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SUPPLEMENT ARTICLE

Participatory Syndromic Surveillance of Influenza in Europe

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The growth of digital communication technologies for public health is offering an unconventional means to engage the general public in monitoring community health. Here we present Influenzanet, a participatory system for the syndromic surveillance of influenza-like illness (ILI) in Europe. Through standardized online surveys, the system collects detailed profile information and self-reported symptoms volunteered by participants resident in the Influenzanet countries. Established in 2009, it now includes 10 countries representing more than half of the 28 member states of the European Union population. The experience of 7 influenza seasons illustrates how Influenzanet has become an adjunct to existing ILI surveillance networks, offering coherence across countries, inclusion of nonmedically attended ILI, flexibility in case definition, and facilitating individual-level epidemiological analyses generally not possible in standard systems. Having the sensitivity to timely detect substantial changes in population health, Influenzanet has the potential to become a viable instrument for a wide variety of applications in public health preparedness and control.

Keywords. influenza; surveillance; crowdsourced data; Internet; cohort; risk factors.

INFLUENZA SURVEILLANCE IN EUROPE

Seasonal influenza is a contagious respiratory disease that annually infects approximately 10%–30% of Europe's population, causing increased hospitalization rates and excess deaths during winter [1]. Influenza surveillance is conducted by European Union member states and coordinated by the European Center for Disease Prevention and Control (ECDC) via the European Influenza Surveillance Network (EISN). The EISN combines epidemiological and virological data obtained at different layers of surveillance. Nationally organized networks of general practitioners (GPs) constitute the basis of public health surveillance (Figure 1*A*), reporting the weekly number of patients visited with influenza-like illness (ILI) or acute respiratory infection (ARI) in selected healthcare facilities (sentinels). Some countries also report virological information from a subset of patients, influenza-confirmed hospitalizations, or mortality data. The aim of collating data from different layers of surveillance is to better assess the intensity and spread of influenza, identify trends and risk groups, and inform actions to reduce the influenza-associated burden in Europe.

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The increased use of digital communication technologies for public health [2] has recently facilitated adding the general public as a key actor for surveillance, thereby enabling individuals to contribute to monitoring the health of their community. The result is a large amount of crowdsourced digital data that can be rapidly analyzed to track disease activity directly in the general population, thus providing health authorities with an additional and potentially scalable layer of surveillance (Figure 1*A*). Participatory systems generally rely on individuals' self-assessment of their health. ILI has thus offered a straightforward surveillance objective for the early development of these systems [3–7], given its seasonal occurrence, its large incidence in the population, and the set of easily recognizable clinical symptoms that it may cause [8].

The Influenzanet participatory surveillance system was established in Europe in 2009 and included 5 countries (Figure 1*B*), 4 of which (the Netherlands, Belgium, Portugal, and Italy) already had prior web-based participatory surveillance experience [4]. The system is based on online survey technology to conduct syndromic surveillance through self-reported symptoms volunteered by participants resident in the Influenzanet countries. It is based on a website describing the system, its objectives, and main results (available at: http://www.influenzanet.eu) and pointing to the national web platforms responsible for data collection for national surveillance. These platforms collect background demographic and risk-factor data from participants upon enrollment, capture their weekly symptoms, and report analyzed surveillance results.

At the outset, the Influenzanet platform was not homogeneous across countries because of historical developments leading to the

