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Interventions to prevent surface transmission of an infectious virus based on real human touch behavior: a case study of the norovirus

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ABSTRACT

Objectives: Infectious viruses (e.g., SARS-CoV-2, norovirus) can transmit through surfaces. Norovirus has infected millions of individuals annually. Interventions on norovirus transmission in high-risk indoor environment are important.

Methods: This study focused on a restaurant in Guangzhou, China. More than 41,000 touches by both diners and staff members were collected using video cameras. A surface transmission model was developed and combined with these real human touch behaviors to analyze the effectiveness of different norovirus prevention strategies.

Results: When the virus carrier was a diner, the virus intake fraction of diners in the same table was the highest. Increasing the touch frequency on personal private surfaces would reduce the virus exposure. The virus intake fraction was reduced by 18.4% on average if public surfaces were not touched. Optimization on surface materials could reduce the virus intake fraction by 86.6%. Additionally, disinfecting tablecloths, clothes of diners, and chairs were the three most effective surface disinfection strategies.

Conclusion: Controlling human touch behavior (e.g., reducing the self-touches on mucous membranes) is more effective than surface disinfection in controlling norovirus transmission, but surface disinfection cannot be ignored because human behavior is difficult to be controlled.

Introduction

Norovirus is the main cause of acute gastroenteritis (AGE) and diarrhea worldwide (Lucero et al., 2020; Mikounou Louya et al., 2019) and is responsible for economic losses of more than $60 billion annually (Bartsch et al., 2016). Approximately 20% of all AGE cases are caused by the norovirus, and it is estimated to cause more than 200,000 deaths annually (Lopman et al., 2016).

Restaurant is a high-risk indoor environment for norovirus transmission because of frequent contact between hands and food, meal sharing, and frequent contact with public surfaces (e.g., rotary plate, public kettle). In September 2015, a norovirus outbreak in a restaurant in Finland resulted in half of the present diners being infected (Vo et al., 2016). In September 2016, a norovirus outbreak in a Spanish restaurant infected 123 diners and 28 staff members (Doménech-Sánchez et al., 2021). It is obviously critical to develop effective strategies to control norovirus transmission in restaurants.

Norovirus mainly transmits through surfaces, food, and water (Sakon et al., 2018). Some researchers believe that airborne transmission is also possible for the norovirus, although this is not widely accepted (Alsved et al., 2020; Xiao et al., 2017). Norovirus has a high viability and can remain active for up to 2 weeks on surfaces and for up to 2 months in water (Teunis et al., 2008).

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Interventions, such as hand sanitization and surface disinfection, are commonly used for norovirus transmission control (Calderon-Margalit et al., 2005). However, some disadvantages existed in previous research. First, all interventions are hand sanitization and surface disinfection, with no interventions focusing on human touch behavior. Second, norovirus transmission cannot be accurately simulated due to the lack of data on real touch behaviors. Therefore, it is difficult to quantitatively evaluate the effectiveness of these interventions.

This study focused on a restaurant in Guangzhou. More than 380,000 data points related to human touch behavior were analyzed, and 41,042 touches by both diners and staff members were recorded. We established surface touch databases by collecting the real touch behaviors in the restaurant and developed a surface transmission model on the basis of Markov chains, which are widely used in virus transmission through fomite route (King et al., 2022; Zhang et al., 2021c), to randomly generate touch behaviors of both diners and staff members on the basis of the database. We explored the effect of surface to hand transfer rate (and *vice versa*). Finally, we quantitatively analyzed interventions, such as surface design, changing human touch behavior, and surface disinfection. This model was developed on the basis of norovirus transmission, but this method is applicable to all virus transmitting through surfaces.

Methods

Data collection

A restaurant where there had been a COVID-19 outbreak was selected to study human touch behaviors because we were able to obtain the video from CCTV cameras in the restaurant. In this restaurant, there was a restroom, a kitchen, an elevator exit, an emergency exit (stairs), a reception desk, 18 tables, and various corridors. At this meal, there were 89 diners from 17 different family groups (one table for each family group) (Figure 1 in Zhang et al., 2021a). There were 18 staff members working in the restaurant during the recording time of the lunch. Because human touch behaviors in the restroom cannot be collected, virus transmission in the restroom was not considered.

Three high-resolution video cameras, which were placed on the ceiling of the restaurant, recorded the touch behavior of 81 visible diners and 18 staff members from 12:01:30 to 14:20:20. We collected more than 380,000 seconds of data, covering surface touch behaviors. Six trained video analysts recorded who touched which and whose surfaces, with which hand (e.g., left hand and right hand) for each second. The detailed recorded data include time, individual's ID, the hand that touched the surface (left or right), which surface was touched, whose (e.g., a specific diner/staff member) surface was touched, the duration of each contact, and whether the individuals cleaned their hands using hand sanitizer (Zhang et al., 2021a). No personal identification data such as name, age, or sex were collected. This study was approved by the medical research ethics review committee of Guangdong Provincial Center for Disease Control and Prevention (approval no. W96-027E-202106).

We used Markov chain models to generate surface touch behaviors (which surface was touched, duration of the touch, what is the next surface would be touched on the basis of the probability matrix obtained from the real touch behaviors) of both diners and staff members in the restaurant. When the source patient was diner, each case was simulated 810 times (each diner was regarded as the source patient for 10 times, 81 diners × 10 times = 810 times). When the source patient was a staff member, each scenario was simulated 180 times (18 staff members × 10 times =180 times).

From the data analysis, a total of 87 subsurfaces in the restaurant were identified as being involved. We divided them into seven groups (Figure S1): mucous membranes (*M*), hand (*H*), body (*B*, includes head, main body, and limbs), personal private objects (*PP*), personal object provided by the restaurant for each table's use (*PT*, personal table's objects), table's object for public use (*T*, table's public objects), and object for public use for all individuals in the restaurant (*R*, restaurant's public and common objects). Other settings could be referred to Appendix A.

Model

Because fomites are the main route of norovirus transmission, no other transmission routes (e.g., airborne) were considered in this study (Lei et al., 2017; Overbey et al., 2021). Figure 1 shows how norovirus spreads through surfaces in an indoor environment (Appendix B).

