

# Effects of human behaviour changes during the COVID-19 pandemic on influenza spread in Hong Kong

Nan Zhang<sup>1,2,#</sup>, Wei Jia<sup>2,#</sup>, Hao Lei<sup>3</sup>, Peihua Wang<sup>2</sup>, Pengcheng Zhao<sup>2</sup>, Yong Guo<sup>4</sup>, Chung-Hin Dung<sup>2</sup>, Zhongming Bu<sup>5</sup>, Peng Xue<sup>1</sup>, Jingchao Xie<sup>1</sup>, Yingping Zhang<sup>4</sup>, Reynold Cheng<sup>6</sup>, Yuguo Li<sup>2,7,\*</sup>

# These authors contributed equally to this work.

<sup>1</sup> Key Laboratory of Green Built Environment and Energy Efficient Technology, Beijing University of Technology, Beijing, China

<sup>2</sup> Department of Mechanical Engineering, The University of Hong Kong, Hong Kong SAR, China

<sup>3</sup> School of Public Health, Zhejiang University, Hangzhou, Zhejiang, China

<sup>4</sup> Department of Building Science, Tsinghua University, Beijing, China

<sup>5</sup> Department of Energy and Environmental System Engineering, Zhejiang University of Science and Technology, 310023, Hangzhou, China

<sup>6</sup> Department of Computer Science, The University of Hong Kong, Hong Kong SAR, China

<sup>7</sup> School of Public Health, Li Ka Shing Faculty of Medicine, University of Hong Kong, Hong Kong SAR, China

**Corresponding Author :**

Prof. Yuguo Li

Room 709, Haking Wong Building, The University of Hong Kong, Pokfulam Road, Hong Kong, China

Email: [liyg@hku.hk](mailto:liyg@hku.hk)

Telephone: +852 3917 2625

**Summary**

In Hong Kong, during the COVID-19 pandemic, the number of closely contacted people reduced by 59%. Close contact control contributed more than 47% to infection risk reduction, confirming that human behaviours were significantly influenced by the COVID-19 pandemic.

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## Abstract

**Background** COVID-19 continues to threaten human life worldwide. We explored how human behaviours have been influenced by the COVID-19 pandemic in Hong Kong, and how the transmission of other respiratory diseases (e.g. influenza) has been influenced by human behaviour.

**Methods** We focused on the spread of COVID-19 and influenza infections based on reported COVID-19 cases and influenza surveillance data, and investigated the changes in human behaviour due to COVID-19 based on mass transit railway data and the data from a telephone survey. We did the simulation based on SEIR model to assess the risk reduction of influenza transmission caused by the changes in human behaviour.

**Results** During the COVID-19 pandemic, the number of passengers fell by 52.0% compared with the same period in 2019. Residents spent 32.2% more time at home. Each person on average came into close contact with 17.6 and 7.1 people per day during the normal and pandemic periods, respectively. Students, workers, and older people reduced their daily number of close contacts by 83.0%, 48.1%, and 40.3%, respectively. The close contact rates in residences, workplaces, places of study, restaurants, shopping centres, markets, and public transport decreased by 8.3%, 30.8%, 66.0%, 38.5%, 48.6%, 41.0%, and 36.1%, respectively. Based on the simulation, these changes in human behaviours reduced the effective reproduction number of influenza by 63.1%.

**Conclusions** Human behaviours were significantly influenced by the COVID-19 pandemic in Hong Kong. Close contact control contributed more than 47% to the reduction in infection risk of COVID-19.

**Keywords:** COVID-19; influenza; close contact; human behaviour; non-pharmaceutical interventions

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## Background

Coronavirus disease 2019 (COVID-19) has been threatening human life. In 2003, 1,755 out of the 8,096 (21.7%) confirmed cases of severe acute respiratory syndrome (SARS) were from Hong Kong<sup>1</sup>. Other respiratory infections such as influenza (e.g. H1N1, H5N1, and H7N9) have also been widely spread in Hong Kong<sup>2-4</sup>. During the COVID-19 pandemic, up to 30 June 2020, Hong Kong had 1,197 confirmed cases<sup>5</sup>.

The SARS coronavirus 2 (SARS-CoV-2) is believed to be mainly transmitted via the close contact route<sup>6,7</sup>. The infection risk in indoor environments is much higher than that in outdoor environments because of possible insufficient ventilation, long periods spent indoors, high close contact rate, and many frequently touched public surfaces<sup>8-11</sup>. Many non-pharmaceutical interventions, which aim to encourage social distancing and reduce the exposure time and the risk of infection during close contact, have been implemented for infection prevention and control<sup>12-17</sup>. Human behaviour change is crucial to prevent transmission in the absence of pharmaceutical interventions<sup>18</sup>. However, data on the relevant human behaviours are lacking.

In the study, we analysed how human behaviours including local travel, indoor-stay, close contacts, mask wearing, and behaviours during the symptom onset period were influenced by the COVID-19 pandemic in Hong Kong based on more than one billion records of smart card data of the mass transit railway (MTR) and 1,021 data points from a telephone survey. We also analysed how human behaviours influenced the spread of respiratory infections based on

a comparison of influenza transmission in Hong Kong during 1 January to 31 May 2019 and the same period in 2020.

## **Methods**

### ***Data collection***

Data on the occurrence of COVID-19 and sentinel surveillance data on influenza-like illness were obtained from Hong Kong Centre for Health Protection<sup>5,19</sup>. Centre for Health Protection (CHP) in Hong Kong provides a definition of cases of COVID-19. In brief, confirmation of a case required the detection (e.g., by reverse transcription-polymerase chain reaction (RT-PCR)) of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in a clinical specimen. Demographic data were obtained from the Census and Statistics Department of Hong Kong<sup>20</sup>. We obtained local travel data from Hong Kong Mass Transit Railway Corporation covered the period from 1 January to 30 April of both 2019 and 2020 (Appendix A for detailed description). A cross-sectional telephone survey was also performed from 22 May to 7 June 2020 to collect Hong Kong residents' information including general personal information (e.g. age and sex) and their infection-related behaviour. The specific survey methods are described in Appendix B; 1,021 surveys were finally completed.