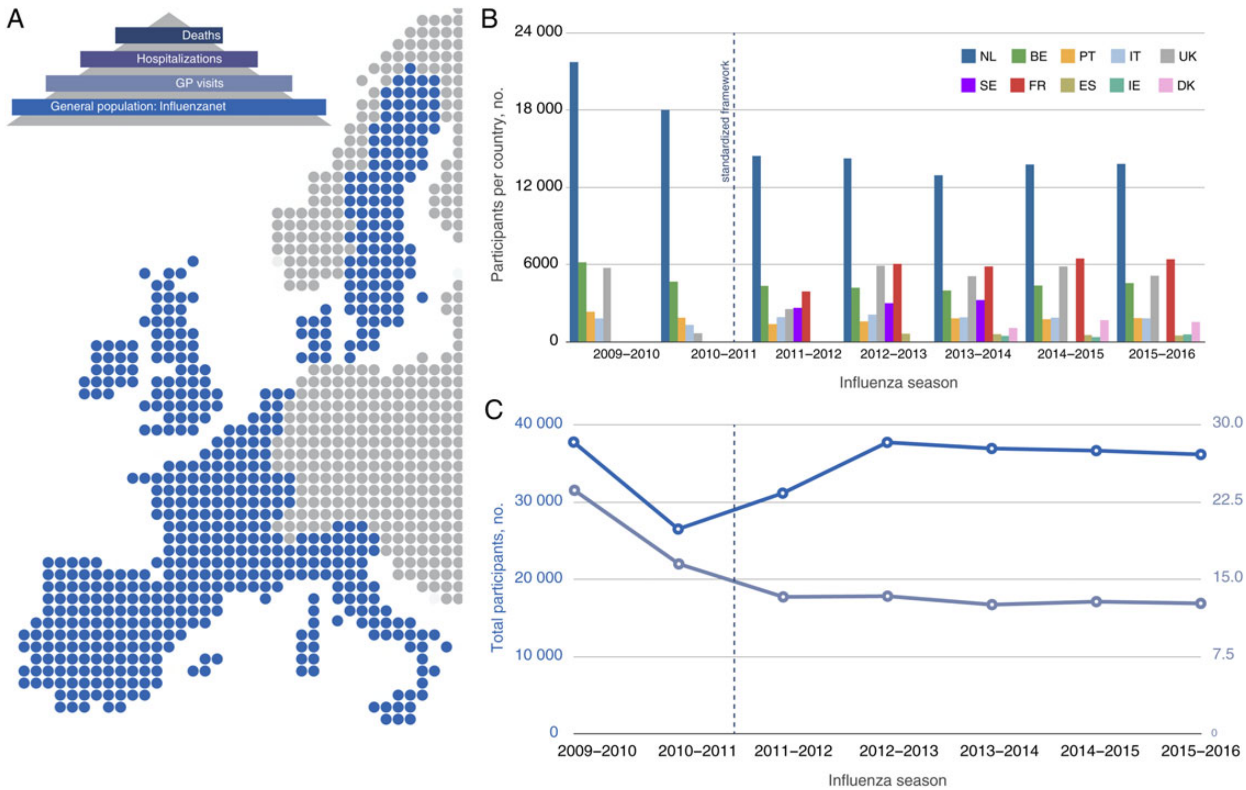

Figure 1. Influenzanet participatory surveillance system for influenza-like illness (ILI). *A*, ILI monitoring scheme illustrating different layers of surveillance used by public health authorities, including (depending on the country) sentinel general practitioner (GP) networks counting ILI visits, ILI-associated hospitalization data, and ILI-associated mortality data. Influenzanet represents an additional layer for ILI monitoring, through syndromic surveillance in the general population by means of a web-based participatory system. It includes the following 10 countries schematically represented in the map: the Netherlands (NL; available at: http://www.degrotegriepmeting.nl), Belgium (BE; http://www.degrotegriepmeting.be), Portugal (PT; http://www.gripenet.pt), Italy (IT; http://www.influweb.it), the United Kingdom (UK; http://flusurvey.org.uk), Sweden (SE; http://www.halsorapport.se), France (FR; http://www.grippenet.fr), Spain (ES; http://www.gripenet.es), Ireland (IE; http://flusurvey.ie), and Denmark (DK; http://influmeter.dk). *B*, Number of Influenzanet participants per country per season since its launch in 2009–2010 influenza season. The dashed vertical line indicates the standardized framework introduced from the 2011–2012 season. *C*, Total number of Influenzanet participants per season (left axis) and rate of Influenzanet participation per season (right axis) expressed as the number of participants per 100 000 individuals of the total population of Influenzanet countries.

project [4]. It was built on the Dutch and Belgian experience of de Grote Griepmeting (The Great Influenza Survey) launched during the 2003–2004 influenza season [3]. The system was then adopted by Portugal (in 2005) and Italy (in 2008) with a different technological platform although similar survey. The aim of Influenzanet was to establish a standardized syndromic surveillance system across European countries from both a technological and epidemiological point of view. Standardized technology is crucial for the seamless introduction of the system in a new country, thus minimizing costs and technological challenges in the implementation and adaptation to a different population (eg, language, content, and server), while ensuring high functionality and usability. A standardized epidemiological survey is needed to maximize coherence across national surveillance networks and thus overcome the differences in case definitions, population under surveillance, and data formats across countries, currently present in sentinel influenza surveillance in Europe [1].

