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Original Article

Did symptomatic index cases propagate COVID-19 more effectively than the asymptomatic ones? Analysis of Phuket contact tracing data in the first half of 2020 and 2021

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Abstract

Unlike SARS and MERS, COVID-19 had a stealth mode. This present study aims to compare the secondary attack rate among high-risk contacts exposed to symptomatic index cases with those exposed to asymptomatic ones. The chi-square statistic and logistic regression analysis are used to compare infection probabilities of HRCs who have been exposed to symptomatic and asymptomatic cases. Results indicate no statistical difference in infection probability between HRCs exposed to asymptomatic cases and HRCs exposed to symptomatic cases. This present study also revealed a significant impact of close contact with those who share the same household. The contacts in the same household of the index case had eightfold odds to the non-household of COVID-19 index cases, during the April 2020 wave, and fivefold odds during the April 2021 wave. We further recommend adding consistent active case finding as a prerequisite to eliminating both symptomatic and asymptomatic COVID-19 cases from households.

Keywords: asymptomatic transmission, COVID-19, high-risk contact (HRC), household, disease propagation

1. Introduction

The multiple waves of the COVID-19 pandemic in many nations empirically highlight its highly contagious character. Recent studies by Buitrago-Garcia *et al.* (2020) have revealed that 20% of the 6,166 COVID-19 cases showed no symptoms throughout the infectious period. The World Health Organization defines symptomatic cases as infected people who have developed symptoms, while asymptomatic cases refer to people who are infected but never develop any symptoms (The World Health Organization [WHO], 2020a).

Following the early stages of the outbreak in China, in January 2020, Thailand was the second nation in the world to report COVID-19 infections. First cases in Phuket were logged in late January 2020, at which time the disease was elsewhere only found in Wuhan (WHO, 2020a). Following the initially documented cases in January 2020, the number of COVID-19 infections in Phuket sharply rose in late March and mid-April 2020. By the end of the first week of May 2020, the total number of COVID-19 cases stabilized at 227, which remained the total recorded number of infections until 2021. The infection rate in Phuket rose again at the beginning of April 2021 before the vaccination period; the total number of index cases had reached 329 at the end of April.

From the total of 214 index cases during the April 2020 wave, we found that 21% of these were categorized as asymptomatic, and 35% of the index cases did not show any signs of the disease during the April 2021 wave. Although infected people have not developed symptoms, WHO confirmed that infected people could transmit the SARS-CoV-2 virus both when they have symptoms and when they do not have any symptoms (The World Health Organization [WHO], 2020b). Multiple findings also confirmed the transmissibility of COVID-19 from asymptomatic cases (Bai, *et al.*, 2020;

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Sayampanathan, *et al.*, 2020). A recent study that used systematic review found the global percentage of asymptomatic SARS-CoV-2 infections as 40.5 percent among the confirmed diagnoses, and the result suggests that asymptomatic individuals might be an essential driver of transmission in communities (Ma, *et al.*, 2021). Similarly, He *et al.* (2020) and Choi, Kim, Kang, Kim, and Cho (2020) found that SARS-CoV-2 could be transmitted before any respiratory symptoms develop. Song Song, Yun, Noh, Cheong, and Kim, (2020), Arons *et al.* (2020), and Bai *et al.* (2020) found evidence of transmission from both pre-symptomatic and asymptomatic cases. These previous studies suggest that asymptomatic carriers cause a sizeable portion of COVID-19 transmissions. It could be hypothesized that asymptomatic cases can cause a relatively high threat to the public health, as they tend not to self-isolate but remain circulating 'in' the community. However, Byambasuren *et al.* (2020) found asymptomatic individuals 42% less likely to transmit the virus than symptomatic cases. Sayampanathan *et al.* (2020) and Oran and Topol (2020) also found that an index case with asymptomatic COVID-19 is contagious but might be less so than the symptomatic case. Gao, *et al.* (2020) conclude that SARS-CoV-2 patients who are asymptomatic can transmit the virus, but the infectivity of some asymptomatic patient carriers might be weak.

