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Association between growth of the SARS-CoV-2 epidemic and increased coughing rate in cold temperatures: surveillance in Hokkaido, Japan

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ABSTRACT

Objective Although the transmissibility of SARS-CoV-2 in winter is thought to increase through viral droplets when coughing, current epidemiological data in this regard are limited.

Setting Using the national epidemiological surveillance data in the autumn and winter seasons in Hokkaido, Japan, between February 2020 and February 2021, we analysed the relationship between case increase ratio and prevalence rate of coughing in patients with PCR-confirmed SARS-CoV-2 in two age groups (0—40s and 50—100s) with concomitant air temperature and humidity.

Participants The 7893 cases of symptomatic PCR-positive patients consisted of 5361 cases in the young age group and 2532 cases in the older age group.

Primary and secondary outcome measures Pearson's correlation analysis and regression models were used to assess the relationships. Sex-adjusted OR of having cough in the young and old age groups in the autumn and winter seasons was calculated using logistic regression analysis.

Results The monthly prevalence rate of coughing in the young age group was negatively correlated with temperature ($r=-0.77$, $p<0.05$), and in the old age group it was negatively correlated with humidity ($r=-0.71$, $p<0.05$). Quadratic regression models were fitted for the relationship between cold temperatures and rate of coughing rate in the young age group and case increase ratios. The sex-adjusted OR of having a cough in the young age group in winter was 1.18 (95% CI 1.05 to 1.31) as compared with autumn.

Conclusions The results suggest increased rate of coughing contributes to the epidemic of SARS-CoV-2 in the winter. An effective control with a focus on these trends should be considered.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ We included a large data set (>7000) of PCR-confirmed COVID-19 cases with detailed associated symptoms.
- ⇒ The data cover the SARS-CoV-2 epidemic waves in the winter and autumn seasons.
- ⇒ The study was geographically restricted to Hokkaido, Japan.
- ⇒ The data included no knowledge of underlying comorbidities.

INTRODUCTION

The transmissibility of SARS-CoV-2 is thought to be dependent on each mode and setting of virus spread, such as person-to-person contact or through viral droplets when sneezing and coughing, rate of social mobility, condition of indoor ventilation, as well as individual distancing and personal protection (ie, wearing mask and hand hygiene).[1] Significant viral transmission occurs through droplet nuclei in the air, and for SARS-CoV-2 in particular the role of aerosols in the growth of the epidemic has been suggested.[2 3] Saliva droplets and aerosols exhaled when breathing or coughing are thus considered among the main causes of the spread of SARS-CoV-2 and many studies have modelled how contamination can occur within confined spaces through such aerosols.[4 5] Ventilation systems are recognised to play an important role in viral dissemination, as evidenced by the 2003 severe acute respiratory syndrome epidemic, when one index case led to 292 secondary cases living in the same block of flats, mostly likely transmitted through the ventilation system.[6] Closing or restricting social and economic activities in the community significantly impacts the epidemic dynamics.[7] Meanwhile, the transmissibility of SARS-CoV-2 varied over place and time.[8–10] In particular, in many countries in the northern hemisphere a more rapid increase of the epidemic was detected after the summer season in 2020, a trend suggesting the winter seasonality of the SARS-CoV-2 epidemic.[11 12] However, epidemiological data in this regard are limited. In this study, we compared the weekly case increase ratio and the prevalence rate of coughing, as well as air temperature and humidity, in order to examine the seasonal characteristics of SARS-CoV-2. We assumed that a change in the prevalence rate of coughing affects the rate of virus spread and transmission. We used data on the symptoms of patients with PCR-confirmed SARS-CoV-2 in Hokkaido, Japan. Data were collected by the local health office using an existing surveillance system of infectious diseases which has been in operation for over decades in the area.