The first Influenzanet season (2009–2010) was rather unusual as it was characterized by the spread of 2009 pandemic influenza A(H1N1) strain (A[H1N1]pdm09). Technological development of Influenzanet was halted to give priority to ILI surveillance through intensified recruitment efforts and surveillance during summer 2009. By the start of the 2011–2012 influenza season, the Influenzanet standardized framework was ready and implemented in all countries.

Since its launch in 2009, Influenzanet has doubled the number of participating countries, now representing 36% of the 28 member states and more than half (58%) of the population in the European Union. Its web approach has the ability to generate data from the general population and not only from medically attended ILI. Its crowdsourced data offer flexibility for the exploration of different ILI or ARI case definitions, provide detailed information to profile the population under surveillance, to estimate vaccine coverage or assess ILI-associated behaviors. Its standardized framework and centralized European database allow for country-level analyses and rapid extension to the European level, maintaining identical criteria and definitions. Here we review the Influenzanet surveillance system since its launch, summarize main findings and limitations, present a new study on ILI risk factors as an example application, discuss Influenzanet's value for public health, and explore its future developments.

INFLUENZANET SYSTEM: DATA COLLECTION, MANAGEMENT, AND ANALYSES

Participation in Influenzanet is voluntary and anonymous, and it is open to all residents of participating countries. Recruitment occurs through communications of supporting institutions, mainstream and social media, dissemination events (eg, science fairs or school dissemination activities), and word of mouth (social media or email invitations through the system).

To join the network, individuals register on their national platform and complete an intake survey covering demographic, geographic, socioeconomic (household size and composition, occupation, education, and transportation), and health (vaccination, diet, pregnancy, smoking, and underlying medical conditions) indicators. The intake survey can be updated throughout the season to account for changes (eg, vaccination or pregnancy). Multiuser accounts are also available to facilitate group participation and reporting for individuals, such as children or elderly people, who are unable to navigate the Internet.

Crowdsourced symptom data are obtained on a weekly basis through a symptom survey. Participants are asked whether they experienced any of the following symptoms (or "no symptoms") since their last survey: fever, chills, runny or blocked nose, sneezing, sore throat, cough, shortness of breath, headache, muscle/joint pain, chest pain, feeling tired or exhausted, loss of appetite, colored sputum, watery/bloodshot eyes, nausea, vomiting, diarrhea, stomach ache, or other symptoms. If symptoms are reported, further questions are asked to assess the syndrome (eg, sudden onset of symptoms and body temperature) and participant behavior (eg, health-seeking behavior and medicine uptake, including painkillers or antipyretics, cough medications, antivirals, and antibiotics).

The list of symptoms was chosen to include the various ILI definitions adopted by national surveillance systems in Europe. Moreover, following the A(H1N1)pdm09 experience, we decided to enlarge the list to include gastroenterological symptoms. The aim was to get a comprehensive list of symptoms that could be clearly articulated and understood by participants and would enable us to distinguish within a range of potentially flu-related illnesses.

Individuals can access and complete the survey at any time and are reminded weekly by a newsletter, which also summarizes Influenzanet findings. Additional questions can be implemented by countries for specific studies. Crowdsourced data are analyzed in real time, and national and regional results are posted on the system websites. They are also published in the weekly national surveillance bulletins of some participating countries (also increasing the system's visibility for recruitment). Targeted and more-local information are accessible to participants only.

Influenzanet is performed by universities and research institutions (in Italy, Spain, and Ireland), public health agencies (in the United Kingdom, Sweden, France, Portugal, and Denmark), and private companies (in the Netherlands and Belgium); some countries transitioned in recent years (United Kingdom and Portugal have been supported by public health agencies since 2015). Some of the teams (in France, Portugal, and Sweden) are also members of the EISN. Influenzanet is conducted in agreement with national regulations on privacy and data collection and treatment [9].

The Influenzanet surveillance season generally runs from October/November to April/May, allowing for flexibility (eg, a press conference on the vaccination campaign, to increase dissemination at season launch). ILI syndrome assessment is built on the basis of reported symptoms. Influenzanet uses the ECDC case definition (sudden onset of symptoms; at least 1 of fever or chills, malaise, headache, or muscle pain; and at least 1 of cough, sore throat, or shortness of breath) [8], in addition to country-specific case definitions, to allow for comparison with GP surveillance [10].