### ***Behavioural data categorisation***

We considered five groups of human behaviours: local travel, indoor-stay, close contact, mask wearing, and visiting the doctor or other public places during the symptom onset period. The local travel behaviour was analysed based on the MTR data, with passengers divided into five categories (adults, children, students, older people, and others) based on the type of their smart card. The other four behaviour types were analysed based on the

telephone-survey data (Appendix C). In the survey, respondents answered questions on various behaviours during the normal period (26 March to 1 April 2019) and the COVID-19 pandemic (26 March to 1 April 2020). We divided all respondents into four categories: workers, students, older people, and others (all people excluding workers, students, and older people). All indoor environments were divided into eight categories<sup>12</sup>: residence (e.g. home, dormitory, and hotel), workplace (only indoors), place of study, restaurant (including dining rooms in workplaces and places of study), shopping centre, market (including supermarkets), public transport, and others. In the survey, a close contact was defined as either a two-way conversation involving five or more words in the physical presence of another person, or a direct physical contact (e.g. a handshake or a hug)<sup>21</sup>. The close contact rate was defined as the ratio of close contact time to total indoor time (time spent asleep in one's residence is not counted in total indoor time). The effective reproduction number ( $R_t$ ) was calculated (Appendix D).

### ***Infection data processing***

In the study, we used the susceptible–exposed–infected–recovered (SEIR) model to simulate the transmission of both COVID-19 and influenza (Appendix E for detailed calculation and parameter setting). Because Hong Kong had a strict strategy on mandatory quarantine for imported population and the arrival population was reduced by more than 97% after March (Appendix F), we did not consider the influence by imported and exported population.

## Results

### *COVID-19 infection in Hong Kong*

As of 31 May 2020, Hong Kong had 1,085 confirmed COVID-19 cases, including 178 imported cases without 14-day mandatory quarantine, 487 cases with 14-day mandatory quarantine, 327 local cases, and 93 unidentified cases (possible imported and local infections). Among the 1,085 cases, 234 were asymptomatic and 851 were symptomatic. Figure 1a shows the timeline of COVID-19 infection and travel-related and local government interventions. The effective reproduction number decreased from 1.49 on 23 January to 0.04 on 19 April, but increased again to 1.54 on 4 May (Figure 1b). The uncertainty was very large because of the low number of new daily cases.

### *Human behaviour changes due to the COVID-19 pandemic*

#### (1) Local travel behaviour

During the pandemic period (26 March to 1 April), the number of passengers taking subway fell by 52.0% (49.1% on weekdays, 56.2% on Saturday, and 64.6% on Sunday) compared with the same period in 2019. During this period, adults, children, students, and older people reduced their local travel by 48.5%, 87.4%, 84.3%, and 44.2%, respectively, compared with the same period in 2019 (Appendix G for detailed values).

#### (2) Indoor-stay behaviour

The average indoor-stay time and its probability distribution for different groups (workers, students, and older people) on weekdays and weekends during the normal and pandemic periods are listed in Table 1 and Figure 2. Hong Kong residents spent 90.9% (weekdays: 92.7%, weekends: 84.2%) and 92.0% (weekdays: 92.7%, weekends: 90.1%) of their time in



indoor environments during the normal period and the COVID-19 pandemic, respectively. During the pandemic, people spent 1.4 extra hours per day in indoor environments at weekends, compared with the normal period. People spent 32.2% more time at home during the pandemic. Students spent 55.3% more time at home and 96.5% less time at their places of study due to closures. Older people, however, spent only 15.7% more time at home. For workers, the average number of workdays and time spent in workplaces decreased by 28.4% and 31.0%, respectively (Table 2). Specifically, time spent in shopping centres, restaurants, public transport, and markets decreased by 73.5%, 67.8%, 51.1%, and 41.3%, respectively.

### (3) Close contact behaviour

Resident type and pandemic status impacted the frequency of daily close contacts (Figure 3). Daily close contact numbers of all four types of residents were significantly smaller during the pandemic period than during the normal period (Appendix H for detailed values).

Hong Kong residents on average had close contact with 17.6 and 7.1 others per day during the normal and pandemic periods (Figure 3a). In the normal period, students had daily contact with the largest number of people (28.1 individuals), whereas older people had contacts with the fewest (6.6 individuals). Students had close contact with an average of 25.0 people per day in their places of study during the normal period (Figure 3b). However, because of school and university closures during the pandemic, the students' average number of daily close contacts decreased by 83.0% (to 4.8 individuals). The corresponding numbers for workers and older people decreased from 20.5 and 9.7 to 10.6 and 3.9, with reductions of 48.1% and 40.3%, respectively (Appendix H for detailed values).

During the normal period (blue lines in Figure 4), places of study had the highest close contact rate (more than 60%) among all indoor locations (Figure 4z), followed by residences (50%) (Figure 4b), workplaces (38%) (Figure 4s), and restaurants (24%) (Figure 4c). In general, the indoor close contact rate decreased from 45.7% during the normal period to 41.0% during the pandemic period, a reduction of 10.1% (Figure 4a). The close contact rate in residences was comparatively weakly influenced by the pandemic, being reduced by only 8.3% (Figure 4b). For workers and students the close contact rate in workplaces (Figure 4s) and places of study (Figure 4z) decreased by 30.8% and 66.0%, respectively. During the normal period, students had the highest close contact rate of 57.4% (Figure 4t), followed by workers (46.0%) (Figure 4m) and older people (29.1%) (Figure 4g). During the COVID-19 pandemic, the greatest reduction in the indoor close contact rate was observed for workers (11.6%) (Figure 4m), followed by older people (10.6%) (Figure 4g). For students, the close contact rate reduced only by 9.0% in indoor environments (Figure 4t). In other public indoor environments, the close contact rate in restaurants, shopping centres, markets, and public transport decreased by 38.5% (Figure 4c), 48.6% (Figure 4d), 31.0% (Figure 4e), and 36.1% (Figure 4f), respectively.

#### (4) Mask-wearing behaviour during symptom onset period

During the pandemic, almost all people (98%–100%) responded that they would wear a mask in all public indoor environments if they had the symptom (Table 3). Restaurants had a relatively low mask-wearing rate (only non-eating time was considered). Few people (6.9%)

wore a mask in residences. Students had the highest mask-wearing rate when ill. The detailed time-variant mask-wearing rate is shown in Appendix I.

