Supplemental Information—Influenza and CoV Modes of Transmission and Environmental Stability

Review of Transmission Modes

Respiratory pathogens typically transmit between one of three modes: contact, droplet, and aerosol. Contact transmission occurs in two ways: when physical contact between individuals spreads virus from body to body through, for example, kissing or touching of contaminated skin (handshakes, etc.) or through fomites. Droplet transmission occurs through droplets, which are airborne particles generated through coughing and sneezing that are too large to remain airborne and fall in a ballistic trajectory. These droplets may be inhaled by nearby persons prior to them hitting the ground. Aerosol transmission occurs via small droplets (<5um) that remain airborne for significant periods of time. These aerosolized droplets are also inhaled by nearby individuals, or later passersby.

Influenza

Influenza Environmental Persistence

Several studies have examined the survivability of influenza in aerosols and fomites. Influenza appears to be short lived on fingertips in mucus. Eighteen fingers were inoculated with a 2uL droplet of either H3N2 at 1.8e7 $TCID_{50}$/mL or H1N1 at 1e5 $TCID_{50}$/mL. After 30 minutes, 2 out of 18 fingers remained positive for each of the two viruses tested (Figure S1).[1]

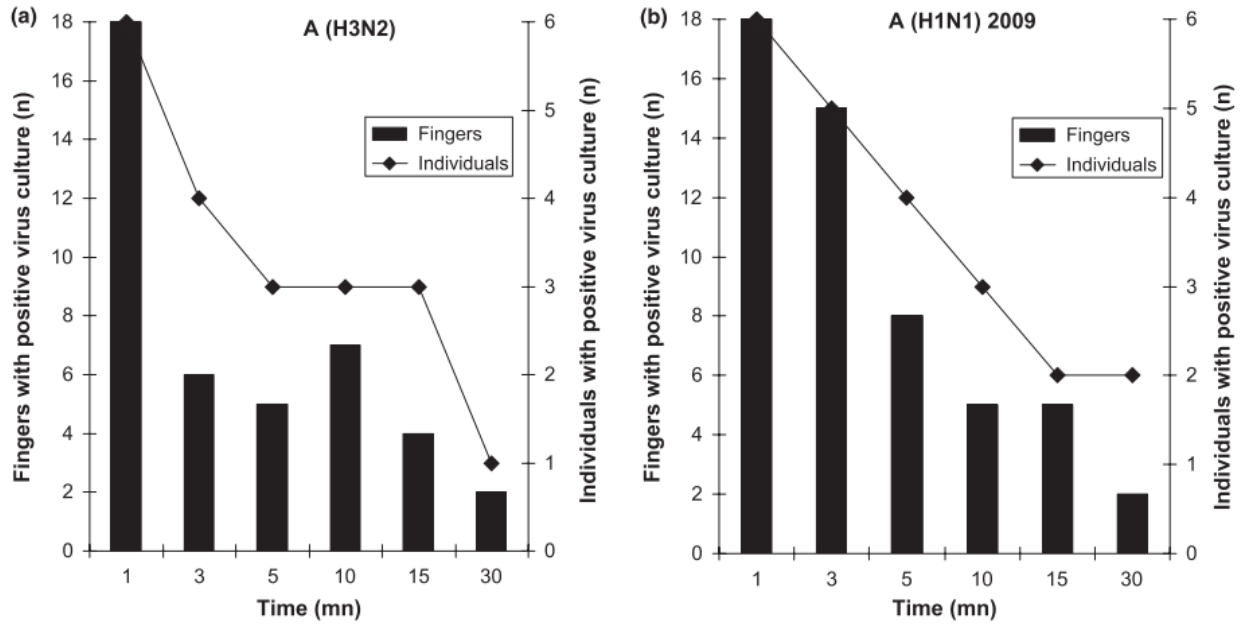

Figure S1. Inoculated fingers with positive virus culture based on time, reproduced from Thomas et al.[2]

[1] Thomas Y *et al* (2014) Survival of influenza virus on human fingers. *Clinical microbiology and infection : the official publication of the European Society of Clinical Microbiology and Infectious Diseases* 20**:** O58-64

[2] Ibid.

To fit a distribution to these numbers, it was assumed that the detection threshold of virus was 4 $TCID_{50}$, resulting in a 12.5% chance of a false negative. It was also assumed that the virus had decayed to just below detection immediately prior to the measurement when it was not detected, resulting in a maximal estimation of actual half-life. An approximate half-life was computed for each finger, and the data for both strains were combined into a single histogram. The data were best fit by a gamma distribution with the following parameters.

Table S1. Distribution Parameters at Minutes	
Distribution Parameter	**Value (minutes)**
A	1.00911 (Std Err. 0.222)
B	1.53685 (Std Err. 0.433)
Mean	1.55085
Variance	2.38343

In addition, a complex relationship exists between survival, dose, and volume. When H3N2 inoculum volume is increased (from the 2uL droplets used to measure survival) while the titer of the droplet is kept constant (1.8e7 $TCID_{50}$/mL), the number of fingers remaining positive after 15 minutes increases significantly; only 3 data points are available, which is too few to fit properly to any model. In addition, it appears that the volume used to wash fingers in this experiment remains constant, thus increasing the recovery titer from the larger droplets, raising the number of fingers expected to be positive. The number of fingers positive after 15 minutes increases more slowly than the total amount of virus inoculated, indicating a potential increased rate of decay for larger droplets containing more virus; however, the data are too sparse to draw any significant conclusions. The figure from this experiment is reproduced below (Figure S2). Additionally, one data point from this experiment (the 2uL droplet test) is identical to the earlier survival experiments, yet shows a 50% decrease in the number of fingers positive for viruses after 15 minutes, indicating significant variability in these types of experiments.

