Supporting Information

Supplementary methods

This appendix was part of the submitted manuscript and has been peer reviewed. It is posted as supplied by the authors.

Appendix to: Furuse Y. What would happen if Santa Claus is sick? His impact on communicable disease transmission. *Med J Aust* 2019; doi: 10.5694/mja2.50420.

Supplementary materials

Methods

SEIR model

A discrete-time stochastic SEIR compartmental model was developed for simulations in which a population consists of susceptible individuals (*S)*, those who have been exposed to the disease but yet non-infectious (*E*), individuals already infectious (*I*), and those who have previously had the disease and recovered from it *(R)*. The number of people at state *S*, *E*, *I*, and *R* on day *t* were described as *S(t), E(t), I(t),* and *R(t)*, respectively. The population remained constant throughout the study. There were no births or deaths during the study interval. When *I* subjects make effective contact with *S* individuals, they transmit a disease during an infectious period in the homogeneous mixing population. R_0 signifies the basic reproduction number; 1/α is the incubation period; and 1/γ is the infectious period. The probability [*p(t)*] of transition from *S* to *E* on day *t* was described by the following equation:

$$p(t) = 1 - \left(1 - \frac{R_0 \times \gamma}{N}\right)^{I(t)}$$

The population was divided into *child* and *adult* groups. The R_0 of both influenza and measles was assumed to be proportional to the daily number of contacts between and within the groups of children and adults (Table). Overall, R_0 is equivalent to the largest eigenvalue of the vector of intra- and inter-group R_0 [1]. The probability [$p(t)_{child}$] of transition from S_{child} to E_{child} and [$p(t)_{adult}$] from S_{adult} to E_{adult} on day *t* was described by the following equations:

$$p(t)_{child} = 1 - \left(1 - \frac{R_{0_{child-to-child}} \times \gamma}{N_{child}}\right)^{I(t)_{child}} \times \left(1 - \frac{R_{0_{adult-to-child}} \times \gamma}{N_{child}}\right)^{I(t)_{adult}}$$

$$p(t)_{adult} = 1 - \left(1 - \frac{R_{0_{child-to-adult}} \times \gamma}{N_{adult}}\right)^{I(t)_{child}} \times \left(1 - \frac{R_{0_{adult-to-adult}} \times \gamma}{N_{adult}}\right)^{I(t)_{adult}}$$

During the simulations, 90% of S_{child} contact Santa Claus (I_{adult}) on Christmas Eve. Number of daily contacts of generic adult with children = three (Table). Transmission efficiency of infectious disease from Santa Claus to children was initially assumed to be equivalent to that from generic adult to children. However, the contact between Santa Claus and each child is transient and therefore less likely to transmit disease than other adults in generic. Here we set a rate (f = *santa-factor*) to reduce the probability [p_{santa}] of transition from S_{child} to E_{child} by contact with Santa Claus. The probability [p_{santa}] was described as follows:

$$p_{santa} = \frac{R_{0_{adult-to-child}} \times \gamma \times f}{3}$$

Then, probability [$P(\text{christmas})_{child}$] of transmission from S_{child} to E_{child} on Christmas Eve was described as follows:

$$\begin{aligned} p(christmas)_{child} &\\ &= 1 \\ &- \left(1 - \frac{R_{0_{child-to-child}} \times \gamma}{N_{child}}\right)^{I(christmas)_{child}} \\ &\times \left(1 - \frac{R_{0_{adult-to-child}} \times \gamma}{N_{child}}\right)^{I(christmas)_{adult}} \times (1 - p_{santa}) \end{aligned}$$

Probability of transition from E to I is α and I to R is γ for both child and adult. Parameters used in this study are listed in Table. Epidemiological parameters for the simulation were extracted from published studies. Each simulation was stopped on day 200.

To make sure disease reaches epidemic proportions, the initial number of people at state I [$I(0)_{child}$ and $I(0)_{adult}$] were set for 10 each for influenza (Table). To assess the impact of visit of Santa Claus on influenza epidemic, we assumed the location of the simulation as the northern hemisphere. In 100 simulations, the median peak of the outbreak was day 48. Since Christmas Eve almost coincides with the peak of influenza outbreak in the UK [2], we set Christmas Eve on day 48 in simulations (Table).Vaccination was not taken into account in the influenza simulations.

We set two scenarios based on previous measles vaccination coverage: 1) 95% of children and 90% of adults were at state *R* and 2) 85% of children and 90% adults were at state *R* on day 0. Santa Claus with measles or one generic adult infected with the disease was introduced on day 1 in the measles simulations.

The house-made script for the simulations was attached at the end of this document.

