ED) gastroenteritis visits, interrupted time-series regression model with level change and harmonic adjustment for seasonality, **a)** all ages and **b)** young children (0-4 years), week 27 2011 to week 26 2016 (grey box represents the rotavirus vaccine period).



In addition to the lowest levels of gastroenteritis visits being identified in other, older age groups (5+years) there was also less seasonal variation in visits, and less obvious differences between pre-RV and post-RV introduction. The modelling indicated similar results for the model fit to the actual data and the counterfactual model (**Figure 5-3**).

There was evidence of autocorrelation in the data, as would often be expected with time-series data. However, this was largely due to the seasonality observed in the data and removed by the introduction of a harmonic term into the models.

Figure 5-3: Weekly emergency department (ED) gastroenteritis visits, interrupted time-series regression model with level change and harmonic adjustment for seasonality, **a)** older children (5-14 years) and adults **b)** 15-44 years, **c)** 45-64 years and **d)** 65+ years, week 27 2011 to week 26 2016 (grey box represents the rotavirus vaccine period).



5.5 Discussion

The descriptive time-series analysis of ED syndromic surveillance data identified seasonal trends in gastroenteritis ED visits in England prior to RV introduction, both for all ages in total and for young children. Gastroenteritis ED visits increased around the time of known seasonal rotavirus activity, as indicated by increased rotavirus laboratory confirmations. Prior to RV introduction, gastroenteritis levels in the youngest age group (0-4 years) were at much higher levels and showed greater seasonal variation than in older age groups. During periods of known rotavirus activity (2011 weeks 4-16, 2012 weeks 8-16) over 10% of ED visits (peaking at 16% of ED visits) made by children aged 0-4 years were identified as having a diagnosis of gastroenteritis.

The seasonal trends observed in all ages, and the high levels in young children implied a considerable burden of ED visits were associated with RV. This highlighted the usefulness of ED syndromic surveillance data for investigating the impact of rotavirus vaccine introduction into the childhood vaccination schedule.

Following the introduction of the national RV programme, the change in the seasonal variability of ED gastroenteritis visits was particularly notable in the youngest age group. The magnitude of the seasonal trend was reduced in comparison to the counterfactual model in the interrupted time series analysis, becoming more similar to the more stable (non-seasonal) trend observed in older age groups. Although gastroenteritis visits for young children (0-4 years) remained higher than older age groups, the variation week on week became attenuated, with smaller seasonal peaks (and troughs) observed in the ED data. This implies a change in the case mix of the youngest children seen in EDs, particularly during what had previously been recognised as the rotavirus season. This reduced level of gastroenteritis supports previous findings of a reduction in gastroenteritis immediately following RV introduction in both England[8-12] and other countries.[14-18]

These results also highlight decreasing trends in ED attendances for gastroenteritis pre-vaccine, and post vaccine in the counterfactual model (i.e. in the absence of vaccine). Previous studies in England have demonstrated longer term falls in community-based general practitioner consultations for infectious intestinal disease.[32,33] The findings here may indicate that public health messaging aimed at discouraging patients using health care services for mild self-limiting gastrointestinal infections, and changes in health care seeking behaviour is continuing to reduce the community burden from gastrointestinal infections on healthcare services.

There is evidence that introduction of rotavirus vaccination in infants may subsequently reduce gastroenteritis in adults,[12,18] however no clear decreases were observed in either the levels or seasonality of gastroenteritis visits in older age groups post-RV. The numbers of severely ill patients attending EDs may be too few to have a notable impact on ED workload. ED gastroenteritis visits levels for older children and adults continued to make up a smaller percentage of total visits in those age groups (0-6% for older children 5-14yrs, 0-3% for adults). The reduction in gastroenteritis attendances for young children did, however, result in reductions in the all age gastroenteritis attendances to EDs, changing the overall workload and case mix in EDs in general.

The observed reduction in ED gastroenteritis visits by young children reported here was not as great as the reductions reported in confirmed rotavirus hospitalisations.[9,13-18] though this was to be expected since ED syndromic surveillance gastroenteritis attendances are unlikely to be solely due to rotavirus. In the absence of a confirmatory testing (which is often unnecessary for successful treatment of gastroenteritis in an ED setting) there is no specific

rotavirus syndromic indicator available; the gastroenteritis indicator used here for ED syndromic surveillance includes all pathogens and causes.

This work has further demonstrated the ability for non-pathogen specific syndromic surveillance to detect and describe a change in level of health seeking behaviour in the community for the more severe cases of illness (i.e. in the ED setting), following the introduction of a vaccine programme. During 2013 an initial pilot of the live attenuated influenza vaccine (LAIV) in the UK childhood vaccination programme used a range of different syndromic surveillance data (including ED attendances) to assess the impact and effectiveness.[34] The near real-time nature of ED syndromic surveillance data collection supported the timely assessment of LAIV impact in England, thereby supporting expansion of the pilot to the national immunisation programme.

Strength and weaknesses

The EDSSS provides the potential to identify, quantify and monitor the levels of illness in the population requiring ED care. As the largest proportion of those affected by rotavirus infection do not need ED care i.e. they 'self-treat',[2] the numbers of cases eligible for inclusion in this study were limited and the findings should not be extended to estimate levels of less severe illness in the community. Despite the non-specific nature of syndromic surveillance, reliant on a preliminary/low detail/non-specific diagnoses from EDs (e.g. 'gastroenteritis' rather than confirmed rotavirus infection), clear trends in presentations of illness were identified here that coincided with rotavirus seasonality.

We have shown here the utility of EDSSS in monitoring the likely impact of rotavirus activity, despite the system itself being limited by the data available at both geographical coverage/number of EDs and the time periods available. The EDSSS was established to support the 2012 London Olympic and Paralympic Games using routinely collected data in a standardised format, allowing for identification of gastroenteritis in geographically distinct locations. Changes in system coverage and local work practices were unavoidable. Though individual EDs did provide data from late July 2010 both the pre-RV and post-RV data had to be limited to include data reported to EDSSS from only those EDs reporting consistently. This resulted in the inclusion of data from 3 EDs which reported from 2011 week 27 to 2016 week 26 in this study.

Syndromic surveillance in general is limited by the availability and quality of the data received. Here we included young children in the analysis as a 0-4 years age group. In the year following introduction of vaccine, the 0-4 years age group used here would have

included those infants in the vaccine cohort and those who would not have received vaccine. Refining the analysis by year of age may have illustrated an increased impact of RV, however it was not possible to use a finer resolution of age (by year) in this youngest group using the data received in EDSSS for the time periods under investigation. Furthermore, with near real-time data extraction there is potential for incomplete records where the patient is still on their journey through the ED, so there may be no recorded diagnosis at the time of data extraction. The reasons for these gaps are unknown. Although the causes may be ED specific, it is assumed that they are also a constant in each site, allowing for comparison on trends over time. No changes in diagnosis data quality were identified in the EDs included in the analysis reported here.

As ED records do not routinely include information on vaccine status it was not possible to ascertain the vaccine status of those ED patients during the study period.

Future work

ED syndromic surveillance systems exist in a number of different countries. Previous collaborative work has shown these systems to be compatible, with syndromic indicators used to describe and compare trends across international borders,[35,36] giving opportunity for similar work on the impact of vaccination implementation on ED visits on a larger scale.

A second period of increased gastroenteritis visits was identified during the pre-RV time period, particularly in those aged 0-4 years during September-October 2012. These increases may indicate increased activity of other gastrointestinal pathogens and coincided with increased seasonal laboratory reporting of cryptosporidium.[37] This suggests that ED surveillance may be of use in identifying periods of increased gastrointestinal pathogen activity in the community, which merits further exploration.

The introduction of the Emergency Care Data Set in England during 2018 has provided further opportunities for EDSSS.[38] The newly standardised, routine, mandated collection of emergency care data has widened the potential of EDSSS as a surveillance tool by creating a data source capable of providing the data required for long term studies of public health importance. By January 2020, the sentinel EDSSS described here had developed from a voluntary, sentinel surveillance system with limited coverage, to the national EDSSS; with almost every ED in England providing data. This development opens the possibility for using ED syndromic surveillance in future rapid studies on the impact of public health interventions. Such examples include the future introduction of a respiratory syncytial virus (RSV) vaccine: EDSSS has previously been shown to be sensitive to increases in RSV

circulation in the community thus making it a suitable tool for monitoring impact post-vaccine implementation.[39] Additionally, EDSSS has recently been used to monitor the impact of interventions used during COVID-19 pandemic in England. Social distancing and shielding measures alongside changes in guidance on how the public accessed health care services were introduced in England during March 2020. EDSSS was able to provide real-time intelligence on the impact of these restrictions, demonstrating significant decreases in patient attendances in EDs in England during the period of the COVID-19 intervention.[40-42]

5.6 Declarations

Consent for publication

Not applicable.

Availability of data and materials

The datasets analysed used in this study are not publicly available. Syndromic surveillance and laboratory data are collected and held by PHE for surveillance purposes, with no provision for use other than national surveillance outputs (https://www.gov.uk/government/publications/accessing-public-health-england-data/about-the-phe-odr-and-accessing-data).

Competing interests

Roberto Vivancos and Daniel Hungerford have worked in an evaluation of the childhood rotavirus vaccination programme in Merseyside which was partly funded by GlaxoSmithKline Biologicals. Daniel Hungerford is in receipt of research grant support from Sanofi Pasteur-MSD (SPMSD). This does not alter our adherence to PLOS ONE policies on sharing data and materials.

Funding

HEH, AJE, DH, GES and RV are partly funded by the National Institute for Health Research (NIHR) Health Protection Research Unit in Gastrointestinal Infections, a partnership between Public Health England and the University of Liverpool. The views expressed are those of the author(s) and not necessarily those of the NIHR, Public Health England or the Department of Health and Social Care.

Authors' contributions

HEH: EDSSS system design, study design, data preparation, formal analysis, drafted the manuscript, critical revision and final approval of the manuscript

AJE: EDSSS system design, study design, critical revision and final approval of the manuscript

TH: EDSSS system design, critical revision and final approval of the manuscript

DH: Study design, critical revision and final approval of the manuscript

RM: Study design, critical revision and final approval of the manuscript

RV: Study design, critical revision and final approval of the manuscript

GES: EDSSS system design, study design, critical revision and final approval of the manuscript

SJOB: Study design, critical revision and final approval of the manuscript

Acknowledgements

We acknowledge the contribution and support from the ED clinicians and Trust staff; the on-going support of the Royal College of Emergency Medicine; the technical support provided by EMIS Health and L2S2 Ltd in developing the sentinel EDSSS in England and Northern Ireland; and NHS Digital and NHS England for their support in the development of national EDSSS in England.

5.7 References

1. World Health Organisation. Rotavirus vaccines. WHO position paper – January 2013. Wkly Epidemiol Rec 2013;88: 49-64. Available: http://www.who.int/wer/2013/wer8805.pdf?ua=2011.
2. Harris JP, Jit M, Cooper D, Edmunds WJ. Evaluating rotavirus vaccination in England and Wales: Part I. Estimating the burden of disease. Vaccine 2007;25: 3962-3970. https://doi.org/10.1016/j.vaccine.2007.02.072
3. Hungerford D, Vivancos R, EuroRotaNet network members. In-season and out-of-season variation of rotavirus genotype distribution and age of infection across 12 European countries before the introduction of routine vaccination, 2007/08 to 2012/13. Eurosurveillance 2016;21: pii=30106. https://doi.org/10.2807/1560-7917.ES.2016.21.2.30106
4. Public Health England. Immunisations against infectious disease. Rotavirus: Chapter 27b. 2015. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/457263/Green_Book_Chapter_27b_v3_0.pdf.
5. Department of Health. Millions more protected against disease through improved vaccination programme. 2013. Available: https://www.gov.uk/government/news/millions-more-protected-against-disease-through-improved-vaccination-programme.
6. Public Health England. National rotavirus immunisation programme: preliminary data for England, October 2013 to September 2014. Health Protection Report Weekly Report 2014;8: Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/367155/hpr364114_rotavirus_v367154.pdf.
7. Public Health England. National rotavirus immunisation programme update: preliminary vaccine coverage for England, February 2016 to July 2016. Health Protection Report Weekly Report 2014;10: Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/555048/hpr553216_rtvrs_VC.pdf.
8. Inns T, Trindall A, Dunling-Hall S, Shankar AG. Introduction of a new Rotavirus vaccine: Initial results of uptake and impact on laboratory confirmed cases in Anglia and Essex, United Kingdom, July 2015. Hum Vaccin Immunother 2016;12: 1040-1044. https://doi.org/10.1080/21645515.2015.1108501
9. Bawa Z, Elliot AJ, Morbey RA, Ladhani S, Cunliffe NA, et al. Assessing the Likely Impact of a Rotavirus Vaccination Program in England: The Contribution of Syndromic Surveillance. Clin Infect Dis 2015;61: 77-85. https://doi.org/10.1093/cid/civ264
10. Atchison CJ, Stowe J, Andrews N, Collins S, Allen DJ, et al. Rapid declines in age group–specific rotavirus infection and acute gastroenteritis among vaccinated and unvaccinated individuals within 1 year of rotavirus vaccine introduction in England and Wales. J Infect Dis 2016;213: 243-249. https://doi.org/10.1093/infdis/jiv398
11. Hungerford D, Read JM, Cooke RPD, Vivancos R, Iturriza-Gómara M, et al. Early impact of rotavirus vaccination in a large paediatric hospital in the UK. J Hosp Infect 2016;93: 117-120. https://doi.org/10.1016/j.jhin.2015.12.010
12. Hungerford D, Vivancos R, Read JM, Iturriza-Gómara M, French N, et al. Rotavirus vaccine impact and socioeconomic deprivation: an interrupted time-series analysis of

gastrointestinal disease outcomes across primary and secondary care in the UK. BMC Med 2018;16. https://doi.org/10.1186/s12916-017-0989-z

13. Thomas SL, Walker JL, Fenty J, Atkins KE, Elliot AJ, et al. Impact of the national rotavirus vaccination programme on acute gastroenteritis in England and associated costs averted. Vaccine 2017;35: 680-686. https://doi.org/10.1016/j.vaccine.2016.11.057

14. Field EJ, Vally H, Grimwood K, Lambert SB. Pentavalent rotavirus vaccine and prevention of gastroenteritis hospitalizations in Australia. Pediatrics 2010;126: e506-e512. https://doi.org/10.1542/peds.2010-0443

15. Caruzo TAR. Human rotavirus genotypes circulating in Brazil before and after a nationwide rotavirus vaccination program established in 2006. Res Rep Trop Med 2011;2: 57-64. https://doi.org/10.2147/RRTM.S13650

16. Wilson SE, Rosella LC, Wang J, Renaud A, Le Saux N, et al. Equity and impact: Ontario's infant rotavirus immunization program five years following implementation. A population-based cohort study. Vaccine 2019;37: 2408-2414. https://doi.org/10.1016/j.vaccine.2019.01.061

17. Mwenda JM, Parashar UD, Cohen AL, Tate JE. Impact of rotavirus vaccines in Sub-Saharan African countries. Vaccine 2018;36: 7119-7123. https://doi.org/10.1016/j.vaccine.2018.06.026

18. Karafillakis E, Hassounah S, Atchison C. Effectiveness and impact of rotavirus vaccines in Europe, 2006–2014. Vaccine 2015;33: 2097-2107. https://doi.org/10.1016/j.vaccine.2015.03.016

19. Hahné S, Hooiveld M, Vennema H, van Ginkel A, de Melker H, et al. Exceptionally low rotavirus incidence in the Netherlands in 2013/14 in the absence of rotavirus vaccination. Eurosurveillance 2014;19: pii=20945. https://doi.org/10.2807/1560-7917.ES2014.19.43.20945

20. Triple S Project. Assessment of syndromic surveillance in Europe. Lancet 2011;378: 1833-1834. https://doi.org/10.1016/S0140-6736(11)60834-9

21. Pebody RG, Green HK, Andrews N, Boddington NL, Zhao H, et al. Uptake and impact of vaccinating school age children against influenza during a season with circulation of drifted influenza A and B strains, England, 2014/15. Eurosurveillance 2015;20: pii=30029. http://www.ncbi.nlm.nih.gov/pubmed/26537222.

22. Public Health England. Syndromic surveillance: systems and analyses. 2015. Available: https://www.gov.uk/government/collections/syndromic-surveillance-systems-and-analyses.

23. Elliot AJ, Hughes HE, Hughes TC, Locker TE, Shannon T, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. Emerg Med J 2012;29: 954-960. https://doi.org/10.1136/emermed-2011-200684

24. NHS Digital. Accident and Emergency Diagnosis Tables. 2013. Available: http://www.datadictionary.nhs.uk/web_site_content/supporting_information/clinical_coding/accident_and_emergency_diagnosis_tables.asp?shownav=1.

25. World Health Organisation. International Classification of Disease (ICD). 2020. Available: http://www.who.int/classifications/icd/en/.

26. International Health Terminology Standards Development Organisation. SNOMED CT. 2020. Available: http://www.ihtsdo.org/snomed-ct/.

27. Public Health England. Laboratory reporting to Public Health England. A guide for diagnostic laboratories. 2016. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545183/PHE_Laboratory_Reporting_Guidelines.pdf.

28. R Development Core Team. 2008. A language and environment for statistical computing. R Foundation for Statistical Computing. Available: http://www.R-project.org.

29. Venables WN, Ripley BD (2002) Modern Applied Statistics with S. New York: Springer.

30. Peng RD, McDermott A. 2013. tsModel: Time Series Modeling for Air Pollution and Health. Available: https://CRAN.R-project.org/package=tsModel.

31. Carstensen B, Plummer M, Laara E, Hills M. 2017. Epi: A Package for Statistical Analysis in Epidemiology. Available: https://CRAN.R-project.org/package=Epi.

32. Tam CC, Rodrigues LC, Viviani L, Dodds JP, Evans MR, et al. Longitudinal study of infectious intestinal disease in the UK (IID2 study): incidence in the community and presenting to general practice. Gut 2012;61: 69-77. 10.1136/gut.2011.238386

33. Fleming DM, Elliot AJ. Changing disease incidence: the consulting room perspective. Br J Gen Pract 2006;56: 820-824.

34. Pebody R, Green H, Andrews N, Zhao H, Boddington N, et al. Uptake and impact of a new live attenuated influenza vaccine programme in England: early results of a pilot in primary school-age children, 2013/14 influenza season. Euro Surveill 2014;19: pii=20823.

35. Hughes HE, Morbey R, Fouillet A, Caserio-Schönemann C, Dobney A, et al. Retrospective observational study of emergency department syndromic surveillance data during air pollution episodes across London and Paris in 2014. BMJ Open 2018;8: e018732. https://doi.org/10.1136/bmjopen-2017-018732

36. Hughes HE, Colon-Gonzalez FJ, Fouillet A, Elliot AJ, Caserio-Schonemann C, et al. The influence of a major sporting event upon emergency department attendances; A retrospective cross-national European study. PLoS ONE 2018;13: e0198665. https://doi.org/10.1371/journal.pone.0198665

37. Public Health England. Cryptosporidium spp data 2007 to 2016: National laboratory data for residents of England and Wales. 2018. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/711919/cryptosporidium_spp_data_2007_to_2016_may_2018.pdf.

38. Hughes HE, Hughes TC, Haile A, Smith GE, McCloskey B, et al. Syndromic surveillance revolution? Public health benefits of modernizing the emergency care patient health record in England. Public Health Rep 2017;132: 12S-15S. https://doi.org/10.1177/0033354917706955

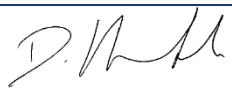
39. Hughes HE, Morbey R, Hughes TC, Locker TE, Pebody R, et al. Emergency department syndromic surveillance providing early warning of seasonal respiratory activity in England. Epidemiol Infect 2015;144: 1052-1064. https://doi.org/10.1017/S0950268815002125

40. Hughes HE, Hughes TC, Morbey R, Challen K, Oliver I, et al. Emergency department use during COVID-19 as described by syndromic surveillance. Emerg Med J 2020: 37:600-604Under review. http://dx.doi.org/10.1136/emermed-2020-209980

41. Thornton J. Covid-19: A&E visits in England fall by 25% in week after lockdown. BMJ 2020;369: m1401. 10.1136/bmj.m1401

42. Elliot AJ, Harcourt SE, Hughes HE, Loveridge P, Morbey RA, et al. The COVID-19 pandemic: a new challenge for syndromic surveillance. Epidemiol Infect 2020;148: e122. 10.1017/S0950268820001314

5.8 Co-author declaration

I confirm the specific contribution of **Helen Hughes** to this publication is as described in the Co-author declaration statement and give my permission for this paper to be appear in her thesis.	
 Alex J. Elliot	*12/02/2020* Date
 Thomas C. Hughes	*30/11/2020* Date
 Daniel Hungerford	*12/02/2020* Date
 Roger A. Morbey	*12/02/2020* Date
 Gillian E. Smith	*02/03/2020* Date
 Roberto Vivancos	*12/02/2020* Date
 Sarah J. O'Brien	*26/10/2020* Date

5.9 Addendum

This addendum further describes the interrupted time series analysis model used in the analysis in **Chapter 5**. Additional modifications are also described, which could be considered for the application of interrupted time series analysis of EDSSS data in the investigation of the impact of public health interventions in future.

The interrupted time series model constructed in this investigation of the impact of the introduction of rotavirus vaccination into the childhood vaccination schedule in England allowed for:

- a single point for the implementation of intervention (week 27, 2013);
- no change in slope of the modelled trend post intervention;
- the modelling of seasonality (with a harmonic Fourier term);
- the model to be applied to percentage, rather than count data (through the inclusion of the total number of ED visits as an offset).

A single point of intervention:

The inclusion of the rotavirus vaccine into the UK childhood vaccination schedule had a clearly defined start point (from Monday 1 July 2013, the beginning of week 27, 2013), which was used as the single point of intervention for this analysis. This single point approach was used due to high levels of vaccine coverage being reached quickly in the target age group (>85% coverage by February 2014).

Though high levels of vaccine coverage were attained quickly, the uptake of this vaccine did, of course, increase over time. The ability for ED syndromic surveillance to be used for near real-time investigation of the impact of vaccine implementation in future may require initial modelling to use a single point of intervention (as used in this study). A more detailed interrupted time series model may subsequently be constructed, including a second point of intervention from when herd immunity had been reached. Published vaccine coverage data could be used to identify the point at which sufficient coverage had been reached, though is not likely to be available as close to real-time as the EDSSS data is available.

Change in slope of modelled trend:

There is potential that post implementation of a public health intervention there may be a change in any overall trend of disease presentations identified pre-intervention.

An overall decrease in gastroenteritis ED attendances was identified in the pre-vaccination period, similar to the long term decreasing trend in GP consultations for infectious

intestinal disease identified elsewhere and described in the **Discussion**. It was considered unlikely that the vaccine would change the direction of this trend, i.e. cause an increase in (or stabilisation of) ED attendances, so the model used here did not allow for a change in trend.

However, it may be appropriate for future investigations using EDSSS data to allow for a change in slope of trend to be specifically factored into any interrupted time series analyses carried out.

Modelling seasonal variation:

Initial descriptive analysis showed ED gastroenteritis attendances, in total and for younger children in particular, followed clear seasonal trends, similar to the seasonality observed in rotavirus laboratory data for England. For this reason, the time period included for analysis both pre and post vaccine introduction included full years (rather than possibly partial seasons) and the interrupted time series model included Fourier terms to allow for seasonal increases and decreases.

The presence of an unexpected, out of rotavirus season, increase in gastroenteritis during the summer 2012 was of public health interest (possibly associated with high levels of Cryptosporidium activity as identified in laboratory surveillance). This was not controlled for in the model used in this study but could be in future similar analyses as appropriate.

Model based on percentage of attendances

The analysis carried out in this work was based on the standard surveillance activities of the sentinel EDSSS: reporting on the percentage of attendances due to the gastroenteritis indicator, rather than numbers of attendances recorded. The inclusion of an offset (total number of ED attendances) ensured the suitability of the interrupted time series methodology.

Though the reporting on workload and case mix as a percentage of attendances is of value within the ED setting, the COVID-19 pandemic has changed the appropriateness of this method of reporting from EDSSS. As detailed in *Emergency department use during COVID-19 as described by syndromic surveillance* (**Chapter 9**), overall ED attendances following the introduction of COVID-19 public health intervention measures and changes in health seeking behaviour in general greatly reduced the overall numbers of attendances at EDs. This unanticipated change required all national EDSSS reporting to change to numbers of attendances as standard, with all future analyses expected to be carried out in this format going forward.

Chapter 6 A retrospective observational study of emergency department syndromic surveillance data during air pollution episodes across London and Paris in 2014

Helen E. Hughes

Roger A. Morbey

Anne Fouillet

Céline Caserio-Schonemann

Alec Dobney

Thomas C. Hughes

Gillian E. Smith

Alex J. Elliot

BMJ Open. 2018 Apr 19;8(4):e018732. Crown Copyright.

DOI 10.1136/bmjopen-2017-018732

The near real-time (next day) nature of syndromic surveillance provides opportunities for the improved provision of health messages, tailored to a developing situation. This information may enable individuals to make simple changes in behaviour, having a protective effect on their health and reducing the overall impact of an otherwise adverse event.

Poor air quality (AQ) is a global public health issue, with exposure causing both short term and long-term effects in humans. Short term impacts, such as asthma, acute breathing difficulties and cardiac events may have an identifiable impact on attendances at EDs.

AQ events are not contained by political borders. Poor AQ can affect large geographical areas, cross borders and develop over time. Using ED syndromic surveillance from England and France, in the first cross national study of its kind, the changes in human health indicators during periods of particularly poor AQ in London and Paris during 2014 are described.

6.1 Abstract

Introduction

Poor air quality (AQ) is a global public health issue and AQ events can span across countries. Using emergency department (ED) syndromic surveillance from England and France, we describe changes in human health indicators during periods of particularly poor AQ in London and Paris during 2014.

Methods

Using daily AQ data for 2014, we identified 3 periods of poor AQ affecting both London and Paris. Anonymised near real-time ED attendance syndromic surveillance data from EDs across England and France were used to monitor the health impact of poor AQ.

Using the routine English syndromic surveillance detection methods, increases in selected ED syndromic indicators (asthma, difficulty breathing and myocardial ischaemia), in total and by age, were identified and compared to periods of poor AQ in each city. Retrospective Wilcoxon-Mann-Whitney tests were used to identify significant increases in ED attendance data on days with (and up to 3 days following) poor AQ.

Results

Almost 1.5 million ED attendances were recorded during the study period (27/2/14-1/10/14). Significant increases in ED attendances for asthma were identified around periods of poor AQ in both cities, especially in children (0-14yrs). Some variation was seen in Paris with a rapid increase during the first AQ period in asthma attendances amongst children (0-14yrs), whereas during the second period the increase was greater in adults.

Discussion

This work demonstrates the public health value of syndromic surveillance during air pollution incidents. There is potential for further cross-border harmonisation to provide Europe-wide early alerting to health impacts and improve future public health messaging to health care services to provide warning of increases in demand.

Strengths and limitations of this study

- routinely collected syndromic surveillance data from both England (London) and France (Paris) were analysed using similar health indicators;
- a single statistical method, designed specifically for daily syndromic surveillance, was applied to data from both cities;

- air quality measurements were standardised across both cities, to overcome differences in the standard reporting from each;
- pollutants other than particulate matter were not included, though they may be responsible for impacts on human health;
- we could not control for the potential effects of health warnings and media coverage on health care seeking behaviour.

6.2 Introduction

Air quality

Air pollution has negative impacts on human health. Short term exposure to poor air quality can affect lung function, including exacerbating asthma symptoms, and is associated with other acute deteriorations in respiratory and cardiovascular health.[1] Similar health effects have also been reported due to long term exposure, with exposure to ambient air pollution associated with lung cancer and chronic respiratory and cardiovascular conditions.[1] In addition to illness within the community and increased need for health care, air pollution is also associated with increased mortality, with an estimated 4.7% of deaths in the England attributed to air pollution[2] and 9% of deaths in France attributed to PM2.5.[3]

Air quality (AQ) monitoring identifies long term trends informing policy, provides evidence of meeting (or missing) statutory target levels and quantifies the impact of preventative measures.[4,5] Daily AQ monitoring enables daily reporting of both actual and modelled AQ (predicting one or more days in advance), for whole countries and/or individual cities, as well as on a smaller scale around individual monitoring stations.[6-8] This information is increasingly easy to access through websites and apps and is often reported through the media, especially following formal health warnings.[9]

Syndromic surveillance

Syndromic surveillance initially focussed on infectious diseases such as influenza but is increasingly being used for other non-infectious public health events. This type of surveillance uses real-time data from patient contacts with health care services (e.g. telephone helplines, general practice/family doctors, or emergency departments). Patient contacts/attendances are grouped by diagnoses/symptoms creating syndromic indicators such as ‘respiratory’ or ‘gastrointestinal’, providing valuable information for public health action.[10] The use of emergency department (ED) data lends itself particularly well to the syndromic surveillance of non-infectious public health events, with patients seeking attention for a range of acute conditions.[11-13] Previous investigation of periods of poor AQ have shown associated increases in health seeking behaviour as evidenced by syndromic surveillance, particularly for asthma and/or difficulty breathing and heart failure,[14-16] though not for myocardial infarction.[16]

Aims

During March and early April 2014 there was a period of widespread poor AQ across Europe. In particular, the urban conurbations of London (England) and Paris (France) were affected by high temperatures, Saharan dust and industrial emissions, resulting in widespread media attention.[17-19] Here, we use routine ED syndromic surveillance data collected across London and Paris during poor AQ periods throughout 2014 to investigate the compatibility of the two countries' ED syndromic surveillance systems and describe the public health impact and associated short-term changes in health care seeking behaviour for selected respiratory and cardiac syndromes across different age groups.

6.3 Methods

Air quality data

The area studied here has been limited to London and the whole Paris region (Île-de-France), rather than a country level. In England, the Department for Environment, Food and Rural Affairs monitors and reports on levels of air pollution using monitoring stations and provides health advice using the Daily Air Quality Index (DAQI).[9] Air quality in the Paris region is monitored by Airparif and reported using the Citeair index.[20]

Both DAQI and Citeair systems monitor and report on multiple pollutants, however each index is reported using different methodology. Therefore the daily pollution levels across both London and Paris were standardised here, using the reported levels of particulate matter (PM2.5 and PM10). The city wide average value for each PM on each calendar day was calculated as a mean of the maximum values reported for each monitoring station on that day, in that city.[21,22] Periods of poor AQ were then defined as those when the calculated PM2.5 and/or calculated PM10 average value corresponded to the DAQI index levels of 7-10, which are the particulate matter levels classified as 'high' to 'very high' (PM2.5 >=54 µg/m³ and/ or PM10 >=76 µg/m³). At these levels people, including those with no pre-existing medical conditions, are advised to consider reducing their activity levels, particularly outdoors.[8]

Emergency department syndromic surveillance data

The Emergency Department Syndromic Surveillance System (EDSSS), is a sentinel ED system coordinated by Public Health England (PHE), collecting anonymised data from participating EDs on a daily basis (data for the previous day 00:00 to 23:59 are transferred to PHE the following morning).[23] Diagnosis coding in EDs in England was not standardised at the time

of this investigation. Each ED had a list of diagnosis terms created locally which was available for selection in the patient attendance record. These diagnostic terms have associated codes linked to them with each ED using one of three codesets: Commissioning Data Set (CDS) Accident and Emergency Diagnosis Tables,[24] ICD-10[25] or Snomed CT.[26] EDs eligible for inclusion in this study were defined as those reporting using ICD-10 or Snomed CT diagnosis coding systems which provide the level of detail required for the identification of the indicators of interest; EDs using the CDS coding system were not able to provide the coded diagnosis data in this detail. This investigation included 5 eligible EDSSS participating EDs in London (all located within the London PHE Centre).

The French national ED syndromic surveillance system collects daily data from the Organisation de la Surveillance COordonnée des URgences (OSCOUR®) network of EDs, coordinated by Santé Publique France[27] (data for the previous day 00:00 to 23:59 are transferred and analysed the following morning for 85% of attendances at participating OSCOUR® EDs. The OSCOUR® system allows for updates and delayed reporting, the missing 15% of ED attendances from OSCOUR® EDs are reported in the following 2 days[28]). All EDs reporting to OSCOUR® use ICD-10 for the coding of diagnoses selected in the patient attendance record.[28] Aggregated, anonymised daily data for the Paris region (including 58 eligible EDs) were made available for this analysis.

Epidemiological analysis

Syndromic indicators (asthma, difficulty breathing and myocardial ischaemia (MI); **Table 6-1**) were selected from the comparable indicators already created for each system, based on clinical knowledge and experience of the potential health effects linked to air pollution and those used in previous syndromic surveillance work.

These syndromic surveillance indicators, which are routinely used in both EDSSS and OSCOUR®, are an aggregation of relevant diagnostic codes representing similar diagnostic terms and available in the patient record. These 'diagnoses' may not be confirmed or final and may be based on the symptoms presented, with no level of certainty indicated. The overall asthma and MI indicator groupings were very similar in each system, with the terms included all describing either asthma or myocardial ischaemic conditions. Differences were found in non-asthma difficulty breathing type indicators; EDSSS included symptomatic wheeze/difficulty breathing type diagnoses whereas OSCOUR® included dyspnoea/respiratory failure diagnoses (**Appendix C**). Please note: not every code listed was reported by – or even available for selection from – every ED. More relevant codes may

exist for each indicator than described here, however only codes reported to EDSSS/OSCOUR® in this study are included. Though each system was found to include different codes and even numbers of codes within each indicator, they would identify most of the same patients for inclusion within the indicators used here.

Table 6-1: Syndromic surveillance indicators included in the EDSSS (London) and OSCOUR® (Paris) emergency department systems and used in the study

EDSSS (London)	OSCOUR® (Paris)	Reported here as
Asthma	Asthme	Asthma
Wheeze/ difficulty breathing	Dyspnée/ Insuffisance respiratoire	Difficulty breathing
Myocardial ischaemia	Ischémie myocardique	Myocardial Ischaemia (MI)

For each syndromic surveillance system, attendances were aggregated by age group defined as 0-14, 15-44, 45-64 and 65 years and over.

The epidemiological analysis of ED attendance data included construction of trends in attendances for each syndromic indicator, both for all ages and for each age group, and city. The daily percentage(s) of attendances for each indicator were calculated using the number of attendances within an indicator (numerator) and the daily number of total (all cause) attendances with a diagnosis code within each surveillance system (denominator).

Statistical analysis

The EDSSS and OSCOUR® are both live public health surveillance systems prospectively collecting data with automated contemporaneous statistical algorithms underpinning the detection of unusual activity. We applied the routine syndromic surveillance statistical detection algorithm from England: the RAMMIE method (Rising Activity, Multi-level Mixed effects Indicator Emphasis).[29] RAMMIE was applied to both English and French ED data, including to age specific data. Using RAMMIE two separate statistical thresholds were calculated: a '2-year' threshold (based on the previous 2 years of data) to identify significant activity compared to previous years, and a '2-week' threshold (based on the previous two weeks) to identify recent, statistically significant, increases in daily activity. RAMMIE routinely allows for the prioritisation of alarms to facilitate the identification of significant activity, however, this function was not used here to ensure that all statistically significant activity was identified, and not just those signals prioritised by RAMMIE.

To ensure that sufficient data were included here to cover each of the AQ events identified, a study period of a minimum of 7 days pre the first and 7 days post the final period of poor AQ identified in London/ Paris during 2014 was selected. A further period of 2 years of data prior to the first AQ event provided required baseline data for the RAMMIE method.

In addition to the RAMMIE analysis, the Wilcoxon-Mann-Whitney non-parametric test was used to test for significant differences in the syndromic indicators during the 2014 study period, by age group between those days with poor AQ and those without. To allow for the possibility of a delayed response, separate analyses were conducted incorporating lags of one to three days following a day of poor AQ.

All analyses were undertaken using Stata v13.1.[30]

6.4 Results

Air quality events

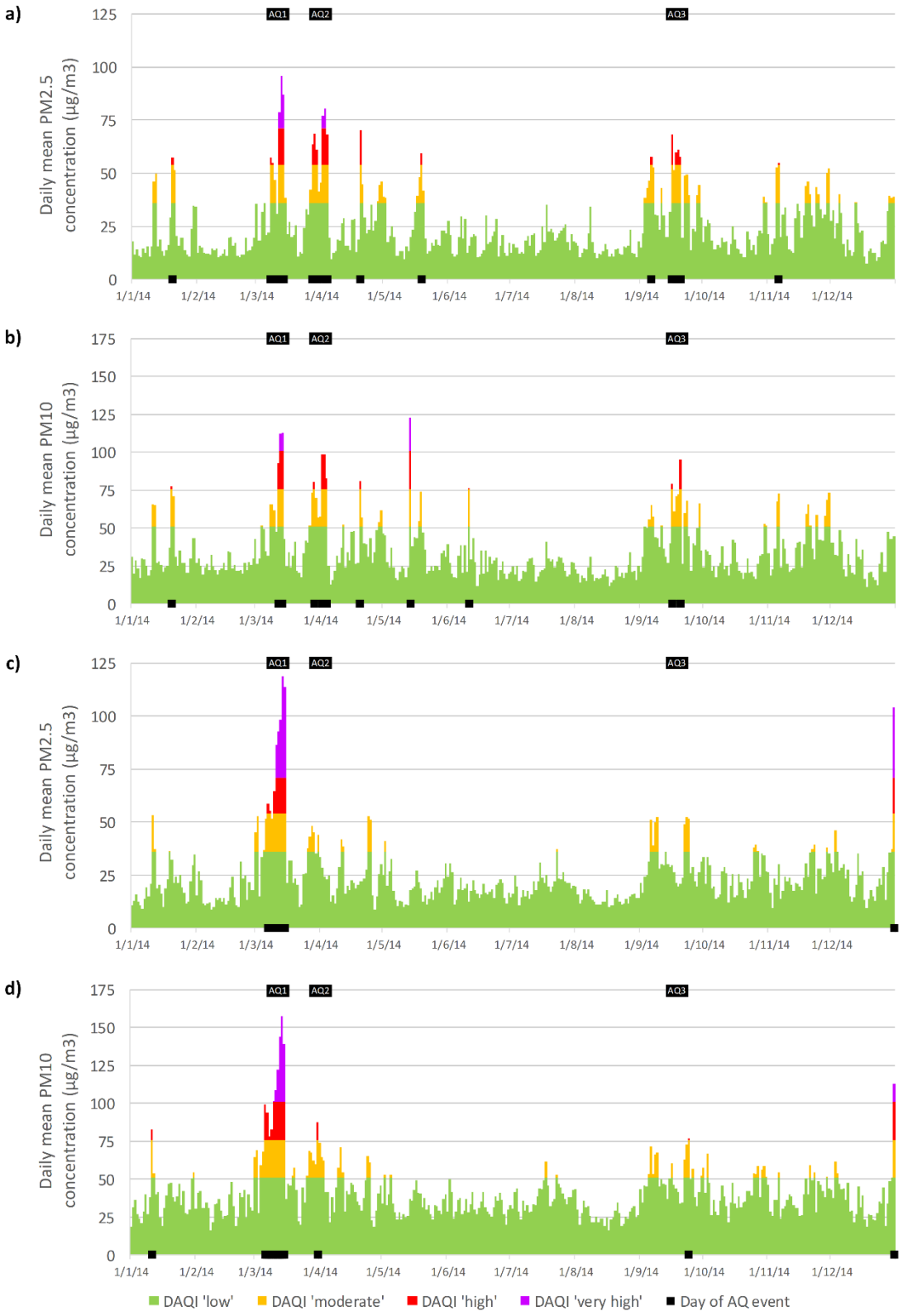
During 2014, several periods of poor AQ were identified where the 'high' or 'very high' air pollution thresholds for particulate matter (PM2.5 and/or PM10) had been breached in both London and Paris (**Figure 6-1**). Periods of poor air quality in Paris were generally observed to be of a longer duration and with higher DAQI levels than in London, though more individual days of poor AQ were identified in London. Two main periods of poor AQ overlapped in these cities in mid-March and early April. AQ1 was the largest event in both locations and where transboundary dust from the Sahara contributed to the makeup of the particulate matter fraction.[14] AQ2 was apparent mainly in London (though a 1 day PM10 spike in Paris was recorded). A third, less severe period occurred in both cities during September within a 7 day period (AQ3; **Table 6-2**).

Table 6-2: Dates of poor air quality, coinciding in London and Paris during 2014

	AQ1	AQ2	AQ3	Total AQ days
London	08/03/14 - 14/03/14	28/03/14 - 04/04/14	16/09/14 - 20/09/14	15
Paris	06/03/14 - 15/03/14	31/03/14	24/09/14	12

An overall study period was defined as 27 February 2014 – 1 October 2014 (216 days), to encompass each period where poor AQ occurred in both London and Paris, including 7 days before and after the first and final AQ events identified (**Table 6-2**).

Figure 6-1: Calculated mean daily PM value and corresponding Daily Air Quality Index band, by day during 2014 in London **a)** PM2.5, **b)** PM10: Paris **c)** PM2.5, **d)** PM10.



ED attendances

Over the study period 1,436,163 ED attendances were recorded across both London and Paris (**Table 6-4**). Total attendances were higher in Paris (1,163,353; from 58 EDs; >75% of all attendances[31]) than London (272,810; from 5 EDs, 3 using ICD-10, 2 using Snomed CT; <25% of attendances). A comparable level of diagnosis coding was included in each city with 79% of London attendances and 72% of Paris attendances including a clinical diagnosis code.

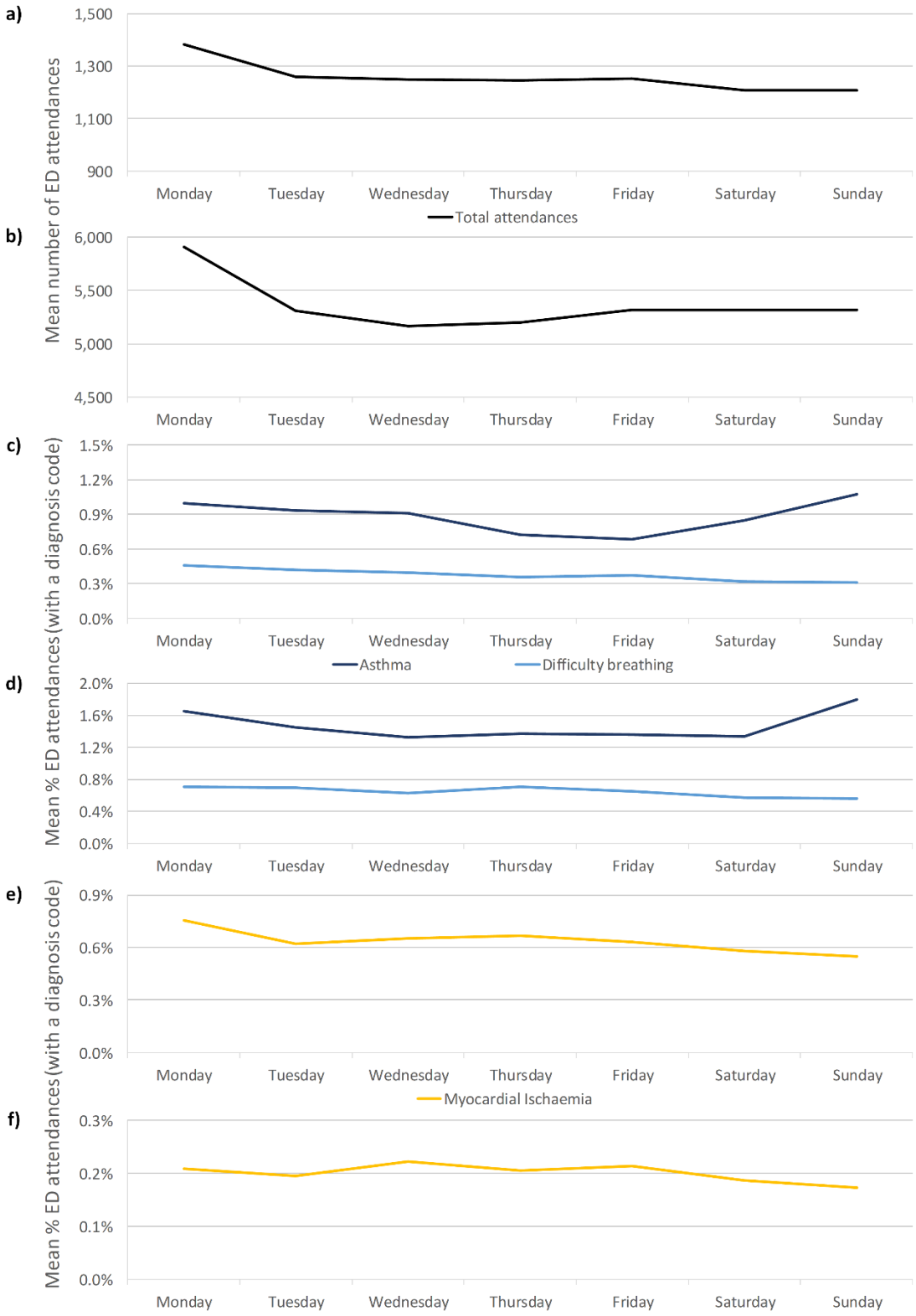
On a weekly basis, total ED attendances in both London and Paris showed similar trends, with a peak observed on a Monday. Examination of indicator trends illustrated that there were further similarities between EDSSS and OSCOUR® with highest levels of asthma attendances (as a percentage of attendances with a diagnosis code); and lowest levels of MI attendances, reported on Sundays (**Figure 6-2**).