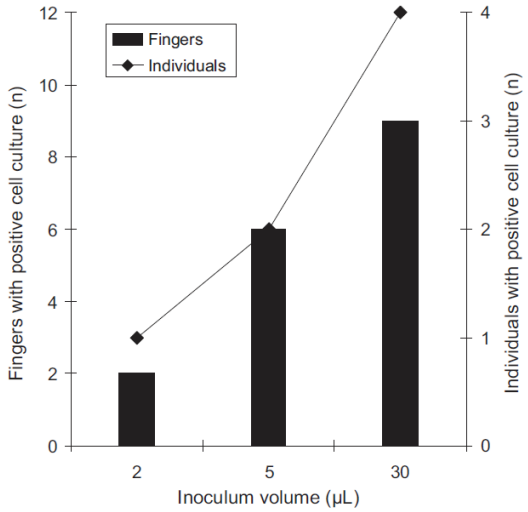

Figure S2. Volume of Positive Cell Culture on Fingers, reproduced from Thomas et al. *(Thomas et al, 2014)*

When H3N2 droplet size was increased while keeping the total amount of virus constant, thus decreasing the titer, the number of fingers with virus after 15 minutes remains fairly constant; however, none of the conditions used in this experiment are comparable to any other experiments, thus making it difficult to establish a baseline value for how many fingers would be expected to be positive.

In testing influenza stability on bank notes, H3N2 appears to have higher stability than H1N1, with Moscow H3N2 positive for up to 3 days at a starting titer of 8.9e6 $TCID_{50}$/mL and Wisconsin H3N2 positive for up to 1 day at a titer of 5e4. A New Caledonia H1 strain was negative at 2 hours using a concentration of 2.8e5. When H3N2 is mixed with mucus, it survives for much longer, up to 17 days at 9e5 TCID50/ml. For H3N2, the authors also show a dose dependence after varying the initial tier over an 8 fold range (9e5 $TCID_{50}$/ML to 1.1 $TCID_{50}$/mL). Like the paper on flu on fingers, no information about the titer on banknotes is presented, just whether the sample was positive or negative.[3]

On surfaces and common objects, influenza survives up to 24 hours on hard plastic and stainless steel surfaces, but declines rapidly on porous surfaces such as tissues, pajamas, and paper magazines.[4] Using a fit to a model of single exponential decline and estimates of titer from a Bean et al. (1982), resulting in good fits with R^2>0.98 for all fits, the following half-lives were derived.

Table S2. Half-Life of Influenza A H1N1 on Surfaces

Surface	Half-Life in Hours
Stainless steel counter top	2.3
Plastic dishpan	2.5
Cotton handkerchief	0.43
Paper facial tissue	0.46
Non glossy magazine page	0.57
Cotton, flame retardant pajamas	0.80

On PPE, influenza appears to survive at least 24 hours on gloves, Tyvek gowns, and stainless steel surfaces. The virus appears to survive at least 8 hours on surgical masks, N95 respirators, and wooden desk surfaces.[5] Using data from Sakaguchi et al. (2010), single exponential fits were made for all surfaces, and half-lives were computed.[6] In one case, for the rubber glove, the paper text and figure data did not agree, and the figure data were used.

Table S3. Half-Life of Influenza A H1N1 PR8 on Surfaces

Surface	Half-Life in Hours
Rubber Glove	ND*
N95 Respirator	ND*
Surgical Mask	ND*
Tyvek	2.8
Finished Wood	1.7
Stainless steel surface	0.38
**For these surfaces, the data were not well represented by a single exponential decay due to an increase in titer returning to starting levels after 8 hours; points were not removed as outliers as they were consistent across materials.*	

In summary, influenza appears to survive considerably longer on nonporous surfaces compared to porous ones, and has a considerable life time.

[3] Thomas Y *et al* (2008) Survival of influenza virus on banknotes. *Applied and environmental microbiology* 74**:** 3002-3007
[4] Bean B *et al* (1982) Survival of influenza viruses on environmental surfaces. *The Journal of infectious diseases* 146**:** 47-51
[5] Sakaguchi H *et al* (2010) Maintenance of influenza virus infectivity on the surfaces of personal protective equipment and clothing used in healthcare settings. *Environmental health and preventive medicine* 15**:** 344-349
[6] Ibid.

Aerosol Survivability

Aerosol Generation Survival

Influenza virus strain 2009 H1N1 was put through an aerosol generator, subjected to continuous aerosol generation for 10 minutes, and then viability by $TCID_{50}$ was measured immediately after the aerosol generator was stopped. These experiments were conducted under two relative humidities, 40% and 70%.[7] As no time elapsed between the ceasing of the generator and the measurement of the virus, these experiments measure the survivability of the virus in an aerosol generation process and not the decay rate over time once aerosolized. Immediately after the generator was stopped, genomic copy number was determined by RT-PCR and converted to $TCID_{50}$ equivalents, using a standard curve based on MERS-CoV stocks of known titer that had not been aerosolized, and then converted to survival fraction. In these experiments, 2009 H1N1 virus decreased under both conditions with 95% loss after 10 minutes of aerosol generation for 40% RH and 62% loss after 10 minutes of aerosol generation for 70% RH respectively. This decrease was found to be significant at 40% RH ($p=0.0095$), but not at 70% RH and did not differ significantly between the two conditions. No other conditions were measured, and only the single 10 minute generation time was used, using a single starting titer of 10^6 $TCID_{50}$/mL.

