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Impact of a hygiene intervention on virus spread in an office building

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ABSTRACT

Viral illnesses have a significant direct and indirect impact on the workplace that burdens employers with increased healthcare costs, low productivity, and absenteeism. Workers' direct contact with each other and contaminated surfaces contributes to the spread of viruses at work. This study quantifies the impact of an office wellness intervention (OWI) to reduce viral load in the workplace. The OWI includes the use of a spray disinfectant on high-touch surfaces and providing workers with alcohol-based hand sanitizer gel and hand sanitizing wipes along with user instructions. Viral transmission was monitored by applying an MS2 phage tracer to a door handle and the hand of a single volunteer participant. At the same time, a placebo inoculum was applied to the hands of four additional volunteers. The purpose was to evaluate the concentration of viruses on workers' hands and office surfaces before and after the OWI. Results showed that the OWI significantly reduced viable phage concentrations per surface area on participants' hands, shared fomites, and personal fomites ($p = 0.0001$) with an 85.4% average reduction. Reduction of virus concentrations on hands and fomites is expected to subsequently minimize the risk of infections from common enteric and respiratory pathogens. The surfaces identified as most contaminated were the refrigerator, drawer handles and sink faucets in the break room, along with pushbar on the main exit of the building, and the soap dispensers in the women's restroom. A comparison of contamination in different locations within the office showed that the break room and women's restrooms were the sites with the highest tracer counts. Results of this study can be used to inform quantitative microbial risk assessment (QMRA) models aimed at defining the relationship between surface contamination, pathogen exposure and the probability of disease that contributes to high healthcare costs, absenteeism, presenteeism, and loss of productivity in the workplace.

1. Introduction

Acute respiratory infections (ARIs) are common illnesses in both the developed and developing world. Viral pathogens account for 90% of the upper respiratory tract infections (URTIs), while 10% are caused by bacterial pathogens (Fahey et al., 1998). Disease-causing viruses and bacteria can be spread by direct contact with aerosols from infected individuals through coughing and sneezing or indirectly from contaminated surfaces where infectious droplets have settled (Jones and Brosseau, 2015). In shared office spaces, viral pathogens spread rapidly through contact with infected people or contaminated fomites, due to increased potential for contact between healthy and ill individuals (Beamer et al., 2015; Zivich et al., 2018). Furthermore, the spread of infectious pathogens is intensified by employees sharing equipment, such as copy machines, kitchens, restrooms, computer keyboards, and desks (Hewitt et al., 2012; Zivich et al., 2018), and work spaces, such as unassigned tables open for employees to use. One 16-month study of over 230 adult office employees found that those exposed to individuals with symptoms of a respiratory tract infection were 5-fold more likely to report a similar infection during the same week (Hovi et al., 2015). This study implied significant benefits of social distancing from sick individuals, both at work and elsewhere. Consequences of ARIs are attributed to their prevalence and seriousness that result in clinical and economic burdens, as well as workflow interruption (i.e., missed working time and reduced productivity) (Bramley et al., 2002; Palmer et al., 2010).

Influenza, one of the most prevalent viral respiratory infections worldwide, causes significant health and economic impacts (Chowell

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et al., 2008). Employees miss between < 1 and 4.3 work days when an influenza episode occurs, accounting for 5%–20% of illness related absences (Keech and Beardsworth, 2008; Schanzer et al., 2011). Moreover, presenteeism (workers being present at work while ill), is associated with a > 30% reduction in individual efficiency and leads to a decrease in worker productivity while increasing the risk of influenza transmission to co-workers (Edwards et al., 2016; Hemp, 2004). In the United States, both influenza and non-influenza ARIs result in an annual economic burden of $87 billion and $40 billion respectively, although this may be underestimated (Fendrick et al., 2003; Molinari et al., 2007). Although influenza incidences are mostly treated in outpatient physician visits, some patients may experience significant clinical complications that require hospitalization (Meier et al., 2000). Once infected with influenza viruses, an adult may be contagious a day before the onset of symptoms and up to five days after (Harper et al., 2004), thus increasing the risk of illness transmission at the workplace. Persons infected with influenza may shed millions of infectious viral particles into the environment where they can survive for 24–48 h on non-porous surfaces, such as stainless steel door handles (Bean et al., 1982). Smaller aerosol particles may remain suspended in the air for hours before settling on fomites (Nikitin et al., 2014). Contamination of frequently touched surfaces can lead to high rates of transmission through contact from hands to fomites, increasing risk of infection in the workplace (Li et al., 2009). More than 70 million lost workdays to absenteeism and 145 million lost workdays to presenteeism are due to the common cold and other respiratory tract infections (Bramley et al., 2002; Fendrick et al., 2003).