Table 6-3: Attendances recorded in EDs, by city, over the study period (27/02/14-01/10/14)

		ED Attendances			Attendances with a diagnosis			Indicator attendances		
City	**EDs**	ICD-10	Snomed	Total	ICD-10	Snomed	Total	Asthma	Difficulty breathing	Myocardial ischaemia
London	5*	115,539	157,271	272,810	81,980 (71%)	132,750 (84%)	214,730 (79%)	1,893 (0.9%)	812 (0.4%)	1,370 (0.6%)
Paris	58	1,163,353	-	1,163,353	840,309 (72%)	-	840,309 (72%)	12,374 (1.5%)	5,433 (0.6%)	1,685 (0.2%)

*1 small ED (which used ICD-10) stopped reporting to EDSSS on 10/09/2014. All 5 EDs were included in descriptive and RAMMIE analysis; 4 EDs that reported throughout were included in Wilcoxon-Mann-Whitney testing.

Figure 6-2: Mean emergency department attendances by day of week, 27 February 2014 – 1 October 2014, by syndromic indicators, London reported to EDSSS: **a)** total attendances, **c)** Asthma and Difficulty breathing, **e)** Myocardial Ischaemia and Paris reported to OSCOUR®: **b)** total attendances, **d)** Asthma and Difficulty breathing, **f)** Myocardial Ischaemia.



ED attendances during poor air quality periods

London ED attendances

Small increases in asthma attendances (all ages) in London EDs were observed following AQ1 (**Figure 6-3a**). ED asthma attendances continued to increase during and immediately following AQ2. RAMMIE 2-week alarms were reported for the increases in asthma (all ages) immediately following AQ1 in London, indicating an attendance level higher than the previous 2 weeks. However, single 2-week alarms were not unusual in these data and were also observed during periods with no reported AQ issues. 2-year asthma alarms were not observed in the all ages asthma attendances data during the study period.

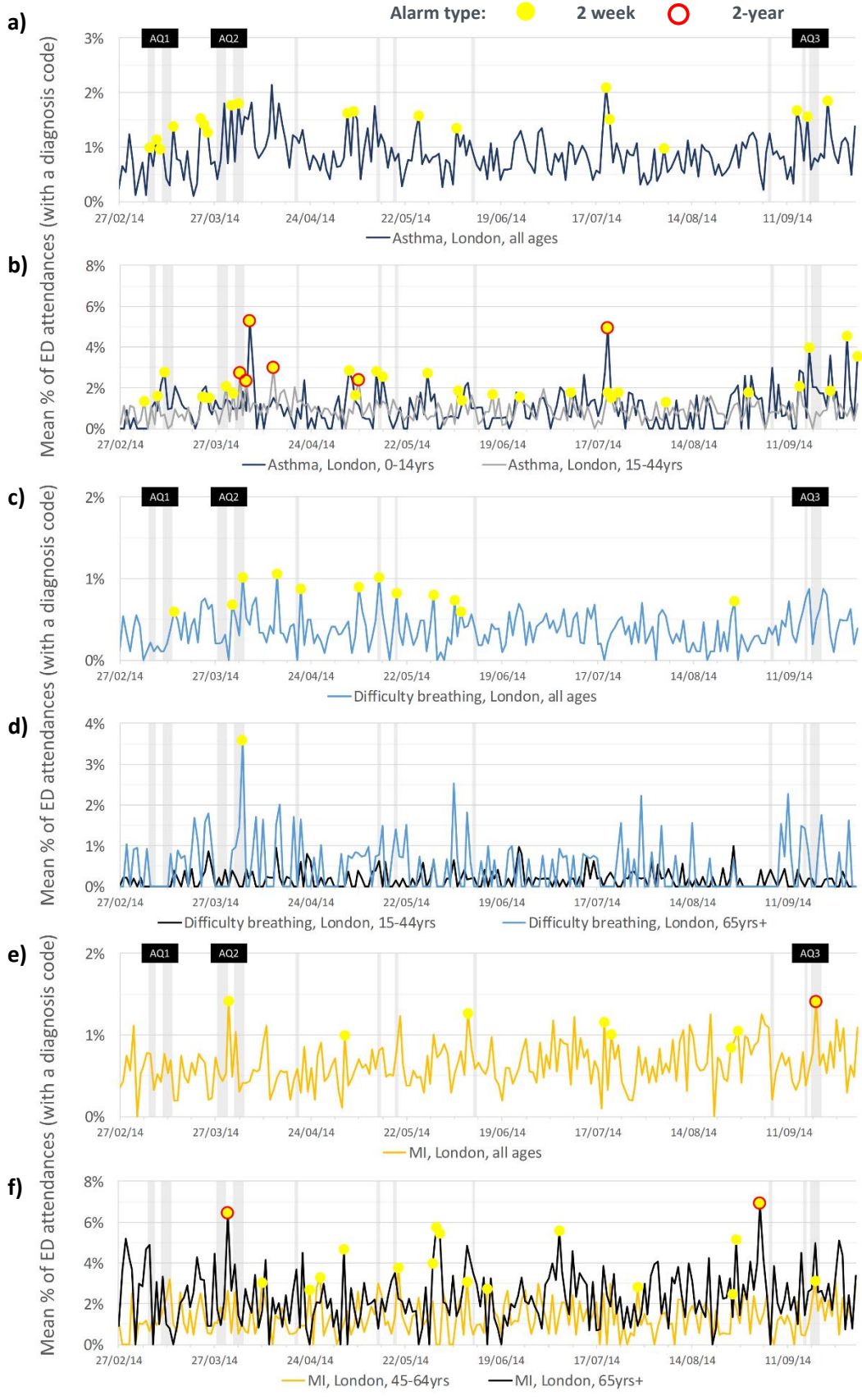
The observed increase of asthma attendances during the AQ2 episode in London was most evident in children aged 0-14 years, and young adults (15-44 years) with each age group reaching a peak in attendances 1 to 2 days later (**Figure 6-3b**). Asthma attendances for older adults showed no evidence of increase around periods of poor AQ (data not shown).

An additional peak in asthma (all ages) attendances was observed on 20/7/14 (**Figure 6-3a**), particularly in children (0-14yrs; **Figure 6-3b**), though there was no poor AQ identified at that time. During early September increases in all age attendances for asthma, largely driven by child attendances (0-14yrs), were observed to have started prior to AQ3.

A small increase in difficulty breathing attendances (all ages) immediately following AQ2 (**Figure 6-3c**), was most apparent in the older adults (65 and over years; **Figure 6-3d**). This single day peak was the highest level seen in this age group, around double the usual level, though not significantly higher than historical data. Other age groups were not affected.

MI attendances were less common than asthma attendances in London EDs (**Table 6-3**) and affected the adult age groups almost exclusively, as would be expected. Though a peak (resulting in both 2-week and 2-year alarm) in MI attendances was observed during AQ2, particularly in those aged 65yrs and over, a similar peak also occurred in late September, several days prior to the AQ3. 2-week alarms occurred quite frequently throughout the year (**Figure 6-3e & f**).

Figure 6-3: Daily percentages of London ED attendances for syndromic surveillance indicators of **a)** asthma all ages, **b)** asthma 0-14 and 15-44years, **c)** Difficulty breathing all ages, **d)** Difficulty breathing 15-44 and 65+ years, **e)** Myocardial Ischaemia all ages and **f)** Myocardial ischaemia 45-64 and 65+ years, with statistical alarms.



Paris ED attendances

Clear increases in ED attendances (all ages) for asthma occurred during both AQ1 and AQ2 in Paris (**Figure 6-4a**) and were statistically significant (2-year and 2-week alarms). However, when broken down by age, the increase in asthma attendances in the 0-14 years age group occurred during AQ1, but not AQ2; while asthma attendances in young adults (15-44yrs) were greater during AQ2 than AQ1. No statistical alarms were observed for asthma in children around AQ2, though they were present for young adults (**Figure 6-4b**).

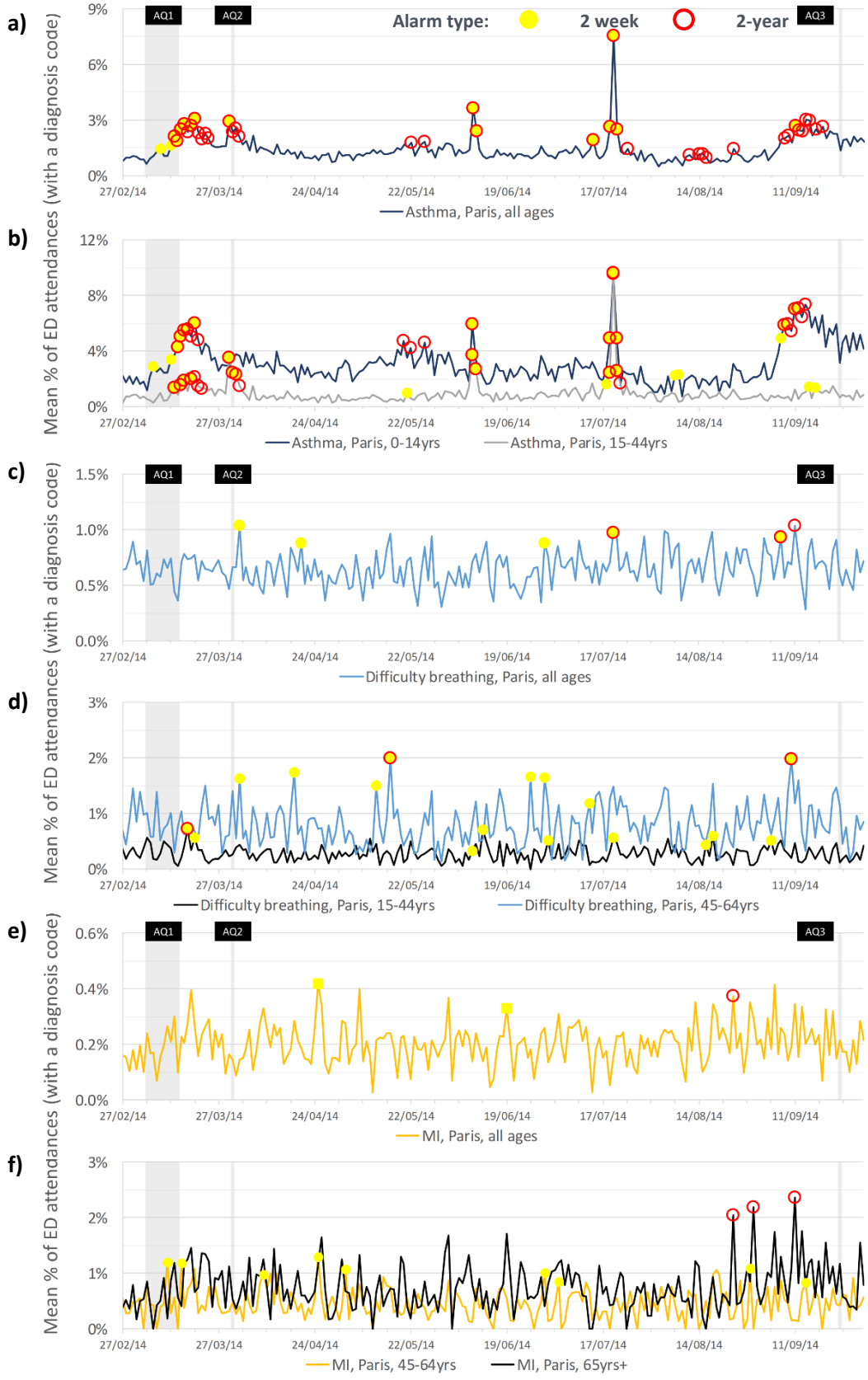
The largest peak in asthma attendances was observed on 20/07/14, for all ages apart from 65yrs and over (data not shown), matching the spike seen in London, despite air quality not being identified as poor on that day. One further peak in asthma attendances, apparent in all ages and individual age groups, was observed on 9-10/6/14 (**Figure 6-4a & b**). The observed peaks were not concomitant with any period of poor AQ in Paris, nor London.

Similar to London, an increase in asthma attendances was observed in Paris at the beginning of September, prior to AQ3, driven predominantly by children (0-14 years).

Difficulty breathing attendances in Paris were much lower than for asthma overall, with a single increase after AQ2 (**Figure 6-4c**). Within the 15-44yrs age group there was, however an increase in difficulty breathing attendances following AQ1 (**Figure 6-4d**).

Attendances for MI in Paris showed no evidence of increase in Paris during/ following days of poor AQ (**Figure 6-4e & f**), though some statistical alarms were observed throughout the year, particularly a series of three 2-year alarms during late August and September in those aged 65 years and over.

Figure 6-4: Daily percentages of Paris ED attendances for syndromic surveillance indicators of **a)** asthma all ages, **b**) asthma 0-14 and 15-44years, **c)** Difficulty breathing all ages, **d)** Difficulty breathing 15-44 and 45-64 years, **e)** Myocardial Ischaemia all ages and **f)** Myocardial ischaemia 45-64 and 65+ years, with statistical alarms.



Retrospective statistical analysis

Wilcoxon-Mann-Whitney test results provide further evidence, alongside the descriptive epidemiology and RAMMIE results, that there is a strong association between days of poor AQ and asthma attendances all ages and particularly in children 0-14 years (**Table 6-4**). Furthermore, the statistical significances of the associations between asthma attendances and poor AQ were highest when modelled with a lag between the day of poor AQ and attendances; two days for London and three days for Paris. Though there was some evidence of increased attendances for difficulty breathing and MI in some age groups in London one day after poor AQ, these alarms were single significant values (rather than the grouping of significant asthma results by age group; **Figure 6-3d & f**). These increased MI and difficulty breathing attendances in the day following poor AQ were not seen in the Paris data (**Figure 6-4d & f**).

Table 6-4: Results of the Wilcoxon-Mann-Whitney test illustrating the standardised value (z value) and significance (P value) of syndromic indicators to days of poor air quality (including 1-3 day lag).

Indicator	City	lag (days)	all ages		0-14yrs		15-44yrs		46-64yrs		65yrs+	
			z value	p value	z value	p value	z value	p value	z value	p value	z value	p value
Asthma	London	0	-0.227	0.8204	-2.857	**0.0043**	1.287	0.1982	1.077	0.2813	-1.009	0.3128
		1	-1.443	0.1490	-3.213	**0.0013**	0.556	0.5784	-0.791	0.4291	-1.026	0.3048
		2	-1.713	**0.0867**	-3.838	**0.0001**	0.787	0.4310	-0.558	0.5768	-1.438	0.1503
		3	-1.627	0.1038	-2.574	**0.0100**	-0.141	0.8876	-0.442	0.6586	0.816	0.4145
	Paris	0	-0.963	0.3356	-1.566	0.1173	0.529	0.5971	-0.624	0.5326	0.000	1.0000
		1	-2.035	**0.0419**	-2.576	**0.0100**	-0.330	0.7418	-1.582	0.1137	-0.354	0.7237
		2	-2.706	**0.0068**	-3.090	**0.0020**	-0.943	0.3454	-2.558	**0.0105**	-0.194	0.8464
		3	-3.049	**0.0023**	-3.201	**0.0014**	-1.797	**0.0724**	-2.77	**0.0056**	-0.756	0.4499
Difficulty Breathing	London	0	-0.055	0.9563	-0.963	0.3357	1.311	0.1898	-0.361	0.7181	-0.140	0.8889
		1	-1.261	0.2073	-2.975	**0.0029**	1.797	**0.0723**	0.445	0.6564	-0.728	0.4666
		2	-0.444	0.6573	-1.385	0.1659	0.223	0.8236	1.452	0.1464	-0.580	0.5620
		3	-1.552	0.1207	-1.236	0.2166	-0.695	0.4872	-0.01	0.9916	-0.296	0.7670
	Paris	0	-0.604	0.5459	0.031	0.9749	-0.585	0.5582	-0.736	0.4615	-0.147	0.8830
		1	-0.057	0.9547	-1.032	0.3021	-0.490	0.6242	0.603	0.5466	-0.078	0.9376
		2	-1.364	0.1725	-1.095	0.2735	-0.674	0.5004	-0.565	0.5722	-1.521	0.1283
		3	-1.144	0.2526	-0.528	0.5974	-0.942	0.3464	0.427	0.6697	-1.222	0.2217

Indicator	City	lag (days)	all ages		0-14yrs		15-44yrs		46-64yrs		65yrs+	
			z value	p value	z value	p value	z value	p value	z value	p value	z value	p value
MI	London	0	-0.605	0.5452	-	-	-0.084	0.9327	-1.275	0.2022	0.027	0.9787
		1	-0.588	0.5565	-	-	0.329	0.7421	-1.994	**0.0461**	0.374	0.7084
		2	-0.081	0.9354	-	-	-0.084	0.9327	-0.61	0.5419	0.053	0.9574
		3	-0.571	0.5680	-	-	0.544	0.5862	-1.415	0.1571	-0.695	0.4873
	Paris	0	-0.364	0.7158	0.546	0.5850	-1.257	0.2089	-0.089	0.9293	0.367	0.7138
		1	0.243	0.8082	0.546	0.5850	-1.257	0.2089	-0.022	0.9828	1.594	0.1110
		2	-0.331	0.7408	0.546	0.5850	-0.522	0.6016	-0.235	0.8141	0.635	0.5253
		3	-0.676	0.4992	0.546	0.5850	-0.578	0.5630	0.384	0.7011	-0.403	0.6872

Figures in **bold** are significant to the 90% significance level; those **bold and underlined** to the 95% significance level.

6.5 Discussion

Main findings

We used two national ED syndromic surveillance systems to describe and compare the short-term changes in ED indicators during periods of poor AQ in two European capital cities. The AQ events reported here in Paris and London were related to the same pollutants (PM2.5/ PM10), and were very similar in terms of the dates and duration, and changes in public health outcomes in terms of ED attendances.

The most sensitive ED indicator during periods of poor AQ was asthma, with the impact most apparent up to 3 days after a day of poor AQ. The breakdown of attendances by age group revealed some differences, with the strongest associations overall seen between poor AQ and asthma attendances in children. This finding was consistent with previous studies which have shown children to be more susceptible to exacerbation of asthma symptoms requiring health care in association with air pollution.[32]

The investigation of individual AQ incidents demonstrated the potential for differing levels of impact on different age groups at different times. Though generally children were most affected by AQ, a large increase in adult asthma attendances was observed during and immediately following AQ2 in both London and Paris. Within England this increase in attendances around AQ2 has previously been described.[33] As the second period of poor AQ to occur in a short period of time, media coverage and the associated communication of health warning information and interventions put in place during AQ2 may have resulted in changes in behaviour which affected the levels of exposure of different age groups.

In addition to the increases observed during AQ periods, a sharp increase in asthma attendances (all ages) was observed in Paris on 9-10/06/14, and in both London and Paris on 20/07/14. These peaks did not coincide with any AQ event identified here, however, additional meteorological data (not presented) revealed periods of major thunderstorm activity within each city at the time.[34-36] These findings match those previously reported, including from the EDSSS, describing the health effects of 'thunderstorm asthma', where sudden exacerbation of asthma symptoms results in increased health care seeking behaviour over a short time period,[13,37-40] possibly due to increased levels of pollen and fungal spores, though the mechanism has not yet been confirmed.[37]

We also observed further increases in asthma attendances in both Paris and London towards the start of September. This increase was particularly evident in children and is

likely linked to an annual 'back to school' increase in asthma type attendances in EDs during September.[41-43]

Other syndromic indicators investigated showed little (difficulty breathing), to no (MI) association with the AQ incidents identified here.

Strengths and limitations

The OSCOUR® system includes greater representative coverage nationally, with more EDs participating than the sentinel EDSSS system (540 EDs across France were reporting to OSCOUR®.[44] While 34 EDs across England and Northern Ireland were reporting to EDSSS at 20 March 2014, the five reported here were located in London making the EDSSS more representative in London than at the national level[45]). The large number of OSCOUR® EDs reported here resulted in much more stable data from Paris, reducing background noise and allowing clearer differentiation of spikes/increases in attendances. The smaller number of attendances within the EDSSS data made identifying spikes 'harder', however the use of RAMMIE enables significant increases in attendances to be identified, even when not initially obvious.[29]

Despite underlying differences in the method of data collection, with EDSSS taking a single snapshot of daily attendances and OSCOUR® allowing the initial snapshot data to be updated retrospectively, both systems reported over 70% completion of the clinical diagnosis field making diagnostic data comparable. Furthermore, though these systems were developed individually, it was found that the syndromic indicators used within each system were similar, making comparisons of health impact possible. However, the EDSSS used a wheeze/difficulty breathing indicator whereas OSCOUR® used a difficulty breathing/respiratory failure indicator. This difference is, in part, likely to be related to the use of different clinical coding systems, with the identification of symptoms (e.g. wheeze) more difficult using ICD-10 (as used in France) than Snomed CT (used by some EDs in England).

The percentage of ED visits (with a diagnosis code), as an indication of ED attendances, as reported here (rather than actual numbers) may be impacted by the overall levels of ED attendances (and levels of diagnostic coding) on any one day. Though travel and outdoor activities are discouraged during AQ events, there are other factors which have a much greater impact on ED attendances (such as national and school holiday periods). The patterns and total numbers of attendances during 2014, including AQ periods, were not different from those seen in other years. The normal levels of overall ED attendances observed during periods of poor AQ, though travel was discouraged, contrasts with the

reduced overall ED attendances in the English EDSSS seen during extreme cold weather when transportation is not physically possible for most people.[11] By using percentage of attendances the impact of events, such as periods of poor AQ, can be clearly seen in terms of changes in ED workload, such as changes in case mix and/ or age groups attending.

The levels of attendances for each indicator were different between cities, with respiratory indicators higher in Paris (asthma 1.5%, difficulty breathing 0.7%), than London (asthma 0.9%, difficulty breathing 0.4%) and MI attendances higher in London (0.6%) than in Paris (0.2%). This disparity in attendance levels between countries may be due to differences in diagnosis coding practices, clinical procedures used for treating patients (e.g. immediate transfer to cardiac care rather than ED for MI patients) or even areas of specialty for each ED (e.g. some London EDs are part of specialist heart care hospitals so may see more MI patients). However, the trends observed within weeks were very similar in both systems, implying they are broadly comparable (**Figure 6-2**).

A limitation of the statistical methods used here is that the occurrence of previous events (e.g. poor AQ or weather systems) influencing the indicators were not identified or removed from the 2 years of historical data used as RAMMIE training data. The potential inclusion of unrecognised events may impact on the RAMMIE model thresholds, though 2 years is considered sufficient for meaningful results (personal communication with R. Morbey).

This study focussed solely on particulate matter, though other pollutants impact on human health. The application of the DAQI levels to both London and Paris mean daily data allowed for an international comparison, based on days with higher than usual PM2.5 and/ or PM10 specific to each city. The use of the highest daily PM2.5/ PM10 values was considered, but these values were found to be at the high/ very high on the DAQI scale on the majority of days of 2014.

The impact of health warnings and media reporting associated with actual and predicted periods of poor AQ could not be controlled for here. The intention of health warnings, which are reported in the media, is to reduce the impact on human health, encouraging the public to reduce exposure as recommended.[9, 46] There were increases in asthma attendances in children during and following AQ1 in Paris in particular, though these younger age groups appeared unaffected during later events, whereas young adults were more greatly affected by AQ2. These differences of impact by age group in AQ2 may have been due to changes in behaviour of younger age groups so soon after AQ1 and subsequent reduced exposure to poor AQ, rather than a biological response observed in adults only. In

addition to the impact of media reporting, France has introduced several other measures when air quality limit values are exceeded in major cities; speed limits, alternate driving days (to limit the number of cars on the road) and free public transportation. The implementation of these measures could have had an impact on the results presented here.

It is important here to underline that variations of near real-time indicators are not easy to attribute directly to poor AQ. An absence of short term variation (e.g. MI in this study) cannot not be interpreted as a total lack of any longer term impact. Similarly, the identification of a significant increase in syndromic indicators reported here (e.g. asthma) has not formally accounted for other associated factors such as climatic conditions (e.g. weather and allergens) or viral circulation. Further time series analysis should be completed to control potential confounding factors.

Future work

This work has prompted the systematic investigation of asthma attendances by age group around AQ events in England and Northern Ireland, using the EDSSS. In France (following the March 2014 periods of poor AQ reported here), the health authorities requested and are now provided with, systematic surveillance of OSCOUR® ED attendances for asthma by age group during poor quality events. This work shows the potential of real-time syndromic surveillance to enhance the public health response to air pollution incidents, even if real-time changes observed through syndromic surveillance data cannot be absolutely related to air pollution. As the evidence base for the utility of syndromic surveillance during air pollution events increases, it is hoped that it will, in combination with environmental data, be used by authorities to provide public health messaging during future events: messages to the public to advise about risks and preventative measures, and to EDs and other health service providers about increases in patient numbers and changes to the case mix of patients attending.

The increases in attendance levels for specified indicators, particularly asthma in children, provides an insight into not only the age groups affected, but also how the workload and case mix within EDs can rapidly change. Contemporaneous feedback may be given on the utility of health warnings issued which may aid in the targeting of advice to particular age groups and also the preparations made in EDs in terms of staffing and materials required.

Where increased ED attendances were observed during periods of no known changes in AQ, there is potential for further investigation of the potential causes. The identification of

periods of thunderstorm activity on the days of the highest asthma attendances reported here should be investigated further.

This study is the first example of the RAMMIE method being applied to a syndromic surveillance system outside the UK, identifying and highlighting increases in ED attendances during periods of known poor AQ. This work has illustrated the potential for RAMMIE to be applied to countries developing new syndromic surveillance systems, or without the infrastructure to support bespoke statistical developments. However, the limitations of this method must always be considered, where increased levels resulting in statistical alarms (either 2-week or 2-year) must be viewed alongside local intelligence and knowledge, not every alarm will be due to poor AQ, but the indicators can be used for monitoring the impact of AQ events on public health.

This work also promotes further collaboration between different countries to explore methods to harmonize syndromic surveillance systems. Other public health surveillance initiatives have been adopted across Europe to provide a means of reporting singularly comparable variables and statistics across several countries, including: the European monitoring of excess mortality for public health action (EuroMOMO);[47] the European Influenza Surveillance Scheme (EISS);[48] establishment of epidemic thresholds for influenza surveillance;[49] the European Antimicrobial Resistance Surveillance Network (EARS-net);[50] harmonised norovirus surveillance systems also exist.[51, 52] Within this study, although ED indicators were not entirely harmonized, they had been developed to be the most appropriate for each system and country. This work has also stimulated opportunities to explore other areas of public health that could be enhanced using a multinational syndromic surveillance system in particular those due to non-infectious causes such as injury surveillance and these will be addressed in future work.

The apparent difference in the noise to signal ratio between OSCOUR® and EDSSS i.e. background variation was likely due to the size of each respective network. Peaks of abnormal activity were easier to identify in OSCOUR® and therefore future work within PHE is currently focusing on expanding the EDSSS to improve its geographical representativeness and increase the attendance numbers thereby reducing the noise to signal ratio.

The potential for the harmonisation of syndromic surveillance across national borders is also clear, with opportunities to build on local experience to bring international public health benefits.

6.6 Acknowledgements

We acknowledge the contribution and support from the ED clinicians and Trust staff; the on-going support of the Royal College of Emergency Medicine; the technical support provided by EMIS Health and L2S2 Ltd in developing the EDSSS system in England and Northern Ireland. We also acknowledge the contribution from the ED structures and clinicians involved in the OSCOUR® network in France; the on-going support of the Federation of the Regional Observatories of Emergencies; the Scientific Society of Emergency Medicine; the air and climate team of Santé publique France and the Regional Unit of Santé publique France in Paris-Ile-de-France region.

We acknowledge and thank Sylvia Medina (Santé Publique France) for their professional input and critical revision of this manuscript.

HEH receives support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Gastrointestinal Infections. AJE and GES receive support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Emergency Preparedness and Response. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, the Department of Health or Public Health England.

6.7 Declarations

Ethics

Ethical approval for this work was not required. The anonymised EDSSS health data used in this study were routinely collected at part of the public health function of PHE. The collection and analysis of data provided by the OSCOUR network in the frame of public health surveillance and epidemiological studies has been authorized by the French National Commission for Data protection and Liberties (CNIL).

Funding

This research received no specific grant from any funding agency, commercial or not-for-profit sectors. This surveillance is undertaken as part of the national surveillance functions of Public Health England and Santé Publique France.

Conflicts of interest

None

Contributor statement

HEH contributed to the study design, prepared the ED data for England, completed the statistical analyses, drafted the manuscript and provided critical revision and final approval of the manuscript.

RM contributed to the study design, completed the statistical analyses, drafted the manuscript and provided critical revision and final approval of the manuscript.

AF contributed to the study design, prepared the ED data for France and provided critical revision and final approval of the manuscript.

CCS contributed to the study design, critical revision and final approval of the manuscript.

AD contributed to the study design, prepared the air quality data and provided critical revision and final approval of the manuscript.

TCH contributed to the study design, critical revision and final approval of the manuscript.

GES contributed to the study design, critical revision and final approval of the manuscript.

AJE contributed to the study design, critical revision and final approval of the manuscript.

Data sharing statement

Additional data are not available for sharing.

6.8 References

1. World Health Organisation. Air Quality Guidelines Global Update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide: WHO2006.
2. Public Health England. Public Health Outcomes Framework: 3.01 - Fraction of mortality attributable to particulate air pollution. 2017. [Available from: http://www.phoutcomes.info/public-health-outcomes-framework#page/6/gid/1000043/pat/15/par/E92000001/ati/6/are/E12000007/iid/30101/age/230/sex/4. Accessed 30 Mar 2017].
3. Pascal M, de Crouy Chanel P, Wagner V, Corso M, Tillier C, Bentayeb M, et al. The mortality impacts of fine particles in France. Sci Total Environ. 2016;571:416-25.
4. DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe, 2008/50/EC (2008).
5. Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide, (2006).
6. World Air Quality Index project. Air Pollution in the World: Real time Air Quality map. 2016. [Available from: http://waqi.info/. Accessed 01 Mar 2016].
7. CITEAIR. Air Quality in Europe. Compare the current air quality in different European Cities. 2007. [Available from: http://www.airqualitynow.eu/. Accessed 01 Mar 2016.
8. Department for Environment Food & Rural Affairs. UK-AIR: Information Resource. 2016. [Available from: http://uk-air.defra.gov.uk/. Accessed 18 March 2016].
9. Department for Environment Food & Rural Affairs. Daily Air Quality Index. 2013. [Available from: http://uk-air.defra.gov.uk/air-pollution/daqi. Accessed 18 Mar 2016].
10. Triple S Project. Assessment of syndromic surveillance in Europe. Lancet. 2011;378:1833-4.
11. Hughes HE, Morbey R, Hughes TC, Locker TE, Shannon T, Carmichael C, et al. Using an Emergency Department Syndromic Surveillance System to investigate the impact of extreme cold weather events. Public Health. 2014;128:628-35.
12. Josseran L, Caillere N, Brun-Ney D, Rottner J, Filleul L, Brucker G, et al. Syndromic surveillance and heat wave morbidity: a pilot study based on emergency departments in France. BMC Med Inform Decis Mak. 2009;9:DOI: 10.1186/472-6947-9-14.
13. Elliot AJ, Hughes HE, Hughes TC, Locker TE, Brown R, Sarran C, et al. The impact of thunderstorm asthma on emergency department attendances across London during July 2013. Emerg Med J. 2013. Doi: 10.1136/emermed-2013-203122
14. Smith GE, Bawa Z, Macklin Y, Morbey R, Dobney A, Vardoulakis S, et al. Using real-time syndromic surveillance systems to help explore the acute impact of the air pollution incident of March/April 2014 in England. Environ Res. 2015;136:500-4.
15. Johnson J, Ginsberg M. Monitoring health effects of wildfires using the biosense system. MMWR Wkly. 2008;57.
16. Rappold AG, Stone SL, Cascio WE, Neas LM, Kilaru VJ, Carraway MS, et al. Peat bog wildfire smoke exposure in rural North Carolina is associated with cardiopulmonary emergency department visits assessed through syndromic surveillance. Environ Health Perspect. 2011;119:1415-20.
17. Le Monde. Pollution : plus de 30 départements en alerte, transports gratuits en Ile-de-France. 2014. [Available from:

http://www.lemonde.fr/planete/article/2014/03/14/pollution-plus-de-30-departements-en-alerte-transports-gratuits-en-ile-de-france_4382974_3244.html. Accessed 26 May 16].

18. RT news. London to be 'smogged' by polluted Paris. 2014. [Available from: https://www.rt.com/uk/154368-london-smog-pollution-paris/. Accessed 26 May 16].

19. BBC. UK air pollution: How bad is it? 2014. [Available from: http://www.bbc.co.uk/news/uk-26851399. Accessed 26 May 2016].

20. Airparif. Airparif: Air quality monitoring network. 2016. [Available from: http://www.airparif.asso.fr/en/. Accessed 18 Mar 2016].

21. Affairs DfEFR. Data Selector. [Available from: https://uk-air.defra.gov.uk/data/data_selector. Accessed 19 Jul 2016].

22. Airparif. Téléchargements: Results pollutant. [Available from: http://www.airparif.asso.fr/telechargement/telechargement-polluant. Accessed 06 Jun 2016].

23. Elliot AJ, Hughes HE, Hughes TC, Locker TE, Shannon T, Heyworth J, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. Emerg Med J. 2012;29:954-60.

24. NHS digital. Accident and Emergency Diagnosis Tables. 2013. [Available from: http://www.datadictionary.nhs.uk/web_site_content/supporting_information/clinical_coding/accident_and_emergency_diagnosis_tables.asp?shownav=1. Accessed 1 Nov 2013].

25. World Health Organisation. International Classification of Disease (ICD). 2010. [Available from: http://www.who.int/classifications/icd/en/. Accessed 23 Jan 2020].

26. International Health Terminology Standards Development Organisation. SNOMED CT. 2012. [Available from: http://www.ihtsdo.org/snomed-ct/.

27. Caserio-Schonemann C, Bousquet V, Fouillet A, Henry V. Le système de surveillance syndromique SurSaUD®. Bulletin Epidémiologique Hebdomadaire. 2014:38-44.

28. Fouillet A, Bousquet V, Pontais I, Gallay A, Schönemann CC. The French Emergency Department OSCOUR Network: Evaluation After a 10-year Existence. Online Journal of Public Health Informatics. 2015;7:e74.

29. Morbey RA, Elliot AJ, Charlett A, Verlander NQ, Andrews N, Smith GE. The application of a novel 'rising activity, multi-level mixed effects, indicator emphasis' (RAMMIE) method for syndromic surveillance in England. Bioinformatics. 2015;31:3660-5.

30. Stata version 13.1. College Station, TX 77845 USA: Stata Corporation; 2013.

31. Santé publique France. Réseau OSCOUR® - Organisation de la surveillance coordonnée des urgences. 2015. [Available from: http://invs.santepubliquefrance.fr/Espace-professionnels/Surveillance-syndromique-SurSaUD-R/Reseau-OSCOUR-R].

32. Alhanti BA, Chang HH, Winquist A, Mulholland JA, Darrow LA, Sarnat SE. Ambient air pollution and emergency department visits for asthma: a multi-city assessment of effect modification by age. J Expos Sci Environ Epidemiol. 2016;26:180-8.

33. Elliot AJ, Smith S, Dobney A, Thornes J, Smith GE, Vardoulakis S. Monitoring the effect of air pollution episodes on health care consultations and ambulance call-outs in England during March/April 2014: A retrospective observational analysis. Environmental Pollution. 2016;214:903-11.

34. EUMETSAT. Severe thunderstorms over parts of France. 2014. [Available from: http://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_2238698.html. Accessed 25 May 2016].

35.RFI. Storms to return to France after night of hail, rain, thunder, lightning. 2014. [Available from: http://en.rfi.fr/visiting-france/20140609-storms-return-france-after-night-hail-rain-lightning-damage. Accessed 25 May 2016].

36.MetOffice. UK Climate, Climate Summaries, July 2014. 2015. [Available from: http://www.metoffice.gov.uk/climate/uk/summaries/2014/july. Accessed 27 May 16 2016].

37.Dabrera G, Murray V, Emberlin J, Ayres JG, Collier C, Clewlow Y, et al. Thunderstorm asthma: an overview of the evidence base and implications for public health advice. QJM. 2013;106:207-17.

38.Wallis DN, Webb J, Brooke D, Brookes B, Brown R, Findlay A, et al. A major outbreak of asthma associated with a thunderstorm: experience of accident and emergency departments and patients' characteristics. BMJ. 1996;312:601-4.

39.Hajat S, Goubet SA, Haines A. Thunderstorm-associated asthma: the effect on GP consultations. Br J Gen Pract. 1997;47:639-41.

40.BBC. 'Thunderstorm asthma' deaths in Melbourne rise to eight. 2016. [Available from: http://www.bbc.co.uk/news/world-australia-38121579. Accessed 23 Jan 2017].

41.Julious SA, Osman LM, Jiwa M. Increases in asthma hospital admissions associated with the end of the summer vacation for school-age children with asthma in two cities from England and Scotland. Public Health. 2007;121:482-4.

42.Fleming DM, Cross KW, Sunderland R, Ross AM. Comparison of the seasonal patterns of asthma identified in general practitioner episodes, hospital admissions, and deaths. Thorax. 2000;55:662-5.

43.Lincoln D, Morgan G, Sheppeard V, Jalaludin B, Corbett S, Beard J. Childhood asthma and return to school in Sydney, Australia. Public Health. 2006;120:854-62.

44.Institut de Veille Sanitaire. Surveillance syndromique SurSaUD®: Bulletin du réseau OSCOUR®: Institut de Veille Sanitaire2014 1 October 2014 Contract No.: 496.

45.Health Protection Agency. Emergency Department Syndromic Surveillance System Bulletin: Health Protection Agency, Team R-tSS;2014 23 March 2014.

46.McLaren J, Williams ID. The impact of communicating information about air pollution events on public health. Sci Total Environ. 2015;538:478-91.

47.EuroMOMO. European monitoring of excess mortality for public health action. 2017. [Available from: http://www.euromomo.eu/index.html. Accessed 30 Mar 2017].

48.Paget J, Marquet R, Meijer A, van der Velden K. Influenza activity in Europe during eight seasons (1999–2007): an evaluation of the indicators used to measure activity and an assessment of the timing, length and course of peak activity (spread) across Europe. BMC Infect Dis. 2007;7:1-7.

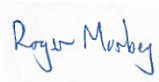
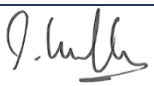
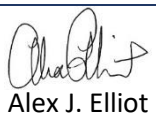
49.Vega T, Lozano JE, Meerhoff T, Snacken R, Mott J, Ortiz de Lejarazu R, et al. Influenza surveillance in Europe: establishing epidemic thresholds by the Moving Epidemic Method. Influenza Other Respir Viruses. 2013;7:546-58.

50.European Centre for Disease Prevention and Control. European Antimicrobial Resistance Surveillance Network (EARS-Net). [Available from: http://ecdc.europa.eu/en/activities/surveillance/EARS-Net/Pages/index.aspx#sthash.5U9aDN1w.dpuf. http://ecdc.europa.eu/en/activities/surveillance/EARS-Net/Pages/index.aspx. Accessed 8 Jun 2016].

51. Vega E, Barclay L, Gregoricus N, Williams K, Lee D, Vinjé J. Novel Surveillance Network for Norovirus Gastroenteritis Outbreaks, United States. Emerg Infect Dis. 2011;17:1389-95.

52. National Institute for Public Health and the Environment R. NoroNet. [Available from: http://www.rivm.nl/en/Topics/N/NoroNet. Accessed 8 Jun 2016].

6.9 Co-author declaration

I confirm the specific contribution of **Helen Hughes** to this publication is as described in the Contributor statement and give my permission for this paper to be appear in her thesis.	
 Roger A. Morbey	*12/02/2020* Date
 Anne Fouillet	*13/02/2020* Date
 Céline Caserio-Schönemann	*30/11/2020* Date
 Alec Dobney	*12/02/2020* Date
 Thomas C. Hughes	*30/11/2020* Date
 Gillian E. Smith	*02/03/2020* Date
 Alex J. Elliot	*12/02/2020* Date

Chapter 7 The influence of a major sporting event upon emergency department attendances; a retrospective cross-national European study

Helen E. Hughes
Felipe J. Colón-González
Anne Fouillet
Alex J. Elliot
Céline Caserio-Schonemann
Thomas C. Hughes
Naomh Gallagher
Roger A. Morbey
Gillian E. Smith
Daniel Rh. Thomas
Iain R. Lake

PLoS One. 2018; 13(6): e0198665. Crown Copyright.
DOI: 10.1371/journal.pone.0198665

Attendances at emergency departments can be caused by and impacted upon by human behaviour. During each 24 hours the lowest numbers of attendances are through the night, when the majority of the population is sleeping. During holiday periods the numbers of attendances can decrease overall, or may even increase for particular types of conditions, particularly when celebrations do not go to plan.

Sporting events have been reported previously to be associated with fluctuations in ED attendances. Wins are celebrated and losses commiserated, often on a large scale. These impacts can occur either in the vicinity of the actual event, or remotely with fans following progress from home or in social gatherings. Here we discuss the impact of a large sporting event (2016 UEFA European Football Championship: Euro 2016) in not only France, the host country, but also in England, Northern Ireland and Wales, countries where large numbers of the population followed the progress of national teams through the tournament.

7.1 Abstract

Major sporting events may influence attendance levels at hospital emergency departments (ED). Previous research has focussed on the impact of single games, or wins/losses for specific teams/countries, limiting wider generalisations. Here we explore the impact of the Euro 2016 football championships on ED attendances across four participating nations (England, France, Northern Ireland, Wales), using a single methodology. Match days were found to have no significant impact upon daily ED attendances levels. Focussing upon hourly attendances, ED attendances across all countries in the four hour pre-match period were statistically significantly lower than would be expected (OR=0.97, 95% CI 0.94-0.99) and further reduced during matches (OR=0.94, 95% CI 0.91-0.97). In the 4 hour post-match period there was no significant increase in attendances (OR=1.01, 95% CI 0.99-1.04). However, these impacts were highly variable between individual matches: for example in the 4 hour period following the final, involving France, the number of ED attendances in France increased significantly (OR=1.27, 95% CI 1.13-1.42). Overall our results indicate relatively small impacts of major sporting events upon ED attendances. The heterogeneity observed makes it difficult for health providers to predict how major sporting events may affect ED attendances but supports the future development of compatible systems in different countries to support cross-border public health surveillance.

7.2 Introduction

Major sporting events have the potential to influence the behaviour of the general public; wins are celebrated and losses commiserated, both locally at the event and for those following remotely (e.g. television). This public response to sporting events may have an effect on the numbers and types of attendances seen in emergency departments (EDs). The organisation of ED staffing and equipment (e.g. inpatient bed availability) in preparation for these events rely on planning assumptions, though few studies have examined the impact of major sporting events on ED attendances in detail.

Where daily ED attendances have been investigated in relation to sports events (both live and televised) there have been contrasting results; from no impact observed,[1,2] to increased assault related attendances either overall,[3] or in the event of a home team win.[4] Previous investigation of daily ED attendances may have missed important hour-by-hour impacts, especially where events are of a short duration. Where potential intra-day impacts have been described there have been reported decreases directly before and during

sporting events for ED attendances[5,6] and ambulance callouts,[7] as well as increases immediately following some events.[6,8] The impact of sporting events on EDs has further been reported to differ by age, gender and reason for attendance, including; age and gender associations with violence related daily ED attendances;[3,4] increased daily cardiovascular[9] and hourly alcohol-related[8] attendances and decreased daily and hourly paediatric attendances.[10]

These earlier studies, from a range of geographical settings, employed a variety of analytical techniques and investigated a mixture of outcome variables. Here we present, to our knowledge, the most comprehensive study to date examining the impacts of a major sporting event on ED attendances. Focussing on one major tournament, the 2016 UEFA European Football Championship (Euro 2016), we use a consistent methodology across four nations involved in the tournament (England, France, Northern Ireland [NI] and Wales).