MATERIALS AND METHODS

We used the surveillance data in Hokkaido Prefecture, which recorded clinical symptoms at the early stage of SARS-CoV-2 infection (a period of 1–2 weeks after any symptom appeared and until PCR test was conducted) in patients with PCR-confirmed SARS-CoV-2 in the autumn and winter seasons (February and March, between September and December 2020, and January and February 2021). The data for autumn included the period between September and November 2020, while the data for winter included the period between February and March 2020, and between December 2020 and February 2021. The data were collected by the local health office and uploaded to the web with an anonymous individual code.[13] In Hokkaido, PCR laboratory testing is conducted by the local health office by nasal or throat swabs of patients who present with any suspected SARS-CoV-2 symptoms. To follow this testing, active surveillance with PCR testing was carried out for people who had been in contact with an infected person. Early clinical symptoms (a period of 1–2 weeks after any symptom appeared) of patients with PCR-confirmed SARS-CoV-2 were then recorded together with patients' baseline information (sex, age group (10-year age group bins) and resident district) and the data uploaded to the web page.[13] We used the data of patients who presented any symptom during the study period based on the onset date.

Weekly prevalence rate and case increase ratio

We depicted the weekly epidemic curve in Hokkaido. We calculated the average of the period between the first symptoms and having the results of the PCR test within symptomatic patients in Hokkaido. We summarised the prevalence rate of all symptoms reported in the surveillance system. After analysing the monthly trend as well as the prevalence rate of coughing in 10-year age group bins, the data were stratified into two age groups (young age group 0—40s and old age group 50—100s) (online supplemental figure S1). χ^2 analysis was used to compare the prevalence rate between the young and the old age group. We also calculated the monthly and weekly prevalence rate of coughing within symptomatic patients based on the week when any symptom appeared (onset date).

We compared the prevalence rate of coughing and the trend in weekly case increase ratio (the ratio between the number of cases of the current week and the number of cases of the previous week) by the estimated infection date (4 days prior to the onset date, based on the average incubation period of COVID-19)[14] between September and October 2020 (from the beginning and midterm of the autumn season, which was before the week of the intervention of closing pubs and restaurants during night hours in the beginning of November and onwards in the area).

Regression models of having cough in winter season

Pearson's correlation analyses (one-sided) between the monthly average of temperature and humidity[15] and the prevalence rate were performed, respectively (using the data between September and November 2020 for autumn and between February and March 2020 and between December 2020 and February 2021 for winter). Quadratic regression models were used to assess the relationship between cold temperatures, coughing rates and case increase ratios. Sex-adjusted ORs of having cough in the young and old age groups in the autumn and winter seasons were calculated using logistic regression analysis. Statistical analysis was performed using SPSS V.21. The level of significance was set at 5%. For multiple comparisons, p values were adjusted using Bonferroni corrections.

Patient and public involvement

We used open-source surveillance data. No patients were involved in this study.

RESULTS

PCR-positive samples and clinical symptoms

The positivity rate of PCR testing in Hokkaido during the study period was 5.3% (online supplemental table S1; the results also included antigen testing but majority of testing conducted was PCR testing). The number of PCR-positive patients with symptoms during the period was 7893 in Hokkaido (excluding cases with no symptoms (n=1413) and with the age group or symptoms unspecified (n=5002)). These consisted of 5361 cases for the young age group and 2532 cases for the old age group.

The PCR-positive cases of SARS-CoV-2 increased gradually in the beginning of the autumn season (figure 1A). The increase in cases was first detected in the young age group and then relatively more rapidly in both age groups after the second week of October.

The average of the period between onset of any symptom and having the results of the PCR test was 4.10 days (95% CI 4.05 to 4.16). The prevalence rates of symptoms reported in the surveillance were ~78% for fever, ~47% for cough, ~31% for malaise, ~30% for sore throat and ~26% for headache (figure 2). The prevalence rate of symptoms was significantly higher in the young age group for sore throat, nasal disorder, headache, taste disorder, olfactory disorder, muscle pain and arthralgia, and chills, while the prevalence rate of symptoms was significantly higher for cough, fever, and pneumonia or breathing disorder in the old age group.