Norovirus is another highly contagious pathogen and a leading cause of viral GI illnesses in the U.S. where outbreaks occur mainly in schools, child daycare facilities, restaurants, and nursing homes (Lopman et al., 2009, 2012; Makary et al., 2009). The economic burden attributed to norovirus due to hospitalization is almost $500 million per year (Lopman et al., 2011). Norovirus may be transmitted directly by aerosol inhalation, as well as indirectly through contact with contaminated surfaces or food (Barker et al., 2004). Aerosol transmission was implicated at a restaurant outbreak where one diner vomited, and an inverse relationship between the distance from the person who vomited and the other afflicted patrons was shown (Marks et al., 2000). High shedding rates, low infectious doses, multiple routes of transmission and long-term environmental stability contribute to high norovirus infectivity (Lopman et al., 2012; Makary et al., 2009; Mathijs et al., 2012). Surfaces commonly contaminated with viruses in office or school settings include computer keyboards, computer mice, soap dispensers, toilet flush handles, restroom faucets, and door handles (Barker et al., 2004; CDC, 2008).

Although annual vaccination can help reduce influenza outbreaks, vaccines are not developed for many other pathogens, such as norovirus (Fiore et al., 2010). Therefore, the best defense for disease prevention is public health hygiene and sanitation interventions, such as the use of hand sanitizers, surface disinfectants, and behavior modification (Leon et al., 2008; Reynolds et al., 2016). A previous study showed a 24.3% lower incidence of healthcare insurance claims for hand hygiene preventable illnesses, such as influenza and colds, following a workplace intervention promoting use of alcohol-based hand sanitizers and hand wipes (Arbogast et al., 2016). Other benefits included improved employee health outcomes and job satisfaction. Behavior modification such as isolation, proper hand hygiene by use of water and soap, and use of antiseptic agents have been shown to decrease the spread of viral and bacterial pathogens in home, healthcare, and military settings (Boyce and Pittet, 2002; Larson, 2007; Mott et al., 2007).

Office environments that include shared equipment, such as desks, printers/copy machines, break rooms, restrooms, and conference rooms, present an ideal location for the spread of infectious pathogens. Tracer studies, using surrogate viruses to mimic infectious microorganisms, have been used extensively to track movement of pathogens throughout indoor environments such as offices, long-term care facilities, and hotels (Reynolds et al., 2016; Sassi et al., 2015; Sifuentes et al., 2014). The purpose of this study was to use viral tracers to identify frequently contaminated fomites in an office environment and evaluate the impact of a hygiene intervention. This information is relevant to the field for improved evaluation of intervention efficacy in real-world exposure scenarios and to provide insights for infection prevention and control.