During the normal period, 4.6% of residents would not see doctor if they had a fever and cough. Older people on average delayed for 0.87 days before visiting a doctor upon the onset of these symptoms, which is shorter than workers (1.04 days) and students (1.07 days). However, during the pandemic period, the overall delay for all types of residents fell to 0.38–0.39 days, a reduction of 63.2%, and only 2.0% of residents reported that they would not see a doctor under any circumstance. Compared with the normal period, residents' probability of visiting public indoor environments during the pandemic period was reduced by at least 90%. (Appendix J for detailed values).

### ***Risk reduction of influenza and COVID-19 in 2020 relative to 2019 due to human behaviour changes***

Few influenza positive cases were reported after the 8<sup>th</sup> week of 2020, in contrast to previous years (2014–2019) when influenza transmission continued even after the 23<sup>rd</sup> week (Figure 5a). The influenza incidence rate during the 2019–2020 winter was reduced by 86.4% and 77.8% compared with the rates during the same period in 2014–2015 and 2018–2019, respectively. Possibly due to the high mask-wearing rate, reduction of close contact rate, school and university closures since 22 January, and the Chinese New Year Holiday between 25 and 28 January, the effective reproduction number ( $R_t$ ) for influenza gradually fell from 1.41 at the end of December 2019 to 0.52 on 20 February 2020 (Figure 5b). After that, because of the low incidence rate, the uncertainty in  $R_t$  was high. There was no sharp decrease in the  $R_t$  for influenza in 2018–2019 following the Chinese New Year Holiday, but

there was a sharp decrease after the same holiday in 2020 because of human behavioural changes in response to the COVID-19 outbreak.

Figure 6 shows the simulated spread of COVID-19 under the close contact behaviour scenarios, based on the telephone survey and MTR data, during the normal and pandemic periods. The average number of close contacts fell from 17.6 during the normal period to 7.1 during the pandemic period, and the total contact duration was reduced by 10%. Due to these behavioural changes, the total infected population according to the SEIR simulation was reduced by 47%. The peak value of the infected percentage was reduced from 49.6% to 6.8%. The  $R_t$  for COVID-19 was reduced from 2.5 to 1.2 due to the changes in close contact behaviours.

## Discussion

Compared with other cities, local travel behaviour in Hong Kong was relatively weakly affected by COVID-19. During the pandemic, travel congestion in Hong Kong decreased by 34.7%, compared with 95.0%, 91.6%, 91.3%, 91.3%, 90.3%, and 75.5% in Singapore, Moscow, New York City, Beijing, Paris, and London, respectively<sup>22</sup>.

In Hong Kong, people spend more than 65% of their indoor time in residences. This reflects the closure of many workplaces and almost all places of study, and the fact that few people visited public indoor environments during this time. In the Netherlands, 44% of workers started working from home or increased their homeworking hours, and 30% had more remote

meetings<sup>23</sup>. Stay-at-home orders were associated with a 59.8% reduction in weekly all-cause mortality in the US<sup>24</sup>. During the pandemic, our data show that the total indoor-stay time in Hong Kong was significantly influenced by sex, age, and indoor environment (e.g. residence, workplace, and restaurant) ( $p < .001$ , Tables S2 to S5). For older people, there was no significant difference in workplace-stay time on weekdays before and during the pandemic ( $p > .5$ ), reflecting the fact that many older people may have no choice but to work to support themselves. The local government should therefore consider prioritising subsidies for older people in Hong Kong during the current pandemic. Young women and girls (aged under 20 years) spent more time in shopping centres than young men and boys ( $p < .001$ ). However, middle-aged women spent less time in restaurants than middle-aged men ( $p < .001$ ) during the pandemic. The number of working/study days differed significantly by age group and pandemic status (Tables S9 and S10).

In the normal period, a Hong Kong resident had close contact with 17.6 people per day on average, which was between the corresponding values for Wuhan (14.6) and Shanghai (18.8)<sup>25</sup>. Both previous research and this study show that younger people have more close contacts per day. During the pandemic, the daily number of close contacts in Hong Kong was reduced, but only to 7.1, which is much higher than the number in Wuhan (2.0) and Shanghai (2.3)<sup>25</sup>. In other words, the human behaviour changes in those cities were much more profound than those in Hong Kong. Some Hong Kong residents had close contact with more than 30 people per day in public indoor environments during the pandemic. If any of these were superspreaders, the cross-infection risk would be very high<sup>26</sup>. During the pandemic, the overall indoor close contact time was only reduced by 10.1%, whereas the daily number of close contacts decreased by 59.4%, implying a large increase in the total contact time between a few specific pairs of people.

The number of daily contacts and the close contact rate had a significant association with resident type (workers, students, older people, and others) and pandemic status (normal/pandemic) (Tables S12 to S16). For all resident groups, the daily number of close contacts and the close contact rate significantly decreased due to the pandemic ( $p < .001$ ). Among all people, students had the largest reduction rate in the number of daily contacts, followed by workers, others, and older people. In addition, the daily number of contacts decreased with increasing age. During the pandemic, workers had many more daily contacts than those in the other three groups. The reduction in close contact rate was the greatest in places of study and the smallest in residences. The close contact time in different indoor environments also showed a significant difference. Places of study, workplaces, and residences had high close contact rates during the normal period, and residences, workplaces, and restaurants had high close contact rates during the pandemic.

In the normal period, a previous study showed that the ratio of close contact rates in homes, schools, workplaces, and shopping malls was 12:6:6:1<sup>27</sup>. However, in Hong Kong, the ratio of close contact rates in these four indoor environments was 16:12:14:7 during the normal period, but 11:22:19:7 during the pandemic.

The incidence rates of influenza in the winters between 2015 and 2019 were much higher than that in 2020. The lowest  $R_t$  generally appears several days before the Chinese New Year (CNY), and  $R_t$  then rises again due to people returning to workplaces and places of study. In 2015, which was the year with the most serious influenza pandemic,  $R_t$  fell from 1.22 at the

end of December 2014 to 0.63 before the CNY, a reduction of 48.4%. Four winters later,  $R_t$  decreased from 1.17 at the end of December 2018 to 0.74 before the CNY in 2019, a reduction of 36.8%. However, the following winter,  $R_t$  decreased from 1.41 at the end of December 2019 to 0.74 before the CNY in 2020, and fell further to 0.52 on 19 February, a total reduction of 63.1%.  $R_t$  continued to decline after the CNY in 2020 because many people worked from home and almost all places of study were closed. Due to the pandemic, the daily close contact number and total close contact time were reduced by 59% and 10%, respectively. These changes in human close contact behaviour reduced the  $R_t$  of COVID-19 from 2.5 to 1.2, a reduction of 52%. If we assume that the transmission routes of influenza and COVID-19 are the same, we can conclude that the restrictions of close contact behaviour contributed more than 80% (52%/63%) to the reduction in influenza infectivity. Other behaviours such as mask wearing and visiting a doctor as soon as possible made a contribution of 20%.