Inclusion criteria for participants may vary depending on the aim of the study. Several Influenzanet works [9, 11–13] included participants who submitted at least 3 reports per season, whereas a more constrained definition was used to study enrollment strategies [14]. Here, for the analysis of ILI risk factors, we included participants who reported at least once before, during, and after the epidemic period, to ensure a minimum participation level throughout the season. We considered data from United Kingdom, France, Spain, Ireland, and Denmark in the 2014–2015 season and used ECDC case definition to complete previous work conducted on the remaining countries [11,13]. Odds ratios (ORs) were calculated for the covariates collected with the intake survey, based on a multivariate logistic regression model through a backward stepwise selection. As the ILI outcome is not a rare event, we also corrected ORs to estimate the relative risk (RR) and 95% confidence intervals. Additional details are provided in Table 1.

INFLUENZANET RESULTS AND DISCUSSION

Since the launch of Influenzanet, 243 109 individuals (considered independently per season) joined the system, completing the intake survey and reporting at least once. Participation across seasons saw a general decrease after the pandemic (Figure 1*B* and 1*C*), visible for the United Kingdom and statistically significant for the Netherlands and Portugal as compared to their previous results (average number of participants per season before vs after 2009: 20 597 vs 15 564 [$P < 10^{-3}$, by the Student *t* test] and 3447 vs 1800 [$P = .003$, by the Student *t* test], respectively). This may be a reaction to the substantial effort required for continued surveillance of participants during a pandemic season. We argue that it may also be a resulting effect of the controversies over vaccine safety and pandemic management [15], fueling public dissonance and translating into negative experiences for individuals [15–17]. The effect appears to rapidly wane in the Influenzanet system, with a stabilized number of Dutch participants (the largest contribution to Influenzanet) and the addition of new countries since 2011.

Table 1. Adjusted Risk Factors, Obtained from Multivariate Regression Analyses, for Influenza-Like Illness (ILI) Across Influenzanet Countries

Countries	NL, BE, PT, IT[a]	UK[b]	FR[b]
Study period	2003–2013	2014–2015	2014–2015
Study participants per season, no., mean	24 666[c]	2629	4475
Female sex	1.22 (1.17–1.28)	1.25 (1.14–1.36)	1.12 (1.02–1.23)
Vaccinated	0.80 (.71–.91)[d]	S[e]	0.87 (.78–.97)
Age, y			
NL, BE, PT, IT			
<18	1.59 (1.46–1.74)	. . .	. . .
18–49	Reference	. . .	. . .
50–64	0.82 (.78–.86)	. . .	. . .
≥65	0.46 (.41–.51)	. . .	. . .
UK, FR			
0–14	. . .	1.27 (1.03–1.50)	0.95 (.76–1.16)
15–44	. . .	Reference	Reference
45–64	. . .	0.99 (.89–1.11)	0.87 (.76–0.98)
≥65	. . .	0.82 (.71–.94)	0.68 (.58–.79)
Children in household (vs living alone)	1.31 (1.22–1.40)	S[e]	S[e]
Contact with groups[f]	ND	1.11 (1.01–1.21)	1.12 (1.01–1.23)
Smoker	1.16 (1.10–1.22)	S[e]	S[e]
Underlying health condition			
Asthma[g]	1.58 (1.47–1.69)	. . .	. . .
Diabetes	1.27 (1.15–1.41)	. . .	. . .
Heart	1.29 (1.13–1.47)	. . .	. . .
Kidney	1.23 (.80–1.90)	. . .	. . .
Immune	1.23 (1.02–1.49)	. . .	. . .
Any	. . .	S[e]	1.17 (1.05–1.30)
Having respiratory allergies	ND	1.14 (1.05–1.24)	1.19 (1.07–1.29)
Declaring often having ILI	ND	ND	1.31 (1.17–1.45)
Sports participation for >1 h/wk	0.95 (.90–1.00)	ND	ND
Having pets			
Dogs	1.15 (1.09–1.22)	. . .	. . .
Cats	1.07 (1.02–1.12)	. . .	. . .
Any	. . .	ND	1.17 (1.08–1.28)
Daily transportation method			
Bike/foot	0.95 (.90–1.00)	NS[h]	S[e]
Car	Reference	. . .	. . .
Public	0.97 (.89–1.05)	. . .	. . .

The analysis for Denmark (981 participants) and Spain (368 participants) for the 2014–2015 season showed similar results for the age classes (for both countries) and for female sex (for Denmark). The analysis for Ireland (210 participants) for the same season did not show significant results.

Abbreviations: BE, Belgium; CI, confidence interval; FR, France; IT, Italy; ND, no data; NL, Netherlands; PT, Portugal; RR, relative risk; UK, United Kingdom.