Case increase ratio, coughing rate, and temperature and humidity

The weekly prevalence rate of coughing gradually increased in both age groups after the beginning of

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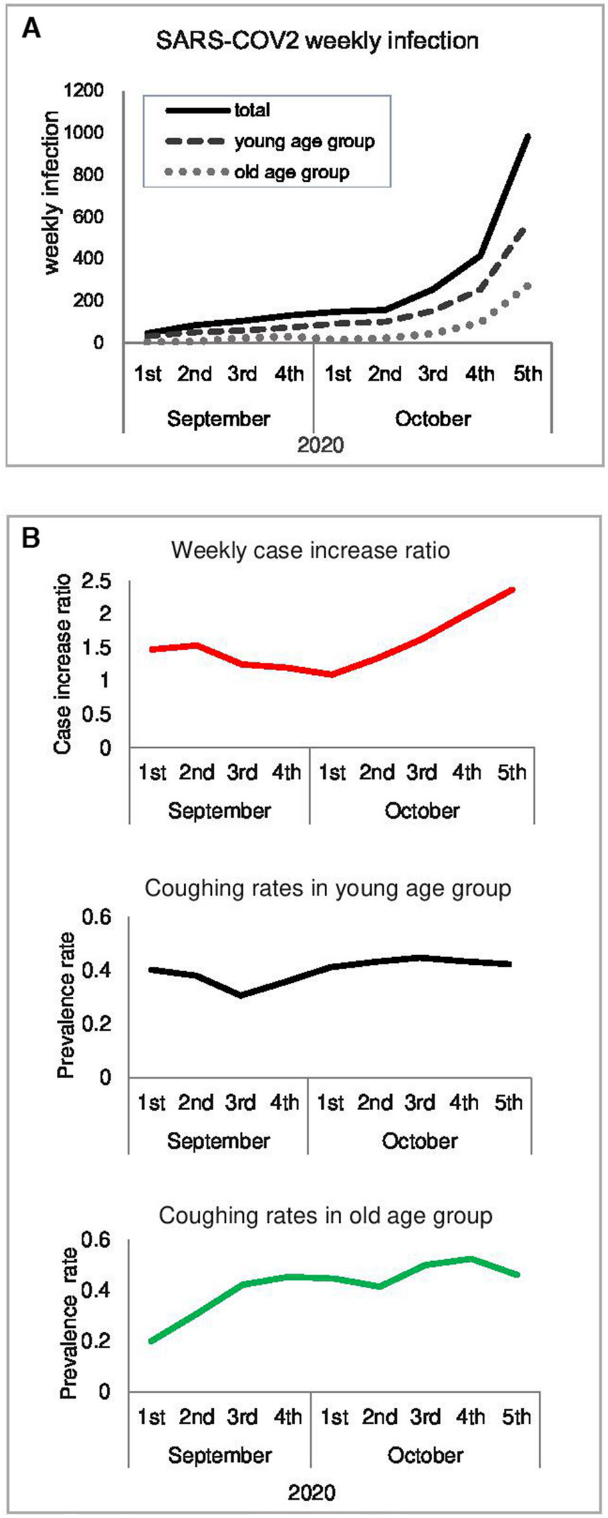

Figure 1 Epidemic curve of SARS-CoV-2. (A) The weekly number of patients with PCR-confirmed SARS-CoV-2 in Hokkaido between September and October 2020 (before the intervention period which started in November 2020 onwards) is shown (n=2325 in total, calculated based on the estimated infected date (4 days prior to the onset date), n=1385 for the young age group and n=571 for the old age group). Patients whose onset date was unknown were counted on the date 7 days prior to the reported date. Patients whose age was unknown were included in the total. Patients with no symptoms were excluded. (B) The weekly case increase ratio (2-week moving average of the weekly ratio of the current week's cases to the cases of the previous week) calculated by the estimated infection date is shown in the upper panel (red line) during the period of the autumn season in 2020. The cases for age and symptoms unspecified were included in the calculation of weekly case increase ratio. The weekly prevalence rate of coughing (2-week moving average) in the young age group is shown in the middle panel (black line) and the prevalence rate of coughing (2-week moving average) in the old age group in the bottom panel (green line). Weekly air temperature and humidity were shown in online supplemental figure S2.