Aerosol Decay Rate

Two sources measured influenza aerosol decay rates. Influenza virus strain PR8 was put through an aerosol generator at various temperature and humidity combination, and samples were collected and stored in a steel drum, after which air samples were taken at various time points to measure viability of the remaining virus.[8] Higher relative humidity and higher temperatures both decreased virus survival. Data were fit to a single exponential decay, which resulted in fits of moderate quality. Values listed as "trace" and "nil" in the original work were set to 0.5% and 0.0% remaining, respectively.

Table S4. Influenza A PR8 Half-Life in Temperature and Humidity Conditions

Temperature and Humidity Condition	Half-Life in Hours
7C and 24% RH	ND*
7C and 51% RH	11
7C and 82% RH	2.5
22C and 21% RH	17
22C and 35% RH	10
22C and 50% RH	0.73
22C and 64% RH	0.39
22C and 81% RH	0.35
32C and 20% RH	1.8
32C and 49% RH	0.087
32C and 81% RH	0.13
**These data were not well represented by a single exponential decay*	

Similar experiments compared the aerosol decay rates of two human and one avian strain at 21C and 75% RH.[9] Data were again fit to a single exponential decay, which resulted in high quality fits.

[7] van Doremalen N *et al* (2013) Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. *Euro surveillance : bulletin Europeen sur les maladies transmissibles = European communicable disease bulletin* 18

[8] Harper GJ (1961) Airborne micro-organisms: survival tests with four viruses. *The Journal of hygiene* 59**:** 479-486

[9] Mitchell CA *et al* (1968) Decay of influenza A viruses of human and avian origin. *Canadian journal of comparative medicine : Revue canadienne de medecine comparee* 32**:** 544-546

Table S5. Half-Life of Influenza Strains	
Strain	Half-Life in Hours
PR8	0.36
A/FMI47 (human origin strain)	0.60
A/Duck Czech-56 (avian origin strain)	1.2

Comparison of Avian, Swine and Human Strains

Two sources compared the lifetimes of avian, swine, and human origin strains, where lifetime is defined as the time since aerosolization when virus is no longer detectible. Human and swine viruses were determined to have similar lifetimes, both of which were significantly shorter than avian lifetimes.[10,11]

Comparison of Aerosol Composition and Growth Host

One study examined the relative effects of different host cells lines for virus preparation, as well as the presence of several additives to the medium used to generate the aerosols.[12] This study did not quantify survival beyond 60 minutes and therefore cannot be used to quantitate decay rates. However, it did demonstrate no strong correlation between protein content and virus survival except when protein concentrations are extremely low, resulting in rapid virus decay. It also demonstrated that inositol and sucrose stabilized virus when present. The paper also noted significant variation in virus aerosol stability from preparation to preparation that made it difficult to draw any conclusions on changes in stability between viruses grown in human cells, chicken cells, bovine cells, and embryonated eggs.

Mode of transmission

Some evidence exists for influenza transmission of all three modes, with no clear causative study eliminating or confirming a particular mode. No direct evidence has shown contact can mediate transmission, and data available do not fully support the contact route playing a significant role.[13] Droplet transmission is a possibility. Given the complex sequence of events required to cause droplet transmission, including production, required infectious dose, timing, and breathing rate, one model estimates that droplet transmission is a rare event.[14,15] The evidence for aerosol transmission is mounting. For example, in a study by Alford et al. (1966), volunteers inhaled aerosolized virus, and several became ill.[16] Although some assumptions had to be made in the calculation, this paper estimates the aerosol

[10] Mitchell CA, Guerin LF (1972) Influenza A of human, swine, equine and avian origin: comparison of survival in aerosol form. *Canadian journal of comparative medicine : Revue canadienne de medecine comparee* 36**:** 9-11

[11] Mitchell CA *et al* (1968) Decay of influenza A viruses of human and avian origin. *Canadian journal of comparative medicine : Revue canadienne de medecine comparee* 32**:** 544-546

[12] Schaffer FL *et al* (1976) Survival of airborne influenza virus: effects of propagating host, relative humidity, and composition of spray fluids. *Archives of virology* 51**:** 263-273

[13] Killingley B, Nguyen-Van-Tam J (2013) Routes of influenza transmission. *Influenza and other respiratory viruses* 7 Suppl 2**:** 42-51

[14] Atkinson MP, Wein LM (2008) Quantifying the routes of transmission for pandemic influenza. *Bulletin of mathematical biology* 70**:** 820-867

[15] Killingley B, Nguyen-Van-Tam J (2013) Routes of influenza transmission. *Influenza and other respiratory viruses* 7 Suppl 2**:** 42-51

[16] Alford RH *et al* (1966) Human influenza resulting from aerosol inhalation. *Proceedings of the Society for Experimental Biology and Medicine Society for Experimental Biology and Medicine* 122**:** 800-804

infectious dose at 0.3-6 $TCID_{50}$. Influenza can also be detected in the air,[17,18] and from the breath of infected individuals,[19] though these data are less informative for our risk analysis.

Generally, long range transmission of influenza has not been directly confirmed. For short range transmission, distinguishing between droplet and aerosol transmission is difficult. However, experiments have confirmed that aerosol infection of human individuals is a possibility, so laboratory aerosols should be considered a viable mode of infection.