A thorough understanding of SARS-CoV-2 transmission mechanisms would help public health policymakers manage disease transmission risks and economic policymakers to restore normal economic circumstances. The review of previous literature encouraged us to compare the differences between infection probabilities in two clusters of high-risk contacts (HRCs), in which context the HRCs mean people who came in contact with the confirmed COVID-19 cases for longer than five minutes without wearing a mask. The first one consists of HRCs who contact asymptomatic cases, and another group refers to HRCs who had been exposed to the symptomatic index case.

2. Data and Methodology

This paper uses inferential statistical techniques to compare the infection probabilities of HRCs. They were exposed to the asymptomatic index cases with a group of HRCs exposed to the symptomatic individuals. The data used this study are a part of the investigation flow-chart which was undertaken by the Phuket Provincial Public Health office. After the person is confirmed by the Polymerase Chain Reaction (PCR) test as a COVID-19 case, an immediate in-depth telephone interview with the patient is conducted. This is done to obtain an extensive list of people with whom the patient might have been in physical contact during the past two weeks and for periods longer than five minutes without wearing a facial mask. With that information, a team from Phuket's Department of Disease Control classified the identified contacts as either high-risk contact (HRC) or low-risk contact (LRC) and further documented all the contacts' demographic information and type of relationship with the index case(s). It should be noted that only a few contacts in Phuket were identified as low-risk contacts (LRCs) so far, and those included convenience store cashiers, food vendors, and people who interacted with index cases for a short period. HRCs' deidentified information is collected in an encrypted spreadsheet, with slight corrections for spelling and date anomalies.

This study divided HRCs observations into two periods**:** the HRCs who contacted the COVID-19 patient in April of the 2020 wave; another is the group of the HRCs exposed to the COVID-19 cases in April of 2021. After that, the data for both periods were analyzed. Firstly, the Chi-Square statistic, which is commonly used for testing relationships between categorical variables (Wilson & Hilferty, 1931), was conducted to verify whether there is a statistically significant difference between the infection variable and the COVID-19 case's symptoms. Then, the infection probability of each HRC was simulated based on the proposed equation 1 including the case's symptom variable to explore the question of this paper.

Since this study's dependent variable is dichotomous, the two choices for this study were logit and probit models. Hahn and Soyer (2005) pointed out that the probit equation is preferable if the testing model does not contain independent variables with extreme values. As this study focuses on finding the marginal effect from each risk factor of transmission, both logit and probit models would yield relatively similar marginal effects (Breen, Karlson, & Holm (2018); Cornelißen & Sonderhof, (2009)). However, as the study's exogenous variables are dummy and numerical, the logit model, which gives results interpretable by public health readers who are policymakers, was selected for the analysis to find the coefficient and odds ratio of each variable. The following equation was employed as the baseline regression.

$$\begin{aligned} Detected_i = {} & \beta_0+\beta_1 Indexcase_{xi}\text{'s}Symptom+ \\ & \beta_2 Household_i+\beta_3 GenderDifferential_i+ \\ & \beta_4 Indexcase_{xi}\text{'s}Age+ \\ & \beta_5 Contact_{xi}\text{'s}Age(0\text{-}4)+ \\ & \beta_6 Contact_{xi}\text{'s}Age(5\text{-}17)+ \\ & \beta_7 Contact_{xi}\text{'s}Age(18\text{-}29)+ \\ & \beta_8 Contact_{xi}\text{'s}Age(30\text{-}39)+ \\ & \beta_9 Contact_{xi}\text{'s}Age(40\text{-}49)+ \\ & \beta_{10} Contact_{xi}\text{'s}Age(50\text{-}64)+ \\ & \beta_{11} Contact_{xi}\text{'s}Age(65 \text{ and above}) \end{aligned} \quad (1)$$

The endogenous variable in this model is whether the HRC i was detected with COVID-19 (1 if infected, 0 non-infected; If contact's PCR test results were reported as positive either during, or before completion of the 14 days of quarantine, they would be regarded as 1.