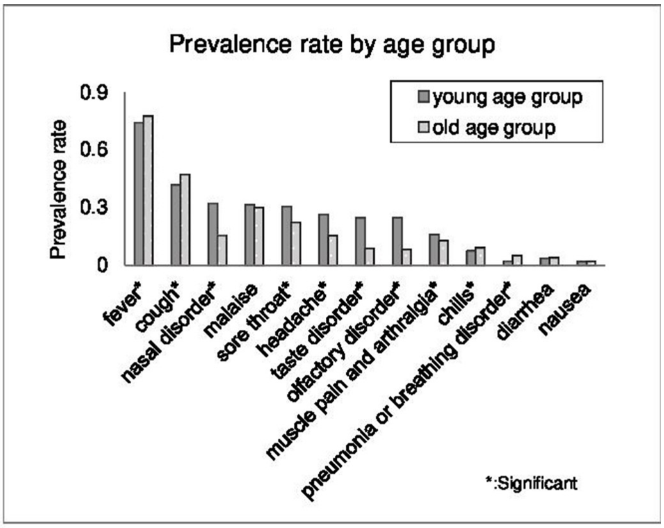

Figure 2 Prevalence rate of symptoms of SARS-CoV-2 patients. The prevalence rates of early symptoms in patients with PCR-confirmed SARS-CoV-2 (for a period of 1–2 weeks after any symptom appeared) in Hokkaido between the autumn and winter season are shown (n=7893, based on the onset date, which consisted of 5361 cases for the young age group [aged 0—40s] and 2532 cases for the old age group [aged 50—100s]). χ^2 analysis was used to compare the prevalence rate between the young and the old age group. Corrected significance is indicated by *. The p values were for fever p=0.001, cough p<0.0001, nasal disorder p<0.0001, malaise p=0.186, sore throat p<0.0001, headache p<0.0001, taste disorder p<0.0001, olfactory disorder p<0.0001, muscle pain and arthralgia p=0.0003, chills p=0.019, pneumonia or breathing disorder p<0.0001, diarrhoea p=0.527, and nausea p=0.831. In the graph, loss of consciousness, which recorded only a few cases, was not included.

September (figure 1B). The monthly prevalence rate of coughing in the young age group was 36% for September and 39% for October. The monthly prevalence rate of coughing in the old age group was 20% for September and 33% for October. The weekly case increase ratio increased similarly in the period after summer.

Through the overall period of the autumn and winter seasons, the monthly prevalence rate of coughing in the young age group was negatively correlated with temperature and humidity (r=−0.77 (p<0.05) and r=−0.63 (p<0.05), respectively). In the old age group the monthly prevalence rate of coughing was negatively correlated only with humidity (r=−0.71, p<0.05). Quadratic regression models were fitted for the relationship between cold temperatures and rates of coughing rates in the young age group and case increase ratios (figure 3A,B and online supplemental figure S3).

The sex-adjusted OR of having cough in the young age group during winter as compared with autumn was 1.18 (95% CI 1.05 to 1.31, p=0.004). No significant OR of having a cough in winter as compared with autumn was observed in the old age group (OR: 0.90, 95% CI 0.77 to 1.06, p=0.19).

DISCUSSION

After summer, the weekly cases of SARS-CoV-2 gradually increased. The epidemic expanded more rapidly in the colder period, which was associated with increased prevalence rate of coughing in patients. The results suggest that the seasonal rate of coughing is an important factor in the spread of the virus. We found a significantly increased occurrence of coughing among SARS-CoV-2 patients in