2. Materials and methods

2.1. Study design

A study with a baseline Arm (1) and two interventions Arms (2 and 3) was conducted in an office building with 80 active employees and approximately 20 graduate students that were using 41 individual offices and 116 cubicles. The building has one main and two side entrances, one shared kitchen and one shared conference room. A typical workday involves arrival between 8 and 9 a.m. with departure between 4 and 5 p.m. The experimental design was reviewed by the University of Arizona's Human Subjects Protection Program and found to meet the criteria for Institutional Review Board approval. Workers were selected based on their consent to participate either to be seeded with MS2 bacteriophage tracers (ATCC 15597-B1) and/or have their office surfaces and hands swabbed. MS2 phage is an ideal surrogate for human viruses due to their similar shape (icosahedral) and size (19–27 nm) to other human viruses, such as influenza and adenovirus, as well as their extended survival time in the environment (Bae and Schwab, 2008; Julian et al., 2010). Phage tracers do not infect humans and therefore are safe, ethical options for monitoring pathogen transmission patterns in hospitals, and other public areas (Sassi et al., 2015; Sifuentes et al., 2014; Valdez et al., 2015).

For all three study arms, the office main entrance door handle was seeded three times (7:30 a.m., 8:00 a.m., and 8:30 a.m.). Five participants were selected for inoculation where only one randomly selected, blinded participant's hands were seeded with 100 µL of 10^8 PFU/mL MS2 tracer and four blinded participants were wetted with 100 µL of Tryptic Soy Broth (Bacto Tryptic Soybean-Casein Digest Medium; BD Diagnostics, Franklin Lakes, NJ) placebo. Participants were asked to rub the palms of their hands together until the solution dried. Sampling was done 6 h post-seeding at 2:30 p.m. During baseline (Arm 1) and Arms 2 and 3, hand soap was available in restrooms and kitchen areas as per usual and janitorial staff continued to clean in the evenings but were asked to not clean or disinfect the study area between 7:00 a.m. and 3:00 p.m.

2.2. Seeding and sample processing

Fomites and hand samples were collected using sterile 3M Swab-Samplers with 10 mL of disinfectant neutralizing Letheen broth (3M Healthcare, St. Paul, MN). A single swab was used to sample both hands on the palm side including all ten fingers and the palm area. Fomite surfaces were measured, and surface areas calculated in cm^2. The double-layer agar technique was used to analyze MS2 (Adams, 1959) (ATCC 15597 *E. coli* host).

2.3. Interventions

Baseline sampling was limited to swabbing non-porous surfaces and hands with no intervention. Arm 2 consisted of disinfecting high-touch surfaces after 3.5 h of seeding at around 11–11:30 a.m. with EPA registered product PURELL Professional Surface Disinfectant with an active ingredient of 29.4% ethyl alcohol (GOJO Industries, Inc. Akron, OH), following manufacturer label instructions, which specify that hard, non-porous surfaces should be sprayed with the product six to eight inches away from the surface until thoroughly wet, allow a contact time of 30 s, and then wiped dry. These surfaces included: the

Table 1
Office wellness interventions.

Type	Intervention steps
Arm 1	Baseline; no intervention
Arm 2	Staff cleaned main shared areas with PURELL Professional Surface Disinfectant after 3.5 h of seeding. Disinfected surfaces included: entrance door handles, refrigerator door handles, microwave, copiers, restrooms (faucets and paper towel dispenser handles), and communal computer station (chair armrests, keyboard, and mouse).
Arm 3	Hand Hygiene Bundle (HHB) was given to individual participants. HHB included: PURELL Sanitizing Wipes- (100 count canister) PURELL Advanced Instant Hand Sanitizer – (8 FL oz. bottle) Three PURELL PERSONAL™ Gear – (1 FL oz. bottle) with JELLYWRAP™ Carrier (GOJO Industries, Inc. Akron, OH) Intervention instructions. Reminder emails were sent to workers once per week and signage was posted throughout the facility encouraging the use of the products during the study period.

entrance door handles, break room countertops, refrigerator door handles, etc. (Table 1).

During Arm 3, the intervention described for Arm 2 was in place with the addition that individual workers were issued a Hand Hygiene Bundle (HHB) (Table 1). Workers were instructed to use the products at least once per day during the study period following the manufacturer's instructions. An email was sent to all employees after one week reminding them to use the products at least once per day. Each arm was repeated three times with at least two days between new seeding trials (March 2017–May 2017). The study was conducted in a sequential order (Arm 1, 2, 3) to minimize any behavior changes that may have affected the results from having a full intervention (Arm 3) precede a lesser one.