The subscript xi represents case x in which contact i was exposed to. Variables included in the model were selected based on the analysis in existing COVID-19 related literature. The following literature review discusses the COVID-19 transmission factors included in the statistical analysis.

Current evidence suggests that the COVID-19 virus spreads between people directly and indirectly (through contaminated objects or surfaces), particularly when in close contact by living within the same household with infected people. Chen *et al.* (2020) and Cauchemez *et al.* (2009), as well as Hui, Azhar, Kim, and Memish (2018) found that the COVID-19 and the respiratory virus spread easier among people living within the same household. Westchester in the

US had clear evidence of family cluster transmissions, while secondary household transmissions of the virus occurred among married couples in California and Illinois (Edwards, 2020). The previous literature also found some differences in the number of infections by gender. A larger portion of COVID-19 reported cases in Switzerland, Spain, and Italy were female, while in Iran, male.

Another variable examined in this study is the infected cases' and their HRCs' ages. This is because Bi *et al.* (2020) found that individuals' infection risks appear statistically similar across various age groups. However, an investigation by Li *et al.* (2020) and Khan (2020) found that the secondary infection rate in children occurred in lower numbers than in adults. However, the recent report of Centers for Disease Control and Prevention (2022b) shows no difference in risk of infection between nine age groups. Thus, the age still remains an ambiguous variable for transmission risk and needs more study.

3. Results

This study applied the statistical analysis of high-risk contacts of COVID-19 index cases in Phuket. The data cover two primary waves of the outbreak in Phuket during April 2020 and April 2021; descriptive information of indexed cases and HRCs is summarized in Table 1. In April of the year 2020, the 214 cases had been recorded between January and April 2020 which account for 93% of all the COVID-19 cases in Phuket as of December 2020, and of these 169 patients showed some symptoms while another 45 cases were asymptomatic patients, and 1,088 HRCs stemmed from the 214 index cases (Phuket Provincial Public Health Office, 2020). For the year 2021, Phuket Provincial Public Health Office recorded 173 index cases during April and 112 of them were verified to be symptomatic index cases and 61 index cases did not show any symptoms; and all the 173 index cases had close contact with 1,368 HRCs (Phuket Provincial Public Health Office, 2021).

172 of the 1,088 HRCs were later diagnosed as COVID-19 cases of the 2020 dataset, and 119 of 1,386 HRCs were later diagnosed as COVID-19 cases during the 2021 wave; this shows the higher infection rate during the initial wave (15.81%) than in the second major wave in April 2021 (8.59%).

The key variable in the testing equation is whether the index case that HRCs had been exposed to is asymptomatic or systematic. It would be myopic to categorize the HRCs exposed to both asymptomatic and symptomatic index cases. This study excluded HRCs who had exposure to more than one index case from the study (detailed information is in Table 2), in order to reduce the repeated measure problems.

The number of selected HRCs in April 2020 was 614; 584 got exposed to the 102 index symptomatic cases, while 30 HRCs got exposed to the five index cases categorized as asymptomatic. While of the 668 HRCs from in April of 2021, 493 had contacted 67 symptomatic index cases, and 175 HRCs got exposed to the 27 asymptomatic index cases. The infection rate of HRCs exposed to asymptomatic cases (16.67% in 2020 and 9.14% in 2021) is higher than that of HRCs exposed to symptomatic cases in both waves (6.51% and 9.14% in 2020 and 2021 respectively) in both periods.