Syndromic surveillance data were used (where available) as a source of ED attendance data from multiple, geographically distinct EDs, collected using standardised methodology. Differential impacts were explored by country, time of day, age, gender and type of diagnosis. Alcohol-related and myocardial ischaemia (MI) attendances, increases in which have been linked to sporting events previously,[8,9] were readily identifiable as syndromic indicators (groupings of diagnoses codes).

7.3 Methods

Data sources

In England and NI the ED Syndromic Surveillance System (EDSSS) is a voluntary network of sentinel EDs covering around 10% of all emergency care attendances in England and over 30% of attendances at type 1 (major) EDs in NI during Euro 2016.[11] The OSCOUR® network in France, initially created as a voluntary network of EDs, became a mandatory national ED syndromic surveillance network during 2014. During Euro 2016 86% of all EDs in France and its overseas territories reported to OSCOUR®.[12] EDs which reported to EDSSS or OSCOUR® throughout the Euro 2016 period and the previous 2 years were eligible for inclusion in this study. Attendance data for all EDs in Wales were obtained using a bespoke query of the ED dataset held by the National Health Service Wales Informatics Service.[13]

Overall attendance data (for any condition) were obtained for 1 June - 14 July 2016, encompassing the entire period of the tournament, as well as for corresponding periods in 2014 and 2015 (matched by day of the week: 3 June - 16 July 2015 and 4 June - 17 July

2014), subdivided by gender and age (0-4, 5-14, 15-44, 45-64, 65+ years). The data from all EDs, were sub-divided by hour of arrival.

Using the syndromic surveillance indicators available in EDSSS (restricted to EDs recording ICD-10[14]/ SNOMED CT[15] diagnosis codes) and OSCOUR® (all EDs report ICD-10 diagnosis codes), daily data on ED attendances with a diagnosis of MI or related to alcohol (EDSSS – acute alcohol intoxication; OSCOUR® – any alcohol related diagnosis) were obtained for each country, 1 June 2014 – 31 July 2016, plus corresponding periods in 2014 and 2015 (matched by day of the week). It is important to note that different codes were used in different countries (and indeed in different EDs), however this is most likely due to the diagnoses available for selection in the patient record, rather than a true difference between presentations. The codes available in each ED would have been likely to identify similar diagnoses (**Appendix D**). Wales was excluded from the syndromic indicator analysis as attendances could not be grouped by diagnosis code.

Statistical analyses

ED attendances are influenced by hour of day, day of the week, holiday periods and time of year,[16] requiring statistical analysis to differentiate between changes in attendance levels related to Euro 2016 and other effects.

Expected hourly numbers of attendances were estimated using negative binomial models, to account for possible over-dispersion in the syndromic surveillance data. The impact of matches was modelled with the inclusion of three Boolean variables (1/0) representing the 'pre-match' (4 hours before), 'during match' (2 hours: 3 hours for the final), and 'post-match' (4 hours after) periods. The pre-match and post-match periods were chosen based upon previous research.[7,8,17]

Models were developed to investigate their effects on the expected hourly number of attendances, for all data pooled and for each nation individually and:

- subdivided by weekend/ weekday;
- subdivided by each individual game separately;
- stratified by gender and age.

Models were specified as:

$$g(\mu_t) = \alpha + \sum_{q=1}^{Q} \beta x_t + HoD + DoW + MoY + Y + \gamma(BHol)$$

Where: g(μ_t) is a logarithmic link function of the expectation $E(Y_t \equiv \mu_t)$ (expected number of cases at time t); α denotes the intercept; x_t are Boolean variables indicating 'pre-match',

'match' and 'post-match' periods. The variables x_t enter the model linearly with related coefficients β. Potential effects of long-term and seasonal trends were controlled by categorical variables for hour of the day (*HoD*), day of the week (*DoW*), month of the year (*MoY*), and year (Y). Bank holidays (*BHol*) were accounted for with a Boolean variable (1/0) with coefficient γ.

The analysis of daily attendances for MI and alcohol-related attendances utilized a negative binomial model with the same specification. The impact of matches was modelled using Boolean variables (1/0) to represent 'day before', 'match day' and 'day after'. All analyses were carried out using the MASS package in R software.[18]

7.4 Results

Euro 2016 was held in France from 10 June to 10 July 2016.[19] Of the 51 matches played, 19 involved the England (n=4), France (n=7), NI (n=4) and Wales (n=6) national teams (Wales played matches against both England and NI).

During the study period over 2 million ED attendances were identified for the analysis of total attendances by day/hour, with the largest number of attendances from France, followed by England and Wales and much lower numbers from NI (Table **7-1**). Attendance levels were similar between males and females (approx. 50/50) and age distributions were similar in each country, although NI included a lower percentage of paediatric attendance levels.

Analysis by syndromic indicator was restricted to those EDs where detailed diagnostic coding was available, including all EDs reporting to syndromic surveillance in France and NI, a limited number of EDs in England (~6% of all ED attendances) and no data available from Wales (**Table 7-2**). France had the highest completion of diagnostic coding (91% of attendances coded). MI attendances compromised 1% of attendances in England and NI and 0.4% in France, with alcohol attendances (all alcohol-related attendances in France and acute alcohol intoxication in England and NI) accounting for 0.6%, 0.8% and 1.2% of attendances, respectively (**Table 7-2**).

Table 7-1: Emergency department attendances for all causes, 1 June - 14 July 2016, by nation, age and gender

	England (9.8% coverage)		France (86% coverage)		Northern Ireland (31.8% coverage*)		Wales (100% coverage)	
Total	286,166		1,837,733		23,966		127,911	
Males	143,005	50.0%	956,300	52.0%	11,980	50.0%	64,320	50.3%
Females	143,088	50.0%	880,989	47.9%	11,980	50.0%	63,587	49.7%
Unknown	73	0.0%	444	0.0%	6	0.0%	4	0.0%
Age 0-4	26,783	9.4%	205,743	11.2%	846	3.5%	9,422	7.4%
Age 5-14	30,814	10.8%	227,616	12.4%	1,417	5.9%	16,639	13.0%
Age 15-44	113,293	39.6%	690,259	37.6%	10,675	44.5%	47,542	37.2%
Age 45-64	55,735	19.5%	345,233	18.8%	5,854	24.4%	25,963	20.3%
Age 65+	59,213	20.7%	368,882	20.1%	5,166	21.6%	28,337	22.1%
Unknown	328	0.1%	0	0.0%	8	0.0%	8	0.0%

*NI coverage of type 1 (major) ED attendances

Table 7-2: Emergency department attendances by syndromic indicator, 1 June - 14 July 2016, by nation

	England (5.8% coverage)		France (86% coverage)		Northern Ireland (31.8% coverage)	
Total	169,870		1,837,733		23,958	
Diagnosis included	128,005	75.4%	1,672,825	91.0%	20,727	86.5%
MI	1,328	1.0%	6,405	0.4%	180	0.9%
Alcohol*	758	0.6%	19,718	1.2%	172	0.8%
Mean daily attendances						
Total	3,861		41,767		545	
MI	30		146		4	
Alcohol*	17		448		4	
Estimated national mean daily attendances (calculated from coverage)						
Total	66,563		48,566		1,712	
MI	520		169		13	
Alcohol*	297		521		12	

* alcohol attendances are included as 'acute alcohol intoxication' in the EDSSS and 'all alcohol attendances' in OSCOUR®

Similar temporal patterns in ED attendances were found in all countries. The lowest hourly attendances occurred during the night (**Figure 7-1**) and the highest daily numbers were recorded on a Monday (**Figure 7-2**). For the two syndromic indicators of interest (England, NI and France only) the highest alcohol-related attendances were recorded during weekends (**Figure 7-3**) while MI attendances were highest during the week (**Figure 7-4**).

Figure 7-1: Hourly emergency department attendances 1 June - 14 July 2016, as a percentage of the total, by country.

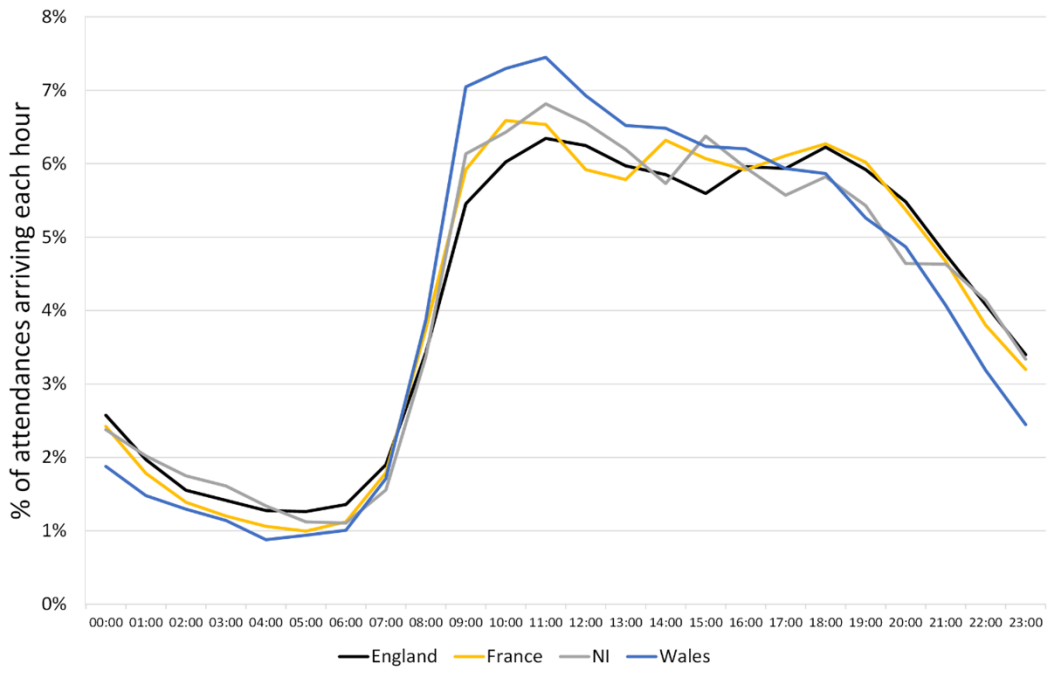


Figure 7-2: Day of the week emergency department attendances 1 June - 14 July 2016, as a percentage of the total, by country.

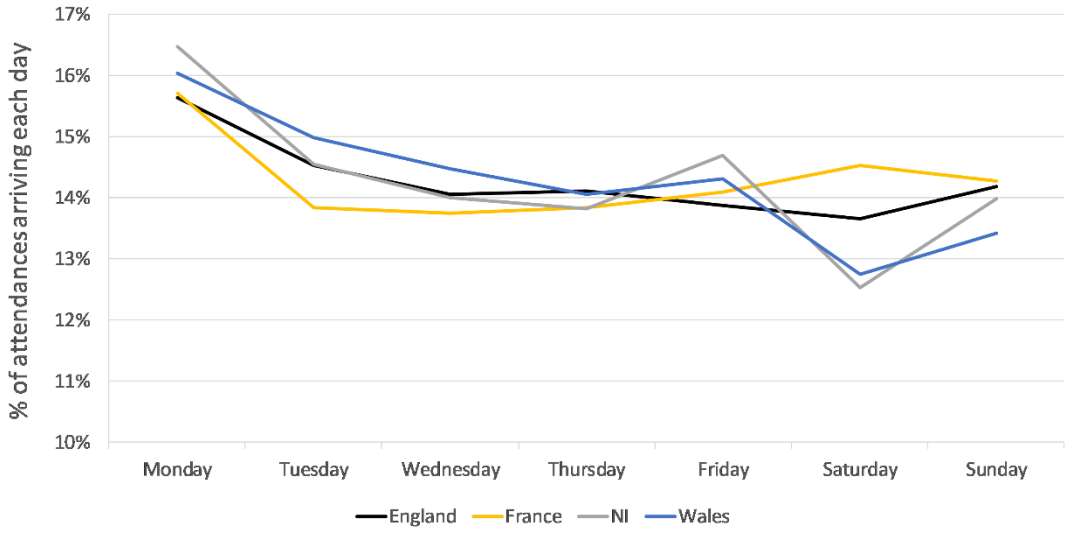


Figure 7-3: Alcohol related emergency department attendances 1 June - 14 July 2016, as a percentage of attendances with a diagnosis code, by day of the week and by country.

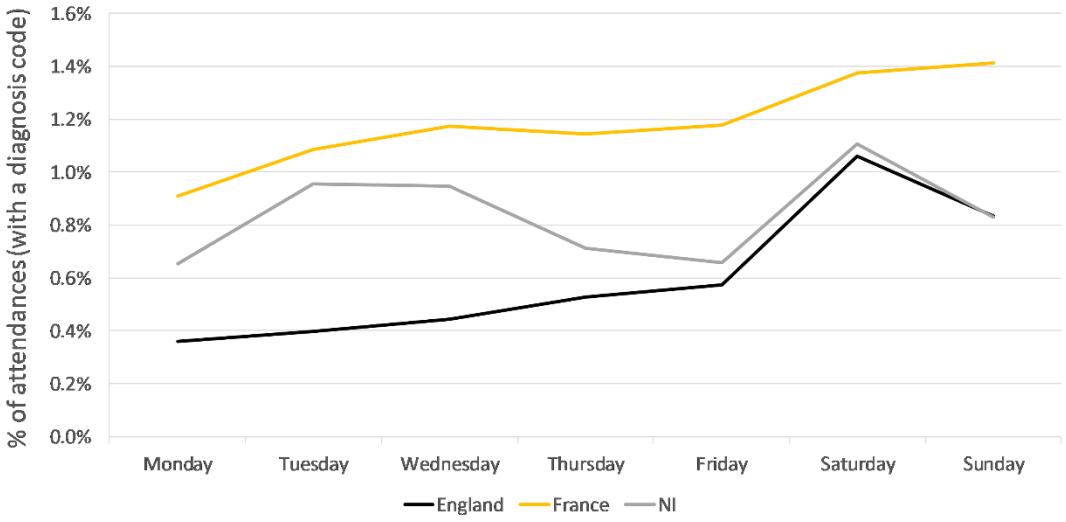
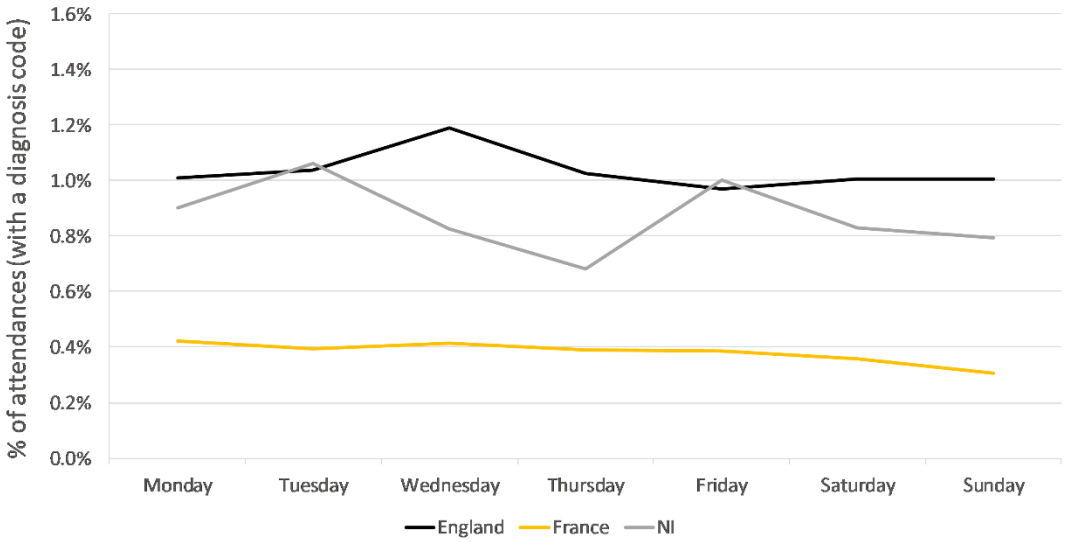


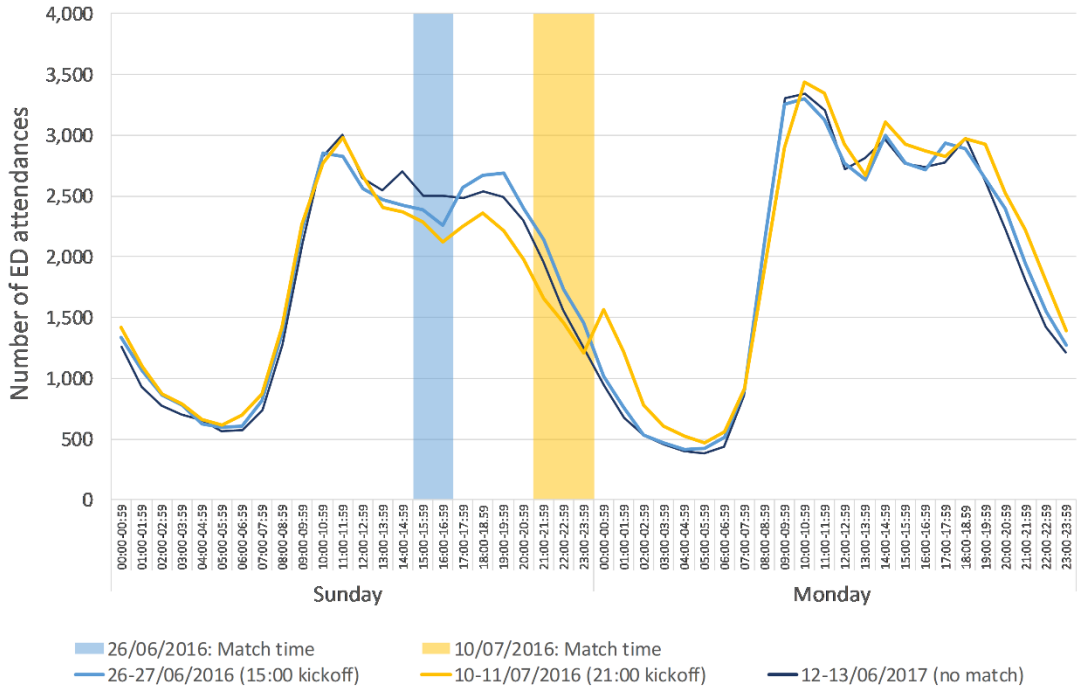
Figure 7-4: Myocardial ischaemia emergency department attendances 1 June - 14 July 2016, as a percentage of attendances with a diagnosis code, by day of the week and by country.



Descriptive analysis of temporal trends by day showed very little difference between daily numbers of attendances on match days compared with non-match days, in total and for alcohol-related or MI attendances (data not shown). Analysis of hourly attendances did, however, show some indication of reduced ED attendances during, and possible increases immediately following matches, particularly in France. The France national team played four Sunday matches during the tournament. The hourly attendances at EDs in France through Sunday afternoon into the early hours of Monday morning showed decreased attendance levels during matches and increased attendance levels immediately following

matches, particularly following the afternoon match 26 July and the evening final 11 July (**Figure 7-5**). The pattern of attendances on each Monday following a Sunday match was consistent with the usual pattern observed, though possibly running an hour later on 11 July, the day after the final (**Figure 7-5**)

Figure 7-5: Hourly ED attendances, France, selected Sunday/Monday 48 hour periods during Euro 2016; football match times involving France are highlighted.

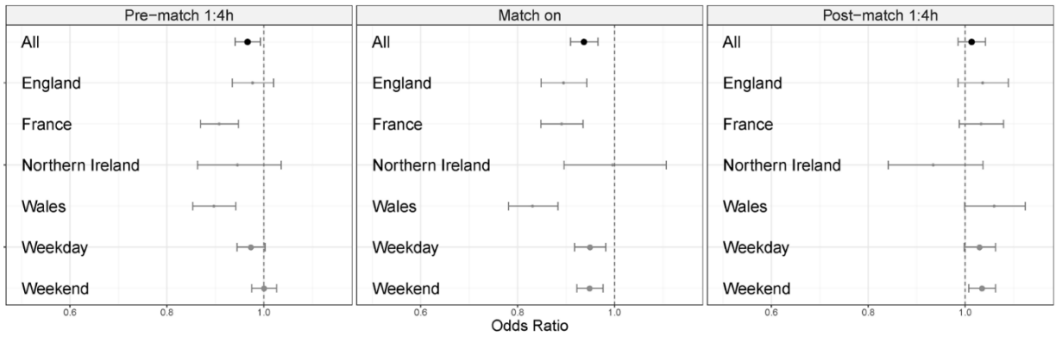


Overall odds ratios (OR) for hourly ED attendances (all countries) compared to the number expected indicate a statistically significant impact, although small, with pre-match and during-match reductions in ED attendances (**Figure 7-6**). Across the whole dataset (all nations, all matches) there was a reduction in pre-match attendances (OR 0.97, CI 0.94-0.99), with a stronger reduction observed on weekdays than weekends (**Figure 7-6**). Pre-match reductions were observed in each country individually and were statistically significant in France and Wales. During match periods statistically significant reductions in ED attendances were observed in all instances, though not statistically significant for Northern Ireland (**Figure 7-6**).

In the post-match 4-hour time period there was no change in ED attendances across all four countries as a whole (OR 1.01, CI, 0.99-1.04). This obscured divergence between the impacts observed in individual countries, with England, France and Wales having non-significant increases while Northern Ireland experienced reductions in ED attendances. Few

differences were apparent between games played on weekends versus those played on weekdays.

Figure 7-6: Odds ratios of ED attendance levels compared to the same time of day with no match for all matches, in total, by country and by weekday/weekend (in total).



Country specific odds ratios calculated for pre-match, during and post-match periods indicated consistency between age groups with increases/ decreases seen in all age groups together. A stronger effect was seen in school aged children (5-14yrs) and young adults (15-44yrs), with indications of a slightly larger effect in males than females (**Figure 7-7**).

Country specific ORs for individual matches showed differences between games (**Figure 7-8**). Relatively large, statistically significant drops in attendances in France were identified prior to France games 3, 5 and 7, though increases were seen prior to the first two matches. ED attendances in France during all games were lower than the same times of non-match days. The most significant post-match impacts, in terms of magnitude, were increases in attendances in France following the French semi-final (G6: OR=1.25; CI 1.11-1.40) and final (G7: OR=1.27; CI 1.13-1.42).

Figure 7-7: Odds ratios of ED attendance levels compared to the same time of day with no match by gender and by age group, by country

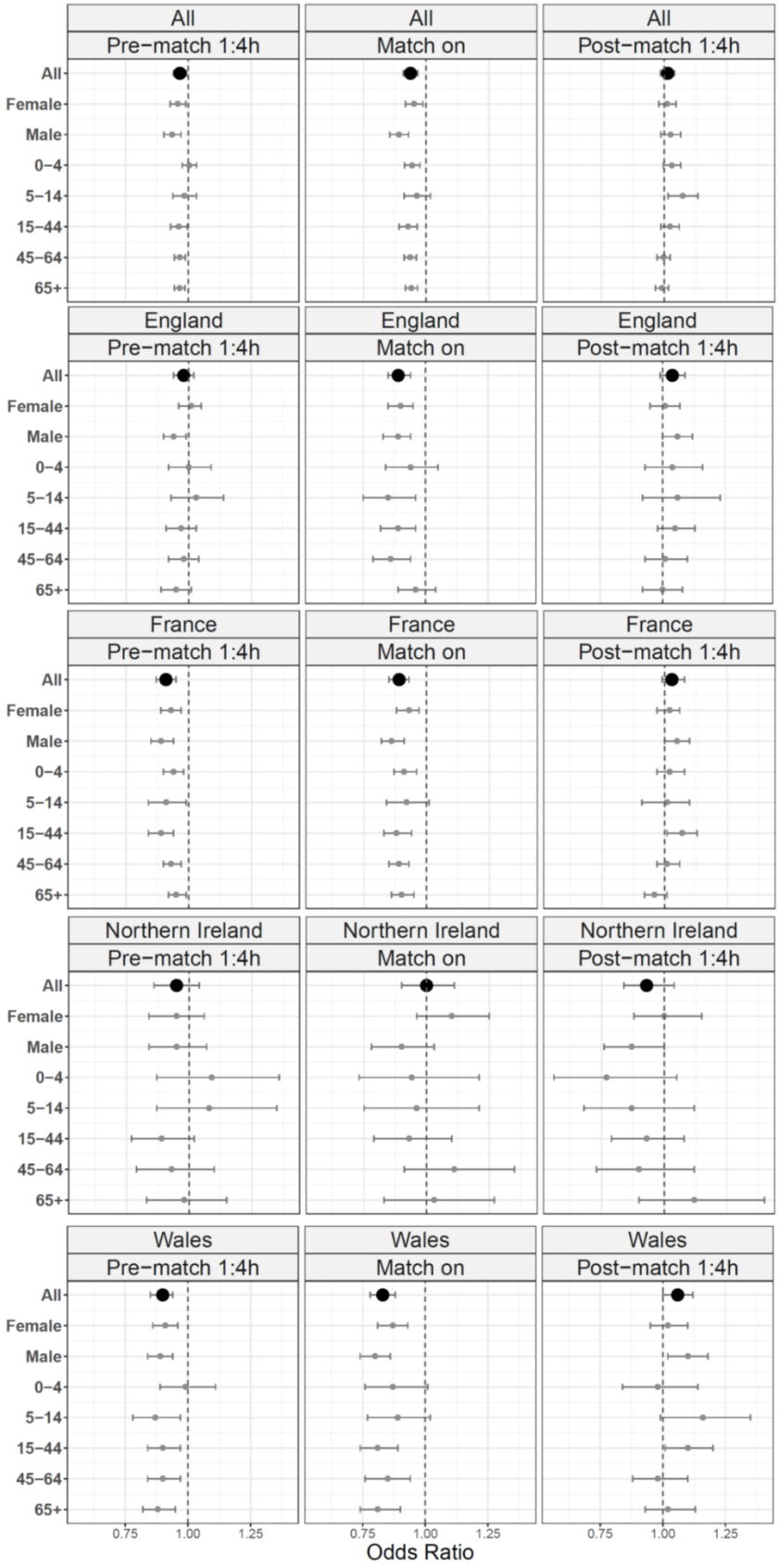
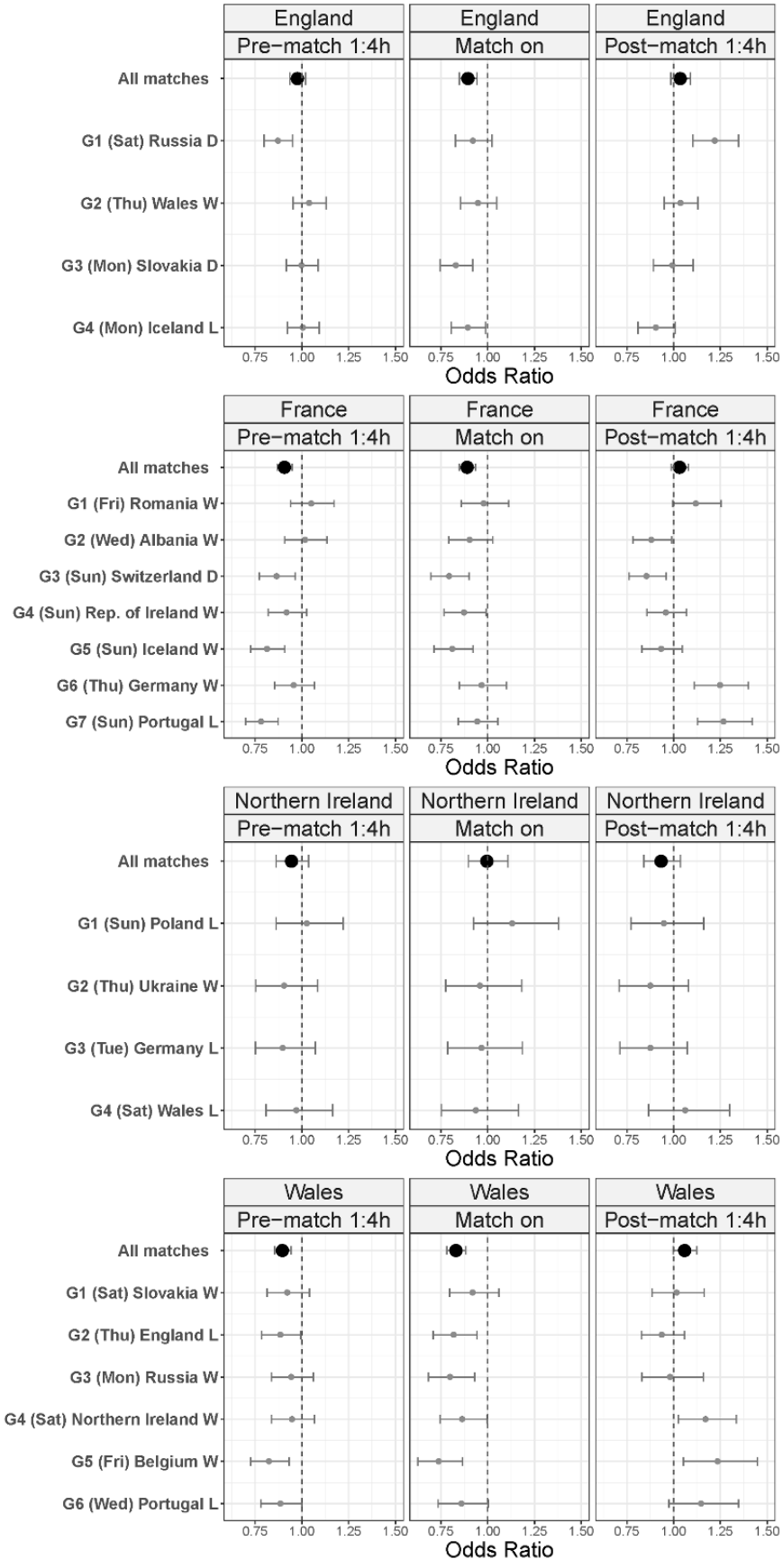


Figure 7-8: Odds ratios of ED attendance levels compared to the same time of day with no match for individual matches, by country



Across EDs in England, decreased attendances were observed during all matches. The biggest impact was around game 1, the only weekend game played by England (**Figure 7-8**): a relatively large decrease in attendances before the match (OR=0.87; CI 0.8-0.95) was followed by a large increase afterwards (OR=1.22; CI 1.1-1.35).

In Wales the greatest impact on ED attendances was during the later stages of the tournament. The first statistically significant increase in post-match attendances in Wales followed match 4, the first game of the knockout stage. The largest, statistically significant, pre-match/ during match reductions and post-match increases were around match 5, a quarter-final (pre OR=0.82; CI 0.73-0.93: during OR=0.74; CI 0.63-0.87: post OR=1.23; CI 1.05-1.45).

No significant changes in ED attendances occurred in NI around or during matches involving the NI team.

The estimated change in total numbers of attendances for each match, varied by country though overall decreases were observed immediately before and during matches, while increases were observed immediately following matches (**Table 7-3**).

The mean post-match increase calculated for France (1%) was the lowest of the four countries reported here. However, the two largest post-match increases were also in France, following the semi-final (France-v-Germany) and the final (France-v-Portugal; **Figure 7-8**). For these two games the nationwide increase in the four hour post-match period attendances were 772 (semi-final: 25% increase above baseline 3130 attendances) and 772 (final: 27% increase above 2912 baseline attendances). Though relatively small numbers across the country, this large percentage increase occurred late Sunday night/ early Monday morning, a time when EDs are usually quiet.

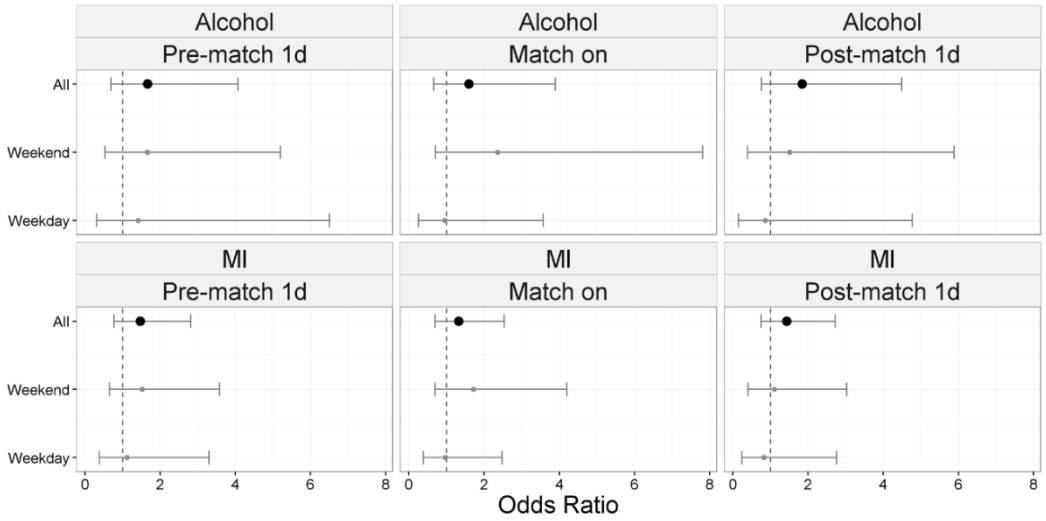
Table 7-3: Mean per match changes in emergency department attendances, in total and by country

	Pre-match			During match			Post-match		
	Baseline	Change (%)		Baseline	Change (%)		Baseline	Change (%)	
All Countries	29,798	-1,577	*(-5)	12,041	-1,247	*(-10)	14,538	281	(2)
England	16,480	-347	(-2)	6,913	-709	*(-10)	9,429	235	(2)
France	12,193	-1,133	*(-9)	4,658	-495	*(-11)	4,487	39	(1)
N Ireland	409	-25	(-6)	182	5	(3)	280	-9	(-3)
Wales	716	-72	*(-10)	287	-47	*(-16)	343	17	(5)

* Effect significant in the statistical model presented in **Figure 7-6**

Investigation of daily alcohol related and MI attendances showed no statistically significant changes in attendances levels, though for both indicators the ORs calculated were consistently higher at weekends than weekdays (**Figure 7-9**).

Figure 7-9: Odds ratios of daily ED attendances for alcohol and myocardial ischaemia (MI), in England, France and Northern Ireland, compared to days with no match: pre-match, match and post-match days, by weekday/weekend



7.5 Discussion

To our knowledge, this is the first cross-national study of the public health impact of a major sporting tournament upon ED attendances. This provides a unique insight into the impact on both the host nation, and countries with fans following the tournament from home. The use of standard public health data and a single methodology across multiple countries contrasts with previous studies which used a variety of different public health data and varying methods. This study focussed on ED attendances only, though there is no reason to believe other measures (e.g. ambulance attendances, hospital admissions) would not have shown similar results.

No significant changes in ED daily attendance levels were observed in any country, similar to the reports for England (host nation) during Euro 96.[2] No impact was found here on alcohol-related or myocardial ischaemia daily ED attendances, however the day of the week may have influenced this result. When separated, the individual ORs for weekdays and weekends do not span the ORs for all attendances, demonstrating that weekends are a confounding factor.

Total ED attendances were further analysed by hour of attendance to identify any intra-day effects. Statistically significant decreases in ED attendances during matches were seen in all

countries, except for Northern Ireland. This overall impact on EDs was estimated to be relatively minor, with minimal public health/ service impact (overall OR=0.93; individual country ORs=0.89-0.92, NI OR=1). Other changes appear highly variable between countries and individual games, with wins and losses both associated in increases/ decreases in ED attendances.

The most significant impacts were demonstrated during the later stages of the tournament, particularly following the semi-final and final matches involving France. Though relatively small post-match increases in terms of actual numbers attending EDs across France (<800 during a 4-hour period), these equated to fairly large percentage increases (>25% more than would usually be expected), not necessarily evenly spread across all EDs. These particular matches ended late on a Sunday evening, with the post-match period extending into the early hours of Monday morning, a period that is usually a quiet in EDs which may be affected by even a small number of extra attendances.

The increased attendances in France following the final match of Euro 2016 contrasts with reports from a previous, similar event: during the 2003 Rugby World Cup, the host country lost in the final match, following extra time. However, following the Rugby World Cup final no significant increase in ED attendances was observed in Australia,[5] contrasting with our results that ED attendances increased in France. The lack of an effect in Australia was attributed to the late end to the final match (23:00 hours) but in France the final game ended even later (00:00 hours).

The next similar football event will be the 2018 FIFA World Cup, to be staged in Russia. England and France are the only two nations included in this study to have qualified for the tournament. Looking further ahead, the Euro 2020 tournament may include all four of the nations included here, though will be hosted across 12 different European countries.[20] Each of these events do allow for the potential to carry out a follow-up study, though without the opportunity to investigate the impact on a single host country as included here.

Strengths and limitations

The main strength of this study was the inclusion of four nations, all competing in the same sporting tournament (including the host nation), with discrete competition times and high levels of public interest. This allowed the examination of the impact of an international sporting event on a more local level.

The levels of alcohol related attendances reported here (0.6%-1.2% of attendances) are likely to have been an underestimate, since attendances where alcohol consumption was a

contributing factor (e.g. injuries from falls/ fights) would not have been identified as alcohol related without an 'alcohol' diagnosis. The investigation of falls/ fights as a separate indicator was not possible: although the resulting diagnosis code would be readily identifiable in the ED data used here (e.g. wrist fracture) the mechanism by which this occurred (e.g. fall/fight) was not available. This type of surveillance would require much more detailed information to be available on the mechanism and intent of a presenting injury, as well as any role played by alcohol or other substances.

The pre-tournament period used for the development of model baselines was limited to 2 years due to the availability of data from the EDSSS system. This two year period was found to give the best balance between maximising the number of EDs included and the length of time available. This time period was replicated for both France and Wales to ensure a standardised methodology.

A possible limitation of this approach was that the two year pre-tournament period included the 2014 FIFA World Cup, staged in Brazil. However, Northern Ireland and Wales did not participate in the tournament, England did not perform well and did not progress past the initial group stage, with only France (of the nations included here) progressing as far as the quarter-finals of the tournament. Therefore, although the inclusion of this event may have introduced potential confounding during the baseline period developed, the failure of teams in the present study to progress to the more exciting, later matches on the 2014 World Cup implies that there will have been no discernible impact on ED attendance levels.

Another possible limitation of this study is that the possible impact of meteorological conditions on ED attendances was not controlled for. The time period included here was during the first part of the European summer, however the potential impact of heat on ED attendances was not included in the analysis. Although heat specific indicators have been developed and used to successfully identify public health impacts of extreme hot weather using ED attendances in both England and France,[21,22] the numbers involved are generally relatively small and unlikely to affect overall attendances as investigated here, particularly when examined by hour of attendance. During the early summer period (June - mid July) in the years reported here (2014-2016) there was no evidence of extreme levels of hot weather: only a single day of 'heatwave' was reported in the United Kingdom (1 July 2015)[23-25] and though hotter than usual summers and several periods of 'heat spike' were reported in France, these were not countrywide.[26-28]

A further potential limitation is that the whole of the Euro 2016 tournament was included in the analysis for each country, introducing a possible bias caused by non-home nation games (a total of 51 games were played across the entire tournament). Matches involving other national teams may have been watched as eagerly as a home nation game (especially if the result could affect tournament progression), potentially reducing the apparent impact of home nation games. This is especially possible in France, which hosted many fans from other countries. It is also worth highlighting that initiatives specifically targeted at reducing the impact of major tournaments on the local population, such as the "Drink Less Enjoy More" campaign,[29] may successfully reduce risky behaviour and the subsequent need for ED attendances.

One major challenge is understanding the human behavioural reasons behind these changes in attendances around match times. There is little research on this subject, but during the 2010 Olympic men's ice hockey significant reductions ED attendances with lower triage severity were reported.[30] Similarly decreases in attendances with lower acuity scores at triage in the EDSSS system (England and NI) have been observed during the Christmas period.[31] Syndromic surveillance often includes the collection of indicators of severity of illness on presentation to the ED and presents opportunity for future investigation of triage severity around events/ holiday periods.

Conclusion

In summary, we highlight that the overall influence of football games within a major European tournament upon ED attendances is relatively minor and only detectable when hourly attendances are examined. The heterogeneity between countries and the games played by individual countries (win/lose/draw and level of tournament progression) make it difficult for health providers to predict how major sporting events may affect ED attendances. However, the overall indication is that in the immediate build up to and during the period of an event, such as a football match, the numbers of attendances at EDs where the local population have an interest in the match (including fans watching from home) may be lower than usually expected, while attendances may increase immediately following the conclusion.

The ability to monitor the impact of large events, including sports and mass gatherings, to identify any need for public health action, is a challenge. The speed with which syndromic surveillance data is collected, processed and analysed enables changes compared to the norm to be detected in near real-time, making it a valuable tool in these situations. The

implementation of compatible systems and analysis in different countries would make this possible not only locally but across international borders.

7.6 Declarations

Ethics approval and consent to participate

Ethical approval and consent to participate for this work was not required.

The anonymised EDSSS data used in this study were routinely collected and analysed as part of the public health function of PHE.

The collection and analysis of data provided by the OSCOUR® network in the frame of public health surveillance and epidemiological studies has been authorized by the French National Commission for Data protection and Liberties (CNIL).

The anonymised ED data used in this study were routinely collected by NHS Wales Informatics Service and analysed as part of the public health function of Public Health Wales.

Consent for publication

Not applicable

Availability of data and materials

The datasets analysed during the current study are from the health records collected during individual patient attendances at EDs. Access to these datasets was possible as part of the public health function of each of the organisations involved, the authors do not have permission to share the data further or make it publicly available. However, the data used here may be made available by the responsible organisations, on request:

Syndromic surveillance data for England and Northern Ireland are collected and held by PHE for surveillance purposes and are not available for access. PHE are data processors for attendance data reported to EDSSS; individual NHS Trusts are data owners. EDSSS governance agreements with each Trust state that ED attendance data collected through the EDSSS will not be shared with other parties to preserve the anonymity of Trusts and patients. The Real-time Syndromic Surveillance Team can be contacted directly at: syndromic.surveillance@phe.gov.uk. Information on the PHE Office for Data Release, including contact details, can be found here: https://www.gov.uk/government/publications/accessing-public-health-england-data/about-the-phe-odr-and-accessing-data.

Syndromic surveillance data for France are collected and held by Santé Publique France for surveillance purposes. Bespoke emergency department data requests for public health research purposes can be formulated and will be reviewed on a case-by-case by the agency. The syndromic surveillance unit can be contacted directly with requests for data at: sursaudhotline@santepubliquefrance.fr.

Emergency Department data for Wales are held by NHS Wales Informatics Service: http://www.infoandstats.wales.nhs.uk/page.cfm?orgid=869&pid=40977. Data requested can be made by contacting: pdit.requests@wales.nhs.uk

Competing interests

None

Funding

This research received no specific grant from any funding agency, commercial or not-for-profit sectors. This surveillance is undertaken as part of the national surveillance functions of Public Health England and Santé Publique France.

HEH and IRL receive support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Gastrointestinal Infections. FJCG, AJE, IRL and GES receive support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Emergency Preparedness and Response. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, the Department of Health or Public Health England.

Authors' contributions

HEH: Study design, data preparation (England & Northern Ireland), drafted the manuscript, critical revision and final approval of the manuscript

FJCG: study design, statistical analysis, critical revision and final approval of the manuscript

AF: Study design, data preparation (France), critical revision and final approval of the manuscript

AJE: Study design, critical revision and final approval of the manuscript

CCS: Study design, critical revision and final approval of the manuscript

TH: Critical revision and final approval of the manuscript

NG: Study design, critical revision and final approval of the manuscript

RM: Study design, statistical analysis, critical revision and final approval of the manuscript

GES: Study design, critical revision and final approval of the manuscript

DRhT: Study design, facilitated data access (Wales), critical revision and final approval of the manuscript

IRL: Study design, statistical analysis, drafted the manuscript, critical revision and final approval of the manuscript

7.7 Acknowledgements

We acknowledge the contribution and support from the ED clinicians and Trust staff; the on-going support of the Royal College of Emergency Medicine; the technical support provided by EMIS Health and L2S2 Ltd in developing the EDSSS system in England and Northern Ireland.

We also acknowledge the contribution from the ED structures and clinicians involved in the OSCOUR® network in France; the on-going support of the Federation of the Regional Observatories of Emergencies and the Scientific Society of Emergency Medicine.

We are grateful to Anna Morris, NHS Wales Informatics Service, for providing ED attendance data for Wales.