There are some limitations of this study. First, we assumed that both COVID-19 and influenza are only transmitted by the close contact route, neglecting the long-range airborne and distant fomite routes<sup>21</sup>. Second, we could not identify which single human behaviour has potentially the most significant association with the spread of infection. Finally, our surveys of population behaviours could have been affected by response bias, because we relied on self-reported data. Devices designed to detect close contacts should be adopted to fulfil the accurate data requirements of future studies<sup>28</sup>.

## Conclusions

In Hong Kong, during the COVID-19 pandemic, the number of closely contacted people reduced by 59% and the total close contact time reduced by 10%. These changes in human behaviours reduced the effective reproduction number of influenza by 63.1%. Close contact control contributed more than 47% to infection risk reduction. Therefore, promoting positive anti-infection behaviours should be an important factor in intervention policy.

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## NOTES

### **Author's contributions**

NZ, HL, and YL conceived the idea. NZ, ZB, CHD and RC collected the data. NZ, WJ, PW, PZ, and YG analysed the data. NZ and WJ prepared the figures. NZ, WJ, and YL wrote the paper. HL, PX, JX, YZ, RC, and YL made constructive amendments. all authors reviewed the paper.

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### **Declaration of interests**

All authors declare no competing interests.

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## Table

**Table 1.** Indoor-stay time on weekdays and weekends during the normal and pandemic periods by respondent categories (workers, students, and older people) in different indoor environments (more detailed data are listed in Table S3).

Indoor environment	Respondent type	Normal period (h)		Pandemic period (h)		Change <sup>1</sup> (%)	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
All indoor environments	Worker	22.7	19.6	22.4	20.9	-1.5	6.7
	Student	23.0	20.5	22.8	22.5	-0.8	9.3
	Older	21.3	21.0	21.7	22.0	2.2	4.9
	All	22.3	20.2	22.2	21.6	0	6.9
Residence	Worker	11.4	14.2	15.3	18.9	35.1	33.8
	Student	13.0	15.8	21.5	21.4	65.1	35.2
	Older	17.5	17.7	20.1	20.7	15.0	17.2
	All	13.7	15.4	18.3	20.1	33.1	30.2
Restaurant	Worker	1.2	1.7	0.5	0.5	-59.7	-70.9
	Student	1.0	1.6	0.3	0.3	-72.0	-78.4
	Older	1.0	1.0	0.4	0.3	-62.9	-71.6
	All	1.1	1.5	0.4	0.4	-64.3	-74.3
Shopping centre	Worker	0.9	1.8	0.3	0.4	-70.4	-76.8
	Student	0.9	1.6	0.3	0.3	-70.3	-81.1
	Older	1.0	0.9	0.3	0.2	-69.5	-73.4
	All	1.0	1.5	0.3	0.3	-70.8	-77.9
Market	Worker	0.6	0.8	0.4	0.5	-29.1	-37.1
	Student	0.4	0.5	0.2	0.2	-58.3	-65.0
	Older	1.0	0.8	0.6	0.5	-42.7	-42.7
	All	0.7	0.8	0.4	0.4	-40.0	-44.4
Public transport	Worker	1.1	0.9	0.7	0.4	-33.7	-56.0
	Student	0.9	0.9	0.2	0.2	-71.7	-73.1
	Older	0.7	0.6	0.3	0.3	-52.8	-56.7
	All	0.9	0.8	0.5	0.3	-47.3	-61.3
Workplace	Worker	7.4		5.1		-31.0	
Place of study	Student	6.2		0.2		-96.5	

$$^1\text{Change} = \frac{\text{time during pandemic period} - \text{time during normal period}}{\text{time during normal period}} \times 100\%$$

**Table 2.** Number of workdays/study days for workers/students and average frequency of eating in restaurants during the normal and pandemic periods.

Indoor environment	Respondent type	Normal period		Pandemic period		Change	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Restaurant <sup>1</sup>	Worker	4.0	1.9	1.7	0.7	-57.9	-64.0
	Student	2.8	1.8	0.6	0.4	-78.1	-76.3
	Older	1.5	0.9	0.5	0.3	-66.0	-69.3
	All	3.1	1.7	1.1	0.5	-64.6	-69.0
Workplace <sup>2</sup>	Worker	5.0		3.6		-28.4	
Place of study	Student	4.6		0.4		-92.0	

<sup>1</sup> The unit of restaurant visits is times per week.

<sup>2</sup> The unit of workdays/study days in workplaces and places of study is days per week.

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**Table 3.** Probability of visiting specific location types if experiencing a fever and cough.

Question	Location	Respondent type	Normal (End of March 2019)	Pandemic (End of March 2020)	Change (%)
Would you wear a mask in the following indoor environments if you had a fever?	Workplace	Worker	69.6	98.0	40.9
	Place of study	Student	78.6	100.0	27.2
	Restaurant	Worker	44.3	96.1	116.7
		Student	55.2	99.0	79.3
		Older person	49.0	94.9	93.8
		All	47.4	96.4	103.3
	Shopping centre and market	Worker	57.0	99.3	74.4
		Student	71.1	100.0	40.6
		Older person	51.5	99.5	93.1
		All	58.8	99.3	69.0
Question	Location	Respondent type	End of Dec.	Pandemic	Change (%)
Would you wear a mask in the following indoor environments if you were healthy?	Workplace	Worker	14.3	91.3	536.4
	Place of study	Student	13.4	97.0	622.2
	Residence	Worker	0.7	9.1	1300.0
		Student	1.0	5.0	400.0
		Older person	1.0	5.1	400.0
		All	0.9	6.9	677.8
	Public area (e.g. restaurant, shopping centre, and market)	Worker	10.9	99.3	814.0
		Student	9.0	100.0	1016.7
		Older person	22.7	99.5	337.8
		All	13.3	99.3	645.6

## Figure legends

**Figure 1.** COVID-19 transmission in Hong Kong. (a) COVID-19 cases by date of reporting, symptom onset, and arrival of imported cases. (Travel-related interventions are labelled in blue and local interventions are labelled in black. Most places of study started holidays on 22 January. ‘Date of symptom onset’ excludes 234 asymptomatic cases. All dates are in 2020); (b) temporal trend of effective reproduction number.