Table 1. Descriptive statistics of two types of confirmed cases and high-risk contacts (HRCs)

Period	Confirmed cases		HRCs' Infection			Percentage of infections
			Non detected	Detected	Total	
April 2020	Symptomatic	169	916	172	1088	15.81%
	Asymptomatic	45				
	Total cases	214				
April 2021	Symptomatic	112	1267	119	1386	8.59%
	Asymptomatic	61				
	Total cases	173				

Table 2. Descriptive statistics of selected confirmed cases and high-risk contacts (HRCs) and Chi-square tests of HRCs' infection between symptomatic and asymptomatic sources of infection

Period	Confirmed cases		HRCs' Infection			Percentage of infected	Chi-Square ests	
			Non detected	Detected	Total		Pearson Chi-Square Sig. (2-tailed)	Fisher's xact est Sig. (2-tailed)
April 2020	Symptomatic	102	546	38	584	6.51%	0.033**	0.050**
	Asymptomatic	5	25	5	30	16.67%		
	Total cases	107	571	43	614	7.00%		
April 2021	Symptomatic	67	453	40	493	8.11%	0.673	0.638
	Asymptomatic	27	159	16	175	9.14%		
	Total cases	94	612	56	668	8.38%		

Note: The figures reported with * are significant with 0.1 significance level, the figures reported with ** are significant with 0.05 significance level, the figures reported with *** are significant at 0.01 significance level.

However, the result from Chi-Square, which tests the difference between the infection variable and the COVID-19 case's symptoms, was significant at a 95% level of confidence only in the 2020 period. This implies that we found a significant difference in infection rates between the HRCs exposed to asymptomatic and symptomatic cases only in 2020. To fully investigate the exposure risk between asymptomatic and symptomatic index cases, logistic regression was conducted to find the coefficient and odds ratio for each variable based on equation 1. The explanation and descriptive result of the variables proposed in the equation, by the time period, are reported in Table 3.

The interpretation of odds ratio (OR) of the variables proposed in equation 1 is reported in Table 4 and interpreted as follows.

Table 4 illustrates COVID-19 exposure risk of HRCs through their exposure to either symptomatic or asymptomatic index cases and other control variables for both periods with the simulated probability of HRC by the logistic regression. It reveals that the difference in infection probability between HRCs exposed to asymptomatic cases and HRCs exposed to symptomatic cases was no longer statistically significant at 95% CI. This result indicates that the potential transmission risk of asymptomatic infections is not different from that of an index case with symptoms. The output of this study is similar to the studies reported earlier in 2020 and 2021 (Bai, et al., 2020; Ma, et al., 2021). The study of 3,790 HRCs in Singapore by Sayampanathan *et al.* (2020) recently revealed no relationship between the infection rate of HRCs and the serology status of the index case, it could be that close contacts tend to regularly get in touch with the index case and virus spreading happens before a person who was infectious turns to seropositive.

However, the analysis of both 2020 and 2021 datasets showed that variables representing household infection attacks were reported at a 99% confidence level. It was found that the odds ratio of contacts who share the same household was as high as 7.93 (95% CI: 3.98-15.80), and 5.05 (95% CI: 2.83 - 9.02) in the years 2020 and 2021. This implies that the HRCs who live in the same household with the index case had eightfold odds of the non-household group of COVID-19 index case in 2020 and approximately fivefold odds in the period of 2021. Similar results were found in the recent studies by Chen *et al.* (2020) and Edwards (2020), as the virus spread more easily amongst people living in the same household.

No relationship was found between HRCs' infection probability and other control variables, meaning age or gender differential; these indicate that the differences in age and gender among the HRCs could not statistically influence infection probability of the HRCs.

4. Discussion and Policy implications

Phuket was among the first areas in the world with reported COVID 19 cases, and its first imported case was detected as early as January 2020. However, the island's major outbreak occurred through local transmissions in April 2020; daily new cases gradually declined toward zero rate at the end of April 2020. A year apart, the second major outbreak on the island started again in April 2021.