7.8 References

1. McGreevy A, Millar L, Murphy B, et al. The effect of sporting events on emergency department attendance rates in a district general hospital in Northern Ireland. *Int J Clin Pract* 2010;64(11):1563-69. DOI: 10.1111/j.1742-1241.2010.02390.x
2. Cooke MW, Allan TF, Wilson S. A major sporting event does not necessarily mean an increased workload for accident and emergency departments. Euro96 Group of Accident and Emergency Departments. *Br J Sports Med* 1999;33(5):333.
3. Quigg Z, Hughes K, Bellis MA. Effects of the 2010 World Cup football tournament on emergency department assault attendances in England *Euro J Public Health* 2013;23(3):383/85. [published Online First: 08 August 2012]
4. Miller P, McDonald L, McKenzie S, et al. When the Cats are away: The impact of sporting events on assault- and alcohol-related emergency department attendances. *Drug and Alcohol Review* 2013;32(1):31-38. DOI: 10.1111/j.1465-3362.2012.00481.x
5. Moody WE, Hendry RG, Muscatello D. Were attendances to accident and emergency departments in England and Australia influenced by the Rugby World Cup Final 2003? *Eur J Emerg Med* 2007;14(2):68-71. DOI: 10.1097/01.mej.0000228450.37974.a8
6. Almeida A, Eusebio M, Almeida J, et al. The impact of the Lisbon Football Derby on the profile of emergency department admissions. *Acta Med Port* 2014;27(6):700-3.
7. Deakin CD, Thompson F, Gibson C, et al. Effects of international football matches on ambulance call profiles and volumes during the 2006 World Cup. *Emerg Med J* 2007;24(6):405-7. DOI: 10.1136/emj.2007.046920
8. Gardener M, Parke T, Jones P. Impact of the New Zealand 2011 Rugby World Cup on an urban emergency department. *N Z Med J* 2015;128(1418):80-4.
9. Wilbert-Lampen U, Leistner D, Greven S, et al. Cardiovascular Events during World Cup Soccer. *N Engl J Med* 2008;358(5):475-83. DOI:10.1056/NEJMoa0707427
10. Fabre A, Mancini J, Boutin A, et al. "Soccer or emergency?" sporting event can lead to a decreased attendance in the pediatric emergency department. *Minerva Pediatr* 2014;66(6):559-62.
11. Elliot AJ, Hughes HE, Hughes TC, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. *Emerg Med J* 2012;29(12):954-60. DOI: 10.1136/emermed-2011-200684
12. Santé publique France. Réseau OSCOUR® - Organisation de la surveillance coordonnée des urgences 2015 [Available from: http://invs.santepubliquefrance.fr/Espace-professionnels/Surveillance-syndromique-SurSaUD-R/Reseau-OSCOUR-R.
13. NHS Wales Informatics Service. NHS Wales Informatics Service [Available from: http://www.wales.nhs.uk/sitesplus/956/home. Accessed 2 Jan 2018].
14. World Health Organisation. International Classification of Disease (ICD) 2010 [Available from: http://www.who.int/classifications/icd/en/. Accessed 23 Jan 2020].
15. International Health Terminology Standards Development Organisation. SNOMED CT 2012 [Available from: http://www.ihtsdo.org/snomed-ct/. Accessed 23 Jan 2020].
16. Buckingham-Jeffery E, Morbey R, House T, et al. Correcting for day of the week and public holiday effects: improving a national daily syndromic surveillance service for detecting public health threats. *BMC Public Health* 2017;17(1):477. DOI: 10.1186/s12889-017-4372-y

17. Kim TY, Barcega BB, Denmark TK. Pediatric emergency department census during major sporting events. *Pediatr Emerg Care* 2012;28(11):1158-61. DOI: 10.1097/PEC.0b013e31827171f0

18. Venables WN, Ripley BD. Modern Applied Statistics with S. 4th ed. New York: Springer 2002.

19. UEFA. 2016 UEFA European Championship 2016 [Available from: http://www.uefa.com/uefaeuro/season=2016/index.html. Access 2 Jan 2018].

20. UEFA. The UEFA EURO 2020 hosts in full 2017 [Available from: http://www.uefa.com/uefaeuro-2020/index.html24 April 2018. Accessed 24 Apr 2018].

21. Josseran L, Fouillet A, Caillere N, et al. Assessment of a Syndromic Surveillance System Based on Morbidity Data: Results from the Oscour Network during a Heat Wave. *PLoS ONE* 2010;5(8):e11984. DOI: 10.1371/journal.pone.0011984. [published Online First: 09/08/2010]

22. Smith S, Elliot AJ, Hajat S, et al. Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance. *Journal of Epidemiology and Community Health* 2016 DOI: 10.1136/jech-2015-206079

23. Met Office. Summer 2014: Summary of the UK summer weather June-August 2014.[Available from: https://www.metoffice.gov.uk/climate/uk/summaries/2014/summer. Accessed 24 Apr 2018].

24. Met Office. Summer 2015: Summary of the UK summer weather June-August 2015. [Available from: https://www.metoffice.gov.uk/climate/uk/summaries/2015/summer. Accessed 24 Apr 2018].

25. Met Office. Summer 2016: Summary of the UK summer weather June-August 2016. [Available from: https://www.metoffice.gov.uk/climate/uk/summaries/2016/summer. Accessed 24 Apr 2018].

26. Météo France. Bilan climatique de l'été 2014: Summary of the France summer weather June-August 2014. [Available from: http://www.meteofrance.fr/climat-passe-et-futur/bilans-climatiques/bilan-2014/bilan-climatique-de-l-ete. Accessed 24 Apr 2018].

27. Météo France. Bilan climatique de l'été 2015: Summary of the France summer weather June-August 2015. [Available from: http://www.meteofrance.fr/climat-passe-et-futur/bilans-climatiques/bilan-2015/bilan-climatique-de-l-ete. Accessed 24 Apr 2018].

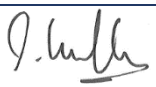
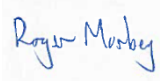
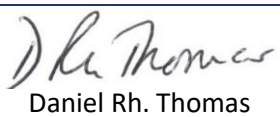
28. Météo France. Bilan climatique de l'été 2016: Summary of the France summer weather June-August 2016. [Available from: http://www.meteofrance.fr/climat-passe-et-futur/bilans-climatiques/bilan-2016/bilan-climatique-de-l-ete-2016. Accessed 24 Apr 2018].

29. Liverpool City Council. Revellers urged to drink less and enjoy more during Euro 2016 Liverpool Express2016. [Available from: http://www.liverpoolexpress.co.uk/revellers-urged-to-drink-less-and-enjoy-more-during-euro-2016/. Accessed 2 Jan 2018].

30. Redelmeier DA, Vermeulen MJ. Emergency department visits during an Olympic gold medal television broadcast. *Open Med* 2011;5(2):e112-9.

31. Public Health England. Emergency Department Syndromic Surveillance System: England & Northern Ireland: Public Health England; 2017 [Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/670863/EDSSSBulletin2017wk51.pdf. Accessed 2 Jan 2018].

7.9 Co-author declaration

I confirm the specific contribution of **Helen Hughes** to this publication is as described in the Authors' contributions statement and give my permission for this paper to be appear in her thesis.	
 Felipe J. Colón-González	*24/10/2020* Date
 Anne Fouillet	*13/02/2020* Date
 Alex J. Elliot	*12/02/2020* Date
 Céline Caserio-Schönemann	*30/11/2020* Date
 Thomas C. Hughes	*30/11/2020* Date
 Naomh Gallagher	*27/10/2020* Date
 Roger A. Morbey	*12/02/2020* Date
 Gillian E. Smith	*02/03/2020* Date
 Daniel Rh. Thomas	*19/01/2021* Date
 Iain R. Lake	*23/10/2020* Date

Chapter 8 Syndromic surveillance revolution? The public health benefits of the evolution and modernisation of the emergency care health patient record in England

Helen E. Hughes

Thomas C. Hughes

Aaron Haile

Gillian E. Smith

Brian McCloskey

Alex J. Elliot

Public Health Reports. **2017 Jul/Aug;132(1_suppl):12S-15S. Crown Copyright.**

DOI:10.1177%2F0033354917706955

Public health surveillance is often described as information for action. The lessons learned through the act of surveillance do not have to be limited to public health specific actions. The technical work behind the scenes may be of an identified use to those involved in other areas of the healthcare provision, particularly with regard to data collection, processing and sharing.

Data collected during a patient's journey through an ED is important for the care of that patient. Improved accuracy, timeliness and availability would result in improved care provision. These data are also vital for the monitoring of local processes and activity levels, information which may also be combined nationally to describe how EDs are performing and to identify any pressures being faced. Syndromic surveillance is classed as secondary use of ED data. However, as discussed in ***Chapter 3****, sentinel EDSSS showed that although there were differences in data between EDs, many items were broadly similar and it was possible to map them to a standard format. Also, sentinel EDSSS had demonstrated the successful use of passive, automated processes to enable near real-time data collection.*

Through collaboration with the RCEM, the EDSSS team became involved in the development of the new Emergency Care Data Set (ECDS): a single standardised format required to be used in all EDs in England. This, we believe, is the first example of a syndromic surveillance system having input in the wider workings of EDs, which will, in turn, result in improvements in the syndromic surveillance system itself.

8.1 Abstract

Though emergency department (ED) care in the United Kingdom is provided under the control of a single body (the National Health Service, NHS), the collection, format and storage of attendance data is currently varied, decided upon locally by individual EDs to suit local work practices. The Public Health England (PHE) Emergency Department Syndromic Surveillance System (EDSSS) is a sentinel surveillance system, recruiting new EDs individually, working with and harmonising the variety of ED data formats available. The resulting process is complex and resource intensive.

The Emergency Care Data Set (ECDS) project has developed a single dataset for implementation throughout EDs in England, with potential for syndromic surveillance to become a standard secondary user of this information. The evolution of the emergency care electronic health care record into a harmonised dataset, used throughout England, will result in a revolution in ED syndromic surveillance in the UK, delivering a national system that can provide an enhanced surveillance capability for years to come. The benefits to syndromic surveillance and public health are discussed in this paper.

8.2 Emergency medicine data in the United Kingdom

Emergency medicine is a recognised specialty in the United Kingdom (UK), with formal training and accreditation conducted and governed by the Royal College of Emergency Medicine (RCEM).[1] Healthcare within the UK is publicly funded and provided through a residence (not insurance) based system provided by the National Health Service (NHS). Emergency care within emergency departments (ED) is currently provided free at the point of delivery for everyone, including non-residents.

Though emergency care within the UK is under the control of a single-payer provider, the NHS, there is currently no single clinically-driven standardised dataset for emergency care in the UK. The collection and storage of information related to individual patients, as required for their care, is managed by each individual ED through locally developed processes for electronic data collection, format and storage. These processes may still include the use of paper records during treatment, to be transcribed to an electronic patient record at a later date. A number of electronic clinical information systems are currently in use, with many differences in data formats between locations, even for those using the same software.

In England there is requirement for a subset of the patient record of each attendance to be collected nationally for basic monitoring of activity and for payment purposes. This, the Commissioning Data Set (CDS) type 010[2] was created in the 1980s[3] and is maintained by NHS Digital, as required by the NHS and the Department of Health. The CDS is not collated centrally in real-time, but is submitted by each hospital approximately monthly following a series of completion and validation processes, before transmission to NHS Digital.

As well as being used for payment purposes the CDS is also made available in certain circumstances not related to direct patient care through the Secondary Uses Service (SUS)[4] for further reporting and analysis to support the delivery of NHS healthcare, as well as for public health purposes.

8.3 Emergency department syndromic surveillance in England

ED syndromic surveillance uses an anonymised feed of electronic records of ED attendances to identify and monitor trends in human health at the more severe end of the disease spectrum i.e. those requiring acute hospital care. The Public Health England (PHE) Emergency Department Syndromic Surveillance System (EDSSS) was originally developed as

part of the public health preparations for the London 2012 Olympic and Paralympic Games in order to meet the surveillance requirements of hosting such a large mass gathering event.[5]

Though 'public health' is listed as a purpose for SUS, there is no provision or potential for real-time surveillance usage given the time delays between patient attendances and data submission to CDS. This limited the potential for developing real-time ED surveillance systems in the UK, requiring EDSSS to be developed as a sentinel surveillance system, relying on the recruitment of individual EDs on an *ad hoc* basis. This approach required the agreement of each ED, gaining initial clinical support followed by a complex and often lengthy process of liaison with (and providing reassurance to) information governance teams.

Without a single centralised data source the opportunity was taken for EDSSS to be developed, in collaboration with RCEM, from a 'blank page'. The types of clinical information that would be useful for syndromic surveillance (including basic patient demographics, diagnoses using coded information not free-text, dates/time of attendance and the destination of the patient on leaving the ED), were first identified, then plans developed to access this information in existing ED clinical software systems. Working with local IT teams, the technical access to the ED attendance data has involved translation and mapping of the ED fields from the data format stored on the local clinical system to a standardised, anonymised data format based upon the RCEM suggested minimum dataset for emergency care.[5] The process of secure data extraction and daily transfer to PHE is automated, with no additional resource required by participating EDs, resulting in a unique anonymised EDSSS dataset collected, stored and used solely for public health purposes.

The EDSSS provided a valuable contribution to the overall surveillance during the 2012 Olympics and continued to develop beyond the initial Olympic period, remaining as a public health legacy of the Games, contributing to national surveillance programmes, vaccine impact studies and supporting the response to public health incidents.[6-10]

By December 2016 a total of 35 different EDs across England and Northern Ireland were reporting to EDSSS.[11] A further 5 EDs have reported previously, however the bespoke nature of the EDSSS data transfer set up has meant that where the software system in a reporting ED changes (resulting in differences in the local dataset format and storage), the EDSSS data transfer set up is no longer valid and the site is lost.

8.4 The Emergency Care Data Set: emergency care evolution

The Emergency Care Data Set (ECDS) project is a collaborative project initiated by the RCEM in early 2015, with representation from government and non-government bodies on its Board.[3,12] The ECDS aims to improve data collection, quality and completeness in English EDs using a single mandated, standardised data format to be implemented during 2017/18 in all EDs, across all software systems. The primary aim is for clinical information captured within EDs to improve in quality, thus improving the delivery of clinical care and treatment of patients. Furthermore, the ECDS aims to make better use of information captured within the EDs, including streamlining local methods for forwarding information on for individual patient care, such as letters to general practitioners. The promotion of the completion of the patient care record in electronic systems in real-time, through use of ECDS, would also make information more readily available locally on capacity, demand for services and workload within each department.

Additionally, some ED locations already collect additional details on patient attendances to fulfil specific project needs/ research interests, such as details on injuries resulting from violence. The ECDS would, for the first time, make this a standardised capability across all English EDs.

The ECDS project is to next develop and replace the existing CDS, allowing collection of an updated and extended dataset enabling the activity across English EDs as a whole to be described more accurately than is currently possible. This would expand the potential information capture availability for SUS, enabling better provision for performance management, surveillance and research, in addition to the local commissioning of and payment for ED services delivered. This process also has the potential to make CDS submission a contemporaneous process, making information available nationally in near real-time, giving a global picture of supply and demand in a more timely manner than is currently possible. Implementation of the ECDS, which will be known as CDS Type 011 – ECDS is mandated in Type 1 and Type 2 emergency departments from October 2017 and in Type 3 and Type 4 departments by October 2018.

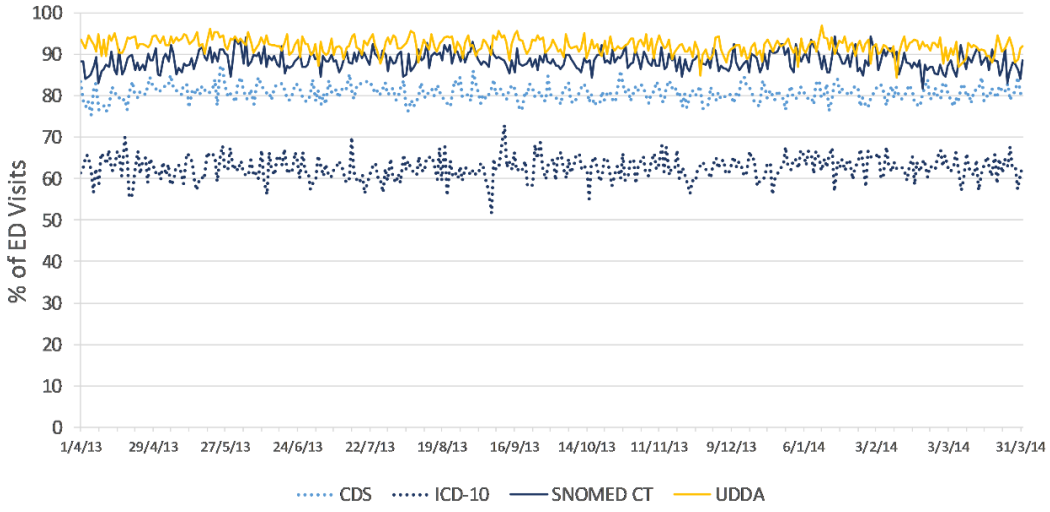
8.5 How EDSSS helped ECDS

Syndromic surveillance systems utilise electronic health data collected for patient care in order to provide information for public health action on a population rather than individual level. Each NHS ED currently has its own way of collecting patient information, focussed on

an individual patient level, not population. The EDSSS has helped to identify the similarities across existing ED systems, where details can be extracted in a standard format and transmitted securely in an anonymised daily feed. EDSSS successfully provided proof of concept of this process, without having caused additional work within the EDs themselves. EDs have been passively providing more detail in the surveillance picture for both infectious diseases (including influenza and respiratory syncytial virus surveillance[6,10]) and the impact of other events (such as air pollution, heat waves and extreme cold weather[7-9]).

As part of this process a number of EDs reporting to EDSSS adopted a unified set of clinical diagnoses codes, a first step to make diagnosis recording easier in the ED, with the intention that a patient with a condition e.g. croup should receive the same diagnosis code, regardless of which ED they attend and which ED clinician they are seen by. The results of this pilot illustrated improved levels of coding compared to other EDSSS EDs using existing coding datasets (**Figure 8-1**).

Figure 8-1: Daily percentage of ED attendances reported to EDSSS with a diagnosis code recorded. EDs are grouped by type of diagnosis coding in use (Snomed-CT, ICD-10, CDS or the new RCEM unified dataset [UDDA]).



8.6 How ECDS may help EDSSS

The implementation of ECDS would immediately remove the primary hurdle which has inhibited the growth of EDSSS: the current lack of standardised data capture across all EDs. Additionally, proposed changes to the infrastructure for the CDS would result in a single national ED data repository which, if collected in near real-time, would potentially make available all English EDs for recruitment to EDSSS through a central resource, rather than each ED individually. The expansion of the EDSSS to all English EDs would increase the ability of the system to report on local public health incidents, improve data quality with

regard to signal to noise ratio, and result in the EDSSS being a leading national ED syndromic surveillance system internationally.

The extension of data recording to include simplified injury fields, as proposed in ECDS,[3] would also further expand the utility of EDSSS, able to provide real-time detail on accidental injuries and violence, both across the country and at more localised geographies. Though many EDs may already collect information on injuries for local public health initiatives/ research, this is not currently done in a manner accessible for EDSSS or other public health/research organisations.

The ECDS project is currently focussed on English EDs, but is being watched closely by colleagues in devolved administrations (Scotland, Wales and Northern Ireland). Northern Ireland already participates in the EDSSS, with five EDs reporting on a daily basis. As the implementation of ECDS is likely to allow the simple expansion of EDSSS across more (if not all) ED locations in England it would have the potential of becoming a standard throughout the UK. A single formal, standardised ED dataset, mandated by the NHS would enable harmonisation of surveillance activities across the UK. The publication of both the ECDS structure and EDSSS outputs also has the potential to harmonise surveillance efforts across country boundaries, into Europe and further afield. The data need not be shared, yet would allow direct comparison across borders if it is more easily understood and similarities can be identified, improving resilience to and providing information for action during large incidents e.g. influenza pandemics or volcanic ash clouds.

8.7 What's new in this approach?

Mandated changes to national clinical emergency care datasets, such as that proposed in ECDS, do not happen very often, though it has been done before, for example in France.[13] The workload required to implement ECDS is significant, including needs and impact assessments, stakeholder consultations and pilot trials of potential technological solutions. This process has, however, allowed ECDS to be developed in a novel way where the consultation has included all stakeholders in emergency care, from the ED clinicians and patient representatives, through to potential secondary users of the data including those in public health.

Syndromic surveillance usually aims to have no impact on front line staff and this principle remains here: patient care and NHS operational benefits are the driving factor for implementation of ECDS. In this instance, rather than remaining behind the scenes,

syndromic surveillance has become part of a wider multidisciplinary conversation, having demonstrated what could be possible.

Following the introduction of ECDS, EDSSS could become a standard, mandated item in English public health surveillance. Again, this has been achieved elsewhere (participation in OSCOUR®, the French equivalent of EDSSS, became mandatory from July 2013)[13], though as far as we are aware this would be the first example of syndromic surveillance being included in the development of national ED data changes.

Improvements in the collection and delivery of more timely and better quality ED data will have a wider reaching impact beyond that of syndromic surveillance, bringing benefit to other areas of the public health system. The evolution of emergency care electronic health care record in England will result in a revolution in ED syndromic surveillance, delivering a national system that can provide an enhanced surveillance capability for years to come.

8.8 Acknowledgements

We acknowledge the ongoing work of the Emergency Care Data Set Project Board project board; the contribution and support from the ED clinicians and Trust staff to EDSSS; the on-going support of the Royal College of Emergency Medicine; the technical support provided by EMIS Health and L2S2 Ltd in developing the EDSSS system.

AJE and GES receive support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Emergency Preparedness and Response. HEH receives support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Gastrointestinal Infections. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, the Department of Health or Public Health England.

8.9 References

1 Royal College of Emergency Medicine. The Royal College of Emergency Medicine: About the College. [Available from: http://www.rcem.ac.uk. Accessed 29 Nov 2016]

2 Health & Social Care Information Centre. CDS V6-2 Type 010 - Accident and Emergency Commissioning Data Set. [Available from: http://www.datadictionary.nhs.uk/data_dictionary/messages/cds_v6-2/data_sets/cds_v6-2_type_010_-_accident_and_emergency_cds.asp?shownav=1. Accessed 31 march 2016]

3 NHS England. Emergency Care Data Set (ECDS). [Available from: https://www.england.nhs.uk/ourwork/tsd/ec-data-set/. Accessed 29 Jun 2016]

4 Health & Social Care Information Centre. Secondary Uses Service. [Available from: http://www.datadictionary.nhs.uk/data_dictionary/nhs_business_definitions/s/secondary_uses_service_de.asp?shownav=1?query=%22sus%22&rank=100&. Accessed 29 Jun 2016]

5 Elliot AJ, Hughes HE, Hughes TC, Locker TE, Shannon T, Heyworth J, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. Emerg Med J 2012;29:954-60.

6 Pebody R, Green H, Andrews N, Boddington N, Zhao H, Yonova I, et al. Uptake and impact of vaccinating school age children against influenza during a season with circulation of drifted influenza A and B strains, England, 2014/15. Eurosurveillance 2015;20.

7 Smith S, Elliot AJ, Hajat S, Bone A, Smith GE, Kovats S. Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance. Journal of Epidemiology and Community Health 2016.

8 Smith GE, Bawa Z, Macklin Y, Morbey R, Dobney A, Vardoulakis S, et al. Using real-time syndromic surveillance systems to help explore the acute impact of the air pollution incident of March/April 2014 in England. Environ Res 2015;136:500-4.

9 Hughes HE, Morbey R, Hughes TC, Locker TE, Shannon T, Carmichael C, et al. Using an Emergency Department Syndromic Surveillance System to investigate the impact of extreme cold weather events. Public Health 2014;128:628-35.

10 Hughes H, Morbey R, Hughes T, Locker T, Smith G, Elliot A. Syndromic Surveillance of Respiratory Pathogens using Routine ED Data in England. Online Journal of Public Health Informatics 2015;7:e81.

11 Public Health England. Emergency Department Syndromic Surveillance System: England & Northern Ireland. [Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/529725/EDSSSBulletin2016wk23.pdf. Accessed 29 November 2016]

12 Royal College of Emergency Medicine. Emergency Care Data Set (ECDS). [Available from: http://www.rcem.ac.uk/Shop-Floor/Informatics/Emergency%20Care%20Data%20Set%20(ECDS). 29 June 2016]

13 Pontais I, Bousquet V, Ruello M, Caserio-Schönemann C, Fouillet A. Factors Influencing the Stability and Quality of the French ED Surveillance System. ISDS 2015. Denver, Colorado, USA: Online Journal of Public Health Informatics, 2015.

8.10 Co-author declaration

HEH drafted the manuscript and provided critical revision and final approval of the manuscript.

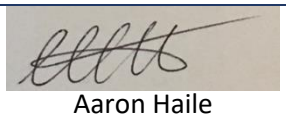
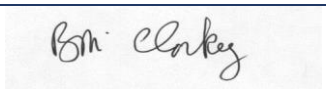
TCH provided critical revision and final approval of the manuscript.

AH provided critical revision and final approval of the manuscript.

GES provided critical revision and final approval of the manuscript.

BM provided critical revision and final approval of the manuscript.

AJE provided critical revision and final approval of the manuscript.

I confirm the specific contribution of **Helen Hughes** to this publication is as described above and give my permission for this paper to be appear in her thesis.	
 Thomas C. Hughes	*30/11/2020* Date
 Aaron Haile	*15/02/2020* Date
 Gillian E. Smith	*02/03/2020* Date
 Bryan McCloskey	*12/02/2020* Date
 Alex J. Elliot	*12/02/2020* Date

Chapter 9 Emergency department use during COVID-19 as described by syndromic surveillance

Helen E. Hughes

Tom C. Hughes

Roger Morbey

Kirsty Challen

Isabel Oliver

Gillian E. Smith

Alex J. Elliot

Emergency Medicine Journal 2020;37:600-604. Crown Copyright.

DOI: 10.1136/emermed-2020-209980

*As described in **Chapter 5**, the implementation of public health interventions and, as described in **Chapter 7**, human behaviour and decision making can each play a notable role in the demand for urgent health care and subsequent levels of attendances seen in emergency departments. In 2018, following the implementation of ECDS (the development of which is described in **Chapter 8**), the EDSSS transitioned from a small, sentinel surveillance system, to a much larger national EDSSS with more complete geographical coverage across England. The sentinel EDSSS had successfully reporting during London 2012. The first, high profile test for national EDSSS was not a planned mass gathering, but a global pandemic of a novel pathogen.*

During the initial stages of the COVID-19 pandemic a wide range of public health interventions were implemented aiming to reduce spread, alongside public health messaging encouraging the public to 'protect the NHS'. Here we describe the impacts seen on ED attendances in England, with focus on age, severity of illness and select syndromic indicators of interest.

9.1 Abstract

Background

On 12 March 2020 the UK entered the 'delay phase' of the COVID-19 pandemic response. The Public Health England Emergency Department Syndromic Surveillance System (EDSSS) carries out daily (near real-time) public health surveillance of ED attendances across England. This retrospective, observational analysis of EDSSS data aimed to describe changes in ED attendances during March-April 2020, and identify the attendance types with the largest impact.

Methods

Type 1 ED attendances were selected from 109 EDs that reported data to EDSSS for the period 01/01/19-26/04/20. The daily numbers of attendances were plotted by age group and acuity of presentation.

The 2020 'COVID-19' period (12/03/20-26/04/20) attendances were compared to the equivalent 2019 'pre-COVID-19' period (14/03/20-28/04/20): in total; by hour and day of the week; age group (<1, 1-4, 15-14, 15-44, 45-64 and 65+ years); gender; acuity; and for selected syndromic indicators (acute respiratory infection, gastroenteritis, myocardial ischaemia).

Results

Daily ED attendances up to 11/03/20 showed regular trends, highest on a Monday and reduced in children during school holidays.

From 12/03/20 ED attendances decreased, across all age groups, all acuity levels, on all days and times. Across age groups the greatest percentage reductions were seen in school age children (5-14 years).

By acuity, the greatest reduction occurred in the less severe presentations.

Syndromic indicators demonstrated that the greatest reductions were in non-respiratory indicators, which fell by 44-67% during 2020 COVID-19, whilst acute respiratory infection was reduced by -4.4% (95% CI: -9.5%,0.6%).

Conclusion

ED attendances in England have been particularly affected during the COVID-19 pandemic, due to changes in healthcare seeking behaviour: EDSSS has enabled real-time daily monitoring of these changes, which are made publicly available to facilitate action. The EDSSS provides valuable surveillance of ED attendances in England. The flexibility of EDSSS

allowed rapid development of new indicators (including COVID-19-like) and reporting methods.

9.2 Background

The COVID-19 pandemic has had major health and societal impacts worldwide. In the UK, the 'delay phase' was introduced in stages from 12 March 2020, including social distancing and shielding measures.[1] These have had a major impact on population movement, day-to-day activities and health care seeking behaviours.

The Public Health England (PHE) Emergency Department Syndromic Surveillance System (EDSSS) is a public health legacy of the London Olympic and Paralympic Games 2012, receiving routine data from emergency departments (EDs) across England, captured through the Emergency Care Dataset (ECDS).[2-4] This anonymised subset of ECDS data, is received on a daily basis, enabling a near real-time syndromic surveillance service, which feeds into PHE public health monitoring activities (including the COVID-19 response) and with weekly EDSSS surveillance bulletins made publicly available.[5,6] The EDSSS is an unvalidated 'snapshot' of raw ED data (updates or completion of missing data are not included), which can be used for timely analysis and identification of trends for public health purposes.

In this short report, we use routine EDSSS data to describe the changes in ED attendances in England from 12 March 2020, and the subsequent challenges that this has brought to undertaking ED syndromic surveillance.

9.3 Methods

Attendance data

Daily ED attendance data were accessed from EDSSS from 01/01/19 to 26/04/20 (routine, anonymised, public health surveillance data, no ethical approval required). Selection criteria for inclusion were: Type 1 ED attendances; EDs reporting attendances for every day during the study period. EDSSS includes only EDs located in England.

ED attendances categorised by syndromic indicator were identified based on the primary diagnosis listed for each attendance (if any). In this report, syndromic indicators routinely identified in EDSSS were: acute respiratory infections (ARI); gastroenteritis; myocardial ischaemia.

Descriptive analysis

Daily attendances were visualised by calendar years (2019 full year; 2020 to 26/04/2020), by age group (0, 1-4 and 15-14, 15-44, 45-64 and 65+ years) and separately by acuity of attendance (ECDS values from 1: immediate, to 5: low acuity).

Separate comparable time periods, matched on day of the week, were identified for the 2019 'pre-COVID-19' period (Thursday 14/03/19 – Sunday 28/04/20) and 2020 'COVID-19' period during the delay phase (Thursday 12/03/20 – Sunday 26/04/20). The mean number of all cause, all age attendances were plotted by hour of day and day of week for both pre-COVID-19 and COVID-19 periods.

The average daily attendances were calculated with the percentage difference between pre-COVID-19 and COVID-19 in total; by sex; by age group; by acuity; by day of the week and by selected syndromic surveillance indicators.

9.4 Results

In total 109 Type 1 EDs met the inclusion criteria, reporting a total of 13,861,889 attendances to EDSSS, from 1/1/2019 to 26/4/2020.

Daily attendances by age group to 11/3/20 showed similar trends: peak attendances on Monday and a notable reduction in child attendances during school holidays. From 12/3/20 the numbers of daily attendances rapidly decreased across all age groups (**Figure 9-1**).

The largest percentage change reduction in attendances were in school age children (**Table 9-1**). There was no clear difference by gender (**Table 9-1**). Age and gender were reported for >99.5% of all attendances in both years.

The level of acuity was identifiable in 83.6% of all attendances (82.9% pre-COVID-19; 83.5% COVID-19). Those with an acuity of '1: immediate' accounted for the smallest numbers of ED attendances and saw the smallest reduction in levels during COVID-19 (31%), and those '4: Standard' the largest (54%; **Table 9-1**; **Figure 9-2**).

Attendance levels were reduced throughout the 24-hour period (**Figure 9-3**). The largest decrease was seen Monday-Wednesday, previously the busiest days of the week (**Table 9-1**).

Syndromic indicators demonstrated the greatest reductions were in non-respiratory indicators. While there was only a 4% reduction in ARI, non-respiratory indicators fell by 44-67% during COVID-19 (**Table 9-1**).

Figure 9-1: Daily EDSSS attendances, 2019 and 2020 by age group **a)** children; **b)** adults (n=109 EDs). The 2020 COVID-19 period (12/03/20-26/04/20) is marked in grey.

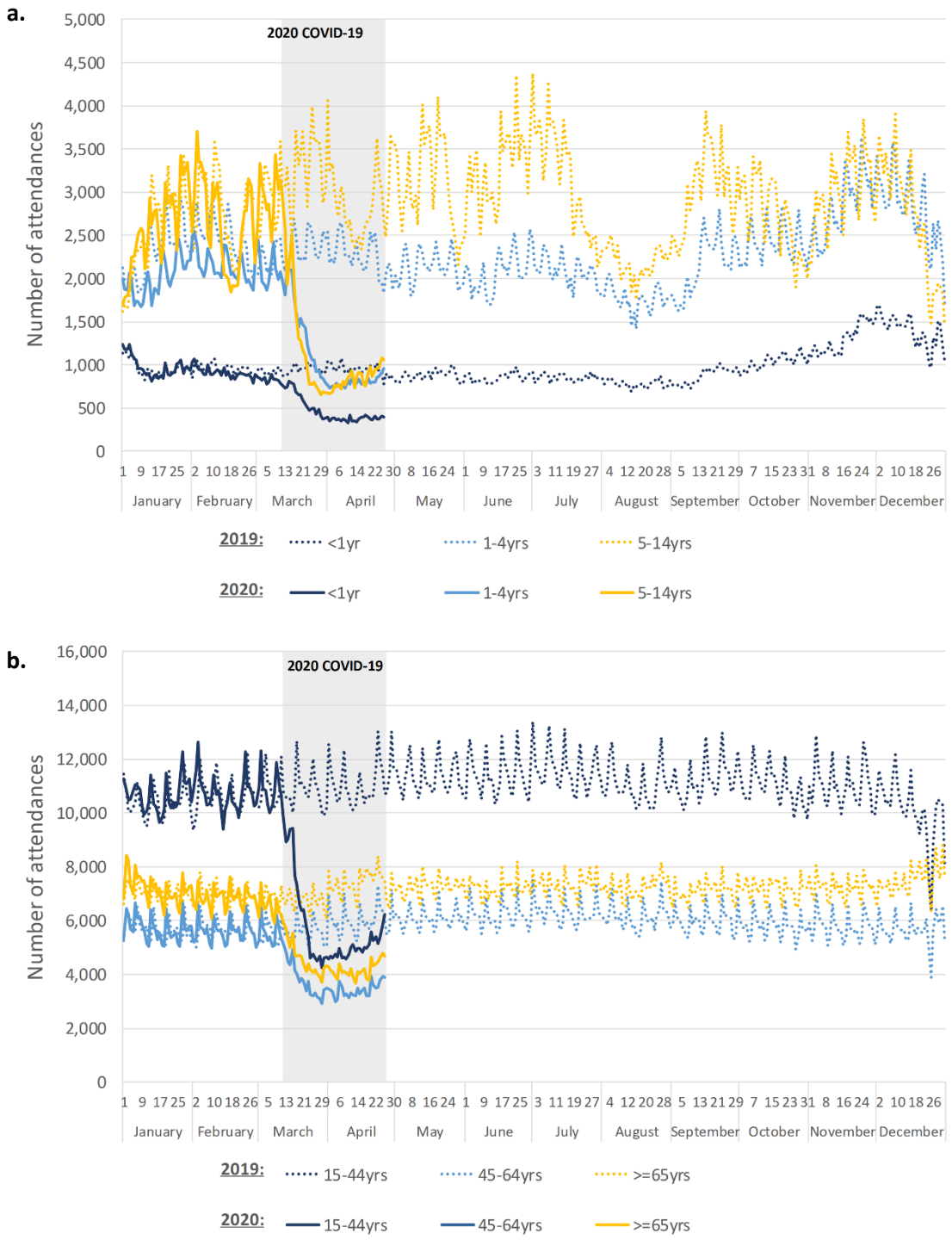


Table 9-1: Differences in ED attendances between 2019 pre-COVID-19 and 2020 COVID-19 (based upon the periods 14/03 – 28/04/20 and 12/03 - 26/04/20 respectively, matched on day of the week).

	2019 Pre-COVID-19	2020 COVID-19	Percentage Change (95% confidence interval)	
Total	30,412	16,217	-46.7%	(-50.4%, -42.9%)
Age				
<1yr	954	471	-50.6%	(-55.2%, -46.1%)
1-4yrs	2,318	1,068	-53.9%	(-59.4%, -48.5%)
5-14yrs	3,026	1,075	-64.5%	(-70.8%, -58.2%)
15-44yrs	10,982	5,636	-48.7%	(-53.0%, -44.4%)
45-64yrs	5,842	3,596	-38.5%	(-42.0%, -34.9%)
>=65yrs	7,143	4,360	-39.0%	(-42.1%, -35.8%)
Gender				
Female	15,438	8,171	-47.1%	(-50.6%, -43.5%)
Male	14,959	8,020	-46.4%	(-50.4%, -42.4%)
Day of the week				
Monday	33,594	16,778	-50.1%	(-59.3%, -40.9%)
Tuesday	31,394	15,627	-50.2%	(-59.2%, -41.2%)
Wednesday	30,498	15,385	-49.6%	(-55.4%, -43.7%)
Thursday	30,241	16,752	-44.6%	(-55.3%, -33.9%)
Friday	29,682	16,456	-44.6%	(-53.5%, -35.6%)
Saturday	28,675	16,358	-43.0%	(-52.8%, -33.1%)
Sunday	29,410	16,042	-45.5%	(-54.2%, -36.7%)
Acuity				
1: Immediate	370	256	-30.7%	(-33.9%, -27.6%)
2: Very Urgent	2,336	1,504	-35.6%	(-38.2%, -33.0%)
3: Urgent	9,416	5,642	-40.1%	(-43.5%, -36.7%)
4: Standard	11,818	5,455	-53.8%	(-58.0%, -49.7%)
5: Low Acuity	1,284	684	-46.7%	(-54.3%, -39.0%)
Selected syndromic indicators				
Acute Respiratory Infections	1,757	1,679	- 4.4%	(- 9.5%, 0.6%)
Gastroenteritis	356	118	-66.9%	(-71.4%, -62.4%)
Myocardial Ischaemia	357	199	-44.2%	(-48.8%, -39.7%)

Figure 9-2: Daily EDSSS attendances, 2019 and 2020, by acuity, where known (n=109 EDs). The 2020 COVID-19 period (12/03/20-26/04/20) is marked in grey.

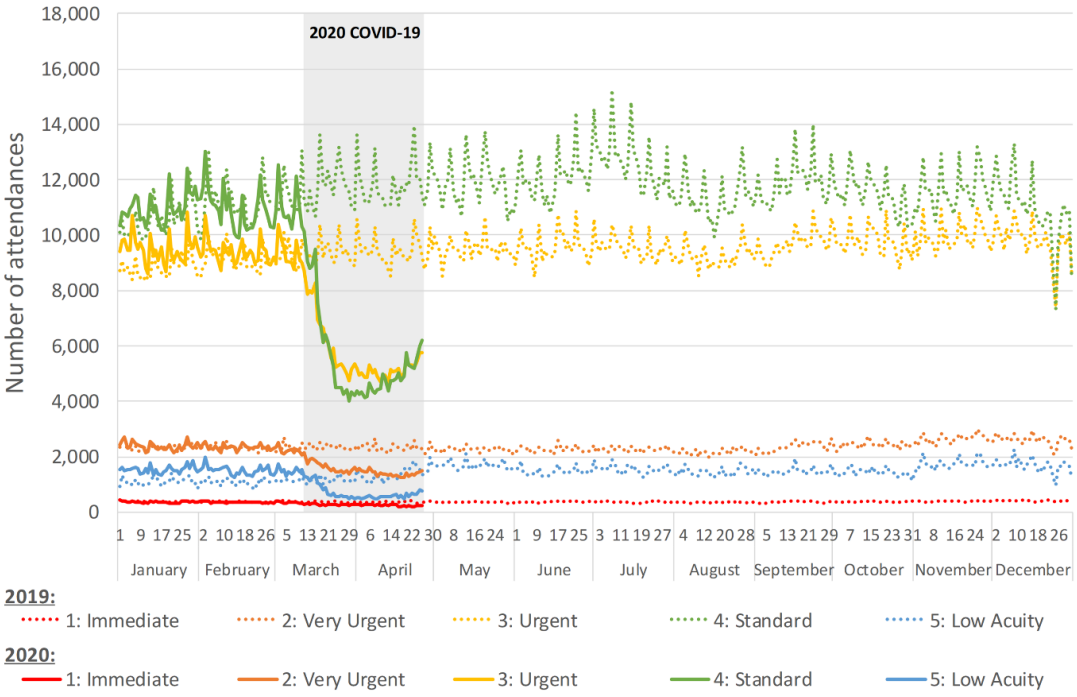
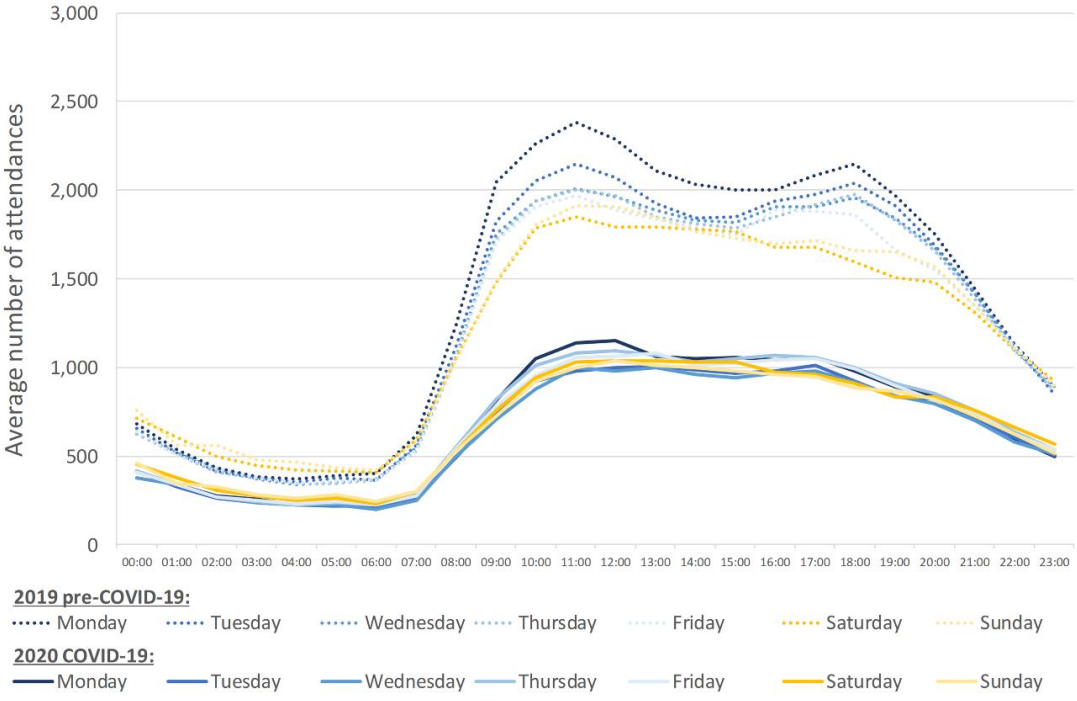


Figure 9-3: EDSSS attendances by hour of day and day of week during 2019 pre-COVID-19 and 2020 COVID-19 (based upon the periods 14/03 – 28/04/20 and 12/03 - 26/04/20 respectively, matched on day of the week).