Statistical analysis

A stochastic simulation was run 100 times for each setting. The number of people infected with influenza in simulations with Santa Claus visit was compared with those who acquired the infection in simulations with no visit of Santa Claus using a one-way ANOVA with Dunnett's post hoc test. Frequency of outbreak size for measles was compared between simulation with and without visit of Santa Claus using a chi-square test. Statistical tests were computed using SPSS version 24. P values < 0.05 were considered statistically significant.

Table

Parameters for the simulation

General parameter	Symbol	Value		Source/comment	
Population	N	10,000		Assumption	
Proportion of children	-	20%		Ref. [3]	
Proportion of children who have a visit of Santa Claus	-	90%		Ref. [4]	
Number of daily contacts of child with children	-	10		Ref. [5,6]	
Number of daily contacts of child with adults	-	5			
Number of daily contacts of adult with children	-	3			
Number of daily contacts of adult with adults	-	9			
Santa-factor	f	1, 0.1, or 0.01		Variable in this study	
Disease-specific parameter					
		Influenza	Measles	Influenza	Measles
Basic reproduction number	R_0	1.50	15.00	Ref. [7,8]	Ref. [9]
	$R_{0child\text{-}to\text{-}child}$	1.13	11.20	See Methods for details	
	$R_{0child\text{-}to\text{-}adult}$	0.57	5.60		
	$R_{0adult\text{-}to\text{-}child}$	0.34	3.36		
	$R_{0adult\text{-}to\text{-}adult}$	1.02	10.08		
Incubation period	$1/\alpha$	2 days	5 days	Ref. [10,11]	Ref. [12]
Infectious period	$1/\gamma$	2 days	8 days		
Initial number of infected people	$I(0)_{child}$	10	0	Assumption	Assumption
	$I(0)_{adult}$	10	0 or 1		
Proportion of people at state R on day 0	-	0%	90% in adults 85% or 95% in children	Assumption	
Christmas Eve	-	Day 48	Day 1	Ref. [2] and determined in this study	Assumption