Virus transfer through the fomite route can be expressed by Equation 1.

$$\begin{cases} V_s(t+1) = V_s(t) + \sum_{i_s(t)}^{n_s(t)} \left[A_{hs} \left(\frac{V_h(t)}{A_h} r_{hs} - \frac{V_s(t)}{A_s} r_{sh} \right) \right] - \frac{I_{ac-s_i}}{60} V_s(t) + \frac{D_{ep}}{3600} V_a(t) - \frac{R_{es}}{3600} V_s(t) \\ V_h(t+1) = V_h(t) + \left[A_{hs} \left(\frac{V_s(t)}{A_s} r_{sh} - \frac{V_h(t)}{A_h} r_{hs} \right) \right] - \frac{I_{ac-h}}{60} V_h(t) + \frac{D_{ep}}{3600} V_a(t) - \frac{R_{es}}{3600} V_h(t) \\ V_a(t+1) = V_a(t) - \frac{I_{ac-a}}{60} V_a(t) - \frac{D_{ep}}{3600} V_a(t) + \frac{R_{es}}{3600} (V_h(t) + V_s(t)) \end{cases} \quad (1)$$

where h is a hand, s is a surface, a is air (the room air is assumed to be well mixed); $V_h(t)$, $V_s(t)$, and $V_a(t)$ are the viral loads on the hand, on a surface, and in the air, respectively; $i_s(t)$ is the surface, which is touched by the hand at time t (the surface is assumed to be homogeneously contaminated immediately as soon as the virus is transferred to it); $n_s(t)$ is the total number of surfaces touched by the hand at time t; A_{hs} is the effective contact area between the hand and the surface (Appendix C); A_s and A_h are the total area of the surface and the hand, respectively; r_{sh}/r_{hs} is the virus transfer rate from the surface/hand to the hand/surface; I_{ac-a} is the inactivation rate (min^{-1}) of the virus in the air; I_{ac-s_i} is the inactivation rate (min^{-1}) of the virus on the surface; I_{ac-h} is the inactivation rate (min^{-1}) of the virus on the hand; D_{ep} is the deposition rate (h^{-1}) of virus-laden aerosols in the air; R_{es} is the resuspension rate (h^{-1}) of virus-laden aerosols from surfaces. In the simulation, the time step is set to be 1 second.

In the simulation, 87 subsurfaces were divided into seven kinds of materials (Table S1). The inactivation rate and transfer rate between hand and surface differ according to material (Table 1).

Model parametric study

Only one infected individual was set for each simulation. To reduce uncertainty, every diner/staff member had a turn to be the

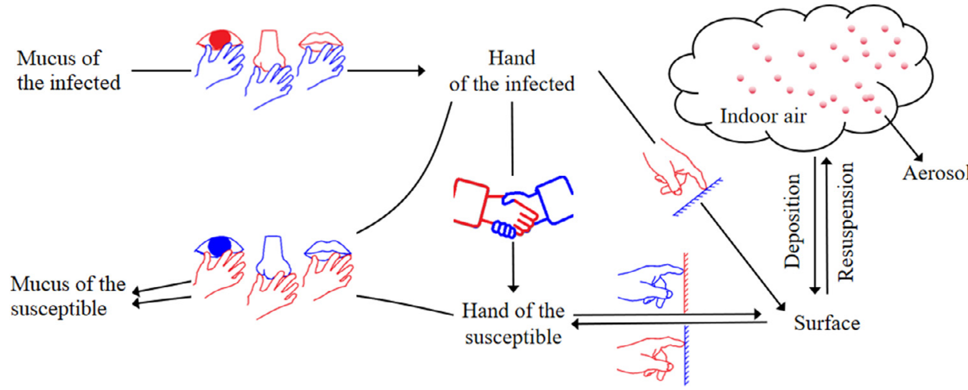

Figure 1. Norovirus transmission through a fomite route.

Table 1
Model parameters (detailed information for each surface is shown in Table S1).

Parameter		Value	Reference
Deposition rate (/h)		0.24	(Buonanno et al., 2020)
Resuspension rate (/h)		0.24	Assumed
Inactivation rate (/min)	Air	0.10	Assumed
	Hand	0.040	(Hajime et al., 2021)
	Glass	0.0021	(Cannon et al., 2006)
	Nonporous	0.0021	(Cannon et al., 2006)
	Porous	0.0080	(Xiao et al., 2017)
	Porcelain	0.0021	(Cannon et al., 2006)
	Fiber/cloth	0.0080	Assumed to be the same as porous
	Stainless steel	0.0021	(Cannon et al., 2006)
Transfer rate (hand to surface/ surface to hand)	Mucous membranes	0.5/0	(Zhang et al., 2021b)
	Nonporous	0.12/0.07	(Lopez et al., 2013; Mokhtari and Jaykus, 2009)
	Glass	0.19/0.13	(Rheinbaben et al., 2000)
	Porcelain	0.048/0.74	(Meadow et al., 2014)
	Fiber/cloth	0.67/0.040	(Fujimura et al., 2014)
	Porous/nonporous	0.46/0.050	(Lopez et al., 2014; Meadow et al., 2014)
	Stainless steel	0.17/0.12	(Boone and Gerba, 2007)
	Skin	0.18/0.17	(Bloomfield et al., 2007)

Table 2
Model setting for different interventions.

Intervention	Description in the model setting
Mask wearing	A person was regarded as touching the outer surface of the mask if they touched their own nose and mouth.
Reduction on surface touch	Randomly reduced the touches on public and private surfaces.
Changes in virus transfer rates between hands and surfaces	The transfer rate of the virus between hands and surfaces during each touch (including mucous membranes).
Disinfection frequency of a specific surface	The time for surface disinfection would be determined based on disinfection frequency. The virus on disinfected surfaces would be removed according to disinfection efficiency.
Disinfection efficiency	99.99% of virus was considered to be removed if a surface/hand is disinfected/sanitized (Pickering et al., 2010).
Disinfection of the surface made by the same material	Disinfect all surfaces made by the same material in the restaurant.

virus carrier in the simulations, and the results gave the average value of virus exposure.