**Figure 2.** Cumulative probability of indoor-stay time on weekdays and weekends during the normal and pandemic periods in different indoor environments. (a) to (r) show the distribution of workers, students, and older people in all indoor environments, residences, restaurants, shopping centres, markets, and public transport, respectively; (s) and (t) show the distribution of number of days of work and study per week for workers and students, respectively. (The unlabelled x-axis shows the number of hours spent indoors, and detailed correlation analysis of work/study days per week is shown in Tables S7 to S9).

**Figure 3.** Cumulative probability of daily number of close contacts (a) for workers, students, and older people (both in the normal and pandemic periods); (b) for students in places of study (only in the normal period).

**Figure 4.** Cumulative probability distribution of close contact rate in different indoor environments during the normal and pandemic periods (CDF: cumulative distribution function). (a-f) and (g-l) show the close contact rate of all residents and older people in all indoor environments, residences, restaurants, shopping centres, markets, and public transport, respectively. (m-s) and (t-z) show the close contact rate of workers and students in all indoor



environments, residences, restaurants, shopping centres, markets, public transport, and workplaces/places of study, respectively.

**Figure 5.** Influenza transmission in the winters of 2014–2020. (a) Incidence rate (number of influenza positive cases [unit: 1000] in 10,000 patients with influenza-like illness [ILI]); (B) effective reproduction number ( $R_t$ ) (red, green, and blue bands show the  $R_t$  with 95% confidence interval).

**Figure 6.** Simulation of COVID-19 transmission based on close contact behaviours (a) during the normal period (end of March 2019) and (b) during the pandemic (end of March 2020).