The descriptive analysis indicated that the infection rate among HRCs exposed to symptomatic index cases was higher than that of HRCs with exposure to asymptomatic index cases, during both waves. However, the Chi-square test only confirms statistically significant differences between the odds of these two groups of HRCs in 2020. In the subsequent regression analysis and 95% CI, an exposure of HRCs to either asymptomatic or symptomatic cases could not result in a difference in HRCs' infection probability. This study indicates that the potential transmission risk of asymptomatic infections is not larger than the transmission risk of an index case with symptoms. Thus, HRCs with recorded exposure to symptomatic or asymptomatic cases should be treated with equivalent measures, including isolation containment and contact tracing procedures (Ma, *et al.*, 2021).

Table 3. The explanation and descriptive statistics of the variables proposed in equation by period.

Characteristic	Measurement		April 2020		April 2021	
			Infected HRC	Non-infected HRC	Infected HRC	Non-infected HRC
Detected	Whether HRC was a COVID-19 confirmed case		43	570	56	612
Index cases' symptom	Whether index cases show any signs that the disease is present in their body.	Symptomatic (1)	38	546	40	453
		Asymptomatic (0)	5	25	16	159
Gender differential	Gender differential between an index case and HRC	Yes (0)	26	342	25	308
		No (1)	17	229	31	304
Household	Whether HRC lived in the same household with the confirmed case during the past 14 days	Yes (1)	20	59	32	136
		No (0)	23	512	24	476
Index cases' age	Age of each index case (year)		44.8-year-old in average	38.7-year-old in average	37.2-year-old in average	39.1-year-old in average
HRC Age[†]	Age of high-risk contact (HRC) by group	0-4	1	15	0	0
		5-17	4	55	0	0
		18-29	13	164	25	198
		30-39	5	139	12	211
		40-49	10	99	12	125
		50-64	7	82	7	78
		65 and above	3	16	0	0

[†]Note: It should be noted for 1 of them were excluded from the analysis, due to missing information about the required variables.

Table 4. Results of secondary attack rate among high risk cases; analysis by logistic regression model

Variable	Odds ratio for COVID-19 secondary attack in April 2020				Odds ratio for COVID-19 secondary attack in April 2021			
	Beta	P value	Odd ratio (OR)	95% CI of OR	Beta	P value	Odd ratio (OR)	95% CI of OR
Intercept (Constant)	-20.46	1.00	<0.001	(-)	-3.19	<0.001	0.04	(-)
Index cases' symptom	-1.07	0.06	0.34	(0.11 - 1.0)	-0.09	0.77	0.91	(0.47 - 1.71)
Household	2.07	<0.001	7.93	(3.98 - 15.80)	1.62	<0.001	5.05	(2.83 - 9.02)
Gender differential	-0.31	0.39	0.74	(0.37 - 1.49)	0.26	0.38	1.30	(0.73 - 2.30)
Index cases' age	0.02	0.08	1.02	(1.00 - 1.039)	-0.01	0.42	0.99	(0.98 - 1.01)
Contacts' age (0-4)	17.54	1.00	>999.99	(<0.001 - >999.99)	-	-	-	(-)
Contacts' age (5-17)	17.53	1.00	>999.99	(<0.001 - >999.99)	-	-	-	(-)
Contacts' age (18-29)	17.76	1.00	>999.99	(<0.001 - >999.99)	0.76	0.11	2.14	(0.85 - 5.40)
Contacts' age (30-39)	17.09	1.00	>999.99	(<0.001 - >999.99)	-0.13	0.80	0.88	(0.32 - 2.40)
Contacts' age (40-49)	18.08	1.00	>999.99	(<0.001 - >999.99)	0.55	0.30	1.72	(0.62 - 4.84)
Contacts' age (50-64)	17.71	1.00	>999.99	(<0.001 - >999.99)	-	-	-	(-)
Contacts' age (65 and above)	18.42	1.00	>999.99	(<0.001 - >999.99)	-	-	-	(-)
Number of observations			613[†]				668	
Observations with dependent variable=0			570				612	
Observations with dependent variable=0			43				56	
Pseudo R Square			0.179				0.123	

[†] It should be noted for 613 observations, 1 of them were excluded from the analysis, due to the missing information about the required variables.