We used the virus intake fraction, which is the ratio of the amount of active virus absorbed by each susceptible individual through mucous membranes to the total amount of virus generated by the infected individual to evaluate the relative personal infection risk. The final viral load was defined as the ratio of the amount of active virus on each surface to the total amount of virus generated by the infected at the time when all diners had left the restaurant. We conducted eight simulations (Table 2) on the basis of different disinfection measures (e.g., hand sanitization, surface disinfection) and protection measures (e.g., mask wearing) taken by diners and staff members in the restaurant. Additionally, sensitivity analysis was performed on the inactivation rate of norovirus on different types of surfaces (Appendix D). Moreover, we also analyzed combinations of disinfection frequency and disinfection efficiency (Figure S3). The default parameter settings for each simulation are given in Table 1 and Table S1.

Results

From 140 minutes of video analysis, we collected 41,042 surface touches by diners and staff members. Diners touched surfaces 449.9 times per hour (228.1 for the left hand; 221.8 for the right hand) and staff members touched surfaces 761.0 times per hour (280.2 for the left hand; 480.8 for the right hand). Diners spent 88.2% and 92.3% of their indoor time touching surfaces with left and right hands, respectively. Staff members spent 86.8% and 86.2% of their indoor time touching surfaces with left and right hands, respectively. Diners touched their mucous membranes (M), hands

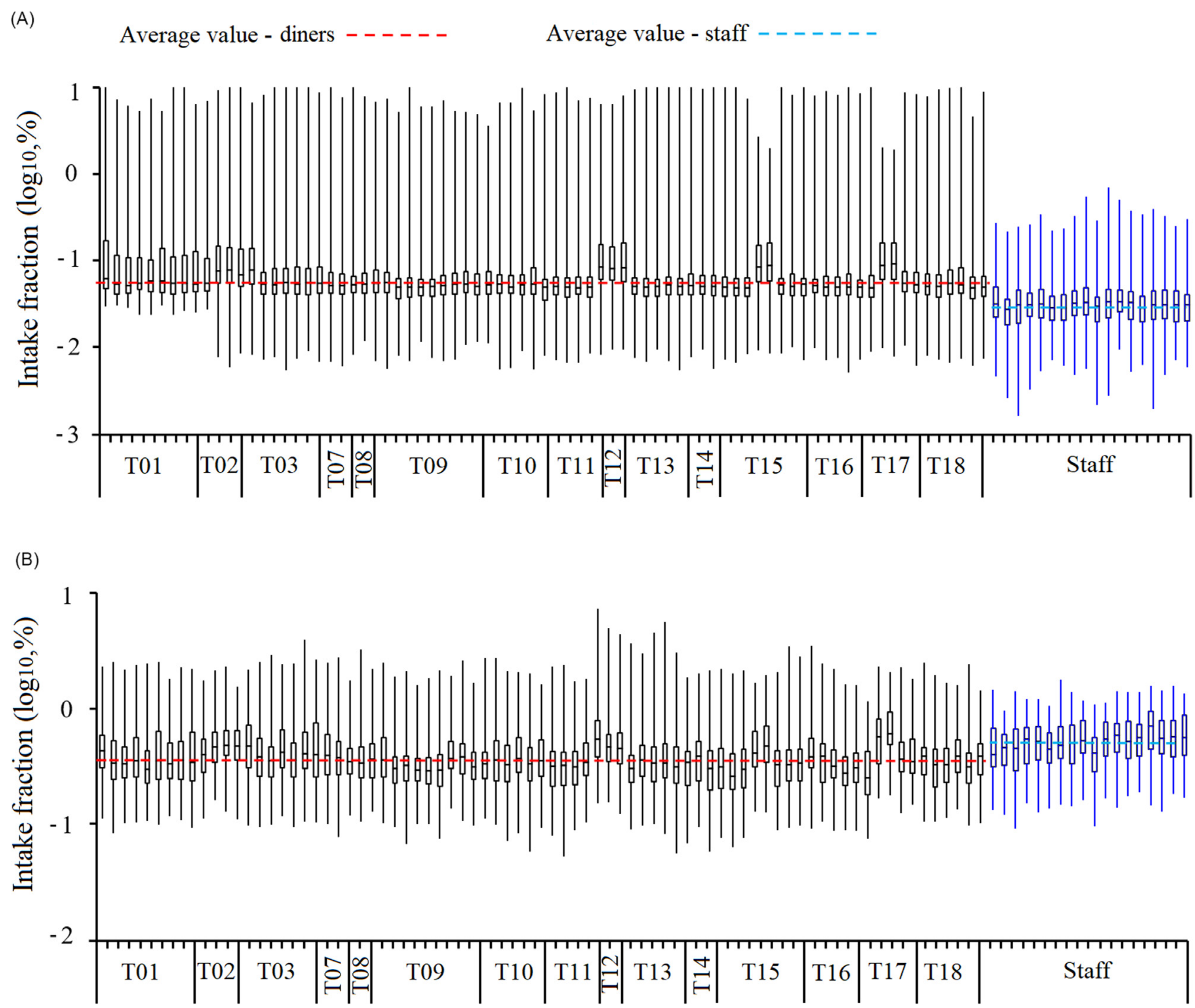

Figure 2. Virus intake fraction when the virus carrier is (A) a diner; (B) a staff member (The box-and-whisker plots represent 2.5, 25, 50, 75, and 97.5 percentiles).

(*H*), body (*B*), table's object for public use (*T*), and object for public use for all individuals in the restaurant (*R*), 39.9, 47.5, 97.3, 38.5, and 4.3 times per hour, respectively. Staff members touched their *M, H, B, T*, and *R*, 7.0, 30.3, 85.0, 245.8, and 299.6 times per hour, respectively. Diners and staff members averagely spent 2.5% and 8.6% of their time on mask wearing, respectively.

Virus intake with no prevention and control measures

In the absence of any prevention or control measures, if the virus carrier was a diner, the intake fraction of diners and staff members were $5.6 \times 10^{-2} \pm 1.1 \times 10^{-2}$% and $3.3 \times 10^{-2} \pm 1.9 \times 10^{-3}$%, respectively (Figure 2A). The highest virus intake fraction among the 81 diners was 9.1×10^{-2}% and 3.6×10^{-2}% among the staff members, which was twice the exposure among the diners. When the virus carrier was a staff member, the intake fraction of diners and staff was 0.4 ± 0.5% and $6.5 \times 10^{-2} \pm 7.2 \times 10^{-2}$%, respectively (Figure 2B).