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Figure 1a

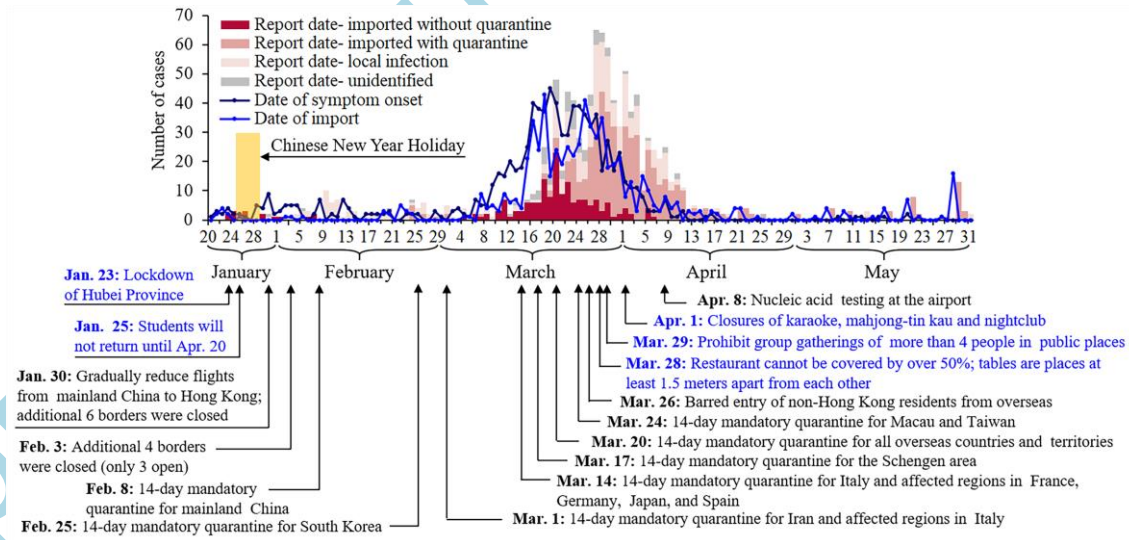


Figure 1b

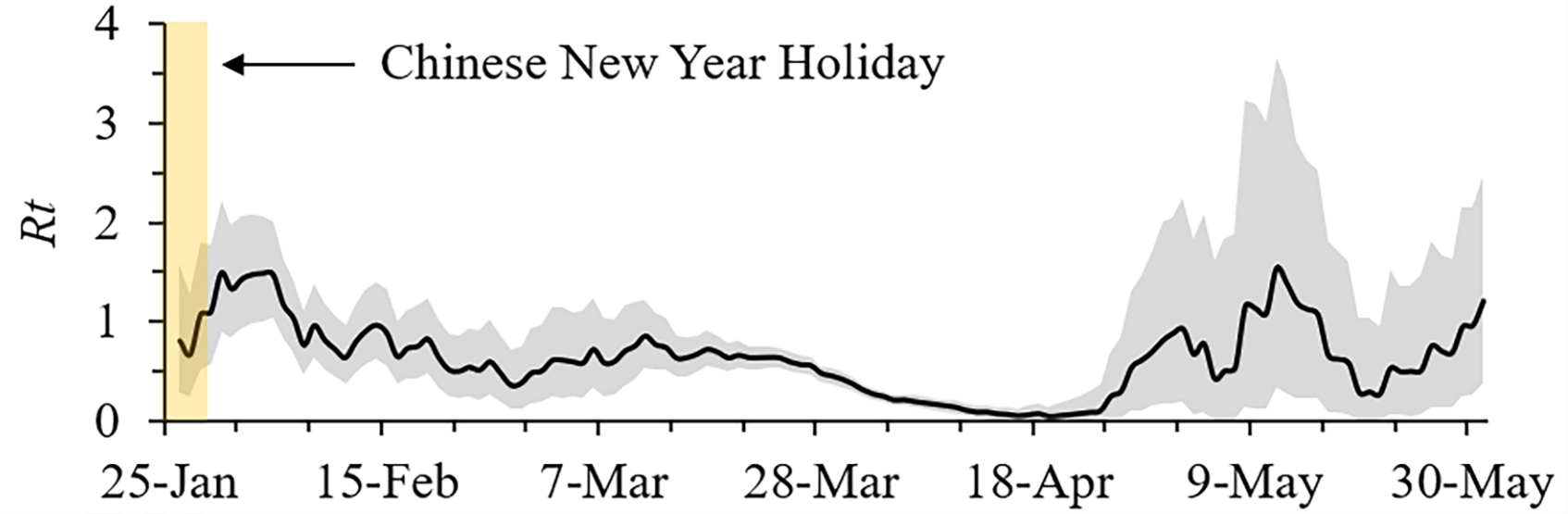