9.5 Discussion

During the 2020 COVID-19 period there were fewer daily ED attendances than the 2019 pre-COVID-19 period. The largest percentage reductions were observed Monday-Wednesday (previously the busiest days of the week) and in the youngest age groups (particularly school age children). The reduction was observed across all acuity categories, though less marked in the most severe attendances presentations. These findings support and quantify a recent Royal College of Emergency Medicine position statement in the UK and also corroborate similar recent findings from the United States.[7,8]

EDSSS reports on high level groupings of disease/condition indicators; this provides additional depth of understanding of ED activity, particularly with respect to infectious diseases. While other official sources of ED activity data in the UK (e.g. the NHS England weekly and month admission statistics[9]) provide information about overall attendance activity, they include other service metrics e.g. patient wait times, to inform performance management. Routine reporting of EDSSS data supplements these other sources and illustrates a differential impact of the changes in health care seeking behaviour (in real-time) e.g. ARI attendances decreased very little, however non-respiratory indicators reported here decreased by 44-67%. Monitoring these changes in healthcare utilisation through surveillance is key to understanding the impact of COVID-19 in the population. These syndromic surveillance data demonstrate possible indirect impacts of social distancing/shielding, both positive (e.g. reduced need for gastroenteritis attendances) and negative (e.g. emergency cardiac care potentially avoided). Recent public health messaging has urged patients to continue to seek medical care as required.[10]

The routine nature of the EDSSS enabled the rapid comparison of pre- and current COVID-19 periods to describe impact using a large subset of English Type 1 ED attendances. However, this analysis is limited by the intentional exclusion of: all non-Type 1 ED attendances; and some Type 1 EDs due to inconsistency in the frequency of data submission. The intent is for NHS acute data to be submitted to NHS Digital, using ECDS, on a daily basis.[4]

One of the biggest challenges for EDSSS has been changes in the total attendances, which resulted in difficulty interpreting syndromic indicators as a percentage of attendances, resulting in false signals. EDSSS reporting was subsequently rapidly adapted, with attendance counts (as used here) presented in all standard EDSSS reporting from

19/03/20.[5] Supplementary EDSSS developments will include severity indicators to provide enhanced intelligence in future.

The EDSSS now reports on COVID-19-like attendances (including new COVID-19 Snomed CT codes).[11] This information now feeds into the PHE COVID-19 response, demonstrating that the information is actionable, as well as in regular weekly EDSSS surveillance bulletins.[5 6] Furthermore, EDSSS outputs are also utilised by the UK Government to support and guide management of the pandemic. EDSSS will continue to be used during the COVID-19 pandemic, delivering real-time monitoring of indicators of both direct (respiratory) and indirect (non-respiratory) healthcare demand. It will also provide valuable surveillance information during any future waves and inform on healthcare pressures during winter 2020/21 when SARS-CoV-2 and other seasonal respiratory pathogens will impact on emergency care services.[12]

Conclusion

ED attendances in England have been affected by changes in healthcare seeking behaviour during the COVID-19 pandemic. EDSSS has enabled real-time daily monitoring of these changes, providing publicly available information to facilitate action. The EDSSS provides valuable surveillance of ED attendances in England. The flexibility of EDSSS allowed rapid development of new indicators (including COVID-19-like) and changes to reporting methods as required.

9.6 Acknowledgements

The authors acknowledge the contribution and support from the ED clinicians and Trust staff in the EDSSS; the ongoing support of the Royal College of Emergency Medicine; the technical support provided by NHS Digital.

9.7 Declarations

Funding

HEH and AJE receive support from the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Gastrointestinal Infections. GES, RM and AJE receive support from the NIHR HPRU in Emergency Preparedness and Response. IO receives support from the NIHR HPRU in Behavioural Science and Evaluation.

The views expressed are those of the author(s) and not necessarily those of the NIHR, Public Health England or the Department of Health and Social Care.

Authors' contributions

HEH: Study design, data preparation, data analysis, drafted the manuscript, critical revision and final approval of the manuscript

TCH: Study design, critical revision and final approval of the manuscript

RM: Study design, data analysis, critical revision and final approval of the manuscript

KC: Study design, critical revision and final approval of the manuscript

IO: Study design, critical revision and final approval of the manuscript

GES: Study design, critical revision and final approval of the manuscript

AJE: Study design, drafted the manuscript, critical revision and final approval of the manuscript

Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

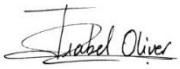
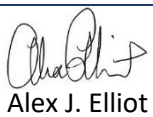
Declaration of competing interests

TCH is a director of L2S2 Ltd.

9.8 References

1. Department of Health and Social Care. COVID-19: government announces moving out of contain phase and into delay: Department of Health and Social Care; 2020 [Available from: https://www.gov.uk/government/news/covid-19-government-announces-moving-out-of-contain-phase-and-into-delay. Accessed 6 May 2020].
2. NHS England. Emergency Care Data Set (ECDS) 2016 [Available from: https://www.england.nhs.uk/ourwork/tsd/ec-data-set/. Accessed 6 May 2020].
3. Hughes HE, Hughes TC, Haile A, et al. Syndromic surveillance revolution? Public health benefits of modernizing the emergency care patient health record in England. *Public Health Rep* 2017;132(1_suppl):12S-15S. DOI: https://doi.org/10.1177/0033354917706955
4. NHS Digital. Emergency Care Data Set (ECDS) 2020 [Available from: https://digital.nhs.uk/data-and-information/data-collections-and-data-sets/data-sets/emergency-care-data-set-ecds. Accessed 6 May 2020].
5. Public Health England. Syndromic surveillance: systems and analyses: Emergency department syndromic surveillance system 2020 [Available from: https://www.gov.uk/government/collections/syndromic-surveillance-systems-and-analyses#emergency-department-syndromic-surveillance-system accessed 4 May 2020].
6. Public Health England. Research and analysis: National COVID-19 surveillance reports 2020 [Available from: https://www.gov.uk/government/publications/national-covid-19-surveillance-reports accessed 26 June 2020.
7. Royal College of Emergency Medicine. RCEM Position Statement. COVID-19: Resetting Emergency Department Care 2020 [Available from: https://www.rcem.ac.uk/docs/Policy/RCEM_Position_statement_Resetting_Emergency_Care_20200506.pdf. Accessed 26 June 2020].
8. Kathleen P. Hartnett, Aaron Kite-Powell, Jourdan DeVies, et al. Impact of the COVID-19 Pandemic on Emergency Department Visits — United States, January 1, 2019–May 30, 2020. *Morbidity and Mortality Weekly Report* 2020;69(23):699-704. DOI: http://dx.doi.org/10.15585/mmwr.mm6923e1
9. NHS Digital. Monthly Trust Situation Reports (MSitAE) data collection [Available from: https://digital.nhs.uk/data-and-information/data-collections-and-data-sets/data-collections/monthly-trust-situation-reports-msitae-data-collection. Accessed 26 Jun 2020].
10. NHS. Help us help you: NHS urges public to get care when they need it 2020 [Available from: https://www.england.nhs.uk/2020/04/help-us-help-you-nhs-urges-public-to-get-care-when-they-need-it/. Accessed 4 May 2020].
11. NHS Digital. ECDS latest update: Recording ECDS instances of COVID-19 2020 [Available from: https://digital.nhs.uk/data-and-information/data-collections-and-data-sets/data-sets/emergency-care-data-set-ecds/ecds-latest-update. Accessed 4 May 2020].
12. Hughes HE, Morbey R, Hughes TC, et al. Emergency department syndromic surveillance providing early warning of seasonal respiratory activity in England. *Epidemiol Infect* 2015;144(5):1052-64. DOI: https://doi.org/10.1017/S0950268815002125

9.9 Co-author declaration

I confirm the specific contribution of **Helen Hughes** to this publication is as described in the **Authors' contributions** statement and give my permission for this paper to be appear in her thesis.	
 Thomas C. Hughes	*30/11/2020* Date
 Roger Morbey	*30/11/2020* Date
 Kirsty Challen	*30/11/2020* Date
 Isabel Oliver	*19/01/2021* Date
 Gillian E. Smith	*01/12/2020* Date
 Alex J. Elliot	*30/11/2020* Date

Chapter 10 Overall discussion and conclusions

The peer reviewed manuscripts presented in this thesis address each of the questions raised in **Chapter 4**.

10.1 Does near real-time emergency department syndromic surveillance provide additional benefit to public health surveillance in England?

The flexibility and near real-time nature of syndromic surveillance affords opportunities for the identification and monitoring of public health threats which may not be possible using traditional public health surveillance methods. The evidence presented in this thesis has demonstrated where the EDSSS has added value for public health surveillance in England, utilising:

- system flexibility;
- timeliness of reporting;
- cross system/international collaborative working.

System flexibility

The papers presented in the previous chapters demonstrate the flexibility of the EDSSS for monitoring of a wide range of health conditions, outcomes and behavioural factors. This thesis includes several peer reviewed examples of how EDSSS has been used to support existing public health surveillance and intervention programs on a wide range of different public health needs. The flexibility of the EDSSS has made for a system capable of many different surveillance functions using information gathered from a single, digitally recorded (automatically transmitted) data source, rather than requiring multiple similar surveillance systems likely developed in isolation from one another:

a. **Infectious disease (Chapter 5):** a previously developed EDSSS syndromic indicator successfully identified seasonal changes in gastroenteritis attendances at EDs. This variation in trend corresponded with the seasonal patterns of rotavirus activity as reported from laboratory confirmations, the traditional surveillance used for monitoring gastrointestinal disease. Despite rotavirus infection generally being considered to cause a relatively mild self-limiting disease in the UK, its impact on ED visits overall (and in young children in particular) was notable. The EDSSS

demonstrated the considerable burden that 'non-severe' disease can place on NHS emergency care services delivered by EDs.

b. **Impact of public health interventions (Chapter 5):** ED attendances for gastroenteritis decreased following the introduction of the rotavirus vaccine into the childhood immunisation schedule in England. EDSSS was used to further investigate this post-intervention decrease and confirmed that the reduction in ED visits for gastroenteritis, particularly in young children, continued into the third year following vaccine introduction. The flexibility of EDSSS offers the potential for other vaccine impact assessments, such as the previous inclusion in monitoring of the live attenuated influenza vaccination in school children.[1,2] The opportunity for development of other syndromic indicators (and ability to create new ones) allows EDSSS to have the potential to report on any other vaccine (assuming the vaccine prevents severe illness likely to be seen in the ED), without the need to establish a whole new surveillance system.

   Chapter 9 further demonstrated the ability of EDSSS to monitor the impact of public health interventions. During the early stages of the COVID-19 pandemic strict, public health measures including shielding, social distancing and 'lockdown', were implemented across England, resulting in a large, rapid reduction in ED attendances. EDSSS provided valuable information for Government and the NHS on this rapid, unanticipated, indirect impact of the COVID-19 pandemic and the interventions put in place.

c. **Impact of environmental events (Chapter 6):** periods of poor air quality were shown to have an association with asthma attendances in EDs in London (and Paris), demonstrating an increase in illness severe enough to require emergency treatment. This confirmed the utility of the existing EDSSS indicators for monitoring the acute, short term public health impact of poor air quality.

d. **Human behaviour (Chapter 7):** in addition to the impact of external factors (such as infectious disease or environmental events), human behaviour may also play a role in the health seeking behaviour and the decision-making processes which may result in ED visits. EDSSS data demonstrated that international football matches may cause changes in ED presentation patterns, such as delaying healthcare seeking behaviour, or may even delay/cause the incident resulting in the healthcare need (e.g. risky behaviour may not occur until after the match is over/may be more likely to occur depending on the result of the match).

e. **Novel disease surveillance (Chapter 9):** the arrival of a new pathogen, SARS-CoV-2, causing the COVID-19 pandemic required the EDSSS to rapidly adapt to make use of new diagnostic codes for the creation and implementation of a new syndromic indicator to monitor and report on COVID-19-like ED attendances.

Timeliness of reporting

As discussed in **Chapter 1**, syndromic surveillance is generally considered more timely than traditional public health surveillance; collecting and analysing data, and providing feedback in (near) real-time to inform public health action. Prior to the introduction of EDSSS routine, rapid analysis across EDs in England was not possible. The pre-existing central collection of data from EDs, as described in **Chapter 3** and **Chapter 8**, allowed for reporting of attendance levels, use for payment purposes, as well as some provision for some purposes not directly related to patient care, including non-rapid public health analyses. Though regular and including all EDs in England, the information collected was not of sufficient detail or timeliness for syndromic surveillance purposes. The evidence presented in this thesis has confirmed the surveillance capabilities of EDSSS, which is an important step in providing an evidence base for the continued use and application of the system in the future.

EDSSS has now been shown to have surveillance indicators sensitive to a range of different public health threats, evidencing the potential to provide real-time information for action:

a. **Rapid intervention impact assessment: Chapter 5** demonstrated the potential for the EDSSS to be used for rapid, standalone analysis and feedback on the impact of public health interventions, such as introduction of new vaccines. The ability to provide this feedback in near real-time, ahead of traditional public health surveillance (i.e. laboratory) datasets provides new opportunities for more rapid assessments to be carried out in future.

b. **Real-time identification of risk groups:** The investigation of individual periods of poor air quality in **Chapter 6** demonstrated the identification of differing levels of impact in different age groups, at different times. These distinctions were made despite the air quality events themselves being very similar in terms of duration and type of exposure. This highlights the value of near real-time surveillance and feedback; the ability to identify changes in presentation of disease enables public health actions and messaging to be tailored and targeted quickly.

c. **Rapid changes in human behaviour:** The ability of EDSSS to identify changes in attendance behaviour in near real-time, as described in **Chapter 7**, and provide timely feedback tailored to the situation, is valuable for both public health authorities and emergency care providers. Though individual EDs (and those working within them) may have anecdotal evidence gained through local experience, the EDSSS provides evidence from EDs across England, helping to identify and highlight similarities (or differences) both geographically and temporally. This detailed intelligence may be used to support and aid resource allocation in EDs to prepare for and manage quiet(er), as well as busier, periods.

d. **Real-time analysis and reporting:** The ability to identify and provide timely warning of public health events severe enough to warrant an ED visit is something which had been previously been limited within the UK. The central collection of data has traditionally been slow, with validation steps and delays in data transfer making data available long after both an event has occurred, and the patient had attended the ED. The importance and value of EDSSS in the monitoring and reporting of overall ED attendances is demonstrated in **Chapter 9**, where the impact of the COVID-19 pandemic on ED attendances (monitored in near real-time) was clearly demonstrated.

Cross system/international collaborative working

EDSSS was initially designed and established as a standalone surveillance system for England. Despite this, the development included consideration for future collaborative working with other ED syndromic systems, both with devolved administrations within the UK and internationally. As detailed in **Chapter 3**, the sentinel EDSSS network was extended to include Northern Ireland in 2012, though the national EDSSS has subsequently been restricted to England only. A major step towards international, cross border surveillance collaboration was achieved in the two studies described in **Chapter 6** and **Chapter 7**, research projects completed using data from both EDSSS and OSCOUR®, the ED syndromic surveillance system in France.

The EDSSS and OSCOUR® systems were found to be broadly compatible, with similar syndromic indicators available and in use in both. There is potential for further collaborative working and even harmonisation of indicators in future.

10.2 What value can ED syndromic surveillance add to emergency care services in England?

Data collection within the ED is of primary importance for patient care. The ED electronic patient record describes a patient's journey through the ED, used for the direct care of the patient, both within the ED and any subsequent follow up outside of the emergency care setting. This information can additionally be used on a population rather than individual patient basis, from the ED to NHS Trust, up to the national level, providing valuable intelligence for the identification and management of local (within a single ED/hospital/NHS Trust) or even national pressures.

At the time of the development of the initial sentinel EDSSS there was no standardisation of ED data collection or formatting across England. The structure and completion of the patient care record was unique to each ED, dependent on local work practices and the software solutions used locally. A wide range of different information was collected in a variety of ways, including the use of free text, local coding or recognised codesets (CDS[3], ICD-10[4] or Snomed CT[5]). This variation limited the capability for the patient care record to provide an auditable record of relevant and consistent information across EDs, as well as inhibiting communication between health professionals. As described in **Chapter 3**, the establishment of the sentinel EDSSS provided evidence of what was achievable, even in a relatively small sentinel network:

- the secure, automated, daily collection of data from across different EDs;
- the reformatting of disparate datasets into a single, standardised codeset;
- the demonstration of the successful use of this data for public health surveillance purposes.

The close working relationship of the EDSSS project group with RCEM began with the initial planning and pilot phase of EDSSS and continued beyond the initial development of and recruitment of EDs to the system. The sentinel EDSSS provided initial evidence of the benefit that may be realised by the standardisation of data collection and storage by EDs in England. The sentinel EDSSS also provided valuable experience and insight into the development of standardisation, used by the RCEM, NHS Digital and NHS England in the development of the Emergency Care Data Set (ECDS),[6] as described in **Chapter 8**.

The subsequent development and roll out of ECDS presented new opportunities to improve data collection to aid in patient care, as well as NHS resource planning. The information

collected in the patient care record in EDs in England is now standardised, meaning that any patient attendance should result in the same final record, regardless of which ED is attended or which health care professional is consulted. This will enable improvement in patient care and facilitate better communication between health care professionals. The ECDS also requires the regular (daily) transfer of a specified portion of the electronic patient care record to be transferred to a central collection point (NHS Digital). This rapid transfer of information will allow for improved and more timely identification of issues on a national level as well as resource planning within the NHS. Additionally this centrally collected and held dataset, including updates and corrections sent through in addition to the daily feed, may also be used for future (longer term, rather than real-time) public health surveillance activities.

The continued (business as usual) operation and ongoing routine weekly public reporting of EDSSS throughout the COVID-19 pandemic has made rapid standardised analysis available for emergency care (within EDs and at governmental/policy level). The previously established historical baselines which determine what is considered 'normal' for ED attendance levels, have been invaluable for identifying the indirect impacts of both the pandemic and control measures, as described in **Chapter 9**. This particular use of EDSSS has been picked up and reported by others.[7]

10.3 How can ED syndromic surveillance in England be further developed for improved public health surveillance?

The introduction of the ECDS into EDs in England (as described in **Chapter 8**), including the requirement for (at least) daily transmission of data to a central point (NHS Digital), has had a major impact on the EDSSS. The sentinel EDSSS ceased to receive data on 31 March 2018, ending almost 8 years of continuous, daily reporting marking the end of phases I-IV described in **Chapter 3**.

From 1 April 2018 the new national EDSSS began receiving data, on a daily basis, from EDs in England, in the newly standardised ECDS format via NHS Digital. As EDs have adopted the ECDS and developed their central daily reporting capability, so the number of EDs included in the anonymised data feed to national EDSSS has increased. The EDSSS has benefited in terms of the use of standardised coding, the breadth of information included, and the geographical coverage achieved.

During the first years of this new national EDSSS, analyses and reporting remained broadly similar to that of the sentinel EDSSS, maintaining continuity of surveillance and reporting. This business as usual approach, reporting on broad health indicators (such as respiratory and cardiac type attendances), with baseline levels included as standard, proved to be of value during the initial phase of the COVID-19 pandemic in England. As described in **Chapter 9** the national EDSSS provided rapid feedback on ED attendance levels during the initial period of intervention measures (including shielding, social distancing and 'lockdown').

The national EDSSS also now offers much greater opportunities for future ED syndromic surveillance development. The following list of potential areas for development of ED syndromic surveillance in England is not exhaustive. Public health surveillance needs are constantly evolving and as the new ECDS data items are used more frequently as standard, new areas of interest are likely to be identified in future.

Refinement of syndromic indicators

The inclusion of ECDS data now offers greater opportunities for developing new ED syndromic surveillance indicators within national EDSSS, resulting from the standardisation of:

- **diagnosis information:** Snomed CT coding is now used across all EDs and diagnoses are expected to be based on only true diagnoses, with a qualifier for suspected/confirmed (signs/symptoms such as 'chest pain' or 'vomiting' are no longer permitted);
- **chief complaint field:** the use of ECDS has ensured the availability of a newly standardised and Snomed CT coded list from which signs/symptoms may be selected for each patient, ensuring the availability of this information for use in syndromic indicators in future. Use of this field allows for the identification of signs/symptoms which are no longer permitted to be recorded as diagnoses.

Chapter 2 illustrated that the use of diagnosis information for the mapping of syndromic indicators was intentionally avoided in a large number of ED syndromic surveillance systems, generally due to the low levels of field completion in real-time. ED syndromic surveillance systems operating in (or using a surveillance tool developed in) North America prefer the use of the chief complaint (entirely based on signs and symptoms) over diagnosis. The national EDSSS now presents an opportunity for the exploration of the use of

both diagnosis and chief complaint for development and refinement of syndromic indicators in future.

Identification and use of severity indicators

Although the ED setting is expected to see patients with the most severe presentations of illness, there is still a range in the levels of severity seen. The ECDS encourages the recording of standardised fields describing the severity of illness throughout the patient journey through the ED including:

- acuity (i.e. how quickly the patient needs to be seen on arrival);
- investigations and treatments administered;
- the type of care the patient moves on to on discharge from the ED (if any).

The further refinement of EDSSS indicators to enable the identification and monitoring of changes in levels of severity of illness will supplement and support surveillance activities and provide valuable intelligence for public health action in future.

New areas of syndromic surveillance

Non-communicable diseases and conditions

The surveillance of non-communicable disease is often carried out based on traditional surveillance methods, such as described in **Chapter 1**. Relatively slow reporting schedules limit the opportunities for public health responses/interventions where rapid response may be appropriate.

Research into the most severe injuries presenting at EDs (such as participation in the Trauma Audit & Research Network[8]) and local collaborations in Violence Reduction Units[9] (and predecessor groups) have highlighted the potential utility of public health surveillance of injuries in EDs. However, prior to the introduction of ECDS, information collected in EDs around injuries was often *ad hoc* and developed locally. While the recording of free text, non-standardised fields or project specific information on injuries may be of benefit for individual patient care, or discrete research projects, it is generally not suitable for onward transmission for secondary purposes at a national level. An inbuilt 'flag' in ECDS now aids in the identification of injury type attendances. An additional standardised injury section of the patient care record has also been included, facilitating the collection of standardised detail of injury type, location and intent, from all EDs in England. This promotes the possibility for EDSSS to expand to include a new area of near real-time surveillance, not previously possible on a continual, national basis.

Within ECDS, flags are also included within the patient record to mark where alcohol and/or drugs are involved in each ED attendance. Current identification of acute alcohol intoxication attendances in EDSSS is based solely on the primary diagnosis of each attendance. The new alcohol flag will likely provide a better estimate of alcohol related attendances (particularly where the main reason for attending is not obviously alcohol related e.g. the primary diagnosis may be the result of an injury). The further extension of this to the ability to identify and monitor drug related attendances may aid in the identification of changing trends (in both numbers and severity of illness), again with potential to provide monitoring of potential public health interventions, if appropriate.

During the initial phases of the COVID-19 pandemic in England, one of the most valuable features of EDSSS was identified as the monitoring of indirect impacts of COVID-19 on ED attendances. Rapid reductions in indicators other than COVID-19-like attendances, such as cardiac conditions, provided information for public health messaging promoting the accessing of emergency care whenever necessary. This has posed further questions as to the impact on other areas such as mental health or cardiovascular disease, including strokes.

Investigation of health inequalities

To date, basic breakdowns of attendances by age are analysed as standard for investigations within EDSSS, with patient sex additionally used in an impact of cold weather indicator.[10] The more detailed data now available in national EDSSS will enable future investigation into the (patient stated) ethnic category, residential status (e.g. homelessness or nursing/residential homes) and drug/alcohol use (as described above). This inclusion of previously unavailable demographic detail is expected to enable the identification of and monitoring for changes in health inequalities in the population attending ED.

The national EDSSS should eventually receive daily data from all EDs in England. The resulting improved ability for geographical based analyses will add strength to the investigation of any disparities identified.

Inclusion of all ED types in EDSSS

To date, EDSSS has focussed on type 01 ED attendances. The introduction of ECDS was initially also focussed on type 01 EDs, then extended to all ED types including: type 02 single specialty EDs; type 3 &4 walk in centres and minor injury units; and the newly formed type 05 ambulatory care.[11] This has subsequently enhanced the national EDSSS, creating an additional all-England all-types ED surveillance network, now including emergency care

attendances for less severe illness and injuries than seen in type 01 EDs alone. Further work will be required to identify how this can add value, complementing both the existing EDSSS and the other community based PHE syndromic surveillance systems.

The future of ED syndromic surveillance globally

As described in **Chapter 2**, the use of ED syndromic surveillance internationally has increased and the systems themselves have evolved over time. The development of truly national systems has occurred in several countries/territories, with England now also fully achieving this status.

With a collective 20 years of global ED syndromic surveillance experience, many lessons have been learned, from which future developments have yet to be made. The potential for cross system learning is ever present and the sharing of the technical details should be encouraged. The further potential for cross system collaboration and possibly even harmonisation of indicators for use across international borders is a very real prospect.

10.4 Limitations

Syndromic surveillance is an opportunistic, secondary use of health care information and is ultimately limited by the coverage attainable and the quality, completeness and availability of the data it uses.

In addition to improving the timeliness of surveillance, the passive nature of EDSSS is intended to aid the ability for this system to respond during periods of service pressure within the ED. All of the information within each patient record is collected primarily for the purpose of managing and recording patient care. EDSSS requires no extra fields, or additional options selected specifically for syndromic surveillance purposes. The provision of data to EDSSS does not require any extra work in terms of data collection, or data transmission. This ‘business as usual’ approach enables EDSSS data preparation and transfer to function in the background of the ED clinical management system. This approach also ensures that during periods of high workload or pressure within the ED, the local processes for patient care and recording of information remain unchanged. Data continues to flow to EDSSS, providing valuable information for public health action from a national to local, ED level. There are, however, several clear limitations of EDSSS, as described below.

Coverage

As described in **Chapter 3**, the sentinel EDSSS required EDs to be individually recruited, through a long, complex recruitment process. In total 40 EDs were successfully recruited to the sentinel EDSSS network, although only a maximum of 36 EDs reported at any one time. Sentinel EDSSS initially focussed on London and cities hosting London 2012 events, but was designed to be expanded as an ongoing Olympic Legacy; to include EDs in large, geographically dispersed cities across England. However, the complexities of recruitment meant the sentinel EDSSS did not achieve fully representative, national coverage. Not all PHE centre areas were included in the network (with no EDs in the North East or East Midlands areas), limiting the ability for public health surveillance to only those areas with a participating ED.

The slow recruitment of EDs over several years further impacted the usable system coverage for research and investigations across extended time periods. In **Chapter 5** the interrupted time series analysis required a stable number of EDs to be included over the maximum time period possible (both before and after the implementation of the rotavirus vaccine); only three EDs met the eligibility criteria over a sufficient length of time for the analysis carried out.

The investigation into the impact of air pollution on ED visits, presented in **Chapter 6**, focussed solely on London which limited the number of EDs eligible for inclusion. Though the relatively short investigation time period (a single calendar year - 2014) helped to maximise the number of EDs eligible, only five EDs in London were included. In contrast, 58 EDs in Paris were available from the OSCOUR® system, which has been a mandatory national surveillance system in France since 2013.[12] Though similar impacts of air quality incidents on human health were observed in both London and Paris, this study clearly showed the advantages of the larger number of EDs from which data was available in Paris: with much more stable data, reduced background noise and clearer distinction of exceedances in attendance levels.

Data quality and completion

EDSSS data collection is restricted to the inclusion of a 'snapshot' of ED data at the time of first extraction, with no provision for inclusion of subsequent updates or corrections made to the patient record. This approach enables the comparison of each day on a like-for-like basis. Whilst this brings the benefit of timely reporting (next day in sentinel, currently second day in national EDSSS), it can also limit both the completeness and correctness of the data. The reasons for missing/incorrect data are assumed to be consistent over time

within each ED, i.e. local working practices affect the speed of completion of the electronic patient record. As a secondary user of this information, the quality of the information captured in EDs is an important factor in success of the EDSSS in meeting its goal of providing timely information for public health action.

EDSSS relies on the use of coded diagnosis information to underpin the development and construction of syndromic indicators. These diagnoses may be related to signs/symptoms as presented by the patient. Not all conditions seen in the ED require confirmatory testing for effective treatment, so for many attendances tests may not be carried out to reach a confirmed, final diagnosis. Additionally, where tests are carried out in the ED, there is potential for the results and subsequent final diagnosis to not have been entered into the patient record at the point the data was extracted for EDSSS.

Using this 'snapshot' method, around 70% of visits were found to include a diagnosis code in both the air quality study (**Chapter 6**) including 5 EDs in London during 2014 and the rotavirus vaccine impact study (**Chapter 5**) which included 3 (non-London) EDs from 2011-2016. This level of diagnosis coding was very similar to the level reported from the Paris EDs during 2014 in the AQ study (**Chapter 6**), despite the OSCOUR® system in France allowing for updates to records in the days immediately following the first report.

Data format and specificity

At the time of establishment of the sentinel EDSSS (2010), there was no standardised minimum requirement for the collection and storage of patient care information in EDs in England. The recruitment of EDs to EDSSS involved the mapping from the local electronic patient care records to a single EDSSS codeset, as described in **Chapter 3**. Different data items, relevant to each patient attendance, were found to be available (or not) in different EDs. Coded diagnosis information was available in all EDs, however, the use of different 'pick lists' to choose from within each ED (with background mapping to the different diagnosis coding systems in use locally) limited compatibility for some syndromic indicators.

In each of the research studies presented in **Chapter 5**, **Chapter 6** and **Chapter 7**, which were carried out using the sentinel EDSSS, these limitations were controlled for where possible, such as the inclusion of only EDs using ICD-10 or Snomed CT diagnosis coding systems in the rotavirus vaccine impact study (**Chapter 5**). The excluded EDs, those not using either of these diagnosis coding systems, were only able to report 'gastrointestinal' conditions, not the 'gastroenteritis' indicator (i.e. gastrointestinal conditions considered to be due to infection) required for the study. While some did provide 'gastrointestinal'

diagnoses throughout the time period required, they still had to be excluded from the study because not enough detail was included in the coding system used.

The national EDSSS, as reported from in **Chapter 9**, now receives all data in Snomed CT coded format. This standardisation ensures that all EDs are now reporting in a consistent way, making them all eligible for future studies (where the time period criteria for reporting are met), which will greatly increase the power and confidence in such studies.

10.5 Recommendations

The evidence presented in this thesis supports the continuation and further development of ED syndromic surveillance in England.

Future research areas identified

Each of the studies in **Chapter 5**, **Chapter 6**, **Chapter 7** and **Chapter 9** presented further investigations which should be followed up:

Use for rapid vaccine impact studies

As an ongoing, routine surveillance system, EDSSS holds an ever-growing historical dataset. This may be used in future as a baseline (pre-vaccination) period, against which the impact of vaccine implementation may be measured, as shown in **Chapter 5**. Such future vaccines may include those currently under development and undergoing clinical trials, such as RSV[13] and norovirus,[14] as well as the rapidly developed, approved and rolled out COVID-19 vaccines.[15-17]

Trends in gastroenteritis ED attendances

Although the introduction of rotavirus vaccination in infants clearly reduced gastroenteritis attendances in EDs overall (**Chapter 5**), the identification of a summer increase during 2012, warrants further investigation. This increase occurred during a year of increased cryptosporidium activity as reported by laboratory surveillance, indicating that EDSSS may be sensitive to increased circulation of this pathogen in the community.

This introduces a wider programme of future work to establish how EDSSS can specifically support national gastrointestinal surveillance programmes, through the development of EDSSS indicators sensitive to specific pathogens.

Trends in asthma ED attendances

Chapter 6 focussed specifically on the health impact of poor air quality on ED attendances for asthma, however, as with all ED syndromic indicators there is potential for other events

to have an impact on ED visits. The study period (2014 calendar year) included thunderstorms and the return to school following the long summer break, which have each been associated with increased levels of asthma.[18,19] These events appear to have had an impact on asthma ED attendances in both London and Paris during the study period. This is an area of research for which there is a limited evidence base and therefore further exploration of these areas is warranted.

Development of severity indicators

The investigation into the impact of events on the timing and types of attendances in EDs described in **Chapter 7** and the initial analysis of ED attendances during the first wave of the COVID-19 pandemic in **Chapter 9** both recommended further investigation of the use of severity indicators, as described **above**.

Service delivery

This thesis has outlined the successful development of a national ED surveillance system and the integration of the system into the public health service in England for routine use.

The work carried out and presented in this thesis has shaped and aided the growth of EDSSS as a system. Having been under constant development from the first establishment of a live data feed in 2010, the EDSSS has continued to grow in terms of the range surveillance activities carried out. The geographical coverage of the system continues to grow, with all type 01 EDs expected to be reporting, via NHS Digital, on daily basis.

The breadth of the system is also under development with other ED types (types 02, 03, 04 and the newly created type 05) also adopting ECDS, both in terms of data collection and daily data provision at a national level. The expansion of national EDSSS from the type 01 EDs, providing urgent care to the most severely ill, to all ED types and the less severe presentations, will increase the surveillance capabilities of EDSSS and potentially the public health actions that may be taken as a result.

The existence and utility of EDSSS has become increasingly well publicised during the COVID-19 pandemic. The next set of challenges will be to realise the potential for this system to provide near real-time surveillance support enabling improved public health response to an increasing range of areas of public health (including non-communicable disease and investigation of health inequalities, as described **above**), whilst also retaining the flexibility to respond to public health threats not yet identified. Further development of reporting capabilities will also be required to ensure surveillance outputs are readily available and easily visible

The future of EDSSS

The evolution of EDSSS, from a sentinel to national surveillance system, and its collaborative input into the standardisation of ED data collection across England, stands as a model that may be reproduced elsewhere. As the EDSSS continues to grow, in terms of geographical coverage, ED type inclusion and areas of public health interest monitored, so does its reputation on the world stage.

The EDSSS has enhanced public health surveillance programmes in England, added benefit to emergency care and has the potential to realise further benefits to both in future.

10.6 References

1. Pebody RG, Green HK, Andrews N, et al. Uptake and impact of vaccinating school age children against influenza during a season with circulation of drifted influenza A and B strains, England, 2014/15. *Euro Surveillance* 2015;20(39):pii=30029. doi: 10.2807/1560-7917.ES.2015.20.39.30029

2. Pebody R, Green H, Andrews N, et al. Uptake and impact of a new live attenuated influenza vaccine programme in England: early results of a pilot in primary school-age children, 2013/14 influenza season. *Euro Surveillance* 2014;19(22):pii=20823.

3. NHS Digital. Supporting Information: Accident and Emergency Diagnosis Tables. [Available from: https://datadictionary.nhs.uk/data_elements/retired/accident_and_emergency_diagnosis_-_second.html?hl=accident%2Cemergency%2Cdiagnosis Accessed: 20 Feb 2021].

4. World Health Organisation. International Classification of Disease (ICD). [Available from: https://icd.who.int/browse10/2010/en Accessed: 20 Feb 2021].

5. International Health Terminology Standards Development Organisation. SNOMED CT. [Available from: http://www.ihtsdo.org/snomed-ct/ Accessed: 20 Feb 2021].

6. NHS Digital. SCCI0092-2062. Commissioning Data Sets (CDS) Version 6.2: Addition of Type 011: Emergency Care Data Set (ECDS). [Available from: http://www.content.digital.nhs.uk/isce/publication/SCCI0092-2062 Accessed: 08 Mar 2017].

7. Mafham MM, Spata E, Goldacre R, et al. COVID-19 pandemic and admission rates for and management of acute coronary syndromes in England. *Lancet* 2020;396(10248):381-89. doi: 10.1016/S0140-6736(20)31356-8

8. Trauma Audit And Research Network. [Available from: https://www.tarn.ac.uk/Home.aspx Accessed: 31 October 2020].

9. West Midlands Violence Reuction Unit. [Available from: https://westmidlands-vru.org/. Accessed 27 Feb 2021].

10. Hughes HE, Morbey R, Hughes TC, et al. Using an Emergency Department Syndromic Surveillance System to investigate the impact of extreme cold weather events. *Public Health* 2014;128(7):628-35. doi: http://dx.doi.org/10.1016/j.puhe.2014.05.007

11. Department of Health. Information Standards Notice SCCI0092-2062 (19 Apr 17): Commissioning Data Sets (CDS) Version 6.2.1: Addition of Type 011: Emergency Care Data Set (ECDS). 2017

12. Fouillet A, Bousquet V, Pontais I, et al. The French Emergency Department OSCOUR Network: Evaluation After a 10-year Existence. Online Journal of Public Health Informatics 2015; Vol 7, No 1.

13. Buchholz UJ, Cunningham CK, Muresan P, et al. Live Respiratory Syncytial Virus (RSV) Vaccine Candidate Containing Stabilized Temperature-Sensitivity Mutations Is Highly Attenuated in RSV-Seronegative Infants and Children. *J Infect Dis* 2018;217(9):1338-46. doi: 10.1093/infdis/jiy066

14. Sherwood J, Mendelman PM, Lloyd E, et al. Efficacy of an intramuscular bivalent norovirus GI.1/GII.4 virus-like particle vaccine candidate in healthy US adults. *Vaccine* 2020;38(41):6442-49. doi: 10.1016/j.vaccine.2020.07.069

15. Mahase E. Covid-19: UK approves Pfizer and BioNTech vaccine with rollout due to start next week. *BMJ* 2020;371:m4714. doi: 10.1136/bmj.m4714

16. Mahase E. Covid-19: UK approves Oxford vaccine as cases of new variant surge. *BMJ* 2020;371:m4968. doi: 10.1136/bmj.m4968

17. Mahase E. Covid-19: UK approves Moderna vaccine to be given as two doses 28 days apart. *BMJ* 2021;372:n74. doi: 10.1136/bmj.n74

18. Elliot AJ, Hughes HE, Hughes TC, et al. The impact of thunderstorm asthma on emergency department attendances across London during July 2013. *Emergency medicine journal : EMJ* 2014;31(8):675-78. doi: doi 10.1136/emermed-2013-203122

19. Bundle N, Verlander NQ, Morbey R, et al. Monitoring epidemiological trends in back to school asthma among preschool and school-aged children using real-time syndromic surveillance in England, 2012-2016. *Journal of Epidemiology and Community Health* 2019: DOI 10.1136/jech-2018-211936. doi: 10.1136/jech-2018-211936

Abbreviations

AI	Artificial Intelligence
AQ	Air Quality
ARI	Acute Respiratory Infection
CDS	Commissioning Data Set
CI	Confidence Interval
CNIL	French National Commission for Data protection and Liberties
DAQI	Daily Air Quality Index
EARS	Early Aberration Reporting System
EARS-net	European Antimicrobial Resistance Surveillance Network
ECDS	Emergency Care Data Set
ED	Emergency Department
EDSSS	Emergency Department Syndromic Surveillance System
EDSyS	Emergency Department Syndromic Surveillance
EISS	European Influenza Surveillance Scheme
ESSENCE	Electronic Surveillance System for the Early Notification of Community-Based Epidemics
Euro 2016	2016 UEFA European Football Championship
EuroMOMO	European monitoring of excess mortality for public health action
FIFA	Fédération Internationale de Football Association
GP	General Practitioner (family doctor)
HDAS	Healthcare Databases Advanced Search: provided by Health Education England and NICE
HPA	Health Protection Agency: predecessor of PHE
HUS	Haemolytic Uraemic Syndrome
ICD	International Classification of Disease
ICD-10	International Statistical Classification of Diseases and Related Health Problems-version 10
ISDS	International Society for Disease Surveillance
ISO	International Organisation for Standardisation
IT	Information Technology
London 2012	London 2012 Olympic and Paralympic Games

MI	Myocardial Ischaemia
NHS	National Health Service
NHS 111	NHS telephone health advice line (in England): successor of NHS Direct
NHS Digital	National information and technology partner to the NHS
NHS Direct	NHS telephone health advice line (in England): predecessor of NHS 111
NHS Trust	NHS organisation which provide goods and services for the purposes of the health service
NI	Northern Ireland
NICE	National Institute for Health and Care Excellence
NIHR HPRU	National Institute for Health Research Health Protection Research Unit
NSSP	National Syndromic Surveillance Program
ODS	Organisation Data Service
OR	Odds Ratio
OSCOUR®	Organisation de la surveillance coordonnée des urgences
PHE	Public Health England: successor of HPA
PII	Patient Identifiable Information
PM	Particulate Matter
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RAMMIE	Rising Activity, Multi-level Mixed effects, Indicator Emphasis: statistical method used by ReSST
RCEM	Royal College of Emergency Medicine
ReSST	Real-time Syndromic Surveillance Team
RODS	Real-time Outbreak and Disease Surveillance
RSV	Respiratory Syncitial Virus
RV	Rotavirus vaccination
SARS	Severe Acute Respiratory Syndrome
SGSS	Second Generation Surveillance System
Snomed-CT	Clinical terminology
SPMSD	Sanofi Pasteur-MSD
SUS	Secondary Uses Service
UDDA	RCEM unified diagnostic dataset
UEFA	Union of European Football Associations
UK	United Kingdom
USA	United States of America

Appendix A: Additional table used in Chapter 2

Emergency Department syndromic surveillance (EDSyS) systems identified in the systematic review in **Chapter 2**, detailing:

- the country/territory, state/province, county/region and city/hospital included;
- the number of EDs in each EDSyS system;
- the year the EDSyS system started;
- the year of latest data and year of last publication identified;
- the references identified for each EDSyS, separated into journal articles and conference abstracts.

The full list of all 559 studies identified for inclusion in the systematic review in **Chapter 2** review follows.