During the study, 20 hands, 24 common fomites, and six offices (four fomites each) were sampled before and after implementation of Office Wellness Interventions (OWIs). The 20 participants were selected based on availability at the time of sampling and location in the office building (to represent the building as a whole). Individual information regarding the participant's sex, behaviors or schedules was not collected. Targeted shared fomites included: exit door push bar, drinking fountain button, conference room door handles, etc. while targeted office fomites included: keyboard, mouse, desk, and chair armrest. Table 2 shows a comprehensive list of all sampling sites.

2.4. Data analysis

Two separate assessments were made, which required the data to be broken down into different units. One goal of this study was to compare the effectiveness of the interventions based on the surface area of the fomites. For this purpose, the total PFU from each swabbed surface was divided by the surface area, changing units from total PFU per surface to PFU/cm^2.

Data analysis was conducted using STATA 13.0 (StataCorp LP, College Station, TX). Log_{10} transformations were performed because the data were not normally distributed. A two-sample independent *t*-test was used to determine if there was a statistically significant reduction of phage concentration per surface area after interventions. An effective intervention for reducing virus concentrations in the workplace was defined at the statistically significant p-value of < 0.05.

The goal of the second assessment was to identify which shared surfaces harbored a higher phage count at the end of the workday, and from that information to determine which sites should be cleaned more frequently in office workplaces. During typical cleaning activities, the entirety of the surface of a fomite is cleaned, rather than cleaning specific areas on the object, therefore the data was not divided by surface area, and so the units remained as total PFU.

Box and whisker plots were used to identify the most contaminated surfaces and to compare phage distribution. The top five most contaminated surfaces and the overall most contaminated locations were selected based on the upper quartile of their distribution and the overall most contaminated sites were also assessed in the same manner. For sites with more than one sampled surface, such as the break room or the restrooms, phage concentrations (PFU/site) were calculated by adding unadjusted concentrations found in each fomite in that location and subsequently adjusted with a log_{10} transformation to normalize the data. Grouping the data in this manner provides a view of a real-world scenario, where an individual's risk of contamination is additive as they touch multiple surfaces on a site.

Table 2
Main office, individual offices, and subjects' sampling sites.

Main Office area (communal fomites)	Exit door push bar Drinking fountain button Conference room door handles (2) Men's and women's restroom soap dispenser handles (2) Men's and women's restroom faucet handles (3) Men's and women's restroom door handles (2) Communal office supplies (9) Copiers (2) Microwave Candy jar Refrigerator Coffee pot Break room sink faucet handle Break room soap dispenser handle Break room drawer handles (8) Communal computer station Communal mini-refrigerator handle
Six Individual offices (personal office fomites)	Desk Keyboard Mouse Chair Armrests
Subjects	20 subjects' right and left hands

3. Results

The results showed that virus tracer moved extensively and rapidly in an office setting even when only a single person and a commonly touched fomite is contaminated. Baseline analysis showed that all sampled surfaces (n = 68) tested positive for the tracer, after 6 h of workday activity, at an average concentration of 1.32 log_{10} PFU/cm^2. Hygiene interventions were shown to have a measurable impact on mean surface concentrations with the greatest impact quantified following mid-day disinfection of high-touched surfaces and worker use of the HHB (Arm 3 intervention). The average percent reduction of phage concentrations when high-touch surfaces were disinfected and without the use of the HHB (Arm 2 intervention) was 41.7% (p = 0.31). In Arm 3, when both interventions were combined (disinfecting high-touch surfaces plus participants using HHB), a statistically significant virus reduction of 85.4% per surface area was seen when concentrations were evaluated for all hand and fomites combined (p = 0.0001) (Table 3). In addition, when evaluating only the reduction on fomites, without including samples from hands, disinfecting high-touch surfaces and

Table 3
Summary of virus concentration on hands and fomites pre- and post-intervention.