SARS-CoV

Environmental Persistence

Compared to influenza, SARS-CoV has a relative dearth of information related to persistence. SARS-CoV stability was measured on polystyrene and in solution with or without the addition of FBS.[20] Fitting these data to a single exponential decay model gave high quality fits. The following half-lives in Table S6 came from the fits.

Table S6. Half-Life of SARS-CoV Under Different Conditions

Condition	Half-Life in Hours
Dry polystyrene at RT	3.6
Dry polystyrene with FBS at RT	4.8
Solution in minimal medium	28*
Solution in minimal medium + FBS	25

** One data point that had a higher titer than the starting condition in the minimal medium condition was removed as an outlier.*

A follow-up study examined SARS-CoV infectivity over time after drying on polystyrene plates under different temperature and humidity conditions, as well as under suspension in minimal medium under one temperature/humidity condition.[21] Generally, increased temperature and increased humidity both decrease stability. Fitting these data to a single exponential decay resulted in fits with moderate quality. In general, the data tended to show multiple plateaus instead of a continuous decay. The following half-lives were derived from the fits.

[17] Lindsley WG *et al* (2010) Distribution of airborne influenza virus and respiratory syncytial virus in an urgent care medical clinic. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America* 50**:** 693-698

[18] Yang W *et al* (2011) Concentrations and size distributions of airborne influenza A viruses measured indoors at a health centre, a day-care centre and on aeroplanes. *Journal of the Royal Society, Interface / the Royal Society* 8**:** 1176-1184

[19] Milton DK *et al* (2013) Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks. *PLoS pathogens* 9**:** e1003205

[20] Rabenau HF *et al* (2005) Stability and inactivation of SARS coronavirus. *Medical microbiology and immunology* 194**:** 1-6

[21] Chan KH *et al* (2011) The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus. *Advances in virology* 2011**:** 734690

Table S7. Half-Life of SARS-CoV Under Different Conditions on Polystyrene Plates	
Condition	**Half-Life in Hours**
Polystyrene, dry, 28 C and 95% RH	9.3
Polystyrene, dry, 33 C and 95% RH	6.5
Polystyrene, dry, 38 C and 95% RH	2.0
Polystyrene, dry, 28C and 80-90% RH	ND*
Polystyrene, dry, 33C and 80-90% RH	6.3
Polystyrene, dry, 38C and 80-90% RH	4.0
Polystyrene, dry, RT and 50% RH	12
Min. Medium in Screw Cap, RT and 50% RH	34
* *These data were not well represented by a single exponential decay*	

In feces and urine, SARS-CoV is stable at room temperature for 1-2 days, extending to 4 days in stool from patients with diarrhea because of the higher pH. No further information or decay rates are available from this source.[22] No empirical data were found to indicate the survival of SARS in aerosols.

Mode of Transmission

Given the highly nosocomial nature of SARS infection, droplet infection is believed to be the primary mode of transmission.[23] However, in a cluster of 300 cases in a large apartment complex in Hong Kong, case structure was not consistent with droplet or contact. Instead, leaking sewers and ventilation systems appeared to transmit aerosolized virus from infected feces.[24]

MERS-CoV

Environmental Persistence

Given the relatively recent emergence of MERS-CoV, very little data exist on the persistence. Virus was tested for stability on plastic and steel washers at three temperature-humidity combinations. The summary table from van Doremalen et al. (2013) is reproduced below.[25]

[22] The World Health Organization (2014) Middle East respiratory syndrome coronavirus (MERS-CoV) summary and literature update–as of 9 May 2014. . *WHO Risk Assesment* May 2014

[23] Centers for Disease Control and Prevention (2005) Frequently Asked Questions About SARS. http://www.cdc.gov/sars/about/faq.html. Last Update July 2012. Accessed June 29, 2015.

[24] Yu IT *et al* (2004) Evidence of airborne transmission of the severe acute respiratory syndrome virus. *The New England journal of medicine* 350**:** 1731-1739

[25] van Doremalen N *et al* (2013) Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. *European communicable disease bulletin* 18

Surface type; temperature, relative humidity	Mean half-life time of MERS-CoV (hours)[a]	Standard deviation
Plastic; 20°C, 40%	0.954523	1.110443
Plastic; 30°C, 30%	0.441822	0.345291
Plastic; 30°C, 80%	0.904005	4.6838
Steel; 20°C, 40%	0.940139	1.837771
Steel; 30°C, 30%	0.973656	0.31109
Steel; 30°C, 80%	0.641163	0.825395

Figure S3. Persistence of MERS-CoV on different surface types under different temperature and relative humidity conditions, reproduced from *van Doremalen et al.*[26]

Aerosol Generation Survivability

Similar to the experiments on influenza, MERS was also subject to aerosol generation using the same methods and equipment. MERS decreased only 7% in viability at 40% RH after 10 minutes of generation, whereas the viability at 70% RH decreased significantly with 89% (p=0.0045) after 10 minutes of generation. Like influenza, only a single generation time/titer measurement was taken.[27]

Mode of Transmission

MERS is also highly nosocomial, and is believed to spread via respiratory secretions However, due to the relatively recent emergence of the viruses, the exactly method by which the virus spreads is unknown.[28] The DPP4 receptor for the virus is present in only 20% of lung cells,[29] leading some to conclude a large dose of virus is necessary to cause infection.[30] The environmental persistence of MERS[31] has led WHO to conclude that contact or fomite transmission of MERS may be possible.[32]

[26] van Doremalen N *et al* (2013) Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. *Euro surveillance : bulletin Europeen sur les maladies transmissibles = European communicable disease bulletin* 18

[27] Ibid.