This study's findings of household secondary attacks in both waves should once again draw attention to the intensity of household COVID-19 attacks, as Li *et al.* (2020) and Phucharoen, Sangkaew, and Stosic (2020) also found. Chen *et al.* (2020), Cauchemez *et al.* (2009), and Hui *et al.* (2018) also found a higher risk of transmission within the households. This finding implies the transmission capabilities of COVID-19 between contacts who work with or live in the same accommodation with an index case. A plausible explanation for continuous transmissions within Thai households could be derived from the recent behavior study (Faculty of Economics, Chulalongkorn University, 2020), which found that 70-80% of Thai households still shared meals for breakfast, lunch, and dinner, even in the midst of the COVID-19 pandemic. These combined findings therefore recommend further studies of ethnic groups' meal preferences within households, in order to better equip public health authorities worldwide to assess the ways of further reducing the transmission probabilities within households.

With the application of this finding to vulnerable infection groups, namely elderly members and household members with chronic health conditions were considered SARS-CoV-2 vulnerable groups (Centers for Disease Control and Prevention, 2022a), these should be separated from sharing the same roof with an index case who either has or does not have symptoms.

The present statistical analysis of this paper does not particularly highlight the camouflage operation of COVID-19, as it can spread during pre-symptomatic or asymptomatic index cases (Bai *et al.*, (2020); Arons *et al.*, (2020); Song *et al.*, (2020). The results of this study further emphasize the potential for infections within households. Early detection, either through self-screening or state provided screening and immediate isolation of indexed cases from the elderly and household members with chronic health conditions could reduce losses or public health burdens, and protect a vulnerable group of household members.

COVID-19 is still considered a concurrent pandemic, and many researchers across the globe are continuously investigating the newly emerged SARS-CoV-2 disease. One of the limitations in this analysis is the construction of the testing models, as they were based on current understanding of the disease. Therefore, the exogenous variables list is incomplete and cannot include all factors that could potentially affect HRCs' infection probability. In addition, the surveillance data could only reflect whether the contact lived in the same household with the index case as a dummy variable. Still, the data in this analysis do not contain detailed information on household sizes, house sharing facilities, or physical dimensions of dwellings. Finally, the present study is based on contact tracing data in Phuket, which has specific geographical characteristics during the two major waves. The data do not represent the Delta and Omicron waves, which imposed even more daily infections on the island. Lastly, Phuket is an island where authorities were able to control the population's mobility at an absolute scale during the first and second waves in 2020 and 2021, respectively. Therefore, it would be interesting to test the applied statistical model on other areas' contact tracing data, on either regional or national scale, and verify the results of this study.

5. Ethics Approval and Consent

For this study, the Institutional Review Board or any formal approval from the ethical committee is not required as the study uses pre-existing and deidentified data. The data were anonymized and irreversibly deidentified to protect index cases and all contacts. It should be noted that the identifying details of observations also remained completely anonymous. No trials were conducted on either humans or animals for this study.

References

Arons, M. M., Hatfield, K. M., Reddy, S. C., Kimball, A., James, A., Jacobs, J. R., . . . CDC COVID-19 Investigation Team. (2020). Presymptomatic SARS-CoV-2 infections and transmission in a skilled nursing facility. *The New England Journal of Medicine, 382*(22), 2081-2090. doi:10.1056/NEJMoa2008457

Bai, Y., Yao, L., Wei, T., Tian, F., Jin, D. Y., Chen, L., & Wang, M. (2020). Presumed asymptomatic carrier transmission of COVID-19. *The Journal of the American Medical Association, 323*(14), 1406-1407. doi:10.1001/jama.2020.2565

Bi, Q., Wu, Y., Meis, Ye, C., Zou, X., Zhang, Z. L., . . . Feng, T. (2020, April 27). Epidemiology and transmission of COVID-19 in Shenzhen China: Analysis of 391 cases and 1,286 of their close contacts. *The Lancet Infectious Diseases, 20*(8), 911-919. doi:10.1016/S1473-3099(20)30287-5.