Figure 2

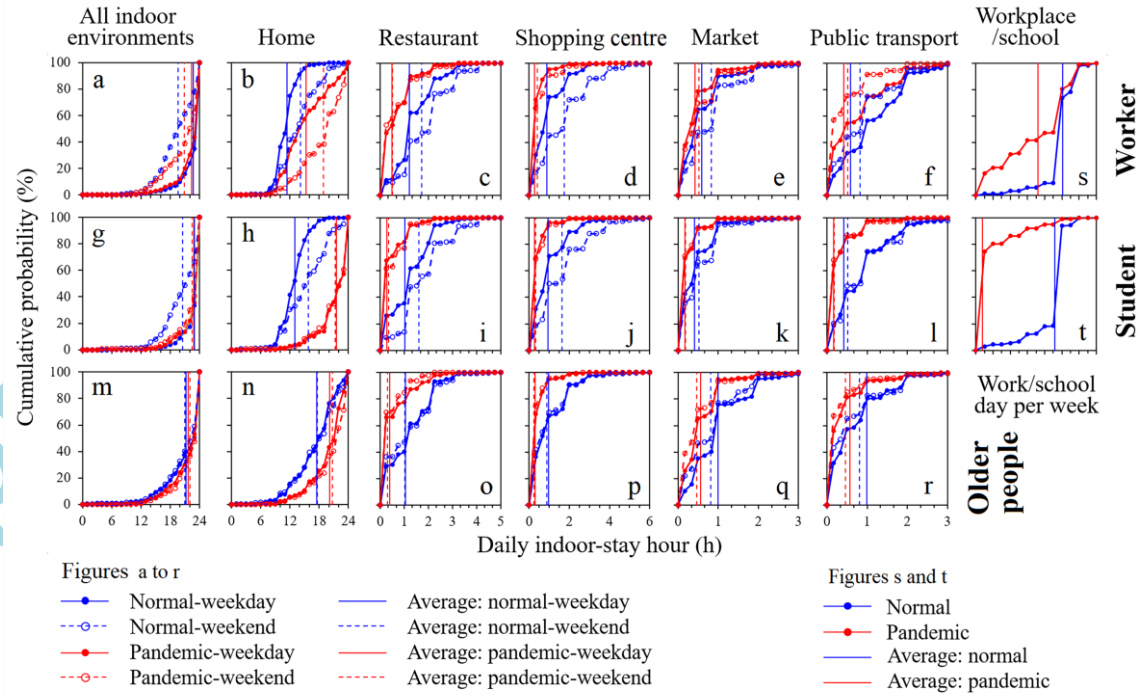
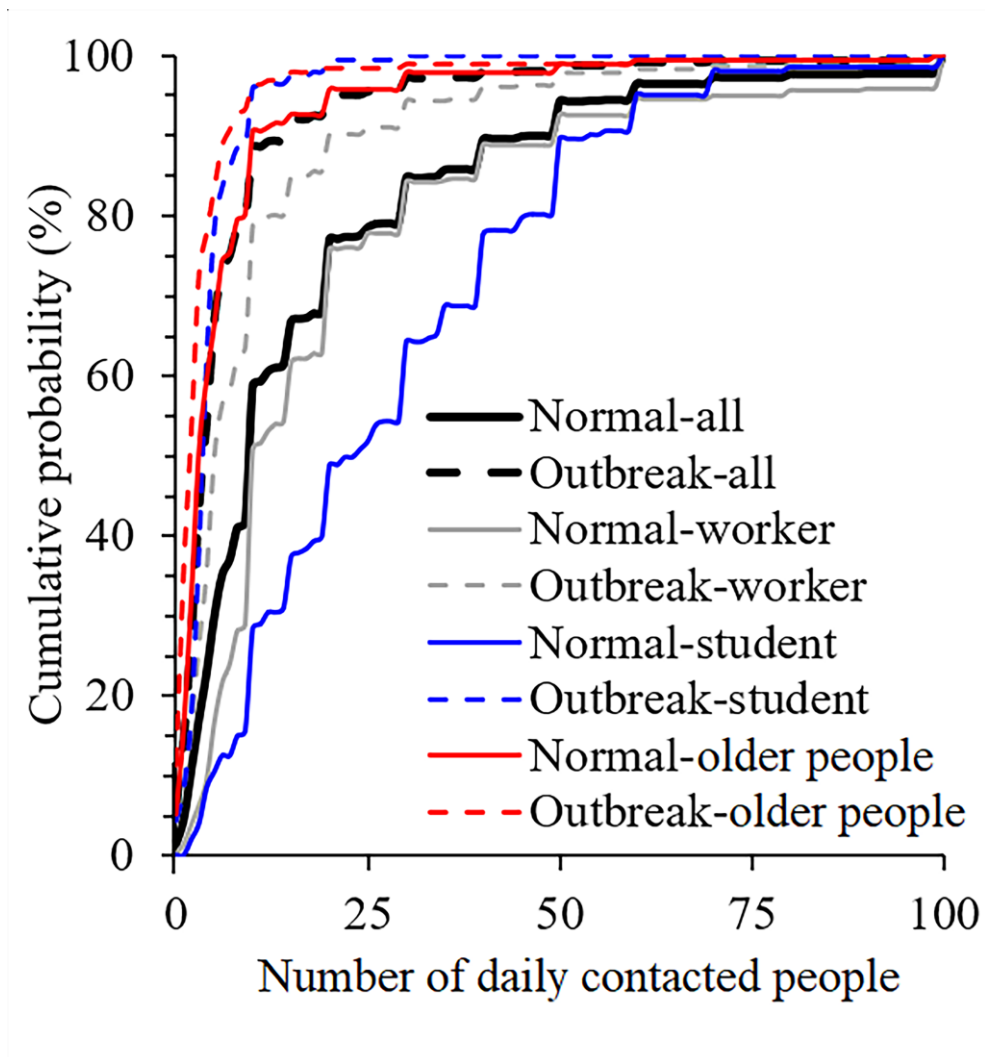
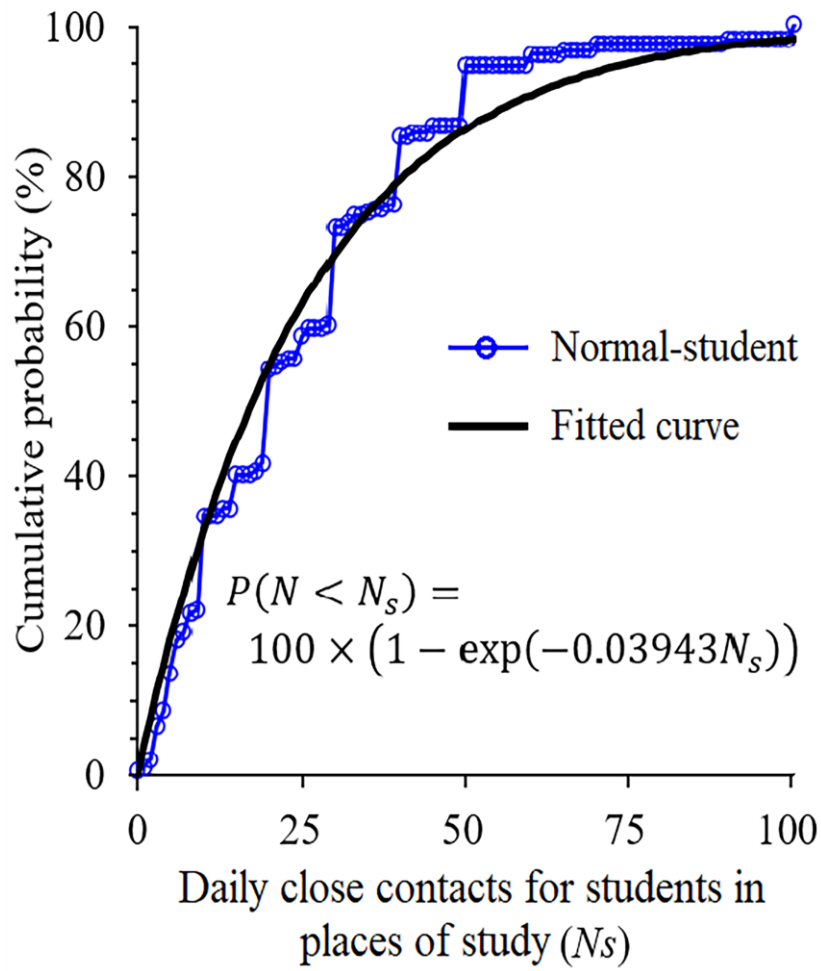