Arm	N	Mean[a]	S D	[95% CL]	% Reduction	[Phage reduction 95% CL]
Hands and Fomites						
Arm 1[c]	68	1.32	1.34	1.00 1.65		
Arm 2[d]	68	1.09	1.37	0.76 1.42	41.7	0.14–0.62
Arm 3[e]	68	0.49	1.06	0.24 0.75	85.4[b]	0.53–1.15
Fomites only						
Arm1	48	1.25	1.46	0.82 1.67		
Arm2	48	1.07	1.44	0.65 1.49	33.0	0.30–0.65
Arm3	48	0.33	1.05	0.02 0.64	87.8[b]	0.55–1.28

[a] Units-Log_{10} PFU/cm^2.
[b] Significant p values.
[c] Arm 1- Baseline.
[d] Arm 2- surface disinfection.
[e] Arm 3- surface disinfection plus Hand Hygiene Bundle intervention.

participants use of hand hygiene products, resulted in a statistically significant 87.8% average reduction of phage concentrations per surface area ($p = 0.0007$).

An assessment of the distribution of phage concentrations per sampled communal fomite was used to identify the office hotspots where the highest concentrations were found throughout all arms of the study (Fig. 1).

In Fig. 1, the sampled surfaces are ranked by highest to lowest phage concentration to compare the tracer load on each fomite. The mean concentrations for all the surfaces were 3.48 ± 1.27 log_{10} PFU, 3.15 ± 1.38 log_{10} PFU, and 2.24 ± 1.02 log_{10} PFU for arms 1, 2, and 3 respectively. There was a wide variability between concentrations of each fomite, ranging from 0 to 7.10 log_{10} PFU/surface. Several surfaces stand out due to their consistently higher phage concentrations, such as the break room refrigerator, the exit door push bar, the soap dispensers in the women's restroom, the sink's faucet handle in the break room, and the drawer handles in the break room. For these five surfaces, the 75th percentile of their concentrations ranged from 4.79 log_{10} PFU/surface to 5.13 log_{10} PFU/surface. The mean phage concentration per site was calculated to compare log_{10} reductions of each intervention to the baseline (Fig. 2).

The overall means of each arm when the concentrations were pooled by location were 4.06 ± 1.18 log_{10} PFU, 3.83 ± 1.43 log_{10} PFU, and 2.69 ± 0.99 log_{10} PFU for arms 1, 2, and 3 respectively. Fig. 3 shows the distributions of phage concentrations per site. Identifying the sites with highest concentrations allows determination of focused intervention protocols. Based on the upper quartiles of phage distributions per sites, break room (75th percentile: 5.88 log_{10} PFU) and the women's restroom (75th percentile: 5.17 log_{10} PFU) are the most contaminated locations (Fig. 3).

4. Discussion

Full implementation of the OWIs resulted in significantly reduced phage concentrations per surface area on communal surfaces, office fomites, and hands, in an office environment. It has been reported that communal shared items in an office setting such desks and computer keyboards have a potential to be fomites, resulting to transmission of infections (Zivich et al., 2018). Viral transmission routes are very diverse, including indirect contact with contaminated fomites, aerosol transmissions such as sneezing, and direct contact with an infected person (La Rosa et al., 2013), and all these are common in an office workplace setting. Full implementation of the disinfection protocol and use of HHB will likely reduce exposure to human viruses in indoor environments due to decreased concentrations on surfaces and hands. This study did not track behavior change regarding the use of the HHB and instructions for use were minimal (use once per day following manufacturer's instructions), but results suggest that by making an HHB available, virus presence on surfaces and hands can be further reduced. This study reinforces previous results by Reynolds et al. (2016), whereby a healthy workplace hygiene intervention reduced viral exposure in an office setting by reducing the frequency of contaminated hands and surfaces by 27% and 46%, respectively (Reynolds et al., 2016). Additionally, the current study further demonstrates the efficacy of the HHB which was part of the Arbogast et al. (2016) study, whereby the HHB was successful at reducing healthcare insurance claims for