[28] Shreaz S *et al* Anticandidal activity of cinnamaldehyde, its ligand and Ni(II) complex: Effect of increase in ring and side chain. *Microb Pathog* [Epub ahead of print]

[29] Raj VS *et al* (2013) Dipeptidyl peptidase 4 is a functional receptor for the emerging human coronavirus-EMC. *Nature* 495**:** 251-254

[30] Butler D (2013) Receptor for new coronavirus found. *Nature* 495

[31] van Doremalen N *et al* (2013) Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. *Euro surveillance : bulletin Europeen sur les maladies transmissibles = European communicable disease bulletin* 18

[32] The World Health Organization (2014) Middle East respiratory syndrome coronavirus (MERS-CoV) summary and literature update–as of 9 May 2014. . *WHO Risk Assesment* May 2014

Other Human Coronavirus

Aerosol Stability

Ijaz et al. (1985) tested the aerosol stability over time of human coronavirus 229E.[33] The authors reported significant survival during aerosol generation, as well as a considerable half-life in aerosolized form. The tables reporting generation and half-life are reproduced below (Figure S4).

Table 1. *Recovery of coronavirus and poliovirus after aerosolization and equilibration of the aerosol cloud*

Relative Humidity (%)	Recovery: Coronavirus 229E, 20 ± 1 °C	Recovery: Coronavirus 229E, 6 ± 1 °C	Recovery: Poliovirus type 1 (Sabin)†, 20 ± 1 °C	Recovery: Poliovirus type 1 (Sabin)†, 6 ± °C
30 ± 5	87·0 ± 2·5	91·0 ± 2·6	0	ND‡
50 ± 5	90·9 ± 1·6	96·5 ± 3·0	0	ND
80 ± 5	55·0 ± 3·5	104·8 ± 5·1	90·0 ± 1·3	ND

* Values are the average of all experiments, minimum of three at each RH.
† Standard reference virus included as an aerosol biological decay control.
‡ ND, Not done.

Table 2. *Half-life of aerosolized viruses under different conditions of relative humidity and temperature*

Virus	Temperature (°C)	Half-life (h): High RH (80 ± 5%)	Half-life (h): Mid RH (50 ± 5%)	Half-life (h): Low RH (30 ± 5%)
Coronavirus 229E	20 ± 1	3·34 ± 0·16	67·33 ± 8·24	26·76 ± 6·21
	6 ± 1*	86·01 ± 5·28	102·53 ± 9·38	34·46 ± 3·21
Poliovirus type 1 (Sabin)	20 ± 1	9·07 ± 1·82	NR†	NR

* Half-life values were predicted by regression analysis of the 24 h results shown in Fig. 2.
† NR, No virus recovered.

Figure S4. Aerosol stability over time of human coronavirus 229E, reproduced from Ijaz et al.[34]

Review of Surface to Finger Transference & Hand to Face Contacts

Surface to Finger Transference

A study by Lopez et al. (2013) examined the transfer efficiency of bacteria and viruses from various surfaces to fingers. They reported pathogen and surface specific transfer rates.[35] In this study, hands were washed and sterilized prior to transference, which has been known to affect results. Some tables from these results are reproduced below (Figure S5).

[33] Ijaz MK *et al* (1985) Survival characteristics of airborne human coronavirus 229E. *The Journal of general virology* 66 (Pt 12)**:** 2743-2748
[34] Ibid.
[35] Lopez GU *et al* (2013) Transfer efficiency of bacteria and viruses from porous and nonporous fomites to fingers under different relative humidity conditions. *Applied and environmental microbiology* 79**:** 5728-5734

TABLE 2 Fomite-to-finger transfer efficiency of microorganisms under low relative humidity of 15% to 32%

	Avg % transfer efficiency ± SD (range)[a]			
Surface type	*E. coli*	*S. aureus*	*B. thuringiensis*	MS-2
Nonporous				
Acrylic	40.7 ± 37.7 (6.4 to 93.5)	3.4 ± 2.5 (0.9 to 8.0)[c]	57.0 ± 12.0 (45.8 to 74.8)	21.7 ± 15.0 (3.0 to 40.6)[c]
Glass	5.1 ± 5.4 (0.7 to 15.1)[c]	20.3 ± 33.4 (0.6 to 85.4)	<0.5 ± 0.2 (<0.3 to 0.9)[b,c]	19.3 ± 13.2 (2.9 to 40.5)[c]
Ceramic tile	11.6 ± 11.8 (0.1 to 33.3)[c]	2.7 ± 2.3 (0.8 to 6.7)[c]	<0.2 ± 0.1 (<0.1 to 0.4)[b]	7.1 ± 4.0 (3.8 to 15.0)[c]
Laminate	21.7 ± 23.9 (5.2 to 66.5)	4.3 ± 2.4 (1.3 to 7.4)[c]	<0.2 ± 0.1 (<0.1 to 0.3)[b,c]	5.4 ± 3.6 (1.0 to 10.0)[c]
Stainless steel	3.8 ± 2.5 (1.5 to 7.1)[c]	4.0 ± 4.0 (1.1 to 11.9)[c]	<0.5 ± 0.2 (<0.4 to <1.0)[b,c]	6.9 ± 8.9 (1.4 to 24.2)[c]
Granite	<7.3 ± 10.6 (<0.1 to 28.0)[b]	3.9 ± 5.0 (0.7 to 13.9)	<0.04 ± 0.03 (<0.02 to 0.1)[b]	10.2 ± 5.0 (4.8 to 16.9)
Porous				
Cotton	<6.8 ± 7.0 (<0.3 to <15.4)[b]	<1.0 ± 0.6 (<0.4 to <1.9)[b]	<0.6 ± 0.1 (<0.5 to <0.8)[b]	0.03 ± 0.02 (0.01 to 0.1)
Polyester	<0.37 ± 0.28 (<0.08 to <0.9)[b]	<0.37 ± 0.48 (0.04 to 1.3)[b]	<0.6 ± 0.6 (<0.2 to <1.7)[b]	0.3 ± 0.2 (0.1 to 0.7)[c]
Paper currency	<0.05 ± 0.04 (<0.02 to 0.1)[b]	0.2 ± 0.1 (0.1 to 0.4)	<0.1 ± 0.1 (<0.02 to 0.2)[b]	0.4 ± 0.4 (0.1 to 0.9)