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
Albania	-	-	-	National	Hospitals in all 36 districts	(2013)	-	2014	(1)	
Australia	New South Wales	-	-	State	68 hospitals, 85% of ED activity	2003	2014	2016	(2-17)	(18, 19)
	Victoria	-	Melbourne	Hospital(s)	2 EDs	2005	2009	2011	(20)	
	Victoria	-	Melbourne	Hospital	1 ED	2006	2008	2010	(21)	
Canada	Alberta	Edmonton	-	Public Health Unit	-	(2007)	2011	2013		(22, 23)
	Manitoba	-	Winnipeg	City	7 EDs	(2006)	2011	2014	(24)	(25, 26)
	Ontario	-	-	Province	132 hospitals, >80% of ED visits in Ontario	2004	2016	2017	(27-36)	(37-48)
		11-15 Public Health Units	-	Public Health Unit	-	(2009)	2015	2017	(36, 49)	(48)
			Toronto	City	-	(2002)	2002	2004		(47)
	Quebec	-	Montreal	City	5 hospitals, 28% ED visits	(2006)	2001	2015	(50)	
China	-	-	Beijing	City	2 major hospitals	(2004)	2004	2006		(51)
	-	-	Wuxu	City	2-3 hospitals	(2004)	2009	2011		(52)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
France	-	-	-	National	>650 EDs, 88% of all ED visits	2004	2016	2017	(53-59)	(60-84)
Greece	-	-	Athens + Olympic host cities	Multi city	17 hospitals	2002	2003	2003		(85, 86)
Italy	-	-	Genoa	City	72% of ED visits	2007	2013	2015	(87-90)	
	-	Lazio	-	Region	36/61 EDs	2000	2004	2009	(91)	
Jamaica	-	-	-	National	-	2007	2007	2007		(92)
Republic of Korea	-	-	-	National	125 EDs	2002	2009	2010	(93, 94)	(95)
New Zealand	-	-	Wellington	Hospital	1 ED	2008	2008	2009	(96)	
Singapore	-	-	-	National	7 hospitals	(2013)	2013	2013		(97)
Spain	-	-	Santander	Hospital	1 ED	(2010)	2012	2014	(98, 99)	
Taiwan	-	-	-	National	170 hospitals: 85% of all visits (earlier study included 189 hospitals but no % value)	2003	2012	2013	(27, 100, 101)	(102, 103)
	-	-	Taipei	City	5 Hospitals	(2005)	2008	2008		(104-106)
UK	-	-	-	National	36 EDS	2010	2015	2017	(107-121)	(84, 122, 123)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
USA	DiSTRIBuTE	-	-	National	>50 state/ local health dept ED syndromic systems	2005	2009	2012	(124)	(125-133)
	Biosense/ NSSP			National	4,000 hospitals, 55% ED visits	2003	2016	2017	(134-141)	(142-173)
	Military	-	-	National	>300 military treatment facilities worldwide	(1999)	2016	2010	(174)	(175-178)
	Multistate (not named)			MultiState	-	(2003)	2003	2008	(27)	
	Arizona	-	-	State	15 EDs	2001	2001	2004	(179)	(180)
		Maricopa	-	County	11 hospitals	2001	2004	2005		(181, 182)
	California	Los Angeles	-	County	>65% of ED patients	2003	2016	2017	(183)	(184-195)
		Santa Clara	-	County	12 EDs	2001	2002	2002		(196)
		San Diego	-	County	16 hospitals - 86% ED visits	1999	2007	2013	(197)	(198-202)
	Colorado	-	-	State	17 EDs	(2015)	2015	2015		(203)
		-	Denver	City	9 EDs	2003	2003	2003		(204)
	Connecticut	-	-	State	21/32 EDs	2004	2011	2012		(205-212)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
USA	Florida	-	-	State	231 of 240 EDs, 96% of EDs	2006	2016	2016	(213, 214)	(215-230)
		Broward	-	County	-	2005	2007	2007		(231, 232)
		Cook	-	County	-	2007	2007	2007		(233)
		Duval	-	County	8/10 EDs	2007	2008	2011		(234-239)
		Hillsborough, Pinellas and Collier	-	multi County	9 EDs	2001	2001	2006		(240, 241)
		Miami-Dade	-	County	17 largest of 23 EDs	2005	2010	2011		(233, 242-257)
	Georgia	-	-	State	112 EDs	2005	2016	2016		(258-267)
	Illinois	-	-	State	-	(2012)	2013	2013		(268)
		Champaign	-	County	-	(2007)	2011	2011		(269)
		Cook	-	County	45 EDs	(2012)	2015	2017	(270)	(271-273)
		-	Chicago	City	1 ED	(2012)	2012	2012		(274)
	Indiana	-	-	State	110 hospitals, 90% of ED visits	2004	2010	2014	(275, 276)	(233, 277-285)
		Marion	-	County	14 EDs	2007	2011	2011		(233, 286)
	Kentucky		Louisville	City	9 EDs	2002	2002	2005	(287)	(288)
	Louisiana	-	-	State	11 EDs (in 2013)	2005	2016	2016		(289-294)
	Massachusetts	-	Boston	City	10/10 EDs	2004	2011	2012	(295, 296)	(239, 297-309)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
USA	Maryland	-	-	State	47 EDs 100% of EDs	2005	2012	2013		(310-320)
		-	Baltimore	City	11/11 EDs	-	-	2002		(321)
	Maine	-	-	State	24 of 37 EDs	2007	2012	2012		(322)
		-	Maine Medical Centre, Portland	Hospital	1 ED	2002	2004	2004		(323)
	Michigan	-	-	State		2006	2014	2014		(324-326)
	Minnesota	-	Children's hospital - Roseville	Hospital	-	(2003)	2003	2004		(327)
		-	Hennepin County Med. Center, Minneapolis	Hospital	1 ED	(2001)	2003	2003		(328)
	Missouri	-	-	State	84 EDs, 90% visits	2001	2013	2013		(329-335)
	Montana	-	-	State	-	-	-	2008		(336)
	North Carolina	-	-	State	122 EDs, around 4.8 million visits per year	1999	2015	2017	(337-341)	(342-374)
		Military	-	State	1 ED	2002	2007	2007		(375)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
USA	North Dakota	-	-	State	1 ED	(2005)	2008	2008		(376, 377)
	Nebraska	-	-	State	32 facilities	(2011)	2016	2016		(378-380)
	New Hampshire	-	-	State	all acute hospitals by 2010	2001	2015	2017	(381)	(382-386)
	New Jersey	-	-	State	79/80 EDs	2001	2016	2017	(387, 388)	(389-399)
		Bergen	-	County	6/6 EDs	2001	2004	2004		(400, 401)
	New Mexico	-	Albuquerque	City	2 EDs in 1 hospital	2002	2003	2005	(402)	
	New York	-	-	State	140 EDs, 4 million visits per year	(2004)	2012	2017	(403)	(404-411)
		Westchester	-	County	7/13 EDs, approx 80% visits	2003	2003	2003		(412, 413)
		-	New York	City	51 EDs (98% of ED visits)	2001	2003	2017	(414-433)	(239, 434-475)
	Ohio	-	-	State	96% of EDs	2003	2012	2012		(285, 476-481)
		-	Akron	City	3 EDs	2003	2003	2003		(204)
	Oklahoma	Tulsa	-	County	7 hospitals	2002	2006	2007		(482)
	Oregon	-	-	State	60/60 EDs	(2011)	2016	2017	(483)	(484-488)
	Pennsylvania	SW state		Regional	-	1999	2002	2004	(489)	
		Allegheny	-	County	7 EDs	2009	2009	2010		(490)
		-	Philadelphia	City	-	(2006)	2011	2017	(491)	

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
USA	Rhode Island	-	-	State	all 11 EDs	(2006)	2013	2013		(492-494)
	South Carolina	-	-	State	22 hospitals	(2008)	2012	2013		(495-499)
		-	Greenville hospital system	Hospital(s)	a level I trauma center plus 3 smaller outlying ERs	2003	2007	2007		(500, 501)
	Tennessee	Knoxville	-	County	3 EDs	2002	2002	2005	(502)	
	Texas	-	Dallas	City	-	(2012)	2012	2013	(503)	
		-	Fort Worth	City	2 hospitals	2003	2003	2003		(204)
		Harris	-	County	34 hospitals, 70% ER beds	2004	2014	2014		(504-509)
		Travis	-	County	14 hospitals	2010	2011	2011		(510)
		Health service region 8	-	Region	3 hospitals	2006	2006	2007		(511)
	Utah	Salt Lake	-	County	15 sites (EDs + Urgent Care Centres)	(2009)	2009	2010		(512)
	Virginia	-	-	State	82 EDs	(2008)	2016	2016		(320, 513-517)
		Tidewater or Hampton Roads region	-	Region	7 EDs	(2002)	2002	2003		(518)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
USA	Washington	King	-	County	19/20 EDs	1999	2013	2014	(519-521)	(239, 522-532)
		Kitsap, heath district	-	Multi County	3 EDs	(2004)	2006	2007		(532-534)
		Pierce	-	County	5 EDs (approx 80% of ED records in county)	(2004)	2005	2007		(532, 535)
		Spokane	-	County	4 major community hospitals	-	-	2007		(536)
	Wisconsin	-	-	State	14 acute-care hospitals in 6 counties	2008	2009	2009		(537)
		-	Milwaukee	City	11 departments	2002	2003	2004	(538, 539)	(204, 540)
		-	University of Wisconsin Hospital	Hospital	1 ED	(2007)	2009	2011	(541)	(542, 543)
	Washington DC	-	-	DC	9 hospitals	2001	2016	2017	(544, 545)	(546-548)
		Capital region - including Virginia and Maryland	-	Region	30% of acute care hospitals in state, 90% in national capital region	2001	2009	2009	(549, 550)	(551-553)
		-	DC university hospitals	Hospital(s)	2 University hospitals	(2009)	2009	2010		(554)

Country/ territory	State/ Province	County(ies)/ region	City/ Hospital	Coverage level	Max EDs included	Start year*	Latest data	Latest publication	Journal article references	Conference abstract references
Unknown	Unknown	Unknown	Unknown	Unknown	-	(2013)	2016	2016		(555, 556)

*(estimated/ earliest data reported)

Reviews describing multiple systems (all included in the table above): (557-559)

References

1. Simaku A, Ulqinaku D, Hatibi I, Robo A, Kakarriqi E, Bino S. Syndromic surveillance for detection of influenza in Albania. Albanian Journal of Agricultural Sciences. 2014;13(1):16-21.
2. Polkinghorne BG, Muscatello DJ, MacIntyre CR, Lawrence GL, Middleton PM, Torvaldsen S. Relationship between the population incidence of febrile convulsions in young children in Sydney, Australia and seasonal epidemics of influenza and respiratory syncytial virus, 2003-2010: a time series analysis. BMC Infectious Diseases. 2011;11(291).
3. Hope KG, Merritt TD, Durrheim DN, Massey PD, Kohlhagen JK, Todd KW, et al. Evaluating the utility of Emergency Department syndromic surveillance for a regional public health service. Communicable Diseases Intelligence. 2010;34(3):310-8.
4. Schindeler SK, Muscatello DJ, Ferson MJ, Rogers KD, Grant P, Churches T. Evaluation of alternative respiratory syndromes for specific syndromic surveillance of influenza and respiratory syncytial virus: a time series analysis. BMC Infectious Diseases. 2009;9(190).
5. Zheng W, Aitken R, Muscatello DJ, Churches T. Potential for early warning of viral influenza activity in the community by monitoring clinical diagnoses of influenza in hospital emergency departments. BMC Public Health. 2007;7(250).
6. Turner RM, Muscatello DJ, Zheng W, Willmore A, Arendts G. An outbreak of cardiovascular syndromes requiring urgent medical treatment and its association with environmental factors: an ecological study. Environmental Health. 2007;6(37).
7. Muscatello DJ, Churches T, Kaldor J, Zheng W, Chiu C, Correll P, et al. An automated, broad-based, near real-time public health surveillance system using presentations to hospital Emergency Departments in New South Wales, Australia. BMC Public Health. 2005;5(141).
8. Dinh MM, Kastelein C, Bein KJ, Green TC, Bautovich T, Ivers R. Use of a syndromic surveillance system to describe the trend in cycling-related presentations to emergency departments in Sydney. Emergency Medicine Australasia. 2015;27(4):343-7.
9. Cashmore AW, Muscatello DJ, Merrifield A, Spokes P, Macartney K, Jalaludin BB. Relationship between the population incidence of pertussis in children in New South Wales, Australia and emergency department visits with cough: a time series analysis. BMC Medical Informatics and Decision Making. 2013;13:40.
10. Hope K, Merritt T, Eastwood K, Main K, Durrheim DN, Muscatello D, et al. The public health value of emergency department syndromic surveillance following a natural disaster. Communicable Diseases Intelligence. 2008;32(1):92-4.
11. Whitlam G, Dinh M, Rodgers C, Muscatello DJ, McGuire R, Ryan T, et al. Diagnosis-based emergency department alcohol harm surveillance: What can it tell us about acute alcohol harms at the population level? Drug and Alcohol Review. 2016;35(6):693-701.
12. Liljeqvist HTG, Muscatello D, Sara G, Dinh M, Lawrence GL. Accuracy of automatic syndromic classification of coded emergency department diagnoses in identifying mental health-related presentations for public health surveillance. BMC Medical Informatics and Decision Making. 2014;14:84.
13. New South Wales public health networ. Progression and impact of the first winter wave of the 2009 pandemic H1N1 influenza in New South Wales, Australia. Euro surveillance. 2009;14(42).
14. Cumming G, Khatami A, McMullan BJ, Musto J, Leung K, Nguyen O, et al. Parechovirus genotype 3 outbreak among infants, New South Wales, Australia, 2013–2014. Emerging Infectious Diseases. 2015;21(7):1144-52.

15. Schaffer A, Muscatello D, Broome R, Corbett S, Smith W. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: A time-series analysis. Environmental Health: A Global Access Science Source. 2012;11(1).

16. Sparks R, Carter C, Graham P, Muscatello D, Churches T, Kaldor J, et al. Understanding sources of variation in syndromic surveillance for early warning of natural or intentional disease outbreaks. IIE Transactions (Institute of Industrial Engineers). 2010;42(9):613-31.

17. Hope K, Durrheim DN, Muscatello D, Merritt T, Zheng W, Massey P, et al. Identifying pneumonia outbreaks of public health importance: Can emergency department data aissist in earlier identification? Australian and New Zealand Journal of Public Health. 2008;32(4):361-3.

18. Muscatello DJ, Churches T, Kaldor J, Zheng W, Chiu C, Correll P, et al. Emergency department surveillance for the 2003 Rugby World Cup -- New South Wales, Australia.Third annual Syndromic Surveillance Conference. Boston, Massachusetts. November 3-4, 2004. MMWR: Morbidity & Mortality Weekly Report; Atlanta, Georgia 2005;54:196.

19. Zheng W, Muscatello DJ, Turner R, Neville L. The Potential of Syndromic Surveillance of Gastrointestinal Illness in the Community for Early Warning of Institutional Gastroenteritis Outbreaks. Advances in Disease Surveillance 2006;1:77.

20. Moore K, Black J, Rowe S, Franklin L. Syndromic surveillance for influenza in two hospital emergency departments. Relationships between ICD-10 codes and notified cases, before and during a pandemic. BMC Public Health. 2011;11(338).

21. Ramsay VC, Simpson P, Hobbs L, Sinickas V. An evaluation of a hospital influenza surveillance program using Emergency Department coding and laboratory data. Healthcare Infection. 2010;15(2):49-55.

22. Fan S, Brown A, Honish L, Hughes T, Jaipaul J, Mashinter L, et al. Enhancing Public Health Surveillance by Using Multiple Data Sources for Syndromic Surveillance: The Alberta Real Time Syndromic Surveillance Net. Advances in Disease Surveillance 2007;4:161.

23. Sikora C, Fournier K, Usman H, Jacobs A, Wicentowich B, Talbot J. Rapid Measles Exposure Assessment in an Urban Emergency Department Using a Syndromic Surveillance System. Online Journal of Public Health Informatics 2014; Vol 6, No 12014;6(1):e161.

24. Thompson LH, Malik MT, Gumel A, Strome T, Mahmud SM. Emergency department and 'Google flu trends' data as syndromic surveillance indicators for seasonal influenza. Epidemiology and Infection. 2014;142(11):2397-405.

25. McDonald L, Edge V, Aramini J, McDonald K. Evaluation of a Systematic Emergency Department Chief Complaint System for Near Real-Time Public Health Surveillance. Advances in Disease Surveillance 2007;2:206.

26. McDonald L, Guthrie G, Edge V, Aramini J. Detection Abilities of Several Commonly Used Algorithms as Determined by Simulation Analysis. Advances in Disease Surveillance 2007;2:205.

27. Krenzelok E, MacPherson E, Mrvos R. Disease surveillance and nonprescription medication sales can predict increases in poison exposure. Journal of Medical Toxicology. 2008;4(1):7-10.

28. Perry AG, Korenberg MJ, Hall GG, Moore KM. Modeling and syndromic surveillance for estimating weather-induced heat-related illness. Journal of Environmental and Public Health. 2011;2011.

29. van Dijk A, Dawson E, Moore KM, Belanger P. Risk Assessment During the Pan American and Parapan American Games, Toronto, 2015. Public Health Reports. 2017;132(1).

30. VanStone N, van Dijk A, Chisamore T, Mosley B, Hall G, Belanger P, et al. Characterizing the Effects of Extreme Cold Using Real-time Syndromic Surveillance, Ontario, Canada, 2010-2016. Public Health Reports. 2017;132:48S.

31. Hall GG, Perry AG, vanDijk A, Moore KM. Influenza assessment centres: a case study of pandemic preparedness to alleviate excess emergency department volume. Canadian Journal of Emergency Medicine. 2013;15(4):198-205.

32. Moore KM, Edgar BL, McGuinness D. Implementation of an automated, real-time public health surveillance system linking emergency departments and health units: rationale and methodology. Canadian Journal of Emergency Medicine. 2008;10(2):114-9.

33. van-Dijk A, Aramini J, Edge G, Moore KM. Real-time surveillance for respiratory disease outbreaks, Ontario, Canada. Emerging Infectious Diseases. 2009;15(5):799-801.

34. Hall G, Krahn T, Majury A, Van Dijk A, Evans G, Moore K, et al. Emergency department surveillance as a proxy for the prediction of circulating respiratory viral disease in Eastern Ontario. Canadian Journal of Infectious Diseases and Medical Microbiology. 2013;24(3):150-4.

35. Caudle JM, Van Dijk A, Rolland E, Moore KM. Telehealth ontario detection of gastrointestinal illness outbreaks. Canadian Journal of Public Health. 2009;100(4):253-7.

36. Rivera LA, Li Y, Savage RD, Crowcroft NS, Bolotin S, Rosella LC, et al. Evaluation of the ability of standardized supports to improve public health response to syndromic surveillance for respiratory diseases in Canada. BMC Public Health. 2017;17(1):199.

37. O'Connor KH, Moore KM, Edgar B, McGuinness D. Maximum Entropy Models in Chief Complaint Classification. Advances in Disease Surveillance 2007;2:23.

38. Moore K, Rimmer M, O'Connor K, McGuinness D, Edgar B. Emergency Syndromic Surveillance: Adapting Real-Time Outbreak and Disease Surveillance (RODS) for Public Health in Canada. Advances in Disease Surveillance 2006;1:50.

39. Moore K, Rimmer M, O'Connor K, McGuinness D, Edgar B. Integration of Hospital Admissions, Febrile Respiratory Illness Screening and Triage Acuity Score into an Emergency Department Syndromic Surveillance System. Advances in Disease Surveillance 2006;1:51.

40. Moore K, Rimmer M, O'Connor K, McGuinness D, Edgar B. Multi-sectored approach to evaluation of a syndromic surveillance system. Advances in Disease Surveillance 2006;1:52.

41. Moore KM, Edgar BL, McGuinness D, O'Connor K. Acute Care Alerting and Integrated Public Health Investigation and Response to Syndromic Surveillance Alerts: Example of a Local Food Borne Outbreak. Advances in Disease Surveillance 2007;2:113.

42. Moore KM, Edgar BL, McGuinness D, O'Connor K. Emergency Department Surveillance of Alcohol-related Violence and Injuries to Enable Event Monitoring and Management. Advances in Disease Surveillance 2007;2:162.

43. Moore KM, Edgar BL, McGuinness D, O'Connor K. Chart review of laboratory-confirmed Salmonella Enteritidis cases in a local food borne outbreak linked to mung bean sprouts. Advances in Disease Surveillance 2007;2:207.

44. Dijk Av, McPherson M, Sambol C, Moore K. Infection Watch Live - A real-time, geospatial mapping tool of hospital triage data for public consumption. Advances in Disease Surveillance 2008;5:194.

45. Moore KM, McGuinness D, Edgar BL, O'Connor K. Early Detection and Integrated Response to Seasonal Influenza. Advances in Disease Surveillance 2007;2:114.

46. Donovan TL, Moore KM, VanDenKerkhof L, McGuinness D, Edgar B. Absenteeism Among Employees in a Southeastern Ontario Hospital: A Novel Application of Syndromic Surveillance. Advances in Disease Surveillance 2007;2:152.

47. Bassil KL, Henry B, Rea E, Varia M, Cole D. Public Health Surveillance for World Youth Day -- Toronto, Canada, 2002. MMWR: Morbidity & Mortality Weekly Report 2005;54:183.

48. Rivera L, Savage R, Crowcroft N, Rosella L, Ye L, Bolotin S, et al. Characterizing Public Health Actions in Response to Syndromic Surveillance Alerts. Online Journal of Public Health Informatics 2016; Vol 8, No 12016;8(1):e34.

49. Chu A, Savage R, Whelan M, Rosella LC, Crowcroft NS, Willison D, et al. Assessing the Relative Timeliness of Ontario's Syndromic Surveillance Systems for Early Detection of the 2009 Influenza H1N1 Pandemic Waves. Canadian Journal of Public Health. 2013;104(4):340-7.

50. Savard N, Bédard L, Allard R, Buckeridge DL. Using age, triage score, and disposition data from emergency department electronic records to improve Influenza-like illness surveillance. Journal of the American Medical Informatics Association: JAMIA. 2015;22(3):688-96.

51. Zhang X, Ding Y, Chen Z, Schable C. Development of an Integrated Surveillance System for Beijing. Advances in Disease Surveillance 2007;2:127.

52. Qian YH, Su J, Shi P, He EQ, Shao J, Sun N, et al. Attempted early detection of influenza A (H1N1) pandemic with surveillance data of influenza-like illness and unexplained pneumonia. Influenza and Other Respiratory Viruses. 2011;5(6):e479-86.

53. Vilain P, Pagès F, Combes X, Marianne Dit Cassou P-J, Mougin-Damour K, Jacques-Antoine Y, et al. Health impact assessment of cyclone bejisa in reunion island (france) using syndromic surveillance. Prehospital and Disaster Medicine. 2015;30(2):137-44.

54. Noel G, Viudes G, Laporte R, Minodier P. Evaluation of the impact of pneumococcal conjugate vaccine on pediatric community-acquired pneumonia using an emergency database system. Journal of the Pediatric Infectious Diseases Society. 2017;6(2):129-33.

55. Josseran L, Nicolau J, Caillere N, Astagneau P, Brucker G. Syndromic surveillance based on emergency department activity and crude mortality: two examples. Euro surveillance. 2006;11(12):225-9.

56. Vilain P, Larrieu S, Mougin-Damour K, Marianne Dit Cassou P-J, Weber M, Combes X, et al. Emergency department syndromic surveillance to investigate the health impact and factors associated with alcohol intoxication in Reunion Island. Emergency Medicine Journal. 2017;34(6):386-90.

57. Josseran L, Fouillet A, Caillère N, Brun-Ney D, Ilef D, Brucker G, et al. Assessment of a syndromic surveillance system based on morbidity data: results from the Oscour network during a heat wave. PLoS ONE. 2010;5(8):e11984.

58. Vandentorren S, Paty AC, Baffert E, Chansard P, Caserio-Schönemann C. Syndromic surveillance during the Paris terrorist attacks. Lancet. 2016;387(10021):846-7.

59. Josseran L, Caillère N, Brun-Ney D, Rottner J, Filleul L, Brucker G, et al. Syndromic surveillance and heat wave morbidity: A pilot study based on emergency departments in France. BMC Medical Informatics and Decision Making. 2009;9(1).

60. Josseran L, Caillère N, Brun-Ney D, Filleul L, Beaujouan L, Ilèf D, et al. Performances of a syndromic surveillance system during a heat wave. Advances in Disease Surveillance 2007;4:253.

61. Josseran L, Caillère N, Brun-Ney D, Rottner J, Ilèf D, Astagneau P. Syndromic Surveillance and Heat Wave: Is it Working? Advances in Disease Surveillance 2007;4:169.

62. Josseran L, Fouillet A, Caillère N, Pascal M, Ilèf D, Astagneau P. Syndromic surveillance and climate change, a possible use? Advances in Disease Surveillance 2008;5:106.

63. Fouillet A, Fournet N, Caillère N, Musset A, Mercier L, Durand C, et al. SurSaUD® Software: A Tool to Support the Data Management, the Analysis and the Dissemination of Results from the French Syndromic Surveillance System. Online Journal of Public Health Informatics 2013; Vol 5, No 12013;5(1):e118.

64. Vilain P, Maillard O, Raslan-Loubatie J, Ahmed Abdou M, Lernout T, Filleul L. Usefulness of Syndromic Surveillance for Early Outbreak Detection in Small Islands: The Case of Mayotte. Online Journal of Public Health Informatics 2013;5(1):e149.

65. Pioche C, Larsen C, Caserio-Schonemann C, Héraud-Bousquet V. Syndromic Surveillance of Acute Liver Failure in Emergency Departments (France, 2010-2012). Online Journal of Public Health Informatics 2014;6(1):e166.

66. Vilain P, Larrieu S, Combes X, Bourdé A, Marianne dit Cassou P-J, Mougin Damour K, et al. Using a Syndromic Approach to Study Health Impact and Risk Factors of Alcohol Intoxication in Reunion Island. Online Journal of Public Health Informatics 2014;6(1):e171.

67. Fouillet A, Bousquet V, Pontais I, Gallay A, Caserio- Schönemann Cl. The French Emergency Department OSCOUR Network: Evaluation After a 10-year Existence. Online Journal of Public Health Informatics 2015; Vol 7, No 12015;7(1):e74.

68. Vilain P, Pagès Fdr, Mougin-Damour K, Combes X, Marianne Dit Cassou P-J, Antoine YJ, et al. Using an Emergency Department Syndromic Surveillance System to Assess the Impact of Cyclone Bejisa, Reunion Island. Online Journal of Public Health Informatics 2015;7(1):e171.

69. Josseran L, Gailhard I, Eboumbou B, Brucker G. Syndromic Surveillance, The First French Experience. Advances in Disease Surveillance 2006;1:37.

70. Burdet S, Fouillet A, Caillere Ng, Brun-Ney D, Desenclos J-C, Josseran Lc. Toward a predictive model of the daily ED visits in Paris area from 2007 to 2010. Emerging Health Threats Journal2011;4:60.

71. Vilain P, Bourde´ A, Cassou P-JMD, Morbidelli P, Jacques-Antoine Y, Ristor B, et al. Integrated approach of nonspecific surveillance in Re´ union Island. Emerging Health Threats Journal2011;4:155.

72. Martin A, Vilain P, Bourdé A, Combes X, Marianne dit Cassou P-J, Jacques-Antoine Y, et al. Usefulness of Syndromic Surveillance during Ultra-endurance Running Races: Example with the “Grand Raid de la Réunion” Ultra Trail. Online Journal of Public Health Informatics 2014;6(1):e79.

73. Caserio-Schönemann Cl, Sanna A, Bousquet V, Medina S, Pascal M, Delmas M-C, et al. Determinants of Daily Attendances in Emergency Departments for Asthma in the Paris Area. Online Journal of Public Health Informatics 2015;7(1):e114.

74. Pontais I, Bousquet V, Ruello M, Caserio-Schönemann Cl, Fouillet A. Factors Influencing the Stability and Quality of the French ED Surveillance System. Online Journal of Public Health Informatics 2016;8(1):e153.

75. Fouillet A, Rosine J, Bousquet V, Cassadou S, Carvalho L, Ledrans M, et al. Chikungunya Epidemic in the French Overseas Territories using Syndromic Surveillance. Online Journal of Public Health Informatics 2015;7(1):e73.

76. Vilain P, Pages F, Henrion G, Combes X, Weber M, Marianne Dit Cassou P-J, et al. Enhanced syndromic surveillance during the 9th Indian Ocean Island Games, 2015. Online Journal of Public Health Informatics 2017;9(1):e167.

77. Fougère E, Caserio-Schönemann C, Daoudi J, Fouillet A, Ruello M, Pontias I, et al. Syndromic surveillance and UEFA Euro 2016 in France – Health impact assessment. Online Journal of Public Health Informatics 2017;9(1):e171.

78. Ruello M, Pelat C, Caserio-Schönemann C, Fouillet A, Bonmarin I, Levy-Brühl D, et al. A regional approach for the influenza surveillance in France. Online Journal of Public Health Informatics 2017;9(1):e89.

79. Vilain P, Larrieu S, Cossin S, Caserio-Schönemann C, Filleul L. Wikipedia: a tool to monitor seasonal diseases trends? Online Journal of Public Health Informatics 2017;9(1):e52.

80. Fouillet A, Ruello M, Leon L, Sommen C, Marie L, Caserio-Schönemann C, et al. User-friendly Rshiny web applications for supporting syndromic surveillance analysis. Online Journal of Public Health Informatics 2017;9(1):e50.

81. Bousquet V, Vernier L, Le Strat Y, Bonmarin I, Leroy C, Raphaël M, et al. Role of Influenza in ED Visits and Hospitalizations of Adults Over 65 Years in France. Online Journal of Public Health Informatics 2016;8(1):e12.

82. Vilain P, Cossin Sb, Filleul L. Interest of Prospective Spatio-Temporal Analysis from ED Data to Detect Unusual Health Events. Online Journal of Public Health Informatics 2016;8(1):e171.

83. Vilain P, Bourde A, Marianne dit Cassou P-J, Jacques-Antoine Y, Morbidelli P, Filleul L. Syndromic Surveillance Based on Emergency Visits: A Reactive Tool for Unusual Events Detection. Online Journal of Public Health Informatics 2013;5(1):e150.

84. Hughes H, Dobney A, Fouillet A, Caserio-Schönemann C, Hughes T, Smith GE, et al. Syndromic surveillance of air pollution incidents across international borders. Online Journal of Public Health Informatics 2017;9(1):e139.

85. Dafni UG, Tsiodras S, Panagiotakos D, Gkolfinopoulou K, Kouvatseas G, Tsourti Z, et al. Algorithm for statistical detection of peaks--syndromic surveillance system for the Athens 2004 Olympic Games. MMWR Morbidity and Mortality Weekly Report 2004;53:86-94.

86. Dafni U, Golfinopoulou K, Tsiodras S, Saroglou G. Planning syndromic surveillance for the Athens 2004 Olympic games: A pilot study. Journal of Urban Health 2003;80(1):i125-i.

87. Ansaldi F, Orsi A, Altomonte F, Bertone G, Parodi V, Carloni R, et al. Syndrome surveillance and molecular epidemiology for early detection and tracing of an outbreak of measles in Liguria, Italy. Journal of Medical Virology. 2009;81(10):1807-13.

88. Ansaldi F, Orsi A, Trucchi C, De Florentiis D, Ceravolo A, Coppelli M, et al. Potential effect of PCV13 introduction on Emergency Department accesses for lower respiratory tract infections in elderly and at risk adults. Human vaccines & immunotherapeutics. 2015;11(1):166-71.

89. Ansaldi F, Orsi A, Altomonte F, Bertone G, Parodi V, Carloni R, et al. Emergency department syndromic surveillance system for early detection of 5 syndromes: a pilot project in a reference teaching hospital in Genoa, Italy. Journal of preventive medicine and hygiene. 2008;49(4):131-5.

90. De Florentiis D, Parodi V, Orsi A, Rossi A, Altomonte F, Canepa P, et al. Impact of influenza during the post-pandemic season: epidemiological picture from syndromic and virological surveillance. Journal of preventive medicine and hygiene. 2011;52(3):134-6.

91. Guasticchi G, Giorgi Rossi P, Lori G, Genio S, Biagetti F, Gabriele S, et al. Syndromic surveillance: Sensitivity and positive predictive value of the case definitions. Epidemiology and Infection. 2009;137(5):662-71.

92. Aung M. Syndromic Surveillance In Major Sporting Event - Jamaican Experience. Advances in Disease Surveillance 2007;4; :144.

93. Ahn S, Lee JH, Kim W, Lim KS. Analysis of the korean emergency department syndromic surveillance system: mass type acute diarrheal syndrome. Healthcare informatics research. 2010;16(3):177-84.

94. Kam HJ, Choi S, Cho JP, Min YG, Park RW. Acute diarrheal syndromic surveillance: effects of weather and holidays. Applied clinical informatics. 2010;1(2):79-95.

95. Cho JP, Kim JS, Yoo IS, Ahn MY, Wang SJ, Hur T, et al. Syndromic surveillance based on the emergency department in Korea. Journal of Urban Health2003;80(1):i124-i5.

96. McLeod M, White P, Read D, Mason K. The 2005 Wellington influenza outbreak: Syndromic surveillance of Wellington Hospital Emergency Department activity may have provided early warning. Australian and New Zealand Journal of Public Health. 2009;33(3):289-94.

97. Hishamuddin P. Evaluation of Syndromic Surveillance Systems in Singapore. Online Journal of Public Health Informatics 2014;6(1):e142.

98. Schrell S, Ziemann A, Garcia-Castrillo Riesgo L, Rosenkötter N, Llorca J, Popa D, et al. Local implementation of a syndromic influenza surveillance system using emergency department data in Santander, Spain. Journal of public health (Oxford, England). 2013;35(3):397-403.

99. Ziemann A, Rosenkötter N, Garcia-Castrillo Riesgo L, Schrell S, Kauhl B, Vergeiner G, et al. A concept for routine emergency-care data-based syndromic surveillance in Europe. Epidemiology and Infection. 2014;142(11):2433-46.

100. Wu T-SJ, Shih F-YF, Yen M-Y, Wu J-SJ, Lu S-W, Chang KC-M, et al. Establishing a nationwide emergency department-based syndromic surveillance system for better public health responses in Taiwan. BMC public health. 2008;8:18.

101. Lo Y-C, Chuang J-H, Kuo H-W, Huang W-T, Hsu Y-F, Liu M-T, et al. Surveillance and vaccine effectiveness of an influenza epidemic predominated by vaccine-mismatched influenza B/Yamagata-lineage viruses in Taiwan, 2011-12 season. PLoS ONE. 2013;8(3):e58222.

102. Chang C, Chan T-C, Lai Y-M, Fang C-C, Shih F-Y, Yen M-Y, et al. Establishment of public-access syndromic surveillance system in Taipei City, Taiwan. Emerging Health Threats Journal2011;4:24.

103. King C-C, Shih F-Y, Yen M-Y, Hu F-C, Wu J-S, Chang F-K, et al. Syndromic Surveillance of Infectious Diseases in Taiwan — Before and After the Challenges of Severe Acute Respiratory Syndrome (SARS). MMWR: Morbidity & Mortality Weekly Report 2004;53:245.

104. Hsiao C-Y, Wu T-SJ, Shih F-YF, Yen M-Y, Tipayamongkholgul M, Pan M-L, et al. Establishing a Syndromic Surveillance System Using Chief-Complaint Data at Emergency Department of One Regional Hospital in Taipei City to Detect Infectious Disease Outbreaks. Advances in Disease Surveillance 2007;2:107.

105. King C-C, Wu T-S, Hsiao C-Y, Shih F-YF, Yen M-Y, Liu D-M, et al. Comparison of Chief-Complaint vs ICD-9 Data Used in an Emergency Departmentbased Hospital Syndromic Surveillance System in Metropolitan Taipei, Taiwan. Advances in Disease Surveillance 2007;2:202.

106. King C-C, Wu T-SJ, Yen M-Y, Huang C, Hsiao J-Y, Kao C-L, et al. INTEGRATED SYNDROMIC AND VIROLOGIC SURVEILLANCE SYSTEMS FROM TAIWAN'S EXPERIENCES IN FACING GLOBAL CHALLENGES OF EMERGING INFECTIOUS DISEASES Advances in Disease Surveillance 2008;5:109.

107. Elliot AJ, Smith S, Dobney A, Thornes J, Smith GE, Vardoulakis S. Monitoring the effect of air pollution episodes on health care consultations and ambulance call-outs in England during March/April 2014: a retrospective observational analysis. Environmental Pollution. 2016;214:903-11.

108. Hughes HE, Morbey R, Hughes TC, Locker TE, Pebody R, Green HK, et al. Emergency department syndromic surveillance providing early warning of seasonal respiratory activity in England. Epidemiology and Infection. 2016;144(5):1052-64.

109. Smith S, Elliot AJ, Hajat S, Bone A, Smith GE, Kovats S. Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance. Journal of Epidemiology & Community Health. 2016;70(5):459-65.

110. Todkill D, Hughes HE, Elliot AJ, Morbey RA, Edeghere O, Harcourt S, et al. An observational study using English syndromic surveillance data collected during the 2012 London Olympics - what did syndromic surveillance show and what can we learn for future mass-gathering events? Prehospital and Disaster Medicine. 2016;31(6):628-34.

111. Smith S, Elliot AJ, Hajat S, Bone A, Bates C, Smith GE, et al. The impact of heatwaves on community morbidity and healthcare usage: a retrospective observational study using real-time syndromic surveillance. International Journal of Environmental Research and Public Health. 2016;13(1):132-.

112. Bawa Z, Elliot AJ, Morbey RA, Ladhani S, Cunliffe NA, O'Brien SJ, et al. Assessing the likely impact of a rotavirus vaccination program in England: the contribution of syndromic surveillance. Clinical Infectious Diseases. 2015;61(1):77-85.

113. Morbey RA, Elliot AJ, Charlett A, Ibbotson S, Verlander NQ, Leach S, et al. Using public health scenarios to predict the utility of a national syndromic surveillance programme during the 2012 London Olympic and Paralympic Games. Epidemiology and Infection. 2014;142(5):984-93.

114. Hughes HE, Morbey R, Hughes TC, Locker TE, Shannon T, Carmichael C, et al. Using an Emergency Department Syndromic Surveillance System to investigate the impact of extreme cold weather events. Public Health. 2014;128(7):628-35.

115. Hughes HE, Hughes TC, Haile A, Smith GE, McCloskey B, Elliot AJ. Syndromic Surveillance Revolution? Public Health Benefits of Modernizing the Emergency Care Patient Health Record in England. Public Health Reports. 2017;132(1).

116. Elliot AJ, Hughes HE, Hughes TC, Locker TE, Brown R, Sarran C, et al. The impact of thunderstorm asthma on emergency department attendances across London during July 2013. Emergency Medicine Journal. 2014;31(8):675-8.

117. Elliot AJ, Morbey R, Edeghere O, Lake IR, Colón-González FJ, Vivancos R, et al. Developing a Multidisciplinary Syndromic Surveillance Academic Research Program in the United Kingdom: Benefits for Public Health Surveillance. Public Health Reports. 2017;132(1).

118. Elliot AJ, Hughes HE, Hughes TC, Locker TE, Shannon T, Heyworth J, et al. Establishing an emergency department syndromic surveillance system to support the London 2012 Olympic and Paralympic Games. Emergency medicine journal : EMJ. 2012;29(12):954-60.

119. Newitt S, Elliot AJ, Morbey R, Durnall H, Pietzsch ME, Medlock JM, et al. The use of syndromic surveillance to monitor the incidence of arthropod bites requiring healthcare in England, 2000-2013: a retrospective ecological study. Epidemiology and infection. 2016;144(11):2251-9.

120. Thomas SL, Walker JL, Fenty J, Atkins KE, Elliot AJ, Hughes HE, et al. Impact of the national rotavirus vaccination programme on acute gastroenteritis in England and associated costs averted. Vaccine. 2017;35(4):680-6.

121. Severi E, Heinsbroek E, Watson C, Catchpole M. Infectious disease surveillance for the London 2012 Olympic and Paralympic Games. Eurosurveillance. 2012;17(31).

122. Morbey R, Elliot AJ, Zambon M, Pebody R, Smith GE. Interpreting specific and general respiratory indicators in syndromic surveillance. Online Journal of Public Health Informatics 2017;9(1):e19.

123. Hughes H, Morbey R, Hughes T, Locker T, Smith G, Elliot A. Syndromic Surveillance of Respiratory Pathogens using Routine ED Data in England. Online Journal of Public Health Informatics 2015;7(1):e81.

124. Kass-Hout TA, Xu Z, McMurray P, Park S, Buckeridge DL, Brownstein JS, et al. Application of change point analysis to daily influenza-like illness emergency department visits. Journal of the American Medical Informatics Association. 2012;19(6):1075-81.

125. Olson DR, Paladini M, Buehler JW, Mostashari F, group tDW. Review of the ISDS Distributed Surveillance Taskforce for Real-time Influenza Burden Tracking & Evaluation (DiSTRIBuTE) Project 2007/08 Influenza Season Proof-of-concept Phase Advances in Disease Surveillance 2008;5:185.

126. Paladinia M, Pendarvisb J, Murraya EL, Gunnb J, Olson D. A Comparison of Locally Developed Influenza-like Syndrome Definitions Using Electronic Emergency Department Data in Boston and New York City Advances in Disease Surveillance 2008;5:50.

127. Painter I, Eaton J, Lober B. Using Change Point Detection for Monitoring the Quality of Aggregate Data. Online Journal of Public Health Informatics 2013;5(1):e186.

128. Olson D, Baer A, Paladini M, Burkom H, Group IDW. Adopting a common influenza-like illness syndrome across multiple health jurisdictions. Emerging Health Threats Journal2011;4:110.

129. Olson D, Painter I, Group IDW. Monitoring winter-seasonal acute gastroenteritis emergency department visits by age. Emerging Health Threats Journal2011;4:111.

130. Painter I, Eaton J, Olson D, Revere D, Lober W. How good is your data? Emerging Health Threats Journal2011;4:114.

131. Painter I, Eaton J, Olson D, Lober W, Revere D. Visualizing data quality: tools and views. Emerging Health Threats Journal2011;4:115.

132. Olson D, Baer A, Paladini M, Burkom H, Revere D, Painter I, et al. Evaluating a standard influenza-like illness syndrome definition across multiple sites in the distribute project: The 'ILI-s' Pilot. Emerging Health Threats Journal2011;4(1):s48.

133. Kniss K, Benoit S, McIntyre A, Buckeridge D, Brownstein J, Brammer L, et al. Comparison of Distribute and ILINet for national influenza surveillance. Emerging Health Threats Journal2011;4(1):s135.

134. White JR, Berisha V, Lane K, Ménager H, Gettel A, Braun CR, et al. Evaluation of a Novel Syndromic Surveillance Query for Heat-Related Illness Using Hospital Data From Maricopa County, Arizona, 2015. Public health reports. 2017;132(1).

135. Coates RJ, Pérez A, Baer A, Zhou H, English R, Coletta M, et al. National and Regional Representativeness of Hospital Emergency Department Visit Data in the National Syndromic Surveillance Program, United States, 2014. Disaster medicine and public health preparedness. 2016;10(4):562-9.

136. Wiedeman C, Shaffner J, Squires K, Leegon J, Murphree R, Petersen PE. Monitoring Out-of-State Patients During a Hurricane Response Using Syndromic Surveillance -- Tennessee, 2017. MMWR: Morbidity & Mortality Weekly Report 2017;66(49):1364-5.

137. Gould DW, Walker D, Yoon PW. The Evolution of BioSense: Lessons Learned and Future Directions. Public Health Reports. 2017;132(1).

138. DeYoung K, Chen Y, Beum R, Askenazi M, Zimmerman C, Davidson AJ. Validation of a Syndromic Case Definition for Detecting Emergency Department Visits Potentially Related to Marijuana. Public health reports. 2017;132(4):471-9.

139. Ayala A, Berisha V, Goodin K, Pogreba-Brown K, Levy C, McKinney B, et al. Public health surveillance strategies for mass gatherings: Super Bowl XLIX and related events, Maricopa County, Arizona, 2015. Health Security. 2016;14(3):173-84.

140. Xing J, Burkom H, Tokars J. Method selection and adaptation for distributed monitoring of infectious diseases for syndromic surveillance. Journal of Biomedical Informatics. 2011;44(6):1093-101.

141. Kass-Hout TA, Buckeridge D, Brownstein J, Xu Z, McMurray P, Ishikawa CKT, et al. Self-reported fever and measured temperature in emergency department records used for syndromic surveillance. Journal of the American Medical Informatics Association. 2012;19(5):775-6.

142. Rezny S, Hoferka S. An R Script for Assessment of Data Quality in the BioSense Locker Database. Online Journal of Public Health Informatics 2016;8(1):e156.

143. Thoburn KK, Miller JR, Tokars JI, Bradley C, Zomer D. The New York State BioSense Sentinel Alert Experience. Advances in Disease Surveillance 2006;1:68.

144. Dey AN, Ma H, Asatryan A, English R, Tokars J. Identifying Fractures in BioSense Radiology Reports Advances in Disease Surveillance 2007;4:159.

145. Lipskiy N, Tokars JI, Copeland J, English R, Patel N. Visits with Nontyphoidal Salmonella Infections Reported to the BioSense System, 2006-2007. Advances in Disease Surveillance 2007;4:173.

146. Martin C, Tokars J, Fowlkes A, Panozzo C. Use of Final Diagnosis Data for Surveillance of Respiratory Syncytial Virus Advances in Disease Surveillance 2007;4:176.

147. Martin CA, Tokars J, Ma H. ICD-9 CM Based Sub-Syndrome Distributions in BioSense Hospital Data. Advances in Disease Surveillance 2007;2:110.

148. Podgornik MN, English R, Tokars JI. Correlation between Real-Time BioSense Influenza Indicators and Data from the U.S. Influenza Sentinel Physicians Surveillance Network Advances in Disease Surveillance 2007;4:109.

149. Rainisch G, Martin C, Tokars J. The Use of BioSense Data for Surveillance of Gastrointestinal Illness. Advances in Disease Surveillance 2007;4:185.

150. Dey AN, Hicks P, Tokars JI. Identifying Clusters of Falls During the 2007-08 Winter Season in the BioSense System. Advances in Disease Surveillance 2008;5:101.

151. Hales C, English R, McMurray P, Tokars J. The BioSense Influenza Module Advances in Disease Surveillance 2008;5:36.

152. Lei WE, Benoit S, Rainisch G, Tokars J. Burns Reported to the BioSense System During the Independence Day Holiday. Advances in Disease Surveillance 2008;5:111.

153. Minor P, English R, Tokars J. Representativeness of Emergency Department Data Reported to the BioSense System. Advances in Disease Surveillance 2008;5:182.

154. Mohammed S, Phillips K, Rainisch G, Minor P, Tokars J. Automated Monitoring of Asthma Using the BioSense System. Advances in Disease Surveillance 2008;5:119.

155. Phillips K, Rainisch G, Tokars J. Automated Monitoring of Exposures Using the BioSense System Advances in Disease Surveillance 2008;5:188.

156. Xing J, Burkom H, Tokars J. Comparison of Regression Models with Modified Time Series Methods for BioSurveillance. Advances in Disease Surveillance 2008;5:72.

157. Arboleda N, Tokars J, English R, McMurray P. BioSense Real-Time Data Initiative: Improving Emergency Preparedness - Monitoring Injury sub-syndromes. Advances in Disease Surveillance 2007;4:142.

158. Martin C, Tokars J, Rainisch G, Burkholder J, Crosby K. Criteria for Prioritizing Statisitical Anomalies Identified in BioSense. Advances in Disease Surveillance 2007;4:174.

159. Hicks P, Edwards A, English R, Tokars JI. BioSense Participation by Non-Federal Hospitals. Advances in Disease Surveillance 2008;5:38.

160. Dey A, Park S, Miller M, Akaka L, McMurray P, Hicks P, et al. Postdisaster surveillance following the Tsunami in Japan: BioSense 2011. Emerging Health Threats Journal2011;4:41.

161. McIntyre A, Finelli L, Burkom H, Benoit S, Kniss K, Kass-Hout T. Quantifying the relationship between influenza-related emergency department visits and hospital admissions in BioSense. Emerging Health Threats Journal2011;4(1):s99.

162. Dey AN, Grigoryan A, Park S, Benoit S, Kass-Hout T. Mental Illness and Co-morbid Conditions: BioSense 2008 - 2011. Online Journal of Public Health Informatics 2013;5(1):e59.

163. Burrer S, Burkom H, Okunseri C, Barker L, Robison V. Nontraumatic Oral Health Classification for Alternative Use of Syndromic Data. Online Journal of Public Health Informatics 2013;5(1):e58.