[a] Data are RR (95% CI), unless otherwise indicated. Inclusion criteria in this study were slightly different [13]: at least 3 symptoms survey, considering ILI episodes during the weeks when influenza virus strains were circulating in the population. All covariates considered as potential risk factors were included and remained in the final multivariate model. All participants were considered independent between seasons. Only vaccination was considered as a season-dependent covariate, and country of residence and season were added in the model as extra covariates.

[b] Data are RR (95% CI), unless otherwise indicated. All covariates collected in the intake survey were considered and included in the final multivariate analyses if they had univariate *P* value of <.2. Backward stepwise selection was considered to retain adjusted covariates with a *P* value of <.05 in the final models. A Hosmer-Lemeshow test was computed to estimate the final model's quality. All models had a *P* value of >.05, suggesting that they were correctly specified.

[c] There were 16 481 subjects from the NL, 5072 from BE, 1894 from PT, and 1219 from IT.

[d] Data are for the 2012–2013 season only.

[e] The covariate was significant (S) in the univariate analyses ($P < .2$) but not selected by multivariate logistic regression ($P > .05$).

[f] Contact with any groups of children, elderly, patients, or crowds during the course of a typical day.

[g] Asthma or other lung diseases.

[h] The covariate was nonsignificant (NS) in the univariate logistic regression analyses ($P > .2$), so it was not tested in the multivariate analyses.

For the 2015–2016 season, Influenzanet registered 36 192 participants with a rate of participation of 13 individuals per 100 000 population. Participation by country varies considerably [9], with averages over all seasons ranging from 1.2 individuals per 100 000 population, for Spain, to almost 100 individuals per 100 000 population for the Netherlands, notably the most successful example within Influenzanet [18]. New countries have shown to be able to quickly attract a large enough number of participants to generate reliable surveillance data [10,19], a promising result for further extending the system.

The observed heterogeneity across countries may be associated with diffused trust in the media and Internet, larger interest of the general public in health-related topics, and larger healthcare expenditure (unpublished Influenzanet data).

Recruitment and retention are the 2 main challenges for Influenzanet. Televised appearances at the early stages of de Grote Griepmeting and dissemination by communication scientists led to considerable growth in the number of participants, successfully retained across years [11, 13]. By comparison, isolated spikes in participation, indicating high drop-out rates, were instead observed in a similar participatory system in the United States [5]. Continuous reporting throughout the season is essential to ensure data quality. Since the standardized framework has been in place, Influenzanet has collected 2 694 065 symptom reports (up to April 2016), with 543 895 collected in the last season and a weekly average of 22 768. Participants can join the system at any time during the surveillance season, and on average they submit 14–16 reports each in a season. A total of 67%–91% of them, depending on the country, submitted at least 3 reports in season 2014–2015, with small variations across seasons [9]. These statistics indicate a good compliance for reporting that can be due to various factors: strong interest in being actively engaged in a health project [18] and rather easy access and use of the Influenzanet platform (>93% of French and Portuguese participants declared that the survey's length was good, and >97% of them were satisfied or very satisfied with the website). Individuals with a higher participation rate were found to have been recruited through offline communication more likely than through online media, except for France [14], where a considerable fraction of participants (21%) is referred to Influenzanet from institutional public health websites. Different strategies need therefore to be considered by countries to promote the project and grow in participation.

Statistically significant differences exist when the Influenzanet cohort is compared to national populations [9, 10]. Higher female participation occurs in the majority of countries, as in other studies [5, 7], possibly because of more-active information-seeking behavior in women [20] . All age classes are represented in the cohort, but younger (age, <30 years) and older (age, ≥70 years) individuals are considerably underrepresented, perhaps for lack of interest or difficulty of access. Specific communication activities and tools (eg, for schools and senior classes) have been implemented in several countries to target these age groups. Also, a marked increase in participation of elderly individuals has been observed over the years [11], likely owing to increasing Internet use in this group, suggesting that discrepancies may decrease in time. Vaccination coverage among individuals aged ≥65 years is generally higher in the Influenzanet population, suggesting a higher health awareness in the cohort.

Despite these discrepancies, trends of estimated ILI incidence from Influenzanet reports compare well with those of national sentinel systems [4, 10, 11, 19, 21]. An anticipation of about 1 week in the peak of Influenzanet incidence is found compared to sentinel estimations, suggesting that the time needed to consult a physician and collate sentinel data may be absorbed once data are collected directly from the general population and analyzed in a timely fashion. The Influenzanet cohort has also been used to estimate vaccine effectiveness in real time [22], vaccine coverage in specific subgroups [23], and individual perceptions toward vaccination [17] and to correct estimations of the pandemic burden by accounting for changes in social contacts patterns and in health-seeking behavior [24, 25].