The private surfaces of the virus carrier (*H, B*, and *PP*) had the highest final virus load (38.8%), followed by the private surfaces of diners at the same table as the virus carrier (3.5%) and the private surfaces of staff (1.3%) (Table 3). The virus load on table surfaces for public use at the table occupied by the virus carrier was 50% lower than those at the other tables. The final virus load on the private surfaces of diners at the table occupied by the virus carrier was 30 times higher than that for diners at the other tables.

Virus intake resulting from human behaviors

Diners were more sensitive to the time spent wearing a mask than staff members (Figure 3A, Figure S4). When the virus carrier was a diner and nobody wore a mask, the diners at the virus carrier's table had the highest virus intake fraction, which was 6.5 times that of diners at other tables. If a staff member always wore a mask, their virus intake fraction was reduced by 87.2%. If diners wore a mask for half of their time indoors, the average virus intake fraction of diners was reduced by 48.3%.

When individuals touched their private surfaces (*PP* and *PT*) less, they would have a higher exposure (Figure 3B, Figure S5). If individuals did not touch *PP*, the virus exposure would increase by nearly 600% compared with the baseline. The virus intake fraction could be reduced by 18.4% if individuals never touched public surfaces in the restaurant.

Virus intake by transfer rate between hands and surfaces

Virus intake fraction of diners and staff members increased with increasing transfer rate from hands to mucous membranes

Table 3
Final virus load on different types of surfaces.

Parameter	Final virus load (%)
H, *B*, and *PP* of the virus carrier	38.8
H, *B*, and *PP* of diners at the same table as the virus carrier	3.5
H, *B*, and *PP* of diners at tables without the virus carrier	0.03
Objects for public use on the table occupied by the virus carrier	0.6
Objects for public use on other tables	1.2
Restaurant's public objects	0.2
PPs of staff members	1.3

B, body; H, hand; PP, personal private object.

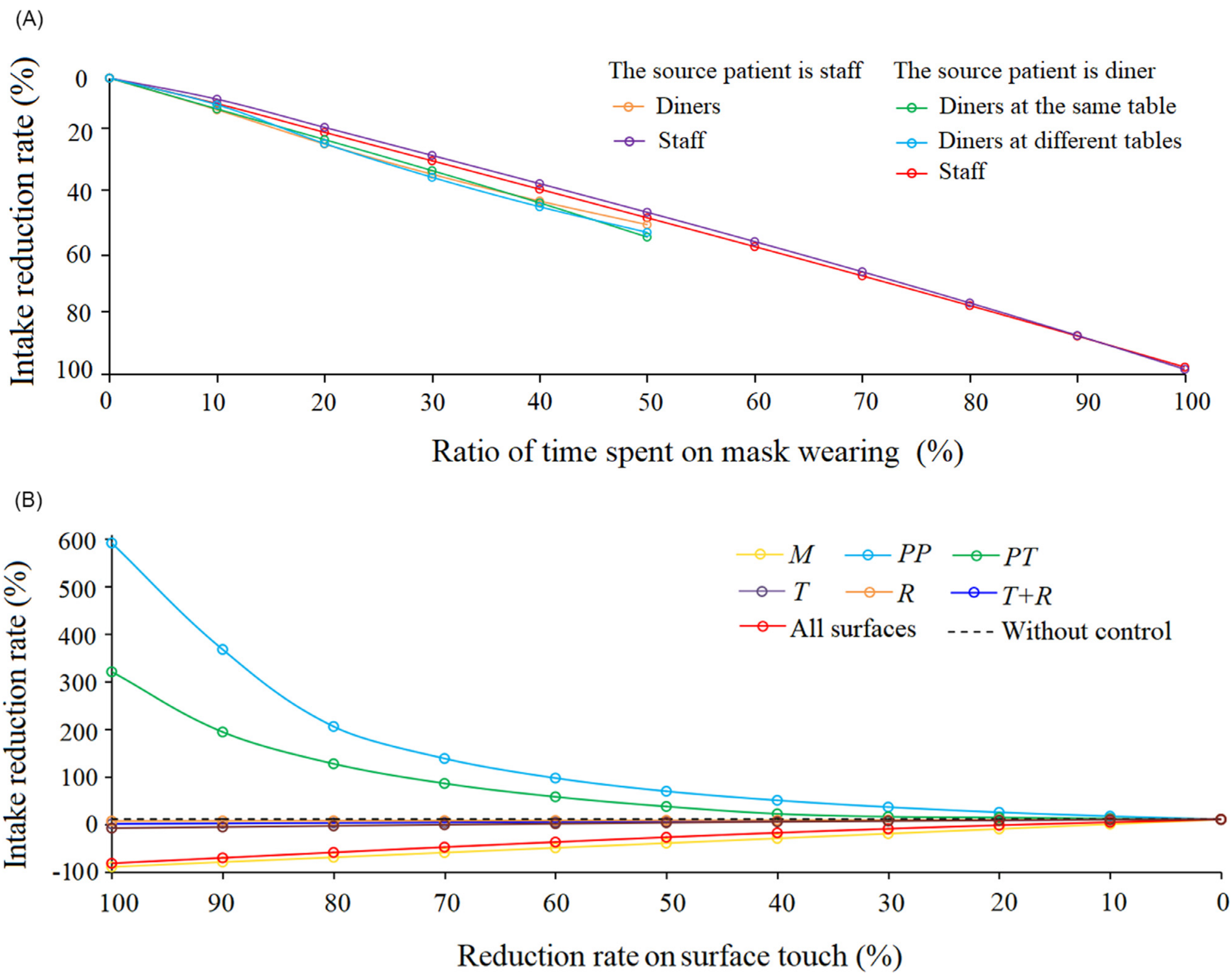

Figure 3. Intake reduction rate by human behavior. (A) Mask wearing (diners need to eat in the restaurant and cannot wear masks all the time, the maximal ratio of time spent by diners on mask wearing is set to be 50%). (B) Surface touch behavior (70% of reduction rate of surface touch means 70% of original touches on a specific surface were randomly avoided. *M*, mucous membranes; *PP*, personal private object; *PT*, table's object for private use; *T*, table's object for public use; *R*, restaurant's object for public use).