Breen, R., Karlson, K. B., & Holm, A. (2018, July). Interpreting and understanding Logits, Probits, and other nonlinear probability models. Annual review of sociology. *Annual Review of Sociology, 44*. doi:10.1146/annurev-soc-073117-041429

Buitrago-Garcia, D., Egli-Gan, D., Counotte, M. J., Hossmann, S., Imeri, H., Ipekci, A. M., . . . Low, N. (2020). Occurrence and transmission potential of asymptomatic and presymptomatic SARS-CoV-2 infections: A living systematic review and meta-analysis. *PLOS Medicine, 17*(9). Retrieved from https://doi.org/10.1371/journal.pmed.1003346

Byambasuren, O., Cardona, M., Bell, K., Clark, J., McLaws, M. L., & Glasziou, P. (2020). Estimating the extent of asymptomatic COVID-19 and its potential for community transmission: systematic review and meta-analysis. *Official Journal of the Association of Medical Microbiology and Infectious Disease Canada.* doi:10.1101/2020.05.10.20097543

Cauchemez, S., Donnelly, C. A., Reed, C., Ghani, A. C., Fraser, C., Kent, C. K., . . . Ferguson, N. M. (2009). Household transmission of 2009 pandemic influenza A (H1N1) virus in the United States. *The New England Journal of Medicine, 361*, 2619-2627. doi:10.1056/NEJMoa0905498

Centers for Disease Control and Prevention. (2022a). *COVID-19 Information for Specific Groups of People.* The national public health agency of the United States, USA. Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/index.html

Centers for Disease Control and Prevention. (2022b). *Risk for COVID-19 Infection, Hospitalization, and Death By Age Group.* The national public health agency of the United States, USA. Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-age.html

Chen, N., Zhou, M., Dong, X., Qu, J., Gong, F., Han, Y., . . . Zhang, L. (2020). Epidemiological and clinical characteristics of 99 cases of 2019 novel corona virus pneumonia in Wuhan, China: A descriptive study. *The Lancet, 395*(10223), 507-513. doi:10.1016/S0140-6736(20)30211-7

Choi, S. H., Kim, H. W., Kang, J. M., Kim, D. H., & Cho, E. Y. (2020). Epidemiology and clinical features of coronavirus disease 2019 in children. *Clinical and Experimental Pediatrics, 63*(4). doi:10.3345/cep.2020.00535

Cornelißen, T., & Sonderhof, K. (2009, June). Partial effects in Probit and Logit models with a triple dummy-variable interaction term. *The Stata Journal, 9*(4), 571-583. Retrieved from https://journals.sagepub.com/doi/pdf/10.1177/1536867X0900900404

Edwards, E. (2020). *Family clusters: A common pattern for how the coronavirus spreads.* Retrieved from https://www.nbcnews.com/health/health-news/family-clusters-common-pattern-how-coronavirus-spreads-n1150646

Faculty of Economics, Chulalongkorn University. (2020). *Behavioral Insights of Thai household under covid-19.* The research project, Chulalongkorn University, Faculty of Economics, Bangkok. Retrieved from https://drive.google.com/…/1s-tvSan9LHnDWbfbs4t8vIeqWA…/view Accessed 12 April 2020

Gao, M., Yang, L., Chen, X., Deng, Y., Yang, S., Xu, H., . . . Gao, X. (2020, August). A study on infectivity of asymptomatic SARS-CoV-2 carriers. *Respiratory Medicine, 169*. doi:10.1016/j.rmed.2020.106026