Most importantly, individual data on demographic indicators and on lifestyle and health variables and the monitoring of a wide variety of cases allow us to examine risk factors for specific conditions to a level of detail that is hardly achievable in sentinel systems. The analysis based on single and multiple influenza seasons (Table 1) suggests that belonging to a younger age group, being female, living with or having contacts with children, having an underlying chronic health conditions, having respiratory allergies, smoking daily, and having pets are factors associated with an increased risk of having an ILI episode during the influenza season. Vaccination provided a reduction in the risk, although it was found to depend on the season [13]. These results are generally consistent with previous findings [26–28]. Children are known to have a major role in the dissemination of influenza [26]. Chronic illness was found to be a major driver for influenza complication and hospitalization [27]. Cigarette smoking represents a substantial risk factor for important bacterial and viral infections [28]. In addition, we found that women have an increased risk in all countries and seasons under study, even when adjusting for living or having contacts with children. Although this risk factor was not reported by GP surveillance, it was found in previous cohort studies involving adults without children [26]. It would be interesting to explore whether this sex-specific differential is not observed in routine GP surveillance, owing to differences in health-seeking behavior between men and women. This is not observed in self-reporting in many Influenzanet countries, and thus other factors, such as unmeasured confounders, may be at play. Daily use of public transportation was not statistically associated with a higher risk of contracting ILI, contrary to widespread public concerns. This is in line with previous work for the risk of ARI once frequent use is considered [29].

Influenzanet flexibility allows the integration of additional questions for specific studies or target populations that are usually not considered in routine analyses. A study of French Influenzanet pregnant women showed a higher ILI incidence among women aged ≥40 years and during the first/second trimester [23]. Investigating stress indicators revealed significant trends between stress and self-reported ILI [30].

CONCLUSIONS

Influenzanet is a well-established standardized participatory surveillance system for ILI in Europe, covering more than one third of the 28 EU member states. Its strength lies in (1) the standardized technological and epidemiological framework for a coherent surveillance across countries; (2) the ability to timely monitor ILI in the general population, including individuals who do not seek medical assistance; (3) its sensitivity in detecting substantial changes in population health earlier than GP sentinel networks; (4) its potential scalability to large numbers with rather limited costs; (5) its flexibility in exploring different ILI definitions; (6) the detailed profile data allowing individual-level epidemiological analyses generally not possible in standard systems; and (7) its potential extension to other diseases. Its limitations are mainly due to the self-selected sample, potential misreporting, and lack of validation by a physician or by virological testing. However, the agreement found with GP incidence trends suggests that these limitations have little effect once results are adjusted for lack of representativeness.

Immediate steps for Influenzanet include the extension to other European countries and establishing a global collaborative framework for ILI surveillance with other similar participatory systems outside Europe. Virological confirmation has also been tested in pilot studies for future integration.

Main challenges remain the baseline maintenance resources to sustain the system in the long run and the recruitment and retention of participants. While the identification of sociocultural determinants for participation will provide additional insights, the strong willingness for engagement found in most countries' participants confirms the feasibility of the approach. Moreover, the platform represents a crucial channel for communication with the public, to inform and increase awareness, an increasingly important aspect after the 2009 pandemic.

Launched as a research project, Influenzanet is currently considered as an adjunct to existing ILI surveillance systems and has been adopted in some cases by public health agencies. Its flexibility in system configuration potentially allows for a wide variety of applications in public health preparedness and control. Sweden, for example, has tested a different method, based on invitation only, in the last 2 seasons to track the health situation of the country.

Influenzanet may therefore represent a viable complement to existing monitoring approaches to provide additional information that standard methods cannot rapidly achieve. Italy is now extending the surveillance effort to monitor cases of Zika virus infection with the approaching of the summer. In France, a food-consumption survey submitted to Influenzanet participants for an outbreak investigation during a *Salmonella* epidemic in early 2016 provided public health authorities with timely findings to identify the source of the outbreak. With the large majority of participants willing to contribute to additional studies beyond ILI, Influenzanet may become in the near future a powerful system that, once adjusted for sample biases, can offer a timely tool to measure the epidemiological status, opinion, or behavior of the general population with regard to different indicators and diseases.

Notes

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