(Figure 4A). When the transfer rate from hands to mucous membranes was zero, virus exposure was zero because all virus particles would stay on the hand when a contact was made between a hand and a mucous membrane. The average virus exposure of diners was 1.2 times higher than that of staff members.

When the transfer rate from hand to surface was a constant, virus exposure increased, with an increasing transfer rate from surface to hand (Figure 4B). The virus intake fraction reached a peak of 9.6% when the transfer rate from surface to hand was 1 and from hand to surface was 0.01. When the transfer rate from surface to hand was 0.01 and from hand to surface was 1, the virus intake fraction was the lowest (2.4×10^{-2}%).

Virus intake and surface disinfection

Disinfecting tablecloth, diners' clothes, and chair were the three most effective surface disinfection actions, and we found that exposure was reduced by 25.2%, 13.5%, and 10.5%, respectively (Figure 5A). Of the top 10 most effective surfaces for disinfection, tablecloths had the highest touch frequency (69.6 times/hour).

The analysis of surface disinfection of different materials showed that surface disinfection of fiber/cloth and porous/nonporous and nonporous surfaces were the most effective ways, with exposure being reduced by 33.5%, 15.1%, and 7.0%, respectively (Figure 5B). Of the seven materials shown in

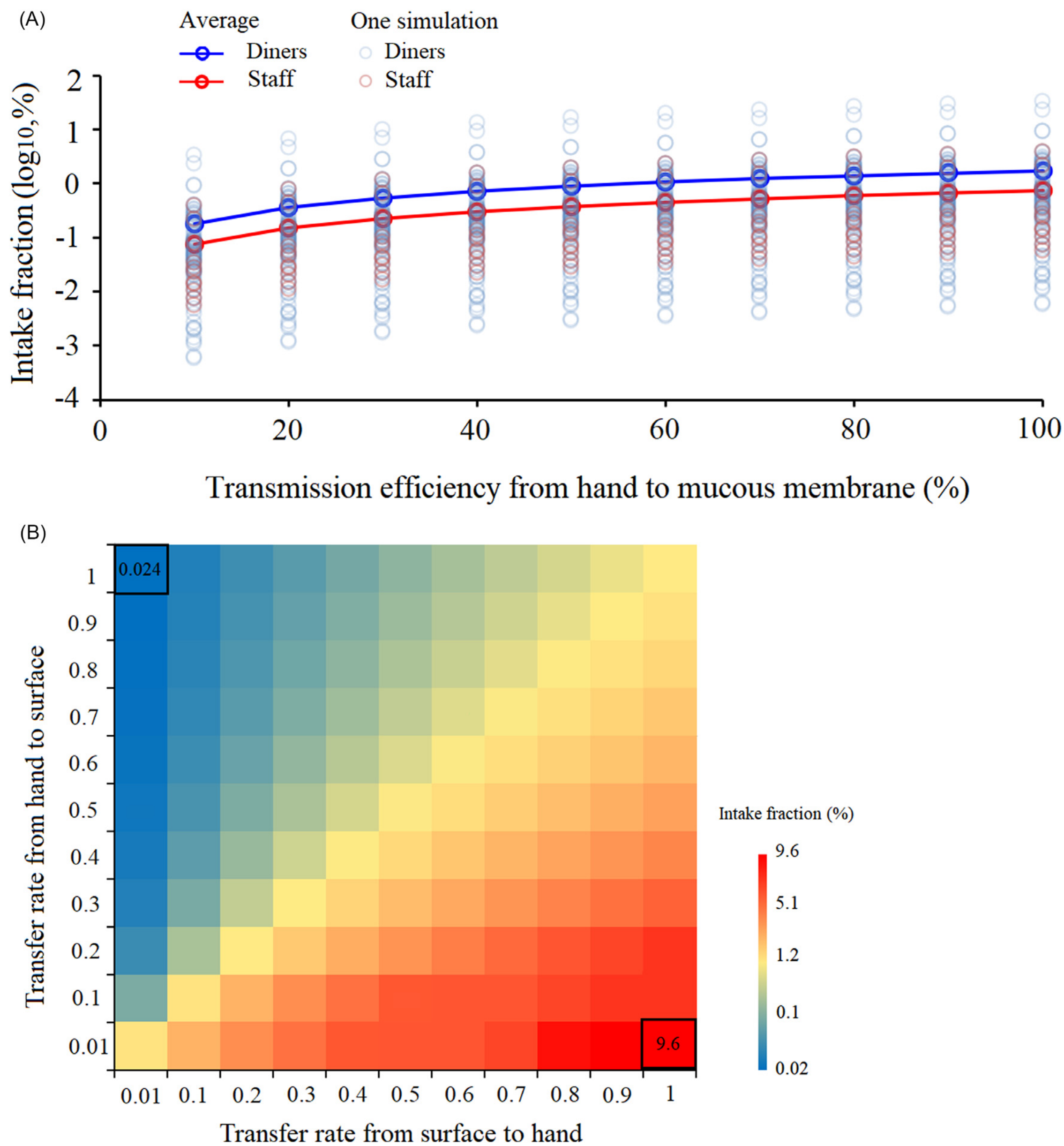

Figure 4. Virus intake fraction changes with transfer rate (A) from hand to mucous membranes (100% of transfer rate means all virus would transfer from hand to mucous membranes when mucous membranes are touched); (B) between hand and surface (transfer rates between hand and mucous membranes/skin shows no change).

Figure 5B, nonporous surfaces had the highest touch frequency (247.5 times/hour). The touch frequency of chairs was only 32.6% of the touch frequency of mobile phones, but the intake reduction rate after disinfecting chairs was 22.4 times than of mobile phone disinfection. The touch frequency of porous/nonporous was lower than nonporous, but the intake reduction rate was twice as much as nonporous.