Ref., reference

References

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Script for the simulations (in Ruby)

```
require 'csv'

output = "output_filename"

simulation_num = 100

print "santa_SIR¥n¥n"

$data = []
$data << ["sim", "t", "Stotal", "Etotal", "Itotal", "Rtotal", "Vtotal", "Schild", "Echild", "Ichild",
"Rchild", "Vchild", "Sadult", "Eadult", "Iadult", "Radult", "Vadult", "N"]

simulation_num.times do |sim_count|

############### settings of parameters ###############

disease = 2    #1 for Flu, 2 for measles

santa = 1 # 0 or 1

santa_factor = 0.01    # 1 / 0.1 / 0.01

vaccine_cov_a = 0.9    # measles 0.9
vaccine_cov_c = 0.85    # measles 0.85 / 0.95
```

```
good_boy = 0.9

if disease == 1
    vaccine_cov_a = 0
    vaccine_cov_c = 0
end

if santa == 0
    cday = -10
elsif disease == 1
    cday = 48
elsif disease == 2
    cday = 1
end

duration = 200

population = 10000
prop_c = 0.2
prop_a = 0.8

if disease == 1
    first_patient_c = 10
    first_patient_a = 10
```

```
elsif disease == 2 && santa == 0
   first_patient_c = 0
   first_patient_a = 1
elsif disease == 2 && santa == 1
   first_patient_c = 0
   first_patient_a = 0
end

sus_c = ((population * prop_c) * (1-vaccine_cov_c) - first_patient_c).round
sus_a = ((population * prop_a) * (1-vaccine_cov_a) - first_patient_a).round
exp_c = 0
exp_a = 0
inf_c = first_patient_c
inf_a = first_patient_a
rec_c = 0
rec_a = 0
vac_c = ((population * prop_c) * vaccine_cov_c).round
vac_a = ((population * prop_a) * vaccine_cov_a).round

# Flu=0.34 (1.5),      Measles=3.36 (15)
if disease == 1
   rep_ac = 0.34
elsif disease == 2
   rep_ac = 3.36
end
```

```
# Flu=2,      Measles=5

if disease == 1

   incubation_period = 2

elsif disease == 2

   incubation_period = 5

end


# Flu=2,      Measles=8

if disease == 1

   infectious_period = 2

elsif disease == 2

   infectious_period = 8

end


contact_ac = 3

contact_aa = 9

contact_cc = 10

contact_ca = 5


rep_ca = rep_ac * (contact_ca.to_f/contact_ac)

rep_cc = rep_ac * (contact_cc.to_f/contact_ac)

rep_aa = rep_ac * (contact_aa.to_f/contact_aa)


onecontact_transmission_rate_ac = rep_ac.to_f / (infectious_period * 3)
```

```
transmission_rate_ac = (rep_ac.to_f / infectious_period) / (population * prop_c)

transmission_rate_ca = (rep_ca.to_f / infectious_period) / (population * prop_a)

transmission_rate_aa = (rep_aa.to_f / infectious_period) / (population * prop_a)

transmission_rate_cc = (rep_cc.to_f / infectious_period) / (population * prop_c)


# power_of_infection_cc = (rep_cc / infectious_period)

# power_of_infection_ac = (rep_ac / infectious_period)

# power_of_infection_ca = (rep_ca / infectious_period)

# power_of_infection_aa = (rep_aa / infectious_period)


r1 = Random.new


############################################################


print "sim ", sim_count+1, "¥n"


$data << [sim_count + 1, 0, (sus_c+sus_a).to_i, (exp_c+exp_a).to_i, (inf_c+inf_a).to_i,
(rec_c+rec_a).to_i, (vac_c+vac_a).to_i, sus_c.to_i, exp_c.to_i, inf_c.to_i, rec_c.to_i, vac_c.to_i,
sus_a.to_i, exp_a.to_i, inf_a.to_i, rec_a.to_i, vac_a.to_i,          (sus_c + exp_c + inf_c + rec_c +
vac_c + sus_a + exp_a + inf_a + rec_a + vac_a).to_i]


duration.times do |t_day|


  sc_to_ec_santa = 0
```

```
if t_day == cday - 1
   (sus_c*good_boy).round.times do
      if r1.rand < onecontact_transmission_rate_ac * santa_factor
         sc_to_ec_santa += 1
      end
   end
sus_c = sus_c - sc_to_ec_santa
end # end of cday

sc_to_ec_general = 0

sus_c.to_i.times do
   need_to_continue = 1
   inf_c.to_i.times do
      if r1.rand < transmission_rate_cc
         sc_to_ec_general += 1
         need_to_continue = 0
         break
      end
   end

   if need_to_continue == 1
      inf_a.to_i.times do
         if r1.rand < transmission_rate_ac
```

```
            sc_to_ec_general += 1
            need_to_continue = 0
            break
          end
        end
      end

    end # sc_to_ec each check
    sus_c = sus_c - sc_to_ec_general

    sa_to_ea = 0

    sus_a.to_i.times do
      need_to_continue = 1
      inf_c.to_i.times do
        if r1.rand < transmission_rate_ca
          sa_to_ea += 1
          need_to_continue = 0
          break
        end
      end

      if need_to_continue == 1
        inf_a.to_i.times do
          if r1.rand < transmission_rate_aa
```

```
            sa_to_ea += 1
            need_to_continue = 0
            break
          end
        end
      end

end # sa_to_ea each check
sus_a = sus_a - sa_to_ea

ec_to_ic = 0

exp_c.to_i.times do
  if r1.rand < 1.to_f / incubation_period
    ec_to_ic += 1
  end
end # ec_to_ic each check
exp_c = exp_c + sc_to_ec_general + sc_to_ec_santa - ec_to_ic

ea_to_ia = 0

exp_a.to_i.times do
  if r1.rand < 1.to_f / incubation_period
    ea_to_ia += 1
  end
```

```
end # ea_to_ia each check
exp_a = exp_a + sa_to_ea - ea_to_ia


ic_to_rc = 0


inf_c.to_i.times do
   if r1.rand < 1.to_f / infectious_period
      ic_to_rc += 1
   end
end # ic_to_rc each check
inf_c = inf_c + ec_to_ic - ic_to_rc


ia_to_ra = 0


inf_a.to_i.times do
   if r1.rand < 1.to_f / infectious_period
      ia_to_ra += 1
   end
end # ic_to_rc each check
inf_a = inf_a + ea_to_ia - ia_to_ra


rec_c = rec_c + ic_to_rc
rec_a = rec_a + ia_to_ra
```

```
# $data << ["t", "Schild", "Echild", "Ichild", "Rchild", "Vchild", "Sadult", "Eadult", "Iadult",
"Radult", "Vadult", "N"]
  $data << [sim_count + 1, t_day + 1, (sus_c+sus_a).to_i, (exp_c+exp_a).to_i, (inf_c+inf_a).to_i,
(rec_c+rec_a).to_i, (vac_c+vac_a).to_i, sus_c.to_i, exp_c.to_i, inf_c.to_i, rec_c.to_i, vac_c.to_i,
sus_a.to_i, exp_a.to_i, inf_a.to_i, rec_a.to_i, vac_a.to_i,              (sus_c + exp_c + inf_c + rec_c +
vac_c + sus_a + exp_a + inf_a + rec_a + vac_a).to_i]

end # day_end

end # sim_end

CSV.open("#{output}.csv",'w+')do |csv|
  $data.each do |value|
    csv << value
  end
end

print "done!¥n"
```