[a] % transfer efficiency = (CFU or PFU finger/CFU or PFU control fomite) × 100 (n = 6 for each fomite and microorganism).
[b] Transfer of organisms from fomite to fingers for one or more transfer events was below the detectable limit of 10 CFU/2 cm^2 (indicated by <).
[c] There was a statistically significant difference (Student's t test; $P \leq 0.05$) in the transfer efficiency results between low and high relative humidity conditions.

TABLE 3 Fomite-to-finger transfer efficiency of organisms under high relative humidity of 40% to 65%

	Avg % transfer efficiency ± SD (range)[a]			
Surface type	*E. coli*	*S. aureus*	*B. thuringiensis*	MS-2
Nonporous				
Acrylic	53.3 ± 27.5 (30.4 to 98.0)	47.2 ± 17.9 (24.4 to 67.3)[d]	65.6 ± 15.9 (48.8 to 94.9)	79.5 ± 21.2 (54.1 to 100)[c,d]
Glass	78.6 ± 27.1 (38.0 to 100)[c,d]	45.5 ± 15.5 (25.7 to 65.5)	<33.8 ± 24.0 (<4.3 to 65.9)[b,d]	67.3 ± 25.0 (37.4 to 96.9)[d]
Ceramic tile	60.7 ± 45.4 (3.7 to 100)[c,d]	54.7 ± 18.8 (27.7 to 77.6)[d]	<21.2 ± 28.2 (<1.3 to 76.4)[b]	41.2 ± 18.8 (18.7 to 74.7)[d]
Laminate	27.4 ± 30.2 (1.9 to 77.0)	61.9 ± 24.7 (30.9 to 89.8)[d]	53.5 ± 19.6 (33.8 to 79.0)[d]	63.5 ± 24.0 (36.2 to 100)[c,d]
Stainless steel	54.1 ± 23.5 (29.4 to 99.0)[d]	48.3 ± 25.4 (16.6 to 85.5)[d]	57.0 ± 9.7 (47.5 to 71.4)[d]	37.4 ± 16.0 (19.5 to 62.4)[d]
Granite	36.5 ± 39.3 (0.3 to 100)[c]	39.6 ± 41.5 (1.3 to 100)[c]	12.8 ± 19.8 (0.1 to 42.7)	30.0 ± 24.3 (4.9 to 59.3)
Porous				
Cotton	<13.4 ± 11.7 (<2.6 to <33.3)[b]	<0.5 ± 0.5 (0.1 to 1.3)[b]	<3.5 ± 3.5 (<0.9 to <10.0)[b]	0.3 ± 0.3 (0.04 to 0.6)
Polyester	<0.7 ± 0.8 (<0.1 to <2.2)[b]	5.0 ± 6.9 (0.1 to 15.5)	<4.6 ± 6.1 (<1.1 to <16.3)[b]	2.3 ± 0.8 (1.2 to 3.2)[d]
Paper currency	<0.1 ± 0.3 (<0.01 to 0.7)[b]	0.2 ± 0.1 (0.1 to 0.3)	<0.1 ± 0.1 (<0.03 to <0.2)[b]	0.7 ± 0.5 (0.1 to 1.5)

[a] % transfer efficiency = (CFU or PFU finger/CFU or PFU control fomite) × 100 (n = 6 for each fomite and microorganism).
[b] The value for the transfer of organisms from fomite to fingers for one or more transfer events was below the detectable limit of 10 CFU/2 cm^2 (indicated by <).
[c] The value for the transfer of organisms from fomite to fingers for one or more transfer events was >100% and was truncated to 100%.
[d] There was a statistically significant difference (Student's t test; $P \leq 0.05$) in the transfer efficiency results between low and high relative humidity conditions.

Figure S5. Transfer efficiency of bacteria and viruses from various surfaces to fingers, reproduced from Lopez et al.[36]

A second study, published in 2010, investigated the transfer efficiencies of three bacteriophages bidirectionally between glass and fingers. The study defined transfer efficiency as the amount of virus on the recipient surface divided by the sum of the virus found on the donor and recipient surfaces, thus eliminating virus decay after inoculation as a source of error.[37] Two different inoculation conditions (100-600 PFU and 1000-6000 PFU) were tested, and titer did not significantly affect the transfer efficiencies. The authors attempted to fit the individual transfer efficiencies to a normal, a lognormal, and a Weibull distribution, though most of the fits were of relatively poor quality. The fits are reproduced in Figure S6.