The virus exposure decreased from 35.3% to 1.8% when the disinfection frequency of tablecloth decreased from 5.0 to 0.1 times per hour (Figure 6A). Disinfecting the public rotary plate of table was more effective than disinfecting the chair when the frequency was 0.1 times per hour, but the intake reduction rate of disinfecting the chair was 7.7 times greater than the public rotary plate of table when the disinfection frequency increased to 5.0 times per hour. For surfaces of fiber/cloth, porous/nonporous, nonporous, glass, and skin, the intake reduction rate when the disinfection efficiency was 99.99% were 2.9, 3.3, 0.9, 4.7, and 5.0 times the rate when the disinfection efficiency was 20%, respectively (Figure 6B).

Diner no. 9 was assumed as the only source of the norovirus (diner no. 9 was the virus carrier in the real COVID-19 outbreak [Zhang et al., 2021a]). In this way, the virus intake of diners from different tables could be compared. After disinfecting all surfaces that could be disinfected in the restaurant, the virus intake fraction for diners at the virus carrier's table, at other tables, and for staff members decreased on average by 84.2%, 16.1%, and 21.2%, respectively (Figure 7).

Discussion

This study assessed the efficiency of interventions on the basis of human touch behavior, surface materials, surface disinfection, and the transfer rate of the norovirus using a Markov chain model for fomite transmission, parametrized by more than 41,000 actual touches by both diners and staff members, that we recorded in the restaurant.

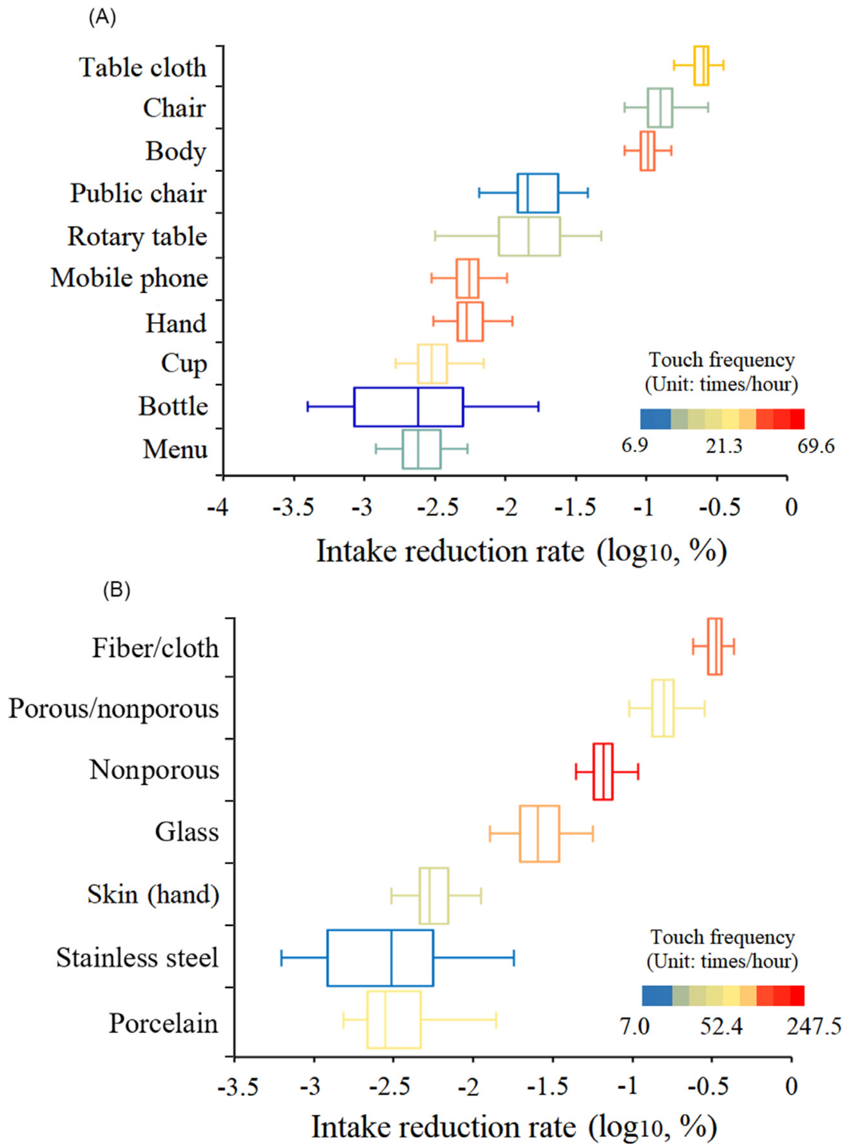

Figure 5. Relationship between virus intake reduction rate and disinfection on (A) top 10 most effective surfaces and (B) different materials (frequency of surface disinfection is twice per hour and disinfection efficiency is set to 99.99%) (The box-and-whisker plots represent 2.5, 25, 50, 75, and 97.5 percentiles).

Surface disinfection and hand sanitization are the most commonly used interventions to stop norovirus transmission through the fomite route. However, few interventions consider human touch behavior. In hospitals, infection risk has been correlated with the total number of surfaces touched (confidence interval = 1.1–5.8, $P = 0.002$) but not with time spent indoors (King et al., 2016; King et al., 2020). In offices, virus exposure through the fomite route is strongly associated with human touch behavior, regardless of the time spent there (Zhang et al., 2021d). Touches on public surfaces (Barker et al., 2004; Rico et al., 2020) play a critical role in virus transmission for viruses that are mainly spread through the fomite route. We found that if individuals never touched any public surfaces in the restaurant, virus exposure would be reduced to 18.4%.

Individuals touch surfaces consciously and unconsciously every day, and touching behavior is influenced by both individual preferences and the environment. In the restaurant, diners, on average, touched surfaces 450 times per hour and staff members touched surfaces 761 times per hour owing to their frequent service. Touching mucous membranes (T-zone), which is influenced by occupations and indoor environments, plays the most critical role in infection risk (Kwok et al., 2015; Rahman et al., 2020). Postgraduate students in offices touched their mucous membranes 35.0 times per hour (Zhang et al., 2021d). Insurance company employees touched their T-zones 62.0 times per hour (20.7 and 23.0 times per hour for nose picking and eyes rubbing, respectively) (Hendley et al., 1973). We found that mucous membranes were touched by diners and staff members on average 40.0 and 7.0 times per hour, respectively. In our simulation, we found that no matter who was the source patient, staff members would have much less virus exposure. There were two main reasons. First, the average touch frequency on mucous membranes of staff was 17.5% of that of diners, which greatly reduced the probability of virus entering the mucous membranes from hands. Second, because staff members served at different tables, when a diner was infected, staff members who did not serve this table had low virus exposure.