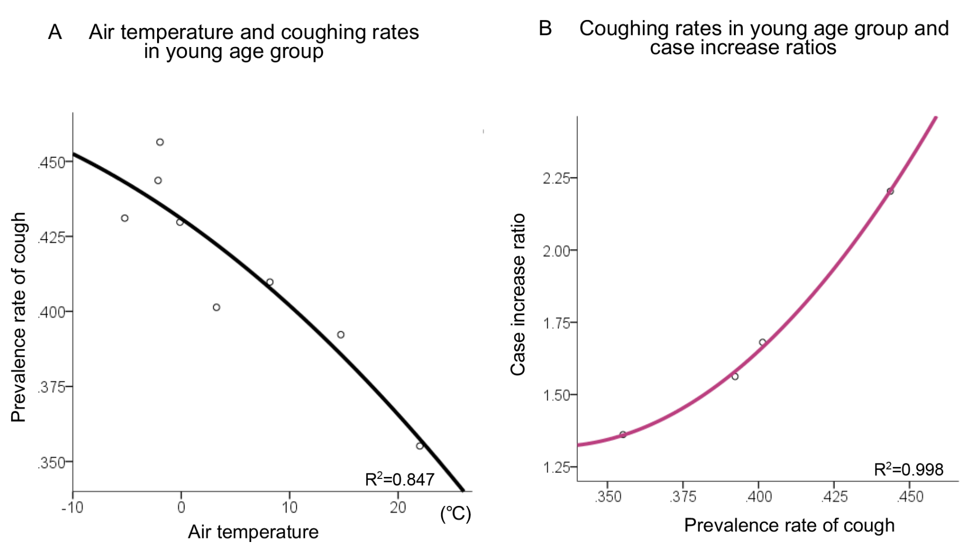

Figure 3 Cold temperatures and coughing rates in the young age group and case increase ratios. Quadratic regression models fitted for the relationship between the monthly average air temperatures (the temperatures were recorded from the data in Sapporo City) and the monthly coughing rates (2-month moving average) in the young age group (A), $f(x)=-3.68E\text{-}005x^2-0.003x+0.43$ (ANOVA F=13.82, p=0.009), and between the monthly coughing rates in the young age group and the monthly average of weekly case increase ratios (B), $f(x)=70.3x^2-46.6x+9.04$ (ANOVA F=317.29, p=0.040), in Hokkaido between the autumn and winter seasons. The data for February 2021 were available until the third week (as of the data downloaded date, 26 February 2021). The data on weekly case increase ratios were only available for February, March, September and October 2020 for the autumn and winter seasons due to the intervention which started November 2020 onwards. ANOVA, analysis of variance.

the younger age group during the colder period. Insofar as these infected younger individuals for the most part did not have severe pneumonia and would thus remain in the community, often without being tested for the virus, their transmission potential could be significant and one that will be greater during the cold months. This could have contributed to a sharp seasonal increase in infectivity and exacerbate the SARS-CoV-2 epidemic in the winter. Improved information dissemination, particularly to the younger population, to increase social distancing and to use personal protective equipment would help reduce their epidemiological role.

We included over 7000 PCR-confirmed SARS-CoV-2 cases with detailed associated symptoms. One of the limitations of the study is that no data on comorbidities and other underlying potential risk factors, such as smoking and obesity, were included.[16] Our data are potentially biased due to an increase in public awareness over time, which may have affected the prevalence rate of symptoms in patients who sought PCR testing for SARS-CoV-2 infection. Also, the data covered the epidemic trend before vaccinations and other new virus variants that appeared in April 2021 onwards[17 18] and thus their impact is not considered here.

Although the present epidemiological data on the prevalence rate of coughing among SARS-CoV-2 patients are relatively limited, other studies have shown coughing to be a common occurrence. A prevalence rate of coughing of 65%–80% was observed in Wuhan in January 2020[19] and a rate of 60% overall in China, with a similar rate also observed in Seattle,[20] but notably in Shenzhen, the southern part of China, the prevalence rate of coughing was much lower (35%).[21] In studies that investigated the reproduction rate of infection, Shandong Province, a northern district in China, had a more rapid increase in incidence, compared with the other southern districts, including Hunan, which is near Shenzhen.[10] Further study on the change in viral transmissibility with coughing with regard to climatic conditions is warranted.[22] The rapid increase of cases from mid-autumn suggests that the rate of symptomatic patients in the infected population may increase during the colder season. The prevalence rate of many of the most common symptoms, such as sore throat, nasal, olfactory and taste disorders, was significantly higher in the young age group than in the old age group, which may indicate a higher rate of immune response in the young age group. Likewise, there were more symptomatic patients in the young age group than in the old age group. A higher risk of virus spread through coughing and sneezing may potentially exist in the young age group in winter, not only due to the increased rate during the cold period, but also potentially due to their relatively higher risk behaviour.[23] The significantly higher rate of fever and pneumonia and breathing disorders in the old age group compared with the young age group suggests that the old age group has more severe forms of disease from symptom onset.

Correction notice This article has been corrected since it was first published. The Supplemental figure 2 is now correct.

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Because we used only open-source data, ethical approval was not sought for this study.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. COVID-19 surveillance report in Hokkaido (in Japanese; https://www.harp.lg.jp/opendata/dataset/1369.html).