164. Baber J, Feist M. Utility of Outpatient Syndromic Data for Monitoring Influenza-like Illness. Online Journal of Public Health Informatics 2017;9(1):e51.

165. Baber J, Miller T. Using Sydromic Surveillance to Track E-cigarette Related Emergency Department Visits. Online Journal of Public Health Informatics 2017;9(1):e144.

166. Burke A, Jackson D, Nakashima AK. An Evaluation of the Biosense 2.0 “Poisoning by Medicines” Syndrome Using Chief-Complaint Data in Utah. Online Journal of Public Health Informatics 2015;7(1):e10.

167. Burke A, Jackson D, Nakashima AK. An Ecological Analysis of the Impact of Temperature Inversion on Emergency Department Visits for Respiratory Syndromes and Subsyndromes using BioSense 2.0 Frontend Data. Online Journal of Public Health Informatics 2015;7(1):e9.

168. Yun LW, Beum R, Askenazi M, Chen Y, McEwen D, Maravi M, et al. Using Emergency Department Data for Detection of a Synthetic Marijuana Outbreak. Online Journal of Public Health Informatics 2015;7(1):e178.

169. Yoon P, Coletta M. Update on the CDC National Syndromic Surveillance Program. Online Journal of Public Health Informatics 2016;8(1):e183.

170. Stein ZM. Creation of a Kansas Spring Extreme Weather Syndrome Definition and Unique Records. Online Journal of Public Health Informatics 2017;9(1):e128.

171. Bova M, Ergas R. Early effect of validation efforts of Massachusetts syndromic surveillance data. Online Journal of Public Health Informatics 2017;9(1):e35.

172. DeYoung KH, Beum R, Chen Y, Maravi M, Yun LW, Askenazi M, et al. Evaluation of Case Detection of Marijuana-Related Emergency Department Visits. Online Journal of Public Health Informatics 2016;8(1):e17.

173. Anderson TC, Yusuf H, McCarthy A, Trivers K, Hicks P, Coletta M, et al. Administrative and syndromic surveillance data can enhance public health surveillance. Online Journal of Public Health Informatics 2017;9(1):e165.

174. Betancourt JA, Hakre S, Polyak CS, Pavlin JA. Evaluation of ICD-9 codes for syndromic surveillance in the Electronic Surveillance System for the Early Notification of Community-based Epidemics. Military Medicine. 2007;172(4):346-52.

175. Pattie DC, Atherton MJ, Savory DJ, Savage GE, Cox KL. ESSENCE Version 2.0: The Department of Defense's Worldwide Syndromic Surveillance System Receives Several Enhancements. Advances in Disease Surveillance 2008;5:51.

176. Lucero C, Schirmer P, Oda G, Holodniy M. Surveillance for nationally notifiable infectious conditions using ICD-9-CM diagnosis codes in the VA ESSENCE biosurveillance system. Emerging Health Threats Journal 2011;4(1):s97.

177. Rangel M, Martinello R, Lucero C, Oda G, Holodniy M, Peterson M, et al. Adapting a syndromic biosurveillance system to monitor veterans' health impact associated with the gulf coast oil spill. Emerging Health Threats Journal 2011;4(1):s138.

178. Oda G, Ryono R, Lucero-Obusan CA, Schirmer P, Holodniy M. Carbon Monoxide Poisoning in the Veterans Health Administration, 2010 - 2016. Online Journal of Public Health Informatics 2017; Vol 9, No 12017;9(1):e126.

179. Fleischauer AT, Silk BJ, Schumacher M, Komatsu K, Santana S, Vaz V, et al. The validity of chief complaint and discharge diagnosis in emergency department-based syndromic surveillance. Academic Emergency Medicine. 2004;11(12):1262-7.

180. Fleischauer AT, Silk B, Schumacher M, Komatsu K, Santana S, Vaz V, et al. Evaluation and Validity of Chief Complaints and Discharge Diagnoses in a Drop-In Syndromic Surveillance System. MMWR: Morbidity & Mortality Weekly Report 2004;53:238.

181. Arboleda N, Fleischauer AT, Sejvar J, Diggs A, Schumacher M, Santana S, et al. An Emergency Department Based Syndromic Surveillance System for Meningitis and Encephalitis, Maricopa County, AZ 2004. Advances in Disease Surveillance 2006;1:4.

182. Schumacher M, Nohre L, Santana S. Partial evaluation of a drop-in bioterrorism surveillance system in phoenix, Arizona. Journal of Urban Health 2003;80(1):i118-i.

183. Kajita E, Luarca MZ, Wu H, Hwang B, Mascola L. Harnessing Syndromic Surveillance Emergency Department Data to Monitor Health Impacts During the 2015 Special Olympics World Games. Public Health Reports. 2017;132(1):99s-105s.

184. Belden J, Araki P, Croker C, Sharip A, Velikina R, Hwang B, et al. Syndromic Surveillance Signal Investigation in Los Angeles County. Advances in Disease Surveillance 2006;1:5.

185. Croker C, Sharip A, Villacorte F, Tormey M, Kim M, Hwang B, et al. Evaluating the Effectiveness of Using Syndromic Surveillance to Identify a Neuro-Invasive Disease Outbreak in Los Angeles County Advances in Disease Surveillance 2006;1:18.

186. Kajita E, Sharip A, Araki P, Hwang B. Emergency Department Syndromic Surveillance and Population-Based Health Monitoring in Los Angeles County. Advances in Disease Surveillance 2007;4:170.

187. Sharip A, Hwang B, Wu H, Yee D, Toyota C, Croker C, et al. Automated Syndromic Surveillance System in Los Angeles County Advances in Disease Surveillance 2007;2:27.

188. Sharip A, Kajita E, Jones M, Hwang B. Health Effects of LA County Wildfires in October 2007 Advances in Disease Surveillance 2008;5:129.

189. Kajita E, Araki P, Luarca M, Hwang B. Monitoring the Impact of Heat Waves with Emergency Service Utilization Data in Los Angeles County. Online Journal of Public Health Informatics 2013;5(1):3153.

190. Oyong K, Kajita E, Araki P, Luarca M, Hwang B. Validation of Los Angeles County Department of Public Health Respiratory Syndrome using Electronic Health Records. Online Journal of Public Health Informatics 2014;6(1):e81.

191. Araki P, Kajita E, Oyong K, Luarca MZ, Hwang B, Mascola L. A Comparison of Fever Classified Chief Complaints and Diagnoses with Recorded Body Temperatures. Online Journal of Public Health Informatics 2015;7(1):e105.

192. Kajita E, Luarca MZ, Chiang C, Wu H, Hwang B. Syndromic Surveillance of Emergency Department Visits for the 2015 Special Olympics. Online Journal of Public Health Informatics 2016;8(1):e129.

193. Sharip A, Monroe J, Croker C, Kim M, Hwang B, Aller R, et al. Preliminary Analysis of SaTScan's Effectiveness to Detect Known Disease Outbreaks Using Emergency Department Syndromic Data in Los Angeles County. Advances in Disease Surveillance 2006;1:83.

194. Luarca M, Kajita E, Faustino C, Jones M, Hwang B. Using syndromic surveillance to assist in a meningitis outbreak investigation. Emerging Health Threats Journal 2011;4:78.

195. Viola R, Luarca MZ, Kajita E, Lim M, Hwang B. Monitoring the 2016 LA County Sand Fire with Multiple Early Detection Systems. Online Journal of Public Health Informatics 2017;9(1):e135.

196. Bravata DM, Rahman MM, Luong N, Divan HA, Cody SH. A comparison of syndromic incidence data collected by triage nurses in Sata Clara county with regional infectious disease data. Journal of Urban Health 2003;80(1):i122-i.

197. Thelen B, French NH, Koziol BW, Billmire M, Owen RC, Johnson J, et al. Modeling acute respiratory illness during the 2007 San Diego wildland fires using a coupled emissions-transport system and generalized additive modeling. Environmental Health: A Global Access Science Source. 2013;12(1).

198. Johnson JM, Hicks L, McClean C, Ginsberg M. Leveraging Syndromic Surveillance During the San Diego Wildfires, 2003. MMWR: Morbidity & Mortality Weekly Report 2005;54:190.

199. McClean C, Johnson J, Colanter B, Ginsberg M. Too Many Signals? Frequency and Quantitative Descriptions of Detected Events. Advances in Disease Surveillance 2006;1:49.

200. Colanter BH, Johnson JM, Maroufi A, Ginsberg MM, Nelson JA. Using Syndromic Surveillance Data for Enhanced Case-Capture of Conditions of Public Health Interest. Advances in Disease Surveillance 2007;4:155.

201. Johnson J, Ginsberg M, French N, Thelen B, Koziol B. Use of Syndromic Surveillance Information for Expanded Assessment of Wildfire Disaster. Online Journal of Public Health Informatics 2013;5(1):e95.

202. Johnson J, McClean C, Poggemeyer K, Ginsberg M. Application of bioterrorism surveillance methods in San Diego County. Journal of Urban Health 2003;80(1):i137.

203. Chen Y, Askenazi M, DeYoung KH, Albanese B, Yun LW, Hockenberry T. ED Visits Related to Marijuana Exposures in the Denver Metropolitan Area of Colorado. Online Journal of Public Health Informatics 2016;8(1):e99.

204. Foldy SL, Barthell E, Silva J, Biedrzycki P, Howe D, Erme M, et al. SARS Surveillance Project -- Internet-Enabled Multiregion Surveillance for Rapidly Emerging Disease. MMWR: Morbidity & Mortality Weekly Report 2004;53:215-20.

205. Dembek ZF, Carley K, Hadler J. Guidelines for Constructing a Statewide Hospital Syndromic Surveillance Network. MMWR: Morbidity & Mortality Weekly Report 2005;54:21-4.

206. Purviance KM, Siniscalchi AJ, Hadler JL. Surveillance for Influenza Using the Emergency Department Syndromic Surveillance and Hospital Admissions Syndromic Surveillance Systems, Connecticut, 2004-2007. Advances in Disease Surveillance 2007;4:184.

207. Purviance KM, Siniscalchi AJ, Hadler JL. Use of the Connecticut Emergency Department Syndromic Surveillance System for Situational Awareness During Public Health Events. Advances in Disease Surveillance 2008;5:125.

208. Soto K, Krasnitski J, Rabatsky-Ehr T, Cartter M. When it Rains it Pours: Real-time Situational Awareness for Two Weather Emergencies in Connecticut. Online Journal of Public Health Informatics 2013;5(1):e97.

209. Soto K, Krasnitski J, Phan Q, Rabatsky-Ehr T, Cartter M. Evaluation of the Connecticut hospital emergency department syndromic surveillance system for monitoring of community gastrointestinal illness. Emerging Health Threats Journal 2011;4:142.

210. Desy K, Purviance K, Cartter M, Hadler J. Relationship between neighborhood poverty and emergency department utilization for fever/flu syndrome. Emerging Health Threats Journal 2011;4(1):s75.

211. Purviance K, Brockmeyer J, Krasnitski J, Siniscalchi A, Cartter M, Hadler J. Experience Using Syndromic Surveillance Systems During the Novel H1N1 Influenza Outbreak, Connecticut, 2009. ISDS; Miami, Fl 2009.

212. Siniscalchi AJ, Andrews MT, Purviance KM, Esponda BL, Brennan T, Nelson RS, et al. Yes We Can! Use of Multiple Syndromic Surveillance Systems for Detection of Post Inauguration and Late Season Influenza Events. ISDS; Miami, Fl 2009.

213. Klekamp BG, Bodager D, Matthews SD. Use of Surveillance Systems in Detection of a Ciguatera Fish Poisoning Outbreak - Orange County, Florida, 2014. MMWR: Morbidity & Mortality Weekly Report. 2015;64(40):1142-4.

214. Hopkins RS, Kite-Powell A, Goodin K, Hamilton JJ. The Ratio of Emergency Department Visits for ILI to Seroprevalence of 2009 Pandemic Influenza A (H1N1) Virus Infection, Florida, 2009. PLoS Currents. 2014;6.

215. Kite-Powell A, Ball LB, Hopkins RS. Use of Syndromic Surveillance of Emergency Room Chief Complaints for Enhanced Situational Awareness during Wildfires, Florida, 2008. Advances in Disease Surveillance 2008;5:110.

216. Thomas MC, Atrubin D, Hamilton J. Assessing Best Practices for Grouping and Analyzing Urgent Care Center (UCC) and Emergency Department (ED) Data Sources within Syndromic Surveillance Systems. Online Journal of Public Health Informatics 2014;6(1):e122.

217. Wiese M, Atrubin D, McDougle W, Lewis J. Effectiveness of Using a Chief Complaint and Discharge Diagnosis Query in ESSENCE-FL to Identify Possible Tuberculosis Patients and Contacts in Hillsborough County, Florida. Online Journal of Public Health Informatics 2014;6(1):e36.

218. Rubino H, Atrubin D, Hamilton JJ. Monitoring Respiratory Syncytial Virus Regionally In Children Aged < 5 Years Old Using Emergency Department and Urgent Care Center Chief

Complaint Data in Florida's Syndromic Surveillance System, Week 1, 2010 - Week 32, 2014. Online Journal of Public Health Informatics 2015;7(1):e50.

219. Atrubin D, Bowden S, Hamilton JJ. Using Syndromic Surveillance to Rapidly Describe the Early Epidemiology of Flakka Use in Florida, June 2014 – August 2015. Online Journal of Public Health Informatics 2016;8(1):e20.

220. Culpepper AB, Atrubin D, Hamilton JJ, Cui D. Day of Week Analysis of Myocardial Infarctions Using ESSENCE-FL Emergency Department Data. Online Journal of Public Health Informatics 2016;8(1):e57.

221. Azarian T, Kite-Powell A, Zaheer S. Syndrome evaluation of individuals reporting emergency department utilization for notifiable disease and conditions. Emerging Health Threats Journal 2011;4(1):s63.

222. Kite-Powell A, Hamilton J, Wojcik R, Loschen W, Hopkins R. Florida's ESSENCE systemFfrom syndromic surveillance to routine epidemiologic analysis across syndromic and non-syndromic data sources. Emerging Health Threats Journal 2011;4(1):s89.

223. Kite-Powell A, Hamilton J, Eisenstein L, Hopkins R. Public health surveillance after the Haiti earthquake: the Florida experience. Emerging Health Threats Journal 2011;4(1):s33.

224. Mulay P, Watkins S, Blackmore C. Utilization of Florida poison control data and Emergency Department chief complaint data to identify clusters of carbon monoxide poisoning. Emerging Health Threats Journal 2011;4(1):s41.

225. Thomas MC, Atrubin D, Hamilton JJ. Impact of Patient Self-Registration in Emergency Departments on Syndromic Surveillance Data. Online Journal of Public Health Informatics 2015;7(1):e93.

226. Munroe J, Straver R, Rubino H, Pritchard S, Atrubin D, Hamilton JJ. MERS PUI Surveillance and Restrospective Identification in ESSENCE-FL, 2013-2015. Online Journal of Public Health Informatics 2017;9(1):e113.

227. Clark CR, Wiese M. Analysis of Daily Enhanced Syndromic Surveillance in Hillsborough County, FL, 2015. Online Journal of Public Health Informatics 2017;9(1):e93.

228. Culpepper AB, Atrubin D, Hamilton JJ. The Evaluation of Triage Notes Using ESSENCE-FL for Active Case Finding of Zika. Online Journal of Public Health Informatics 2017;9(1):e23.

229. Atrubin D. Using ESSENCE-FL for Situational Awareness after National Reports of Increased Enterovirus D68 (EV-D68) Infections with Severe Outcomes, September 2014. Online Journal of Public Health Informatics 2015;7(1):e107.

230. Eisenstein L, Kite-Powell A, Hamilton J, Azarian T. Syndromic Surveillance of Pregnancy and Influenza-Like Illness from Emergency Department Chief Complaints during Pandemic H1N1 Influenza Compared to Seasonal Influenza, Florida 2008-2009. ISDS; Miami, Fl 2009.

231. Kite-Powell A, Livengood J. Use of Syndromic Surveillance during a South Florida Mass Migration Exercise, Broward County, 2007. Advances in Disease Surveillance 2007;4:171.

232. Kite-Powell A, Livengood J. Syndromic Surveillance of Emergency Department Chief Complaints postHurricane Wilma, Broward County, Florida 2005 Advances in Disease Surveillance 2007;2:157.

233. Sniegoski C, Loschen W, Dearth S, Gibson J, Lombardo J, Wade M, et al. Super Bowl Surveillance: A Practical Exercise in Inter-Jurisdictional Public Health Information Sharing. Advances in Disease Surveillance 2007;4:195.

234. Azarian T, Zaheer S, Winn S, Rios L. BioDefend™ Syndromic Surveillance System Influenza Activity Detection. Advances in Disease Surveillance 2007;4:231.

235. Azarian T, Zaheer S, Winn S, Kite-Powell A. Comparison of Influenza-like Illness Syndrome Classification Between Two Syndromic Surveillance Systems. Advances in Disease Surveillance 2008;5:1.

236. Winn SK, Isaac T, Harmon RG. A County Health Department's Analysis and Dissemination Algorithm of a Neurological Syndrome Aberration to Respective Community Stakeholders. Advances in Disease Surveillance 2008;5:137.

237. Zaheer S, Winn S, Perry J, Minden V. Implementation of the BioDefend Syndromic Surveillance System: Electronic Format versus Web-Based Data Entry. Advances in Disease Surveillance 2007;2:30.

238. Azarian T, Kite-Powell A, Zaheer S. Improvement of epidemiology business processes through the evolution of biosurveillance. Emerging Health Threats Journal 2011;4:9.

239. Richardson D, Paladini M, Azarian T, Baer A, Rennick M, Weiss D. Increased emergency department presentations for head trauma following media coverage of a fatal epidural hematoma. Emerging Health Threats Journal 2011;4(1):s51.

240. Kintz J, Gregos E, Atrubin D, Sanchez J. Syndromic Tracking and Reporting System — Overview and Example. MMWR: Morbidity & Mortality Weekly Report 2004;53:246.

241. Zhu Y, Wang W, Atribun D, Carrubba C, Kintz J, Elliot G. A Syndrome Track and Reporting System in Hillsborough County Florida: Findings from a Systematic Evaluation. Advances in Disease Surveillance 2007;2:221.

242. Borroto-Ponce R, Zhang G, Leguen F, Sneed R, Micieli C. Catchment Area of Miami Children's Hospital Emergency Room - Implications for Syndromic Surveillance in Miami-Dade County. Advances in Disease Surveillance 2007;2:194.

243. Micieli C, Sneed R, Erin OC, Borroto-Ponce R, Zhang G. Dual monitoring of ILI syndrome using the ESSENCE system. Advances in Disease Surveillance 2007;2:160.

244. Micieli C, Sneed R, O'Connell E, Borroto-Ponce R, Zhang G, Leguen F. Utility of the ESSENCE system for surveillance of Influenza-like Illness (ILI) in Miami-Dade County. Advances in Disease Surveillance 2007;2:112.

245. O'Connell E, Leguen F, Zhang G, Micieli C, Sneed R, Ponce-Borroto R. Comparison of ICD-9-Coded Chief Complaints and Diagnoses for Identifying Gastrointestinal Syndrome Using ESSENCE. Advances in Disease Surveillance 2007;2:210.

246. Zhang G, O'Connell E, Bustamante M, Rodriguez D, Borroto-Ponce R, Leguen F. Comparison of 2005-2007 Influenza-Like Illness Observed From Emergency Department Visits in Miami-Dade County. Advances in Disease Surveillance 2007;4:272.

247. Zhang G, O'Connell E, Leguen F, Bustamante M, Rodriguez D, Borroto-Ponce R. Use of Epidemiological Knowledge to Create Syndromic Surveillance Reports. Advances in Disease Surveillance 2007;4:211.

248. Zhang G, Sneed R, Leguen F, Cutié LA, Micieli C, Borroto-Ponce R, et al. Use of Syndromic Data for Surveillance of Hurricane-Related Injuries in Miami-Dade County, FL. Advances in Disease Surveillance 2007;2:174.

249. Borroto R, Zhang G. Socio-demographic and temporal patterns of Emergency Department patients who do not reside in Miami-Dade County, 2007. Advances in Disease Surveillance 2008;5:5.

250. O'Connell E, Zhang G, Llau A. Substance Abuse Among Youth in Miami-Dade County, 2005-2007. Advances in Disease Surveillance 2008;5:184.

251. Zhang G, Llau A, Suarez J, O'Connell E, Rico E, Borroto-Ponce R, et al. Using ESSENCE to Track a Gastrointestinal Outbreak in a Homeless Shelter in Miami-Dade County, 2008. Advances in Disease Surveillance 2008;5:139.

252. Rodriguez D, Zhang G, Leguen F, O'Connell E, Bustamante M. Using Public School Absentee Data to Enhance Snydromic Surveillance in Miami-Dade County, 2007. Advances in Disease Surveillance 2007;4:188.

253. O'Connell E, Zhang G, Llau A, Leguen F. Innovative Uses for ESSENCE to Improve Standard Communicable Disease Reporting Practices in Miami-Dade County. Advances in Disease Surveillance 2008;5:122.

254. Borroto R, Suarez J. Emergency Department patients with gastrointestinal symptoms during Federal holidays, Miami-Dade 2007 2010. Emerging Health Threats Journal 2011;4:13.

255. Borroto R, Suarez J, Rico E, O'Connell E, Llau A, Londono L, et al. Tracking emergency department (ED) patients with gastrointestinal symptoms during a Norovirus epidemic in Miami-Dade. Emerging Health Threats Journal 2011;4(1):s121.

256. Borroto R, Zhang G. Using ESSENCE to Identify a Seasonal Pattern of Gastrointestinal Syndrome in Miami-Dade. ISDS; Miami, Fl 2009.

257. Londoño L, O'Connell E, Zhang G, Leguen F. Utility of the Exposure Syndrome in ESSENCE. ISDS; Miami, Fl2009.

258. Cookson ST, Buehler JW, Lance SE. Georgia's Strategy for Targeting Syndromic Surveillance. Advances in Disease Surveillance 2006;1:16.

259. Cameron W, Neu AL, Murray EL, Soetebier K, Cookson ST. Responding to Syndromic Surveillance Alerts: An Adaptable Protocol for Georgia Health Districts. Advances in Disease Surveillance 2007;2:95.

260. Finton RJ, Kolhe P, Katkowski SR, Cameron W, Murray EL. Event Detection in a Vulnerable Population. Advances in Disease Surveillance 2007;4:162.

261. Murray EL, Soetebier K, Cameron W. Syndromic Surveillance and Influenza-like Illness in Georgia. Advances in Disease Surveillance 2007;4:179.

262. Murray EL, Soetebier K, Neu AL, Witherspoon CG, Cookson ST. The Impact of Hurricane Katrina Evacuees from Louisiana and Mississippi on Georgia Emergency Departments: Syndromic Surveillance and Disasters. Advances in Disease Surveillance 2007;2:164.

263. Usman E, Harp S, Koppanyi Z. Late Season Influenza-Like Illness in Georgia: Prospective Detection of an Illness Cluster Using Emergency Department Syndromic Surveillance. Advances in Disease Surveillance 2007;2:170.

264. Gonzalez GA, Murray EL, Soetebier K, Buehler JW, Cookson ST. A Comparison between Syndromic Surveillance 911/EMS and Emergency Department Data. Advances in Disease Surveillance 2007;2:104.

265. Peace D, Smith W, Reeves A, Little D, Soetebier K, Drenzek C. A comparison of syndromic surveillance chief complaint data and discharge data in a pediatric hospital system during 2009 H1N1. Emerging Health Threats Journal 2011;4(1):s151.

266. Borroto R, Williamson B, Pitcher P, Ballester L, Smith W, Soetebier K, et al. Using Syndromic Surveillance Alert Protocols for Epidemiologic Response in Georgia. Online Journal of Public Health Informatics 2017; Vol 9, No 12017;9(1):e123.

267. Hatcher B, Cameron W, Soetebier K, Clarkson L, Cole D, Horan J. An Evaluation of the Georgia Syndromic Surveillance Program using CDC's Guidelines for Evaluating Public Health Surveillance System. ISDS; Miami, Fl 2009.

268. Patel MT, Hoferka S. An Evaluation of Heat-Related Emergency. Online Journal of Public Health Informatics 2014;6(1):e88.

269. Brooks I, Vaid A, Edwards W. Analysis of 5 years of multistream surveillance and weather data in Champaign County. Emerging Health Threats Journal 2011;4:15.

270. Bemis K, Frias M, Patel MT, Christiansen D. Using an Emergency Department Syndromic Surveillance System to Evaluate Reporting of Potential Rabies Exposures, Illinois, 2013-2015. Public Health Reports. 2017;132(1).

271. Bemis K, Patel MT, Frias M, Christiansen D. Utility of Syndromic Surveillance in Detecting Potential Human Exposures to Rabies. Online Journal of Public Health Informatics 2016;8(1):e10.

272. Patel M, Adighibe E, Lombardo J, Loschen W, Stewart M, Vernon MO. Using Cloud Technology to Support Monitoring During High Profile Events. Online Journal of Public Health Informatics 2013;5(1):e73.

273. Bemis K, Gray S, Patel MT, Christiansen D. Disproportionate Emergency Room Use as an Indicator of Community Health. Online Journal of Public Health Informatics 2016;8(1):e9.

274. Silva JC, Rumoro DP, Shah SC, Gibbs GS, Hallock MM, Waddell M, et al. Adaptation of GUARDIAN for Syndromic Surveillance During the NATO Summit. Online Journal of Public Health Informatics 2013;5(1):e192.

275. Hafen RP, Anderson DE, Cleveland WS, Maciejewski R, Ebert DS, Abusalah A, et al. Syndromic surveillance: STL for modeling, visualizing, and monitoring disease counts. BMC Medical Informatics and Decision Making 2009;9:21.

276. Zou J, Karr AF, Datta G, Lynch J, Grannis S. A Bayesian spatio-temporal approach for real-time detection of disease outbreaks: A case study. BMC Medical Informatics and Decision Making 2014;14(1).

277. Hibler E. Evaluation of Pilot Hospitals Participating in the Indiana Public Health Emergency Surveillance System (PHESS). Advances in Disease Surveillance 2006;1:32.

278. Hibler E, Trepanier D, Wade M. Expanding the Functionality of Syndromic Surveillance Systems: Data Mining and Query Development. Advances in Disease Surveillance 2007;2:106.

279. Wade M, Gibson J, Dearth S, Grannis S. Operational Considerations and Early Successes with a Statewide Public Health Surveillance System. Advances in Disease Surveillance 2007;2:123.

280. Wade M, Trepanier D. Increasing Local Access to Syndromic Surveillance Data. Advances in Disease Surveillance 2007;4:203.

281. Maciejewski R, Rudolph S, Grannis SJ, Ebert DS. The Day-of-the-Week Effect: A Study Across the Indiana Public Health Emergency Surveillance System. Advances in Disease Surveillance 2008;5:44.

282. Dearth S, Gibson J. Increasing the Return-on-Investment from Syndromic Surveillance: Putting the Systems to Work for Routine Local Health Department Activities. Advances in Disease Surveillance 2007;4:158.

283. Wade M, Gorsuch S, Duszynski T, Gentry R. Exercise Demonstrates Effective Syndromic Surveillance Response Process. Advances in Disease Surveillance 2007;4:201.

284. Grannis S, Dixon B, Xia Y, Wu J. Using Information Entropy to Monitor Chief Complaint Characteristics and Quality. Online Journal of Public Health Informatics 2013;5(1):e16.

285. Fowler BE, Wade ME, Campbell RJ, DeFrancesco SJ, Grannis SJ, A.Trepanier D. Enhancing Syndromic Surveillance through Cross-border Data Sharing. Advances in Disease Surveillance 2008;5:31.

286. Dearth S, Mulanya K, Butwin J. Using a real-time syndromic surveillance system to track heat-related illnesses during a heat wave. Emerging Health Threats Journal 2011;4:39.

287. Carrico R, Goss L. Syndromic surveillance: Hospital emergency department participation during the Kentucky Derby Festival. Disaster Management and Response 2005;3(3):73-9.

288. Goss L, Carrico R, Hall C, Humbaugh K. A day at the races: Communitywide syndromic surveillance during the 2002 Kentucky Derby Festival. Journal of Urban Health 2003;80(1):i124-i.

289. Fleischauer AT, Young S, Mott J, Ratard R. Disaster Surveillance Revisited: Passive, Active and Electronic Syndromic Surveillance During Hurricane Katrina, New Orleans, LA – 2005. Advances in Disease Surveillance 2007;2:153.

290. Iberg Johnson J, Hand J, Ratard R. Near Real-Time Monitoring of Emergency Department Syndromic Surveillance Data During the 2013 Super Bowl and Mardi Gras Events in New Orleans, LA. Online Journal of Public Health Informatics 2014;6(1):e102.

291. Iberg Johnson J. Comparison of Three Critical Syndrome Classifications: Louisiana vs. BioSense. Online Journal of Public Health Informatics 2015;7(1):e30.

292. Iberg Johnson J, Brown K. Validation of Emergency Department and Outpatient Data Using ILI syndrome classifiers. Online Journal of Public Health Informatics 2015;7(1):e83.

293. Iberg Johnson J, Scott-Waldron C. What's the Buzz About Arboviral Disease Syndromic Surveillance? Online Journal of Public Health Informatics 2016;8(1):e62.

294. Serrano J. Delay between Discharge and Admit Time Delay in ADT-A03 messages via LEEDS. Online Journal of Public Health Informatics 2017;9(1):e34.

295. Kirkwood A, Guenther E, Fleischauer AT, Gunn J, Hutwagner L, Barry MA. Direct cost associated with the development and implementation of a local syndromic surveillance system. Journal of Public Health Management & Practice 2007;13(2):194-9.

296. Centers for Disease Control Prevention. Norovirus activity--United States, 2006-2007. MMWR Morbidity and Mortality Weekly Report 2007;56(33):842-6.

297. Daniel JB, Heisey-Grove D, Gadam P, Yih W, Mandl K, DeMaria Jr A, et al. Connecting Health Departments and Providers: Syndromic Surveillance's Last Mile. MMWR Morbidity & Mortality Weekly Report 2005;54:147-50.

298. Gunn J, Pendarvis J, Barry A. Syndromic Surveillance and Zip Code Data: The Role of Zip Codes in Understanding Populations. Advances in Disease Surveillance 2006;1:29.

299. Gunn J, Pendarvis J, Smith AK, Barry MA. Do women really complain more then men? Looking at gastrointestinal chief complaints in Boston. Advances in Disease Surveillance 2006;1:28.

300. Pendarvis J, Gunn J, Smith AK, Barry A. Syndromic Surveillance in Boston: Validating the Detection of Small Events and Integrating Response from a Local Health Department. Advances in Disease Surveillance 2006;1:59.

301. Donovan M, Gunn JE. Using the Emergency Medical Text Processor to Standardize Chief Complaints in Boston's Syndromic Surveillance System. Advances in Disease Surveillance 2007;4:49.

302. Ostrem M, Gunn JE. Syndromic Surveillance in Support of an Urban Violence Intervention. Advances in Disease Surveillance 2007;2:166.

303. Pendarvis J, Gunn J, Smith AK, Donovan M, Barry A. Sneezes vs. Wheezes: Syndrome Definitions for Influenza-like Illness. Advances in Disease Surveillance 2007;2:115.

304. Schlegelmilch J, Gunn J, Pendarvis J, Donovan M, Vinjé J, Widdowson M-A, et al. Bio-Surveillance and Enhanced Situational Awareness. Advances in Disease Surveillance 2007;4:191.

305. Pendarvis J, Miramontes R, Schlegelmilch J, Fleischauer AT, Gunn J, Hutwagner L, et al. Analysis of Syndrome Definitions for Gastrointestinal Illness with ICD9 Codes for Gastroenteritis during the 2006-07 Norovirus Season in Boston. Advances in Disease Surveillance 2007;4:263.

306. May L, Rennick M, Gustafson L, Gunn J. A Syndromic Approach to Emergency Department Surveillance for Skin and Soft Tissue Infections. Online Journal of Public Health Informatics 2013;5(1):e61.

307. Rennick M, Gunn J, Donovan M, Shah S, Barry MA, Burkom H, et al. Syndromic surveillance for bicycle-related injuries in Boston, 20072010. Emerging Health Threats Journal 2011;4:123.

308. Hoen A, Buckeridge D, Charland K, Mandl K, Brownstein J. Effect of expanded recommendations for pediatric seasonal influenza vaccination: an international comparison. Emerging Health Threats Journal 2011;4(1):s85.

309. Rennick M, Gunn J, Donovan M, Salvia J. Asthma patterns in Boston emergency department visits for children age five and under. Emerging Health Threats Journal 2011;4(1):s145.

310. Brown H, Romanosky A, Aslam S, Chu A, Blythe D. Early Identification of Salmonella Cases Using Syndromic Surveillance. Advances in Disease Surveillance 2008;5:94.

311. Bankoski A, Salim A, Faigen Z. Emergency Department Chief Complaint Versus Discharge Diagnosis for Tracking Disease Measures. Online Journal of Public Health Informatics 2014;6(1):e38.

312. Chu A, Brown H, Blythe D, Romanosky A. Can Syndromic Surveillance Data be Useful for Monitoring Respiratory Illness Activity? Advances in Disease Surveillance 2007;4:154.

313. Faigen Z, Salim A, Rojohn K, Isaac A, Adams S. Monitoring and auditing the transfer of syndromic surveillance data to ensure data completeness. Emerging Health Threats Journal 2011;4:52.

314. Salim A, Faigen Z, Ajit I, Adams S. Trends in emergency department visits for influenza-like illness and antiviral medication transactions. Emerging Health Threats Journal 2011;4:127.

315. Aslam S, Ajit I, Adams S, Faigen Z. Maryland ESSENCE expansion to incorporate prescription medication data. Emerging Health Threats Journal 2011;4(1):s61.

316. Aslam S, Ajit I, Adams S, Faigen Z. Utilities of Maryland's syndromic surveillance system: indentifying threats, case investigation and situational awareness. Emerging Health Threats Journal 2011;4(1):s62.

317. Faigen Z, Ajit I, Aslam S, Adams S. Identification and tracking of heat-related illnesses using syndromic surveillance. Emerging Health Threats Journal 2011;4(1):s21.

318. Brown H, Aslam S, Ajit I, Adams S. Maryland ESSENCE Expansion to Achieve Statewide Coverage. ISDS; Miami, Fl 2009.

319. Brown H, Aslam S, Ajit I, Adams S. Syndromic Surveillance for ILI during H1N1 Response. ISDS; Miami, Fl 2009.

320. Mnatsakanyan ZR, Ashar RJ, Murphy SP, Coberly JS, Burkom H. Increase in Pneumonia Cases as an Early Indicator of Severe and Pandemic Influenza Outbreak. Advances in Disease Surveillance 2007;2:160.

321. Dambita N, Hirshon JM, Beilenson PL, Huffman J. The city of Baltimore's multifaceted bioterrorism surveillance system. Journal of Urban Health 2003;80(1):i139-i.

322. DeVita S, Robbins A. Evaluating Usefulness of Maine's Syndromic Surveillance System for Hospitals, 2012. Online Journal of Public Health Informatics 2013;5(1):e174.

323. Rogers GM, Valenti A. Visual Portrayal of Syndromic Surveillance Data by Using High-Low Charting -- Maine, 2004. MMWR: Morbidity & Mortality Weekly Report 2005;54:207.

324. Sheline KD. Evaluation of the Michigan Emergency Department Syndromic Surveillance System. Advances in Disease Surveillance 2007;4:265.

325. Mamou F, Henderson T. Analysis of Heat Illness using Michigan Emergency Department Syndromic Surveillance. Online Journal of Public Health Informatics 2013;5(1):e139.

326. Swarnavel S, Collins J, Miller C. Validation of the Michigan's Public Health Syndromic System Using Electronic Medical Records. Online Journal of Public Health Informatics 2015;7(1):e207.

327. Raman S, Levin J, Hall D, Frey K. Using Categorization of Reason-for-Visit Strings as the Basis for an Outbreak Detection System -- Minnesota, 2002-2003. MMWR: Morbidity & Mortality Weekly Report 2005;54:200.

328. Green K, Miller B, Hadidi M, Zimmerman M, Danila R. Dual-Model Approach to Syndromic Surveillance Using Hospital Emergency Department Data. MMWR: Morbidity & Mortality Weekly Report 2004;53:242.

329. Resch Z, Bullock C, Winslow A, Kelsey A. Missouri's Syndromic Surveillance Experience. Advances in Disease Surveillance 2007;4:187.

330. Pugh KH, Kelsey A, Tominack R. Comparing Syndromic Surveillance and Poison Center Data for Snake Bites in Missouri. Online Journal of Public Health Informatics 2013;5(1):e102.

331. Wu F, Kelsey A. Early Detection of Influenza Activity Using Syndromic Surveillance in Missouri. Online Journal of Public Health Informatics 2013;5(1):e37.

332. Wu F, Braun C. Missouri Emergency Department Visits for Carbon Monoxide Poisoning. Online Journal of Public Health Informatics 2014;6(1):e50.

333. Kuo E, Wu F, Kelsey A. How Do Temperature, Relative Humidity and Heat Index Compare to Trends in Heat-Related Chief Complaints Captured by ESSENCE? ISDS; Miami, Fl 2009.

334. Wu F, Kuo E, Kelsey A. Utility of Syndromic Surveillance for Evaluating Influenza Trends. ISDS; Miami, Fl 2009.

335. Kuo E, Wu F, Kelsey A. A Comparison of Syndromic Surveillance and Mortality Statistics for Heat-Related Illness in Missouri. ISDS; Miami, Fl 2009.

336. Mohlenbrock WC, Rogers RF. Multi-Agency and Hospital, Syndromic Surveillance System in Montana. Advances in Disease Surveillance 2008;5:46.

337. Rappold AG, Stone SL, Cascio WE, Neas LM, Kilaru VJ, Carraway MS, et al. Peat bog wildfire smoke exposure in rural North Carolina is associated with cardiopulmonary emergency department visits assessed through syndromic surveillance. Environmental Health Perspectives. 2011;119(10):1415-20.

338. Harduar Morano L, Waller AE. Evaluation of the Components of the North Carolina Syndromic Surveillance System Heat Syndrome Case Definition. Public Health Reports. 2017;132(1):40S-7S.

339. Ising A, Proescholdbell S, Harmon KJ, Sachdeva N, Marshall SW, Waller AE. Use of syndromic surveillance data to monitor poisonings and drug overdoses in state and local public health agencies. Injury Prevention 2016;22:i43–i9.

340. Haas SW, Travers D, Waller A, Mahalingam D, Crouch J, Schwartz TA, et al. Emergency Medical Text Classifier: New system improves processing and classification of triage notes. Online Journal of Public Health Informatics. 2014;6(2):e178.

341. Modarai F, Mack K, Hicks P, Benoit S, Park S, Jones C, et al. Relationship of opioid prescription sales and overdoses, North Carolina. Drug and Alcohol Dependence 2013;132(1-2):81-6.

342. Sickbert-Bennett EE, Scholer M, Butler J, Travers D, MacFarquhar J, Waller A, et al. Evaluating a Syndromic Surveillance System for the Detection of Acute Infectious Gastroenteritis Outbreaks -- North Carolina, 2004. MMWR: Morbidity & Mortality Weekly Report 2005;54:201-.

343. Ising AI, Travers DA, MacFarquhar J, Kipp A, Waller AE. Triage Note in Emergency Department-Based Syndromic Surveillance. Advances in Disease Surveillance 2006;1:34.

344. Li M, Ising A, Waller AE, Falls D, Eubanks T, Kipp A. North Carolina Bioterrorism and Emerging Infection Prevention System. Advances in Disease Surveillance 2006;1:80.

345. MacFarquhar J, Sickbert-Bennett E, Waller A, Travers D, Scholer M, Davies M. Evolution of a Syndromic Surveillance Case Definition. Advances in Disease Surveillance 2006;1:46.

346. Travers D, Kipp A, MacFarquhar J, Waller A. Evaluation of Emergency Medical Text Processor For Pre-Processing Chief Complaint Data for Syndromic Surveillance. Advances in Disease Surveillance 2006;1:71.

347. Barnett C, Deyneka L, Waller A. Post-Katrina Situational Awareness in North Carolina. Advances in Disease Surveillance 2007;2:142.

348. Barnett C, Ising A, Travers D, Waller A. Emergency Department Data Quality Best Practices. Advances in Disease Surveillance 2007;2:193.

349. Falls DM, McLamb JR, Ising AI, Waller AE. Using Business Intelligence Tools to Automate Data Capture and Reporting. Advances in Disease Surveillance 2007;2:6.

350. Ising A, Travers D, Crouch J, Waller A. Improving Negation Processing in Triage Notes. Advances in Disease Surveillance 2007;4:50.

351. Li M, Ising A, Havaldar R, Waller A. Multi-Tier Role Based Access for Secure and Flexible Syndromic Surveillance. Advances in Disease Surveillance 2007;2:158.

352. Li M, Ising A, Deyneka L, Falls D, Waller A. Using NC DETECT Summary Reports to Share Syndromic Information. Advances in Disease Surveillance 2008;5:113.

353. Ratcliffe A, Barnett C, Ising A, Waller A. Evaluating the Validity of ED Visit Data for Biosurveillance. Advances in Disease Surveillance 2008;5:57.

354. Burkom H, Burrer S, Barker L, Robison V, Hicks P, Ising A. Use of Syndromic Data to Determine Oral Health Visit Burden on Emergency Departments. Online Journal of Public Health Informatics 2013;5(1):e57.

355. Deyneka L, Ising A, Li M. Enhanced Surveillance during the Democratic National Convention, Charlotte, NC. Online Journal of Public Health Informatics 2013;5(1):e190.

356. Harmon KJ, Proescholdbell S, Marshall S, Waller A. Utilization of Emergency Department Data for Drug Overdose Surveillance in North Carolina. Online Journal of Public Health Informatics 2014;6(1):e174.

357. Ising A, Barnett C, Falls D, Waller AE, Wallace J, Deyneka L. Assessing the Potential Impact of the BioSense 24-hour Rule Using NC DETECT ED Data. Online Journal of Public Health Informatics 2015;7(1):e84.

358. Faigen Z, Ising A, Deyneka L, Waller AE. Triage Notes in Syndromic Surveillance – A Double Edged Sword. Online Journal of Public Health Informatics 2016;8(1):e179.

359. Deyneka L, Costa P, Kipp A. Using Poison Center Syndromic Surveillance for Environmental Health Signals Detection. Advances in Disease Surveillance 2007;2:151.

360. Ising A, Li M, Deyneka L, Barnett C, Scholer M, Waller A. Situational Awareness Using Web-based Annotation and Custom Reporting. Advances in Disease Surveillance 2007;4:167.

361. Brannan S, Evens N, Barnett C, Deyneka L, Ising A, Wheaton B, et al. Web-Based Spatio-Temporal Display of NC DETECT Surveillance Data. Advances in Disease Surveillance 2008;5:6.

362. Ising A, Li M, Deyneka L, Vaughan-Batten H, Waller A. Improving syndromic surveillance for nonpower users: NC DETECT dashboards. Emerging Health Threats Journal 2011;4:75.

363. Rhea S, Ising A, Waller A, Deyneka L, Vaughan-Batten H, Haskell MG. Animal bite surveillance using NC DETECT. Emerging Health Threats Journal 2011;4:124.

364. Travers D, Lich KH, Lippmann S, Waller A, Weinberger M, Yeatts K. Defining emergency department asthma visits for public health surveillance. Emerging Health Threats Journal 2011;4:152.

365. Vaughan-Batten H, Deyneka L, Ising A, Waller A. Data requests for research: best practices based on the North Carolina DETECT experience. Emerging Health Threats Journal 2011;4:153.

366. Lamb E, Vaughan-Batten H, Dailey N, Maillard J-M, Johns L, Fleischauer A, et al. Emergency department diagnosis code data for surveillance of vaccine adverse events: comparison with the national vaccine adverse event reporting system. Emerging Health Threats Journal 2011;4(1):s90.

367. Ising A, Rhea S, Deyneka L, Vaughan-Batten H. The use of NC DETECT ED data to examine heat-related illness. Emerging Health Threats Journal 2011;4(1):s30.

368. King R, Deyneka L, Vaughan-Batten H, Barker L, Robison V, Benoit S, et al. Use of syndromic surveillance systems for oral health surveillance. Emerging Health Threats Journal 2011;4(1):s32.

369. Falls D, Li M, Waller A. Securing protected health information in NC DETECT. Emerging Health Threats Journal 2011;4(1):s79.