Although touch behavior interventions are the most effective, it is hard to control touch behavior. Therefore, other interventions, such as surface disinfection, should be used to stop norovirus

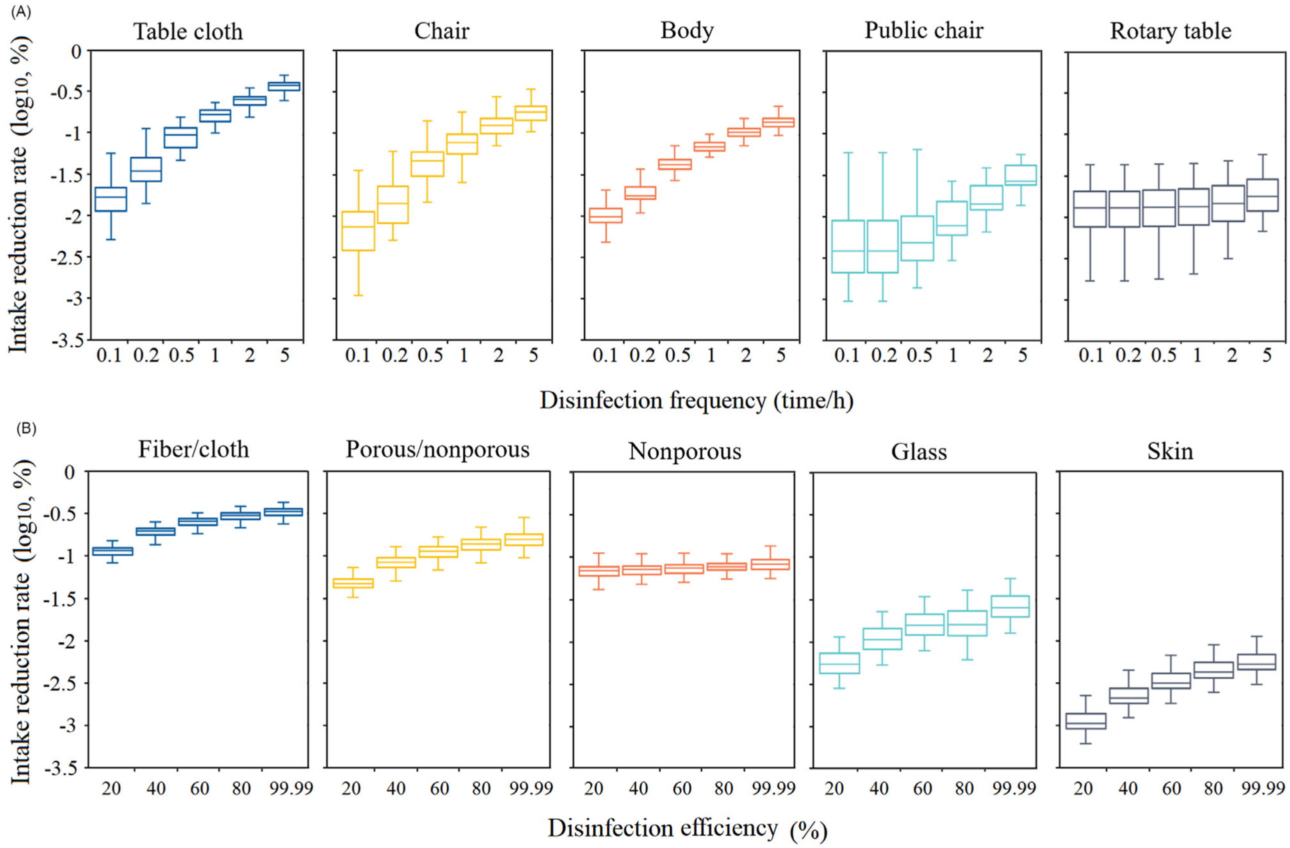

Figure 6. Relationship between intake reduction rate and (A) disinfection frequency for the five most effective surfaces for disinfection (disinfection efficiency is set to 99.99%); (B) disinfection efficiency for the five most effective materials for disinfection (disinfection frequency is twice per hour).