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REFERENCES

1 Eikenberry SE, Mancuso M, Iboi E, *et al*. To mask or not to mask: modeling the potential for face mask use by the general public to curtail the COVID-19 pandemic. *Infect Dis Model* 2020;5:293–308.
2 Edwards DA, Ausiello D, Salzman J, *et al*. Exhaled aerosol increases with COVID-19 infection, age, and obesity. *Proc Natl Acad Sci U S A* 2021;118:e2021830118.
3 Lovato A, de Filippis C. Clinical presentation of COVID-19: a systematic review focusing on upper airway symptoms. *Ear Nose Throat J* 2020;99:569–76.
4 Yu HC, Mui KW, Wong LT, *et al*. Ventilation of General Hospital wards for mitigating infection risks of three kinds of viruses including middle East respiratory syndrome coronavirus. *Indoor Built Environ* 2017;26:514–27.
5 Cravero C, Marsano D. Simulation of COVID-19 indoor emissions from coughing and breathing with air conditioning and mask protection effects. *Indoor Built Environ* 2021;35:1420326X2110395.
6 Yu ITS, Li Y, Wong TW, *et al*. Evidence of airborne transmission of the severe acute respiratory syndrome virus. *N Engl J Med* 2004;350:1731–9.
7 Thurner S, Klimek P, Hanel R. A network-based explanation of why most COVID-19 infection curves are linear. *Proc Natl Acad Sci U S A* 2020;117:22684–9.
8 He X, Lau EHY, Wu P, *et al*. Temporal dynamics in viral shedding and transmissibility of COVID-19. *Nat Med* 2020;26:672–5.
9 Liu Y, Yan L-M, Wan L, *et al*. Viral dynamics in mild and severe cases of COVID-19. *Lancet Infect Dis* 2020;20:656–7.
10 Zhang J, Litvinova M, Wang W, *et al*. Evolving epidemiology and transmission dynamics of coronavirus disease 2019 outside Hubei Province, China: a descriptive and modelling study. *Lancet Infect Dis* 2020;20:793–802.
11 WHO coronavirus disease (COVID-19) dashboard. Available: https://covid19.who.int/
12 Mallapaty S. Why COVID outbreaks look set to worsen this winter. *Nature* 2020;586:653.

13 COVID-19 surveillance report in Hokkaido [in Japanese]. Available: https://www.harp.lg.jp/opendata/dataset/1369.html
14 Guan WJ, ZY N, Hu Y. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med* 2020;27:82.
15 Air temperature and humidity in Japan (Japan Meteorology Agency) [in Japanese]. Available: https://www.data.jma.go.jp/obd/stats/etrn/index.php
16 Hamet P, Pausova Z, Attaoua R, *et al*. SARS–CoV-2 receptor ACE2 gene is associated with hypertension and severity of COVID 19: interaction with sex, obesity, and smoking. *Am J Hypertens* 2021;34:367–76.
17 Hirotsu Y, Omata M. SARS-CoV-2 B.1.1.7 lineage rapidly spreads and replaces R.1 lineage in Japan: serial and stationary observation in a community. *Infect Genet Evol* 2021;95:105088.
18 Kosaka M, Hashimoto T, Ozaki A, *et al*. Delayed COVID-19 vaccine roll-out in Japan. *Lancet* 2021;397:2334–5.
19 Chen T, Dai Z, Mo P, *et al*. Clinical characteristics and outcomes of older patients with coronavirus disease 2019 (COVID-19) in Wuhan, China: a single-centered, retrospective study. *J Gerontol A Biol Sci Med Sci* 2020;75:1788–95.
20 Bhatraju PK, Ghassemieh BJ, Nichols M, *et al*. Covid-19 in Critically Ill Patients in the Seattle Region - Case Series. *N Engl J Med* 2020;382:2012–22.
21 Cai Q, Huang D, Ou P, *et al*. COVID-19 in a designated infectious diseases Hospital outside Hubei Province, China. *Allergy* 2020;75:1742–52.
22 Kissler SM, Tedijanto C, Goldstein E, *et al*. Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. *Science* 2020;368:860–8.
23 Lau JTF, Griffiths S, Choi K-C, *et al*. Prevalence of preventive behaviors and associated factors during early phase of the H1N1 influenza epidemic. *Am J Infect Control* 2010;38:374–80.