[36] Lopez GU *et al* (2013) Transfer efficiency of bacteria and viruses from porous and nonporous fomites to fingers under different relative humidity conditions. *Applied and environmental microbiology* 79**:** 5728-5734

[37] Julian TR *et al* (2010) Virus transfer between fingerpads and fomites. *Journal of applied microbiology* 109**:** 1868-1874

Phage	Direction	Handwash	n	$\hat{\mu}$	Median	$\hat{\sigma}$
MS2	Finger-to-Glass	Unwashed	75	0·24	0·18	0·24
		Washed	75	0·15	0·1	0·16
	Glass-to-Finger	Unwashed	75	0·25	0·19	0·23
		Washed	80	0·26	0·21	0·19
φ-X174	Finger-to-Glass	Unwashed	49	0·26	0·16	0·28
		Washed	50	0·17	0·14	0·17
	Glass-to-Finger	Unwashed	48	0·21	0·07	0·29
		Washed	47	0·11	0·04	0·18
fr	Finger-to-Glass	Unwashed	36	0·28	0·25	0·21
		Washed	40	0·2	0·19	0·16
	Glass-to-Finger	Unwashed	40	0·37	0·39	0·22
		Washed	40	0·39	0·4	0·11

	Normal			Lognormal			Weibull		
Phage type	$\hat{\mu}$	$\hat{\sigma}$	P-value	$\hat{\mu}$	$\hat{\sigma}$	P-value	Shape	Scale	P-value
MS2	0·23	0·22	0·09	−2·1	1·4	0·18	0·96	0·22	0·12
φ-X174	0·19	0·24	0·03	−2·6	1·5	0·43	0·77	0·16	0·84
fr	0·31	0·2	0·45	−1·6	1·1	0·14	1·4	0·34	0·66
All phage	0·23	0·22	<0·01	−2·1	1·4	<0·01	0·94	0·23	0·09

Figure S6. Transfer efficiencies of three bacteriophages bidirectionally between glass and fingers, reproduced from Julian et al.[38]

General Transference Efficiencies for Other Biological Materials

Julian et al. (2012) details the development of a database of surface to skin transference efficiencies of a variety of materials based on a comprehensive literature search.[39] Per the publication, the database was developed in Microsoft Access 2003. It does not appear that a comprehensive list of the articles used to build the database is available, though many of the papers are included as citations in the article describing the database. Figure S7 summarizes the data collected in the publication, showing a very wide variety of transfer efficiencies for biological substances; the reason for the variation is not known (e.g., low number of samples, true differences between substances). Due to this high variation, transfer efficiency data from other biological substances may be not applicable when estimating viral transfer efficiencies.

[38] Julian TR *et al* (2010) Virus transfer between fingerpads and fomites. *Journal of applied microbiology* 109**:** 1868-1874

[39] Ng MG *et al* (2012) The relationship between inadvertent ingestion and dermal exposure pathways: A new integrated conceptual model and a database of dermal and oral transfer efficiencies. *Annals of occupational hygiene*

Table 3. Number of transfer efficiency records, range and median transfer efficiency by type of transfer, transfer definition, and physical state of substances involved in transfer.

Transfer definition	Physical state	Transfer efficiency													
		Powders			Liquids			Solids in solution			Biological substances			Radioisotope	
	Type of transfer	*n*	Range (%)	Median (%)	*n*	Range (%)	Median (%)	*n*	Range (%)	Median (%)	*n*	Range (%)	Median (%)	*n*	Value (%)
Mass per unit area	Surface-to-hand	62	0.15–44.7	11.0	71	0.32–83.0	6.0	206	0.01–95.6	3.8	67	0–157.0[a]	3.4	0	—
	Surface-to-glove	1	13.1	—	9	8.3–79.0	25.0	3	8.1–17.4	16.9	15	17.0–70.0	48.0	0	—
	Surface-to-clothing	0	—	—	9	2.8–34.3	5.4	9	3.1–33.3	6.6	11	29.0–80.0	50.0	0	—
	Hand-to-mouth	1	100.0	—	0	—	—	8	14.0[a]–34.0	2.9	0	—	—	0	—
	Hand-to-perioral	1	37.0	—	0	—	—	0	—	—	0	—	—	0	—
	Perioral-to-oral	1	38.0	—	0	—	—	0	—	—	0	—	—	0	—
	Skin-to-skin	0	—	—	0	—	—	0	—	—	9	0.7–10.0	4.0	1	20.0
	Total	66	—	—	89	—	—	226	—	—	102	—	—	1	—
Total mass	Surface-to-hand	5	0.7–39.0	3.4	0	—	—	5	4.5–75.0	11.0	31	0–100.0	0.1	0	—
	Surface-to-glove	0	—	—	0	—	—	1	2.0	—	1	46.6	—	0	—
	Surface-to-clothing	0	—	—	0	—	—	0	—	—	0	—	—	0	—
	Hand-to-mouth	3	10.1–21.9	15.9	0	—	—	0	—	—	0	—	—	0	—
	Hand-to-perioral	1	8.2	—	0	—	—	0	—	—	3	33.9–41.0	34.0	0	—
	Perioral-to-oral	0	—	—	0	—	—	0	—	—	0	—	—	0	—
	Skin-to-skin	0	—	—	0	—	—	0	—	—	0	—	—	0	—
	Total	9	—	—	0	—	—	6	—	—	35	—	—	0	—

[a]Reported transfer efficiencies greater than 100 or <0 are the result of experimental uncertainty in the laboratory experiments and do not accurately describe expected transfer efficiencies. These reported transfer efficiencies have been included in the database for completeness.