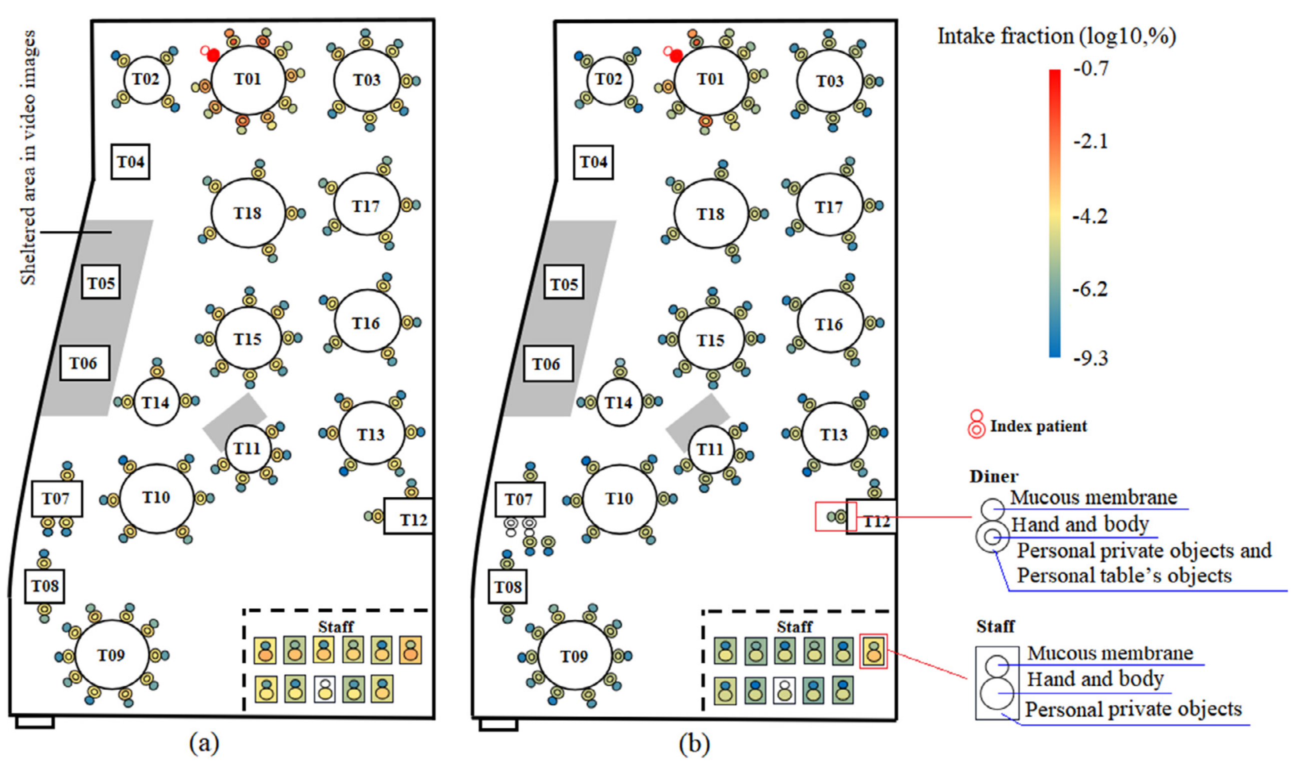

Figure 7. Virus intake fraction (A) without any disinfection; (B) with regular surface disinfection (twice per hour with 99.99% efficiency).

transmission (Bhatta et al., 2020). Improving hand hygiene can significantly reduce the infection risk from norovirus (Sobolik et al., 2021). In the restaurant, we found that hand sanitization is also very effective, and that virus exposure could be reduced by 10.2% if individuals washed their hands twice per hour with a disinfectant of 99.99% effectiveness (Pickering et al., 2010) than washed their hands 0.1 times per hour. The surface was regarded as a high-risk surface if more viruses were transmitted to susceptible individuals through the surface. High-risk surfaces are not determined by the frequency with which they are touched but by how many individuals touched them. Considering children (younger than 5 years) are the most vulnerable population group because they have low immunity, the strategies on norovirus prevention and control for children should be given more attention (Olivares et al., 2021; Safadi et al., 2021).

Instead of disinfecting all surfaces, disinfecting just the high-risk surfaces could reduce the labor needed for disinfecting surfaces, as well as effectively controlling norovirus transmission through surfaces (Kundrapu et al., 2012; Huslage et al., 2010). In the restaurant, a table's rotary plate and menu were the two most high-risk surfaces. An automatic rotary table could be used to reduce unnecessary touches on high-risk surfaces.

Viruses are frequently transferred from public surfaces to human hands in public indoor environments. Because most *PPs* (e.g., clothes, bags) surrounding a susceptible individual are uncontaminated, the virus load on the hand of the susceptible individual can be diluted and virus exposure thus reduced, if they frequently touch their private surfaces. We found that the virus exposure could be reduced if diners touched public surfaces less and personal private surfaces more.

Mask wearing was also found to be effective in preventing infectious virus transmission such as norovirus and SARS-CoV-2 (Lai et al., 2013). Wearing a mask does sharply reduce the number of touches to the mouth and nose (Lucas et al., 2020). The incidence of norovirus outbreaks dramatically declined during the COVID-19 pandemic because of nonpharmaceutical interventions (e.g., mask wearing, close contact reduction) (Kraay et al., 2021; Zhang et al., 2021b). In restaurants, individuals touched their mouth, nose, and eyes 25.7, 8.4, and 2.2 times per hour, respectively, which means more than 47% of mucous membrane touches could be avoided if an individual wore a mask for half of the time they spent indoors. In the United States, outbreaks of norovirus decreased by more than 50% during the COVID-19 pandemic compared with the same period in 2019 (Lennon et al., 2020).

The surface material plays a key role in norovirus transmission. If we could reduce the virus transfer rate from all surfaces to hands (δ_{sh}) to 0.01 and from hands to all surfaces (δ_{hs}) to 1, exposure to the virus could be reduced by 99.9% compared with the worst condition ($\delta_{sh} = 1$; $\delta_{hs} = 0.01$) and by 86.6% compared with the current conditions in the restaurant (transfer rate between hand and surfaces is given in Table 1). It is therefore necessary to develop some materials that would inhibit virus transmission through the fomite route (Park et al., 2014).

We used the beta-Poisson distribution in the dose-response models (Van Abel et al., 2017) to predict the infection risk of both diners and staff members in the restaurant. If 1000 genome equivalent copies (gec) would be transferred to hands by a touch between hands and mouth/nose mucosa, the probability of infection of individuals in the restaurant was about 1.2% (the source patient was a diner) and 1.6% (the source patient was a staff member), respectively (Figure S6).

This study has a few limitations. First, the transfer rate is influenced by many factors, such as hand roughness, humidity, force per touch, and the gradient of concentrations between hands and surfaces (Sobolik et al., 2021; Wilson et al., 2020). Owing to the lack of relevant data, the transfer rate between a hand and a surface made by a specific material was set to be a constant, which would introduce some errors. Second, the contact area between a hand and a surface was estimated on the basis of a previous study (Zhang et al., 2021d), and this may introduce some errors. Third, our study used the virus intake fraction, and it is difficult to quantify the infection risk. Finally, because our study was based on the touch behavior during a lunch time in the restaurant, some conclusions may be only correct for this restaurant.

Declaration of interests

The authors report no declarations of interest.

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Author contributions

T.J. and N.Z. conceived the idea; N.Z. supervised the study; X.C. and M.K. obtained the data; T.J. and L.Z. analyzed the data; T.J., N.M., K.F., and N.Z. prepared the figures; N.M., S.H., T.Y., Y.R., F.K., and M.F.K. provided the critical suggestions and revised the paper; T.J. and N.Z. wrote the paper; all authors reviewed the paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2022.05.047.

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