Hahn, E. D., & Soyer, R. (2005). *Probit and logit models: Differences in the multivariate realm.* Retrieved from http://home.gwu.edu/~soyer/mv1h.pdf

He, X., Lau, E. H., Wu, P., Peng, X., Wang, J., Hao, X., . . . Leung, G. M. (2020). Temporal dynamics in viral shedding and transmissibility of COVID-19. *Nature Medicine, 26*, 672-675. doi:10.1038/s41591-020-0869-5

Hui, D. S., Azhar, E. I., Kim, Y. J., & Memish, Z. (2018, April). Middle East respiratory syndrome coronavirus: Risk factors and determinants of primary, household, and nosocomial transmission. *The Lancet Infectious Diseases, 18*(8), 1-11. doi:10.1016/S0140-6736(20)30211-7

Khan, A. (2020). *What COVID-19 patients young and old can teach us about the coronavirus.* Retrieved from https://www.latimes.com/science/story/2020-05-08/what-younger-covid-19-patients-can-teach-us-about-the-coronavirus

Li, W., Zhang, B., Lu, J., Liu, S., Chang, Z., Cao, P., . . . Chen, J. (2020). The characteristics of household transmission of COVID-19. *Clinical Infectious Diseases, 71*(8), 1943-1946. doi:10.1093/cid/ciaa450

Ma, Q., Liu, J., Liu, Q., Kang, L., Liu, R., Jing, W., . . . Liu, M. (2021). Global percentage of asymptomatic SARS-CoV-2 infections among the tested population and individuals with confirmed COVID-19 diagnosis. *JAMA Netw Open, 4*(12), 1-18. doi:10.1001/jamanetworkopen.2021.37257

Oran, D. P., & Topol, E. J. (202). Prevalence of asymptomatic SARS-CoV-2 infection. *Annals of Internal Medicine, 173*(5). doi:10.7326/M20-3012

Phucharoen, C., Sangkaew, N., & Stosic, K. (2020). The characteristics of COVID-19 transmission from case to high-risk contact, a statistical analysis from contact tracing data. *Eclinicalmedicine, 27*, 1-11.

doi:10.1016/j.eclinm.2020.100543

Phuket Provincial Public Health Office. (2020). *Covid-19 situation in Phuket.* Retrieved from https://www.pkto.moph.go.th

Phuket Provincial Public Health Office. (2021). *Covid-19 situation in Phuket.* Retrieved from https://www.pkto.moph.go.th

Sayampanathan, A. A., Heng, C. S., Pin, P. H., Pang, J., Leong, T. Y., & Lee, V. J. (2020, December 18). Infectivity of asymptomatic versus symptomatic COVID-19. *The Lancet*, 1. doi:10.1016/S0140-6736(20)32651-9

Song, J. Y., Yun, J. G., Noh, J. Y., Cheong, H. J., & Kim, W. J. (2020). Covid-19 in South Korea—challenges of subclinical manifestations. *The New England Journal of Medicine, 382*(19), 1858-1859. doi:10.1056/NEJMc2001801

The World Health Organization [WHO]. (2020a). *Coronavirus disease* (*COVID-19*)*: How is it transmitted?* Retrieved from https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-how-is-it-transmitted#

The World Health Organization [WHO]. (2020b). *Q&A: How is COVID-19 transmitted?* Retrieved from https://www.who.int: https://www.who.int/vietnam/news/detail/14-07-2020-q-a-how-is-covid-19-transmitted#:~:text=Yes%2C%20infected%20people%20can,%2C%20receive%20medical%20care.

Wilson, E. B., & Hilferty, M. M. (1931). The distribution of Chi-Square. *Proceedings of the National Academy of Sciences of the United States of America, USA*. National Academy of Science. doi:10.1073/pnas.17.12.684