Figure 3a



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Figure 3b



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Figure 4

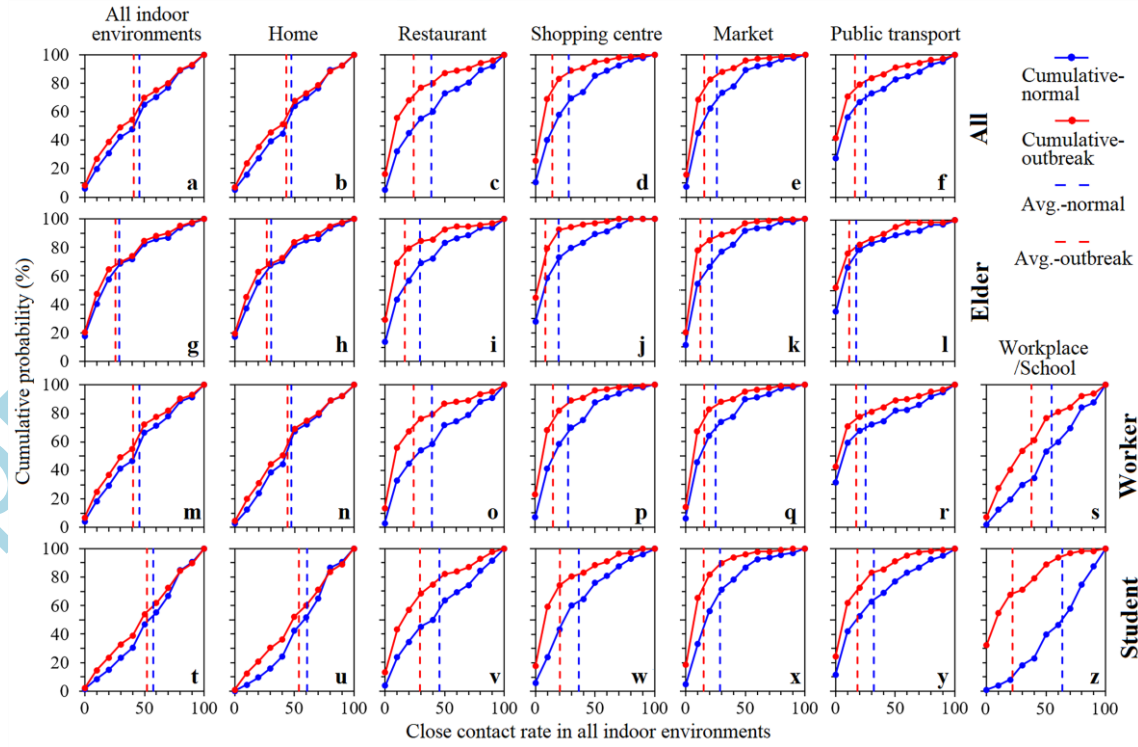


Figure 5a

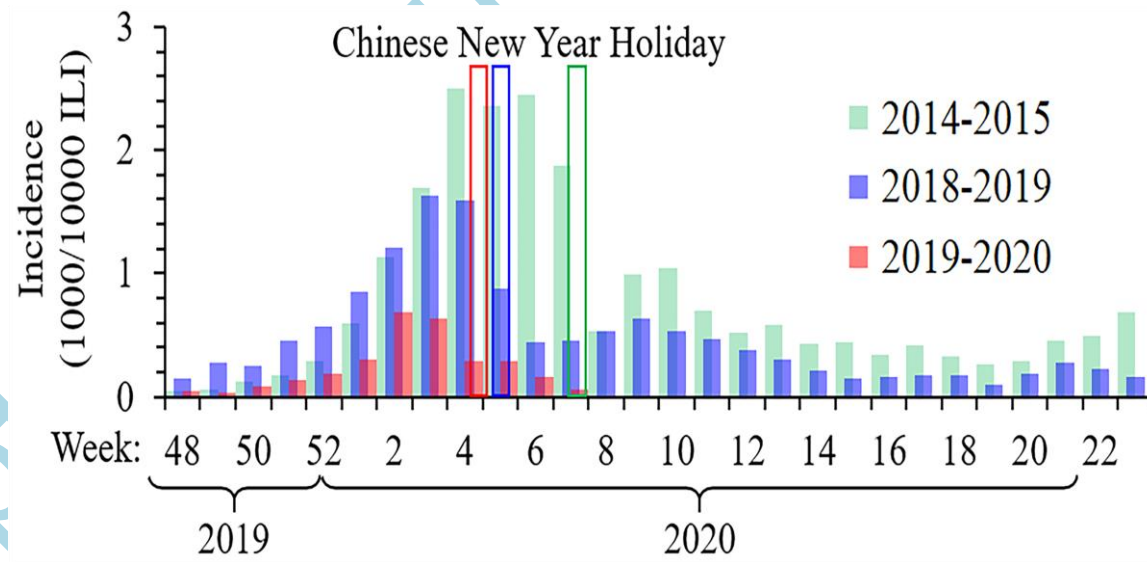




Figure 5b

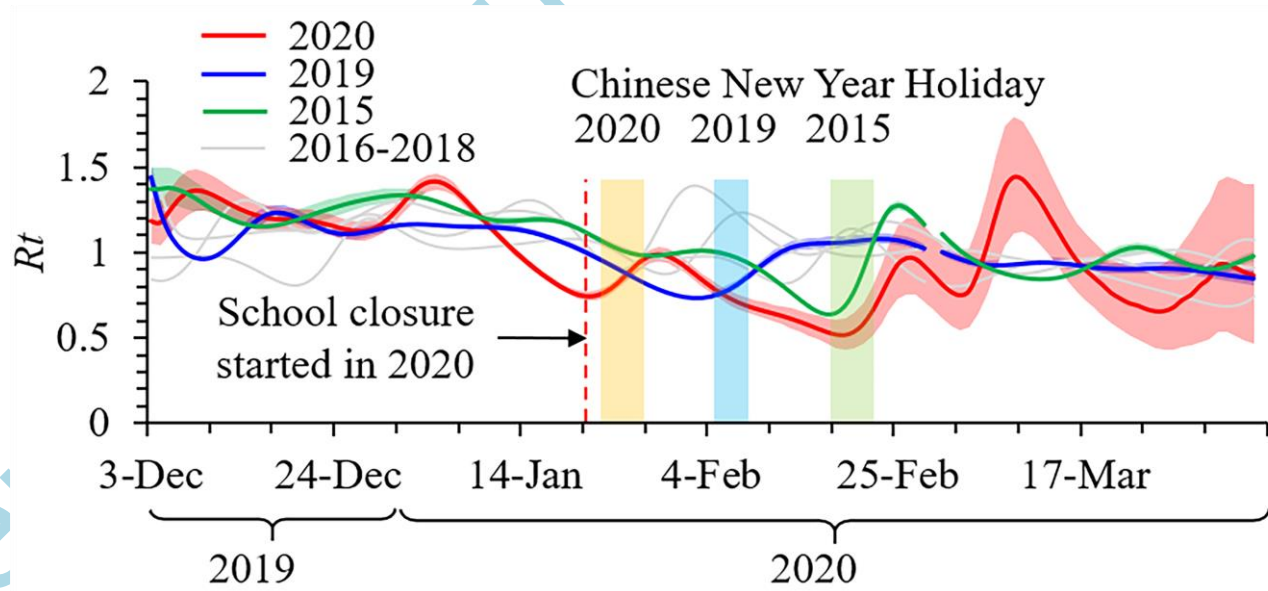


Figure 6a

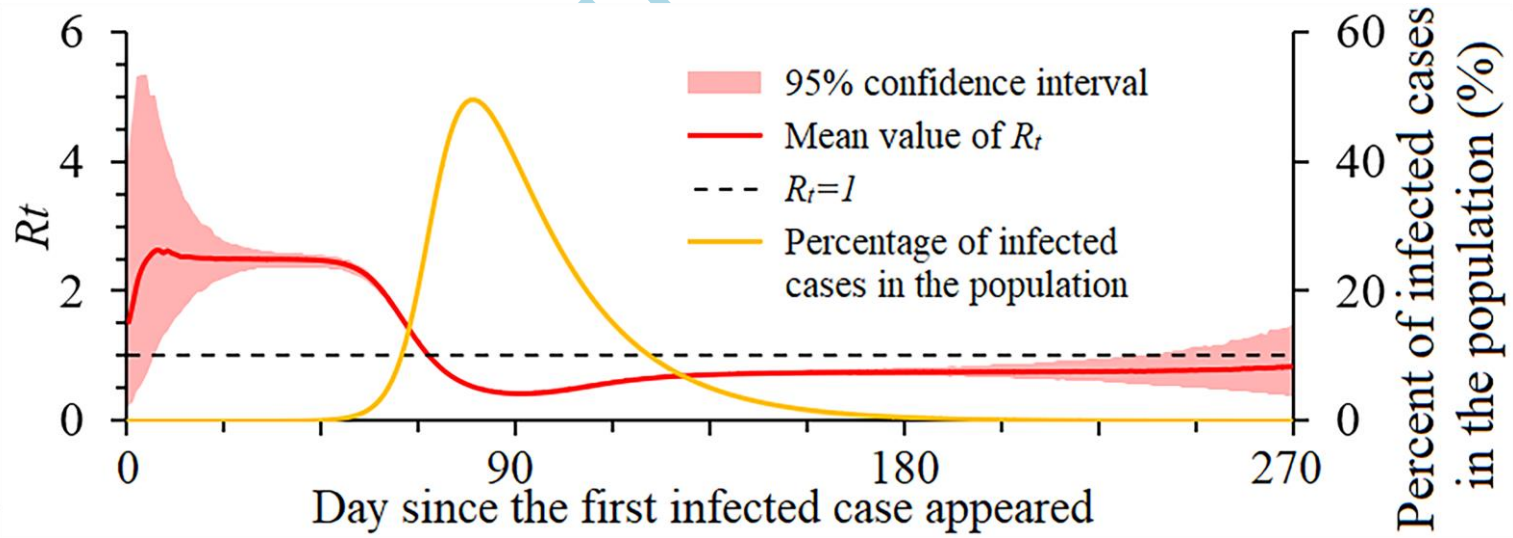


Figure 6b