370. Li M, Loschen W, Deyneka L, Burkom H, Ising A, Waller A. Time of Arrival Analysis in NC DETECT to Find Clusters of Interest from Unclassified Patient Visit Records. Online Journal of Public Health Informatics 2013;5(1):e13.

371. Young A, Fliss MD, Ising A. Improving Local Non-Communicable Disease Surveillance within a Changing Data Environment. Online Journal of Public Health Informatics 2015;7(1):e177.

372. Deyneka L, Hakenewerth A, Faigen Z, Ising A, Barnett C. Using Syndromic Surveillance Data to Monitor Endocarditis and Sepsis among Drug Users. Online Journal of Public Health Informatics 2017;9(1):e124.

373. Waller AE, Lippmann S, Ising A, Crump C. Childhood Injury in Wake County, NC: Local Use of Public Health Surveillance Data. Online Journal of Public Health Informatics 2015;7(1):e172.

374. Samoff E, Fleischauer A, Moore Z, Park M, Deyneka L, Davis M, et al. Use of Syndromic Surveillance for Outbreak Detection and Management, North Carolina 2008-9. ISDS; Miami, Fl 2009.

375. Rao S, Johnson A, Abbott D, Frederick J, Caram LB, Woods C. Clinical Surveillance Markers of Influenza-like Illness (ILI) at a Veterans Affairs (VA) Hospital. Advances in Disease Surveillance 2007;4:186.

376. Musumba A, Feist M, Kubischta L, Miller T, Goplin J. Evaluation of ILI Data Use to Augment Traditional Influenza Surveillance. Advances in Disease Surveillance 2008;5:120.

377. Goplin J, Feist M, Miller T. Variation of Chief Complaint-Based Respiratory Symptom Data in One Hospital's Nurse Advice Call Center and Emergency Department. Advances in Disease Surveillance 2007;2:105.

378. Gonzalez S, Newmyer A, Qu M. Validation of SyS Data to Inform Surveillance of Health Disparities in Nebraska. Online Journal of Public Health Informatics 2016;8(1):e59.

379. Murphy E, Safranek T. Assessing the use of syndromic surveillance data to identify and track heat illness in Nebraska, 20102011. Emerging Health Threats Journal 2011;4:105.

380. Gonzlez S, DeVries D, Qu M. Use of Near-Real–Time Data to Inform Underage Drinking Surveillance in Nebraska. Online Journal of Public Health Informatics 2017;9(1):e142.

381. Daly ER, Dufault K, Swenson DJ, Lakevicius P, Metcalf E, Chan BP. Use of Emergency Department Data to Monitor and Respond to an Increase in Opioid Overdoses in New Hampshire, 2011-2015. Public Health Reports. 2017;132(1).

382. Swenson D, Adamski C, Armenti K. Real-Time Surveillance: Cutting-Edge Technology in NH. Advances in Disease Surveillance 2007;2:29.

383. Swenson DJ, Taylor C, Southworth J, Dufault K. Surveillance Investigation Tool Development Targeted For Results. Advances in Disease Surveillance 2007;4:115.

384. Miller S, Fallon K, Anderson L. New Hampshire emergency department syndromic surveillance system. Journal of Urban Health 2003;80(1):i118-i.

385. Swenson D, Zhang X, Miller S, Dufault K, Taylor C, Fallon K, et al. Ten years of syndromic surveillance in New Hampshire: innovation, experience and outcomes. Emerging Health Threats Journal 2011;4:148.

386. Swenson D, Mayo L, Dufault K, Daly E, Bascom S, Dionne-Odom J, et al. Use of emergency department data for case finding following a community anthrax exposure. Emerging Health Threats Journal 2011;4(1):s118.

387. Borjan M, Lumia M. Evaluation of a state based syndromic surveillance system for the classification and capture of non-fatal occupational injuries and illnesses in New Jersey. American Journal of Industrial Medicine. 2017;60(7):621-6.

388. Tsai S, Hamby T, Chu A, Gleason JA, Goodrow GM, Gu H, et al. Development and Application of Syndromic Surveillance for Severe Weather Events Following Hurricane Sandy. Disaster Medicine and Public Health Preparedness. 2016;10(3):463-71.

389. Berry M, Fagliano J, Tsai S, McGreevy K, Walsh A, Hamby T. Evaluation of Heat-related Illness Surveillance Based on Chief Complaint Data from New Jersey Hospital Emergency Rooms. Online Journal of Public Health Informatics 2013;5(1):e125.

390. Hamby T, Tsai S, Genese C, Walsh A, Bradford L, Lifshitz E. Paralysis Analysis: Investigating Paralysis Visit Anomalies in New Jersey. Online Journal of Public Health Informatics 2013;5(1):e126.

391. Hamby T, Pomary V, Adler E, Tsai S, Walsh A. School Daze: Capturing Chemical Exposures in Syndromic Surveillance - New Jersey 2013. Online Journal of Public Health Informatics 2014;6(1):e64.

392. Chen F, Kostial E, Hamby T, Tsai S. Validation of New Jersey Emergency Department (ED) Registration Data in BioSense 2.0. Online Journal of Public Health Informatics 2015;7(1):e118.

393. Chu AF, Tsai S, Hamby T, Kostial E, Fagliano J. Development of Mental Health Classification Related to Severe Weather Events. Online Journal of Public Health Informatics 2015;7(1):e120.

394. Erdogdu P, Hamby T, Tsai S. Better, Stronger, Faster: Why Add Fields to Syndromic Surveillance? New Jersey, 2015. Online Journal of Public Health Informatics 2016;8(1):e106.

395. Hamby T, Tsai S, McHugh L. Surveillance in New Jersey*from anthrax to automation. Emerging Health Threats Journal 2011;4:70.

396. Borjan M, Lumia M. Classification and Capture of Work-Related Non-Fatal Injuries Through a Real-Time Syndromic Surveillance System. Online Journal of Public Health Informatics 2016;8(1):e94.

397. Hamby T, Tsai S, Gu H. How's the Weather? Severe Weather Classifications in Syndromic Surveillance. Online Journal of Public Health Informatics 2017;9(1):e30.

398. Erdogdu P, Tsai S, Hamby T. HAI Surveillance Enhancement within EpiCenter by Utilization of Triage Notes. Online Journal of Public Health Informatics 2017;9(1):e40.

399. Hamby T, Tsai S, Gu H, Goodrow G, Gleason J, Fagliano J. Weather Outlook: Cloudy with a Chance of...— Classification of Storm-Related ED Visits. Online Journal of Public Health Informatics 2016;8(1):e118.

400. La Forgia B, Fiorenza L, John S, Paladini M. Daily Electronic Disease Surveillance System -- Bergen County, Paramus, New Jersey. MMWR: Morbidity & Mortality Weekly Report 2005;54:192-.

401. Paladini M. Daily Emergency Department Surveillance System — Bergen County, New Jersey. MMWR: Morbidity & Mortality Weekly Report 2004;53:47-9.

402. Brillman JC, Burr T, Forslund D, Joyce E, Picard R, Umland E. Modeling emergency department visit patterns for infectious disease complaints: results and application to disease surveillance. BMC Medical Informatics and Decision Making 2005;5:4.

403. Lauper U, Chen J-H, Lin S. Window of Opportunity for New Disease Surveillance: Developing Keyword Lists for Monitoring Mental Health and Injury Through Syndromic Surveillance. Disaster Medicine and Public Health Preparedness. 2017;11(2):173-8.

404. Chang H-G, Cochrane DG, Tserenpuntsag B, Allegra JR, Smith PF. ICD9 as a Surrogate for Chart Review in the Validation of a Chief Complaint Syndromic Surveillance System. Advances in Disease Surveillance 2006;1:11.

405. Thoburn KK, Miller JR, Chen J-H, Schmit KJ, Chang H-G. The New York State Department of Health's Syndromic Surveillance System. Advances in Disease Surveillance 2006;1:68.

406. Chen J, Schmit K, Chang H, Miller J. Detection of Carbon Monoxide Poisoning in Chief Complaint Data. Advances in Disease Surveillance 2007;4:153.

407. Cochrane DG, Allegra JR, McCarthy C, Luk J, Chang H-G, Chen J-H. The Utility of Patient Chief Complaint and ICD 9 Classifiers for the Influenza Sub-syndrome. Advances in Disease Surveillance 2008;5:15.

408. Chang H-G, Weng C, DiDonato C, DiCesare D, Chen J-H, Blog D. Evaluation of Emergency Department Data Quality following PHIN Syndromic Surveillance Messaging Guide. Online Journal of Public Health Informatics 2013;5(1):e50.

409. Chen J-H, Lauper U, Pantea C, Lin S, Chang H-G. Carbon Monoxide Poisoning during Hurricane Sandy in Affected New York State Counties. Online Journal of Public Health Informatics 2015;7(1):e119.

410. Chang H-G, Chen J-H, Cochrane DG, Allegra JR, Burkom H, Tokars JI, et al. A Pilot Study of Aberration Detection Algorithms with Simulated Data. Advances in Disease Surveillance 2007;4:240.

411. Weng C, Chen J-H, DiDonato C, Chang H-G. Map application to the New York state electronic syndromic surveillance system. Emerging Health Threats Journal 2011;4(1):s156.

412. Terry W, Ostrowsky B, Huang A. Should We Be Worried? Investigation of Signals Generated by an Electronic Syndromic Surveillance System -- Westchester County, New York. MMWR: Morbidity & Mortality Weekly Report 2004;53:190-5.

413. Cho SS, Hackmyer S, Li J, Lipsman J, Meruelo O, Mottola D, et al. Establishing an Automated Surveillance System. MMWR: Morbidity & Mortality Weekly Report 2004;53:232.

414. Mathes RW, Lall R, Levin-Rector A, Sell J, Paladini M, Konty KJ, et al. Evaluating and implementing temporal, spatial, and spatio-temporal methods for outbreak detection in a local syndromic surveillance system. PLoS ONE 2017;12(9):e0184419.

415. Mathes RW, Ito K, Lane K, Matte TD. Real-time surveillance of heat-related morbidity: relation to excess mortality associated with extreme heat. PLoS ONE 2017;12(9):e0184364.

416. Kotzen M, Sell J, Mathes RW, Dentinger C, Lee L, Schiff C, et al. Using syndromic surveillance to investigate tattoo-related skin infections in New York City. PLoS ONE 2015;10(6):e0130468.

417. Bregman B, Slavinski S. Using emergency department data to conduct dog and animal bite surveillance in New York City, 2003-2006. Public Health Reports 2012;127(2):195-201.

418. Plagianos MG, Wu WY, McCullough C, Paladini M, Lurio J, Buck MD, et al. Syndromic surveillance during pandemic (H1N1) 2009 outbreak, New York, New York, USA. Emerging Infectious Diseases 2011;17(9):1724-6.

419. Marx MA, Rodriguez CV, Greenko J, Das D, Heffernan R, Karpati AM, et al. Diarrheal illness detected through syndromic surveillance after a massive power outage: New York City, August 2003. American Journal of Public Health 2006;96(3):547-53.

420. Heffernan R, Mostashari F, Das D, Karpati A, Kulldorff M, Weiss D. Syndromic surveillance in public health practice, New York City. Emerging Infectious Diseases 2004;10(5):858-64.

421. Das D, Weiss D, Mostashari F, Treadwell T, McQuiston J, Hutwagner L, et al. Enhanced drop-in syndromic surveillance in New York City following September 11, 2001. Journal of Urban Health 2003;80:i76-i88.

422. Lall R, Abdelnabi J, Ngai S, Parton HB, Saunders K, Sell J, et al. Advancing the Use of Emergency Department Syndromic Surveillance Data, New York City, 2012-2016. Public Health Reports 2017;132(1).

423. Nolan ML, Kunins HV, Lall R, Paone D. Developing Syndromic Surveillance to Monitor and Respond to Adverse Health Events Related to Psychoactive Substance Use: Methods and Applications. Public Health Reports 2017;132(1).

424. Wilson EL, Egger JR, Konty KJ, Paladini M, Weiss D, Trang QN. Description of a School Nurse Visit Syndromic Surveillance System and Comparison to Emergency Department Visits, New York City. American Journal of Public Health 2014;104(1).

425. Wallace DJ, Arquilla B, Heffernan R, Kramer M, Anderson T, Bernstein D, et al. A test of syndromic surveillance using a severe acute respiratory syndrome model. American Journal of Emergency Medicine 2009;27(4):419-23.

426. J Ackelsberg, S Balter, K Bornschelgel, E Carubis, B Cherry, V D Das, et al. Syndromic surveillance for bioterrorism following the attacks on the World Trade Center -- New York City, 2001. MMWR: Morbidity & Mortality Weekly Report 2002;51:13-5.

427. Hsieh JL, Nguyen TQ, Matte T, Ito K. Drinking water turbidity and emergency department visits for gastrointestinal illness in New York City, 2002-2009. PLoS ONE 2015;10(4).

428. Westheimer E, Paladini M, Balter S, Weiss D, Fine A, Nguyen TQ. Evaluating the New York City emergency department syndromic surveillance for monitoring influenza activity during the 2009-10 influenza season. PLoS Currents 2012:1-15.

429. Mathes RW, Ito K, Matte T. Assessing syndromic surveillance of cardiovascular outcomes from emergency department chief complaint data in New York City. PLoS ONE 2011;6(2).

430. Beatty ME, Phelps S, Rohner C, Weisfuse I. Blackout of 2003: Public Health Effects and Emergency Response. Public Health Reports 2006;121(1):36-44.

431. Seil K, Marcum J, Lall R, Stayton C. Utility of a near real-time emergency department syndromic surveillance system to track injuries in New York City. Injury Epidemiology 2015;2(1):11.

432. Minen MT, Boubour A, Wahnich A, Grudzen C, Friedman BW. A Retrospective Nested Cohort Study of Emergency Department Revisits for Migraine in New York City. Headache 2018;58(3):399-406.

433. Chen BC, Shawn LK, Connors NJ, Wheeler K, Williams N, Hoffman RS, et al. Carbon monoxide exposures in New York City following Hurricane Sandy in 2012. Clinical Toxicology 2013;51(9):879-85.

434. Heffernan R, Mostashari F, Das D, Besculides M, Rodriguez C, Greenko J, et al. New York City Syndromic Surveillance Systems. MMWR: Morbidity & Mortality Weekly Report 2004;53:25-7.

435. Metzger KB, Hajat A, Crawford M, Mostashari F. How Many Illnesses Does One Emergency Department Visit Represent? Using a Population-Based Telephone Survey To Estimate the Syndromic Multiplier. MMWR: Morbidity & Mortality Weekly Report 2004;53:106-11.

436. Steiner-Sichel L, Greenko J, Heffernan R, Layton M, Weiss D. Field Investigations of Emergency Department Syndromic Surveillance Signals -- New York City. MMWR: Morbidity & Mortality Weekly Report 2004;53:184-9.

437. Balter S, Weiss D, Hanson H, Reddy V, Das D, Heffernan R. Three Years of Emergency Department Gastrointestinal Syndromic Surveillance in New York City: What Have we Found? MMWR: Morbidity & Mortality Weekly Report 2005;54:175-80.

438. Goranson C, Konty K, Lu J, Mostashari F. Visualization of Syndromic Surveillance Using GIS. Advances in Disease Surveillance 2006;1:26.

439. Das D, Olson D, Heffernan R. Estimating Hospital Admissions for Influenza Using Emergency Department (ED) Syndromic Surveillance Data, New York City. Advances in Disease Surveillance 2007;2:150.

440. Murray EL, Heffernan R, Yeung A, Kidoguchi LS, Weiss D. Use of Syndromic Surveillance in the Investigation of Salmonella wandsworth Outbreak. Advances in Disease Surveillance 2007;4:180.

441. Lu J, Metzger K, Cajigal A, Konty K, Matte T. Identifying and Modeling Spatial Patterns of Heat-Related Illness in New York City. Advances in Disease Surveillance 2007;4:255.

442. Cajigal A, Heller D, Paone D, Konty K. Monitoring Spatial Patterns of Adverse Drug Events and Morbidity in New York City Using Syndromic Data Streams. Advances in Disease Surveillance 2008;5:168.

443. Goranson C, K T, T T, Cajigal A, Paladini M, Murray EL, et al. Cluster Detection Comparison in Syndromic Surveillance. Advances in Disease Surveillance 2008;5:33.

444. Murray EL. Using Emergency Department Disposition Data to Monitor Hospitalizations for Influenza-like Illness. Advances in Disease Surveillance 2008;5:183.

445. Wilson EL, Murray EL, Jones L, Paladini M, Nguyen TQ. A Comparison of Electronic Emergency Department Visits and Data Collected Manually During a Field Exercise. Advances in Disease Surveillance 2008;5:136.

446. Jasek JP, Hosseinipour N, Rubin T, Lall R. Using Syndromic Emergency Department Data to Augment Oral Health Surveillance. Online Journal of Public Health Informatics 2013;5(1):e112.

447. Lall R, Paladini M. Evaluating Syndromic Data for Surveillance of Non-infectious Disease. Online Journal of Public Health Informatics 2013;5(1):e163.

448. Lane K, Lall R, Wheeler K, Ito K, Matte T. Evaluating Utility of Cold-Injury Syndromic Surveillance Data in New York City. Online Journal of Public Health Informatics 2013;5(1):e122.

449. Mathes R, Ito K, Matte T. Risk of Cardiovascular Morbidity and Mortality in Relation to Temperature. Online Journal of Public Health Informatics 2013;5(1):e144.

450. Mathes R, Metzger KB, Ito K, Matte T. Surveillance of Heat-related Morbidity: Relation to Heat-related Excess Mortality. Online Journal of Public Health Informatics 2013;5(1):e156.

451. Paladini M, Lall R, Schachterle SE. Differentiating ZIP Codes in Syndromic Data; What Can They Tell Us? Online Journal of Public Health Informatics 2013;5(1):e127.

452. Sell J, Mathes R, Paladini M. Detecting Changes in Chief Complaint Word Count: Effects on Syndromic Surveillance. Online Journal of Public Health Informatics 2013;5(1):e21.

453. Sell J, Wong A. A Survey of Data Recording Procedures at New York City Emergency Departments. Online Journal of Public Health Informatics 2013;5(1):e114.

454. Lall R, Levin-Rector A, Mathes R, Weiss D. Detecting Unanticipated Increases in Emergency Department Chief Complaint Keywords. Online Journal of Public Health Informatics 2014;6(1):e93.

455. Agarwal M, Idaikkadar N, Weiss D. Epidemiology of Gunshot-Related Injuries in NYC Emergency Departments from 2004-2014. Online Journal of Public Health Informatics 2015;7(1):e7.

456. Chase AZ. Monitoring Trends of Self-diagnosis in New York City Emergency Departments. Online Journal of Public Health Informatics 2015;7(1):e186.

457. Chase AZ, Agarwal M, Mercurio-Zappala M, Su M. Using Syndromic Surveillance to Characterize Unintentional Ingestions in Children. Online Journal of Public Health Informatics 2015;7(1):e116.

458. Mathes R, Sell J, Tam AW, Levin-Rector A, Lall R. Building a Better Syndromic Surveillance System: the New York City Experience. Online Journal of Public Health Informatics 2015;7(1):e39.

459. Tam AW, Toprani A, Mathes R. Reciprocal Data Sharing: Sending Monthly Summary Reports of Syndromic Data to ED. Online Journal of Public Health Informatics 2015;7(1):e164.

460. Lu J, Konty K, Goranson C, Mostashari F. Algorithms to Characterize Syndromic Surveillance Spatial Alerts. Advances in Disease Surveillance 2007;2:56.

461. Cajigal A, Konty K, Heller D. Using a syndromic approach to monitor alcohol-related visits of college-aged emergency department patients. Emerging Health Threats Journal 2011;4:22.

462. Konty K, Olson D. The spatial-temporal pattern of excess influenza visits at the (sub-)urban scale. Emerging Health Threats Journal 2011;4(1):**s35**.

463. Ngai S, Edelstein Z, Myers J, Weiss D. Tracking HIV Post-Exposure Prophylaxis using Syndromic Surveillance in NYC Emergency Departments. Online Journal of Public Health Informatics 2015;7(1):e89.

464. Westheimer E, Nguyen T, Paladini M, Weiss D, Balter S. Comparison of respiratory, febrile and influenza-like illness syndromes to detect laboratory-reported H1N1 and RSV, Influenza Season 2009–10, New York City. Emerging Health Threats Journal 2011;4(1):s105.

465. Yung J, Nkwocha P, Tam AW, Lall R, Mathes R. Comparison between HL7 and Legacy Syndromic Surveillance Data in New York City. Online Journal of Public Health Informatics 2015;7(1):e179.

466. Wahnich A, Lall R, Weiss D. Monitoring for Local Transmission of Zika Virus using Emergency Department Data. Online Journal of Public Health Informatics 2017;9(1):e115.

467. Olson D, van der Mei W, Lim S, Yoon C, Kull M, Davila M. Monitoring child mental health related emergency department visits in New York City. Online Journal of Public Health Informatics 2017;9(1):e134.

468. Sell J. In Denial: Symptom Negation in New York City Emergency Department Chief Complaints. Online Journal of Public Health Informatics 2017;9(1):e70.

469. Kotzen M, Mathes R, Lee L, Weiss D. Using Syndromic Surveillance to Investigate Tattoo-related Skin Infections in NYC. Online Journal of Public Health Informatics 2014;6(1):e172.

470. Athens J. Can We Use Syndromic Surveillance Data to Identify Primary Care Visits to NYC EDs? Online Journal of Public Health Informatics 2013;5(1):e56.

471. Mathes RW, Matte TD, Ito K. Assessing Syndromic Surveillance of Cardiovascular Outcomes from Emergency Department Chief Complaint Data in New York City. ISDS; Miami, Fl 2009.

472. Racer CF. Novel H1N1 Flu, Type A: the Media, and Syndromic Surveillance, April-July 2009. ISDS; Miami, Fl 2009.

473. Nguyen TQ, Paladini M, Balter S, Thorpe L. Using Emergency Department Syndromic Surveillance Disposition Data to Estimate Influenza-related Severity during Novel H1N1 Outbreak, 2009 — New York City. ISDS; Miami, Fl 2009.

474. Das D, Mostashari F, Weiss D, Balter S, Heffernan R. Monitoring Over-the-Counter Pharmacy Sales for Early Outbreak Detection — New York City, August 2001–September 2003. MMWR: Morbidity & Mortality Weekly Report 2004;53:235.

475. Marx MA, Rodriguez C, Greenko J, Das D, Mostashari F, Balter S, et al. Investigation of Diarrheal Illness Detected Through Syndromic Surveillance After a Massive Blackout — New York City, August 2003. MMWR: Morbidity & Mortality Weekly Report 2004;53:251.

476. Gallagher T. Open Source Development of Syndromic Investigation Decision Support Tools. Advances in Disease Surveillance 2008;5:104.

477. Thomas RM, Fowler BE. Monitoring Hospital Emergency Department Visits for Chief Complaints of Insect Bites after a Major Flood. Advances in Disease Surveillance 2008;5:193.

478. Brown AL, Storm WE, Fowler BE. Tracking Drug Overdose Trends in Ohio using ED Chief Complaints. Online Journal of Public Health Informatics 2013;5(1):e121.

479. Brown A, Storm W, Fowler B. Using syndromic surveillance data to identify emerging trends in designer drug use. Emerging Health Threats Journal 2011;4:16.

480. Gallagher T. Enhancing state biosurveillance: situational awareness via local context analysis. Emerging Health Threats Journal 2011;4:63.

481. Storm W, Bennett B, Fowler B. Using chief complaint data to evaluate the effectiveness of a statewide smoking ban. Emerging Health Threats Journal 2011;4(1):s152.

482. Orr C, VanBuskirk K. Utilization of the Syndromic Surveillance Framework for Detection of Heat-Related illnesses. Advances in Disease Surveillance 2007;4:60.

483. Hines JZ, Bancroft J, Powell M, Hedberg K. Case Finding Using Syndromic Surveillance Data During an Outbreak of Shiga Toxin--Producing Escherichia coli O26 Infections, Oregon, 2015. Public Health Reports 2017;132(4):448-50.

484. Powell M, Ryff K. Marketing a syndromic surveillance system to hospital emergency departments. Emerging Health Threats Journal 2011;4:119.

485. Powell M, Ryff K, Giffin S. Surveillance of poison center data using the National Poison Data System web service. Emerging Health Threats Journal 2011;4:120.

486. Storm B, Fowler B. Evaluating the relationship between heat-related ED visits and weather variables. Emerging Health Threats Journal 2011;4:146.

487. Powell M, Boyd L. Tracking Health Effects of Wildfires: The Oregon ESSENCE Wildfire Pilot Project. Online Journal of Public Health Informatics 2017;9(1):e141.

488. Jagger MA, Jaramillo S, Boyd L, Johnson B, Reed KR, Powell M. Mass Gathering Surveillance: New ESSENCE Report and Collaboration Win Gold in OR. Online Journal of Public Health Informatics 2017;9(1):e133.

489. Chapman WW, Christensen LM, Wagner MM, Haug PJ, Ivanov O, Dowling JN, et al. Classifying free-text triage chief complaints into syndromic categories with natural language processing. Artificial Intelligence in Medicine 2005;33(1):31-40.

490. Tsui F-C, Su H, Dowling J, Voorhees R, Espino J, Wagner M. An automated influenza-like-illness reporting system using freetext emergency department reports. Emerging Health Threats Journal 2011;4(1):s117.

491. Gevitz K, Madera R, Newbern C, Lojo J, Johnson CC. Risk of Fall-Related Injury due to Adverse Weather Events, Philadelphia, Pennsylvania, 2006-2011. Public Health Reports 2017;132(1).

492. Williams KA, Buechner JS. Evaluation of the Rhode Island Real-time Outbreak and Disease Surveillance (RI RODS) System: Disparate Data. Advances in Disease Surveillance 2007;2:219.

493. Lozier M, Martin C, Chaput D. Surveillance of Overdose-related Emergency Department Visits in Rhode Island. Online Journal of Public Health Informatics 2014;6(1):e165.

494. Williams KA, Espino J, Buechner JS. Syndromic Surveillance System User Satisfaction and Attitudes. Advances in Disease Surveillance 2007;2:220.

495. Cheng YE, Dhotre H, Das D, Drociuk D. Automatic and Secure Data Transfer of Syndromic Data between Hospitals and Public Health Using the PHINMS. Advances in Disease Surveillance 2008;5:14.

496. Dhotre H, Das D, Cheng E, Drociuk D. A Closer Look at Developing a Statewide Emergency Department Syndromic Surveillance System in a Rural State. Advances in Disease Surveillance 2008;5:24.

497. Johnson K, Alianell A, Radcliffe R. Seasonal Patterns in Syndromic Surveillance Emergency Department Data due to Respiratory Illnesses. Online Journal of Public Health Informatics 2014;6(1):e66.

498. Dhotre H, Springs C, Drociuk D, Cheng Y. A comparison of the fever–flu syndrome category with the SC ILINet surveillance system in South Carolina: 2009–2010 influenza season. Emerging Health Threats Journal 2011;4(1):s127.

499. Cheng Y, Dhotre H, Drociuk D. PHIN-MS deployment acceptability survey for the data transfer of syndromic data between hospitals and public health. Emerging Health Threats Journal 2011;4(1):s124.

500. Boeker S, Drociuk D, Jankelevich S, Kelly W, Steed C. Mutual Benefits in Partnerships between Hospital-based and Public Health Department Syndromic Surveillance Systems in Outbreak Detection and Investigation. Advances in Disease Surveillance 2007;4:146.

501. Boeker S, Drociuk D, Belflower AE, Steed C. A Novel Approach to Using Chief Complaint-Driven Syndromic Surveillance: Use of CDC's EARS-X by Hospital Infection Control Practitioners. Advances in Disease Surveillance 2007;2(144):144.

502. Lawson BM, Fitzhugh EC, Hall SP, Franklin C, Hutwagner LC, Seeman GM, et al. Multifaceted syndromic surveillance in a public health department using the Early Aberration Reporting System. Journal of Public Health Management & Practice 2005;11(4):274-81.

503. Chung WM, Buseman CM, Joyner SN, Hughes SM, Luby JP, Haley RW, et al. The 2012 West Nile encephalitis epidemic in Dallas, Texas. Journal of the American Medical Association 2013;310(3):297-307.

504. Adeleye O, Carvalho M, Halm M, Eshofonie A, Jr. ACR, AwosikaOlumo D. Using Syndromic Data to Investigate Gastrointestinal Illness Associated with Water Quality Complaints in Houston. Advances in Disease Surveillance 2007;4:141.

505. Halm M, Carvalho M, Eshofonie A, Awosika-Olumo D, Arafat R. Surveillance Zones: Geographic Aggregation of Syndromic Data for Improved Response. Advances in Disease Surveillance 2007;4:96.

506. Yang B, Wang N, McNeely W, Khuwaja S, Arafat R. Association between Influenza-like Illnesses and Social Determinants of Health by Census Tract in Houston/Harris County. Online Journal of Public Health Informatics 2014;6(1):e17.

507. Awosika-Olumo D, Mgbere O, Khuwaja S, Adeleye O, Arafat R. Relationship between Emergency Room (ER) Syndromic surveillance data and Influenza-Like Illness (ILI) Surveillance in Houston, Texas. Advances in Disease Surveillance 2007;4:145.

508. Stewart A, Carvalho M, Awosika-Olumo D. Mental Health Emergency Department Visits in Houston: Developing a Post-Disaster Mental Health Surveillance System. Advances in Disease Surveillance 2008;5:66.

509. Arnold RM, McNeely W, Muhetaer K, Yang B, Arafat RR. Application of Syndromic Surveillance to Describe Gunshot-related Injuries in Houston. Online Journal of Public Health Informatics 2015;7(1):e106.

510. Henry J, Murphy P, Pichette J, Andersen D, Cooks-Sinclair H. Natural disasters and use of syndromic surveillance: Austin, Texas Metro Area 2011. Emerging Health Threats Journal 2011;4:72.

511. Guerrero AC, Shim T, Kemple S, Nancy D. Walea, Viera F, Grota P, et al. Norovirus Outbreak Detected by Emergency Department Syndromic Surveillance using RedBat®. Advances in Disease Surveillance 2007;4:165.

512. Robertson J, Hill M. Evaluating the use of syndromic surveillance for the detection of influenza-like illness in Salt Lake County, Utah. Emerging Health Threats Journal 2011;4(1):s146.

513. Austin EE, Yang J, Powell T. Using GI Syndrome Data as an Early Warning Tool for Norovirus Outbreak Activity. Online Journal of Public Health Informatics 2013;5(1):e69.

514. Austin EE. Using Syndromic Surveillance Data to Describe Chronic High Frequency ED Utilization. Online Journal of Public Health Informatics 2015;7(1):e64.

515. Wahnich A, Hobron K, Austin EE, Powell T. Unintentional Drug Overdoses in Virginia: Analysis of Syndromic and Death Data. Online Journal of Public Health Informatics 2015;7(1):e97.

516. Austin EE. Coordinated Enhanced Surveillance with Healthcare Entities for Mass Gathering Events. Online Journal of Public Health Informatics 2017;9(1):e96.

517. Stephens E. Development of Syndrome Definitions for Acute Unintentional Drug and Heroin Overdose. Online Journal of Public Health Informatics 2017;9(1):e15.

518. Yuan CM, Love S, Wilson M. Syndromic Surveillance at Hospital Emergency Departments -- Southeastern Virginia. MMWR: Morbidity & Mortality Weekly Report 2004;53:56-8.

519. Baer A, Elbert Y, Burkom HS, Holtry R, Lombardo JS, Duchin JS. Usefulness of syndromic data sources for investigating morbidity resulting from a severe weather event. Disaster Medicine and Public Health Preparedness 2011;5(1):37-45.

520. Kwan-Gett TS, Baer A, Duchin JS. Spring 2009 H1N1 influenza outbreak in King County, Washington. Disaster Medicine and Public Health Preparedness 2009;3(Suppl. 2):S109-S16.

521. Lober WB, Baer A, Karras BT, Duchin JS. Collection and integration of clinical data for surveillance. Medinfo 2004;11:1211-5.

522. Baer A, Coberly J, Hung L, Burkom H, Loschen W, Lombardo J, et al. Classification of Emergency Department Syndromic Data for Seasonal Influenza Surveillance. Advances in Disease Surveillance 2007;4:233.

523. Baer A, Duchin J. Performance of a Syndromic Surveillance System for Detecting Carbon Monoxide Poisoning Following a Severe Windstorm. Advances in Disease Surveillance 2007;4:232.

524. Baer A, Jackson M, Duchin JS. What is the Value of a Positive Syndromic Surveillance Signal? Advances in Disease Surveillance 2007;2:192.

525. Baer A, Duchin J. Monitoring Staphylococcus Infection Trends with Biosurveillance Data. Advances in Disease Surveillance 2008;5:162.

526. Baer A, Elbert Y, Burkom H, Holtry R, Duchin J. Utility of Syndromic Surveillance for Investigating Morbidity Resulting from a Severe Weather Event. Advances in Disease Surveillance 2008;5:92.

527. Dilley JA, Baer A, Duchin J, Maher JE. Using a Syndromic Surveillance System to Evaluate the Impact of a Change in Alcohol Law. Online Journal of Public Health Informatics 2015;7(1):e70.

528. Lober WB, Trigg LJ, Karras BT, Bliss D, Ciliberti J, Stewart L, et al. Syndromic surveillance using automated collection of computerized discharge diagnoses. Journal of Urban Health 2003;80(1):i97-i106.

529. Duchin JS. Epidemiological response to syndromic surveillance signals. Journal of Urban Health 2003;80(1):i115-i6.

530. Baer A. An information visualization approach to improving data quality. Emerging Health Threats Journal 2011;4:10.

531. Rodriguez C, Baer A, Baseman J, Painter I, Yanez D, Koepsell T, et al. School absenteeism and emergency department ILI rates in King County, WA 2003–2009. Emerging Health Threats Journal 2011;4(1):s109.

532. Marsden-Haug N, Baer A, Metcalf H, Turner N, Shoemaker P, Duchin J. Syndromic Surveillance for Influenza in Washington State: A Local and Regional Perspective. Advances in Disease Surveillance 2007;4:256.

533. Karras B, Bliss D, Horn S, Metcalf H, Wagner S, BLober, et al. Syndromic Surveillance Information Collection – Geocodes for Urban to Rural Mixed Environments: SSIC-Geo. Advances in Disease Surveillance 2006;1:38.

534. Karras BT, Bliss D, Wagner S, Horn S, Lindquist S. Comparison of automated geocoding methods in a distributed multi-county disease surveillance system. Advances in Disease Surveillance 2007;2:16.

535. Turner N, Klementiev A. Integrating Early Event Detection into Local Disease Surveillance and Response. Advances in Disease Surveillance 2006;1:72.

536. Nania JM, Tansy RM. Monitoring the Vital Signs of Community Health-The Pyramid Syndromic Surveillance Project. Advances in Disease Surveillance 2007;4:58.

537. Karon AE, Heffernan RT. Google Flu Trends® versus ED Syndromic Surveillance, Wisconsin 2009. ISDS; Miami, Fl2009.

538. Foldy S, Biedrzycki PA, Barthell EN, Healy-Haney N, Baker BK, Howe DS, et al. Syndromic surveillance using regional emergency medicine Internet. Annals of Emergency Medicine 2004;44(3):242-6.

539. Foldy SL, Biedrzycki PA, Baker BK, Swain GR, Howe DS, Gieryn D, et al. The Public Health Dashboard: a surveillance model for bioterrorism preparedness. Journal of Public Health Management & Practice 2004;10(3):234-40.

540. Foldy S, Biedrzycki P, Barthell E, Haney-Healey N, Baker B, Howe D, et al. Milwaukee biosurveillance project: Real-time syndromic surveillance using secure regional internet. Journal of Urban Health 2003;80(1):i126-i.

541. Bellazzini MA, Minor KD. ED syndromic surveillance for novel H1N1 spring 2009. American Journal of Emergency Medicine 2011;29(1):70-4.

542. Marc A Bellazzini, Ronald E Gangnon, James E Svenson. Fever as a Measure for Early Detection of Influenza Outbreaks in the Emergency Department. Advances in Disease Surveillance 2008;5:4.

543. Bellazzini MA, Svenson JE. Discrete Data from Electronic Medical Records - Next Generation Data Sets for Syndromic Surveillance. Advances in Disease Surveillance 2008;5:3.

544. Kuramoto-Crawford SJ, Spies EL, Davies-Cole J. Detecting Suicide-Related Emergency Department Visits Among Adults Using the District of Columbia Syndromic Surveillance System. Public Health Reports 2017;132(1).

545. Griffin BA, Jain AK, Davies-Cole J, Glymph C, Lum G, Washington SC, et al. Early detection of influenza outbreaks using the DC Department of Health's syndromic surveillance system. BMC Public Health 2009;9:483.

546. Stoto MA, Jain A, Diamond A, Davies-Cole J, Adade A, Washington S, et al. Syndromic Surveillance System Evaluation -- District of Columbia, 2001-2004. MMWR: Morbidity & Mortality Weekly Report 2005;54:202-.

547. Lum GR, Siaway G, DeHaan K, Kidane G, Washington SC. Geospatial Direction of Syndromes in the District of Columbia. Advances in Disease Surveillance 2007;2:**57**.

548. Stoto MA, Jain A, Griffin BA, Davies-Cole JO, Lum G, Kidane G, et al. Evaluation of the DC Department of Health's Syndromic Surveillance System. Advances in Disease Surveillance 2007;2:213.

549. Lombardo J, Burkom H, Elbert E, Magruder S, Lewis SH, Loschen W, et al. A systems overview of the electronic surveillance system for the Early Notification of Community-Based Epidemics (ESSENCE II). Journal of Urban Health 2003;80:i32-i42.

550. Begier EM, Sockwell D, Branch LM, Davies-Cole JO, Jones LH, Edwards L, et al. The National Capitol Region's emergency department syndromic surveillance system: do chief complaint and discharge diagnosis yield different results? Emerging Infectious Diseases 2003;9(3):393-6.

551. Brown H, Kistner K, Zapata I, Romanosky A. Emergency Department Visits for Influenza-Like Illness and Over the Counter Sales of Flu Remedies in the National Capitol Region, 2003-2007. Advances in Disease Surveillance 2007;4:236.

552. Chu A, Blythe D, Tolson K, Collier D, Minson M. Identifying a Meningitis Case through Syndromic Surveillance: An Example of Detecting Events of Public Health Importance and Improving Situational Awareness. Advances in Disease Surveillance 2007;2:98.

553. Aslam S, , Brown H, , Ajit I, Adams S. Syndromic Surveillance for Historical 2009 Presidential Inauguration. ISDS; Miami, Fl 2009.

554. Zhang Y, May L, Stoto M. Evaluating University syndromic surveillance systems during the 2009 H1N1 influenza pandemic. Emerging Health Threats Journal 2011;4(1):s123.

555. Walsh A. Comparing Emergency Department Gunshot Wound Data with Mass Casualty Shooting Reports. Online Journal of Public Health Informatics 2017;9(1):e33.

556. Walsh A. Going Beyond Chief Complaints to Identify Opioid-Related Emergency Department Visits. Online Journal of Public Health Informatics 2017;9(1):e39.

557. Kaydos-Daniels SC, Rojas Smith L, Farris TR. Biosurveillance in outbreak investigations. Biosecurity and bioterrorism: Biodefense Strategy, Practice, and Science 2013;11(1):20-8.

558. Hiller KM, Stoneking L, Min A, Rhodes SM. Syndromic surveillance for influenza in the emergency department - a systematic review. PLoS ONE 2013;8(9):e73832.

559. Buckeridge DL. Outbreak detection through automated surveillance: a review of the determinants of detection. Journal of Biomedical Informatics 2007;40(4):370-9.

Appendix B: Diagnosis codes used in Chapter 5

Diagnostic codes mapped to the gastroenteritis syndromic surveillance indicator included in the EDSSS and used in **Chapter 5**.

Codes*	Codesystem
A09, R11.X	ICD-10[1]
62315008, 249519007, 75258004, 25374005, 111407006, 266071000, 16932000, 83227006, 11840006, 111843007, 422400008	Snomed CT[2]

*Only codes actually reported to EDSSS and used in this analysis are shown, additional relevant codes may exist

References

1. World Health Organisation. International Classification of Disease (ICD) 2010 [Available from: http://www.who.int/classifications/icd/en/.
2. International Health Terminology Standards Development Organisation. SNOMED CT 2012 [Available from: http://www.ihtsdo.org/snomed-ct/.

Appendix C: Diagnosis codes used in Chapter 6

Diagnostic codes mapped to for syndromic surveillance indicators included in the EDSSS (London) and OSCOUR® (Paris) emergency department systems and used in **Chapter 6**.

EDSSS		
Asthma	ICD-10	J450, J459
	Snomed CT	30352005, 31387002, 55570000, 57546000, 161527007, 182728008, 195967001, 266364000, 281239006, 304527002, 312453004, 370204008, 370218001, 370219009, 389145006, 401135008, 409663006, 425969006, 445427006, 201031000000108, 340901000000107, 589241000000104, 653751000000109
Difficulty breathing/ wheeze	ICD-10	R06.0, R060, R062, R068
	Snomed CT	9763007, 18197001, 23141003, 24612001, 55442000, 56018004, 58596002, 60845006, 62744007, 68095009, 70407001, 161941007, 161947006, 162891007, 162894004, 230145002, 233683003, 267036007, 301703002, 301826004, 307487006, 386813002, 427354000, 427679007, 442025000, 276191000000107, 498001000000107, 498011000000109, 502631000000100, 572661000000100, 755581000000101, 755591000000104, 755611000000107, 756081000000102
Myocardial ischemia	ICD-10	I200, I209, I219, I2510
	Snomed CT	22298006, 48447003, 53741008, 54329005, 57054005, 59021001, 67682002, 73795002, 155308009, 194828000, 233819005, 233822007, 233843008, 394659003, 398274000, 401303003, 401314000, 414545008, 414795007, 671571000000105
OSCOUR		
Asthme (Asthma)		J45, J450, J451, J458, J459, J46
Dyspnée/ Insuffisance respiratoire (Dyspnoea/ respiratory failure)		J960, J961, J961+0, J961+1, J969, R060
Ischémie myocardique (Myocardial ischemia)		I20, I200, I200+0, I201, I208, I209, I21, I210, I2100, I21000, I2108, I211, I2110, I21100, I2118, I2, I212, I2120, I21200, I2128, I213, I2130, I21300, I2138, I214, I2140, I21400, I2148, I219, I2190, I21900, I2198, I22, I220, I2200, I22000, I2208, I221, I2210, I22100, I2218, I228, I2280, I22800, I2288, I229, I2290, I22900, I2298, I23, I230, I231, I232, I233, I234, I235, I236, I238, I24, I240, I241, I248, I249, I25, I250, I251, I252, I253, I254, I255, I256, I258, I259

Appendix D: Diagnosis codes used in Chapter 7

Diagnostic codes mapped to syndromic surveillance indicators included in the EDSSS (England & Northern Ireland) and OSCOUR® (France) emergency department syndromic surveillance systems and used in **Chapter 7**.

Indicator	Country	Codes	Codesystem
Alcohol	England	F100, T519	ICD-10
		160573003, 160592001, 18653004, 191802004, 191806001, 222103001, 228273003, 25702006, 269765000, 2804500, 390941000000103, 42344001, 499611000000106, 53041004, 67426006, 82782008	Snomed CT
	France	F100, F1000, F1001, F1002, F1003, F1004, F1005, F1006, F1007, F102, F1020, F10200, F10201, F10202, F1021, F1022, F1023, F1024, F10240, F10241, F1025, F1026, F103, F1030, F1031, F104, F1040, F1041, Z502	ICD-10
	Northern Ireland	25702006, 67426006	Snomed CT
MI	England	I200, I209 ,I219, I2510	ICD-10
		155308009, 194828000, 22298006, 233819005, 233822007, 233838001, 394659003, 398274000, 401303003, 401314000, 414545008, 414795007, 53741008, 54329005, 57054005, 59021001, 623341000000106, 67682002, 73795002, 73999000	Snomed CT
	France	I20, I200, I200+0, I201, I208, I209, I21, I210, I2100, I21000, I2108, I211, I2110, I21100, I2118, I212, I2120, I21200, I2128, I213, I2130, I21300, I2138, I214, I2140, I21400, I2148, I219, I2190, I21900, I2198, I22, I220, I2200, I22000, I2208, I221, I2210, I22100, I2218, I228, I2280, I22800, I2288, I229, I2290, I22900, I2298, I23, I230, I231, I232, I233, I234, I235, I236, I238, I24, I240, I241, I248, I249, I25, I250, I251, I252, I253, I254, I255, I256, I258, I259	ICD-10
	Northern Ireland	155308009, 194828000, 22298006, 233819005, 394659003, 401303003, 401314000	Snomed CT