Figure S7. Transfer efficiencies for biological substances, reproduced from Ng et al. (2012).[40]

Hand to Face Contacts

Relatively few studies have directly examined the rate of hand to face or object to face touches. In a 2008 study, ten workers in an office were observed for three hours and hand to eye, lip, and nostril touches were recorded. The workers were informed of the intent of the study. The study reports a mean (std. dev) of 47 (35) total touches, with 7.4 (5.7) eye touches, 24 (24) lip touches, and 16 (11) nostril touches per individual over the three hour observation period.[41]

A second study followed workers at several types of businesses, including an animal research facility and several industrial plants. Workers were aware of the observers, but were unaware of what the observers were recording. The study also attempted to quantify the effect wearing a respirator and/or gloves hand on contact rates, as well as rates of contact while at work versus between tasks. Interestingly, wearing gloves appeared to increase contact rates by increasing the contact rate while gloves were not worn. The same was true for respirator use. Two key tables from the paper have been reproduced below.[42]

[40] Ng MG *et al* (2012) The relationship between inadvertent ingestion and dermal exposure pathways: A new integrated conceptual model and a database of dermal and oral transfer efficiencies. *Annals of occupational hygiene*

[41] Nicas M, Best D (2008) A study quantifying the hand-to-face contact rate and its potential application to predicting respiratory tract infection. *Journal of occupational and environmental hygiene* 5**:** 347-352

[42] Ng MG *et al* (2014) Inadvertent ingestion exposure: hand- and object-to-mouth behavior among workers. *Journal of exposure science & environmental epidemiology*

Table 2. Frequency of contact between the mouth and hands, objects and arms (number of observations = 59).

Type of contact	*Frequency of contact per hour*		
	Average	*Median*	*Maximum*
Hand-to-oral	0.4	0.0	17.0
Hand-to-perioral	5.8	4.0	26.0
Hand-to-mouth (oral or perioral)	6.3	4.0	26.0
Object-to-oral	0.5	0.0	14.3
Object-to-perioral	1.1	0.0	11.8
Object-to-mouth (oral or perioral)	1.6	0.0	14.3
Arm-to-oral	0.0	0.0	0.0
Arm-to-perioral	0.1	0.0	3.0
Arm-to-mouth (oral or perioral)	0.1	0.0	3.0
Total contacts	7.9	6.0	30.0

Figure S8. Frequency of contact between mouth and hands, objects, and arms, reproduced from Ng et al. (2014).[43]

[43] Ng MG *et al* (2014) Inadvertent ingestion exposure: hand- and object-to-mouth behavior among workers. *Journal of exposure science & environmental epidemiology*

Table 4. Frequency of hand-to-mouth contact per hour by work-related and personal factor categories.

Factor	*Categories*	N	*Frequency of contact per hour*[a]			P-*value*
			Average	*Median*	*Maximum*	
Any glove use	Used[b]	54	6.4	4.3	26.0	0.753 (Kruskal–Wallis)
	Not used	5	5.0	2.9	12.3	
Periods of time when gloves were used among "gloves used" ($N = 54$)	Time while on	—	1.2	0.0	12.0	< 0.001 (Wilcoxon signed-rank)
	Time while off		4.8	3.1	25.0	
Any respirator use	Used[b]	31	5.5	2.6	26.0	0.083 (Kruskal–Wallis)
	Not used	28	7.1	6.5	25.0	
Periods of time when respirators were used among "gloves used" ($N = 31$)	Time while on	—	0.1	0.0	1.0	< 0.001 (Wilcoxon signed-rank)
	Time while off		5.3	2.6	26.0	
Task category	Manual task	57	2.8	0.0	40.0	< 0.001 (Kruskal–Wallis)
	Desk or paperwork	43	8.4	0.0	60.0	
	Operate machinery	29	2.9	0.0	29.5	
	Between task	55	23.6[c]	18.0	140.0	
% of time "between task"	< 10	14	1.7	0.5	12.3	< 0.001 (Kruskal–Wallis)
	10–30	31	6.7	5.0	26.0	
	> 30	14	9.8[d]	7.8	25.0	
Work sector	Industrial	48	7.6	6.5	26.0	< 0.001 (Kruskal–Wallis)
	Research	11	0.5	0.0	4.0	
Highest risk score	1–7	19	2.9	1.0	17.0	0.001 (Kruskal–Wallis)
	8–10	40	7.9	6.5	26.0	
Smoker	No	41	4.6	2.9	25.0	0.006 (Kruskal–Wallis)
	Yes	18	10.1	8.0	26.0	
Nail biter	No	43	5.0	3.0	21.0	0.027 (Kruskal–Wallis)
	Yes	16	9.5	8.5	26.0	
Facial hair	No	40	6.3	4.0	26.0	0.820 (Kruskal–Wallis)
	Yes	19	6.3	4.5	21.0	

[a]All minimum values = 0. [b]Used: gloves or respirators were used at all during the observation period, not used: they were not used at all during the observation period. [c]"Between task" category significantly different from all other task categories in multiple comparisons with rank sums. [d]"> 30" Group significantly different from "< 10" and "10–30" groups in multiple comparisons with rank sums.

Figure S9. Frequency of hand to mouth contact per hour by work-related and personal factor categories, reproduced from Ng et al. (2014).[44]

[44] Ng MG *et al* (2014) Inadvertent ingestion exposure: hand- and object-to-mouth behavior among workers. *Journal of exposure science & environmental epidemiology*