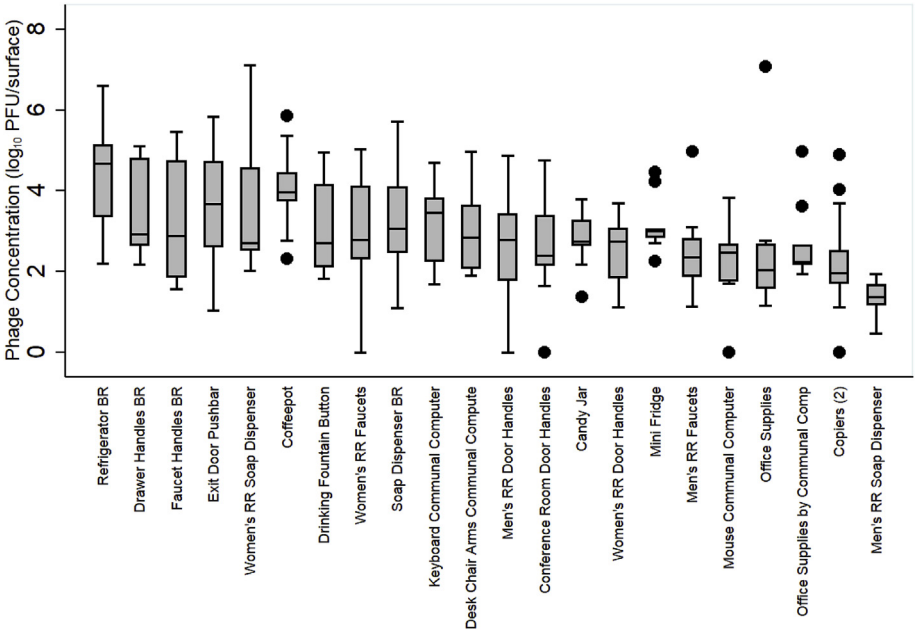

Fig. 1. Comparison of phage concentrations per surface.
BB: Break room
RR- Restroom
Concentrations are log_{10} transformed to normalize the data

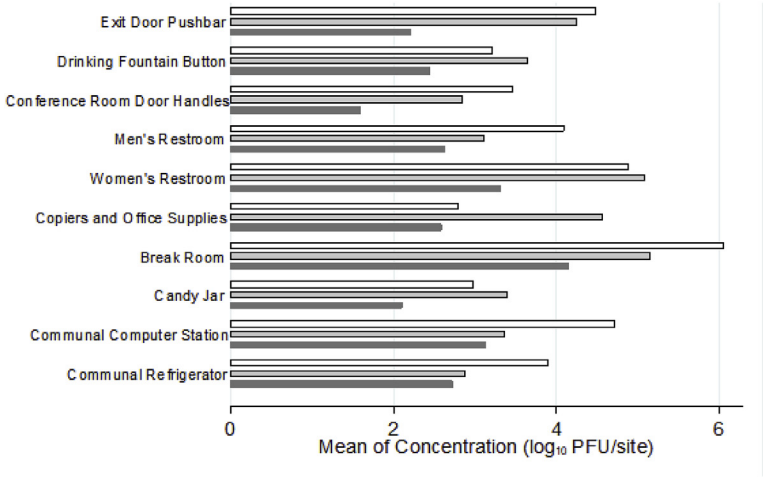

Fig. 2. Comparison of mean phage concentration per sampling site pre- (ARM 1) and post-interventions (ARM 2- manual cleaning; ARM 3- manual cleaning plus product intervention).
Restrooms-door handles, soap dispensers, and faucets.
Break room-microwave, refrigerator, coffeepot, faucet handle, soap dispenser, and drawer handles.
Copiers and Office Supplies-copiers (2), and misc. Supplies (i.e., scissors, staplers, three-hole puncher, pens).
Communal Computer Station-mouse, keyboard, office supplies, and chair arms.

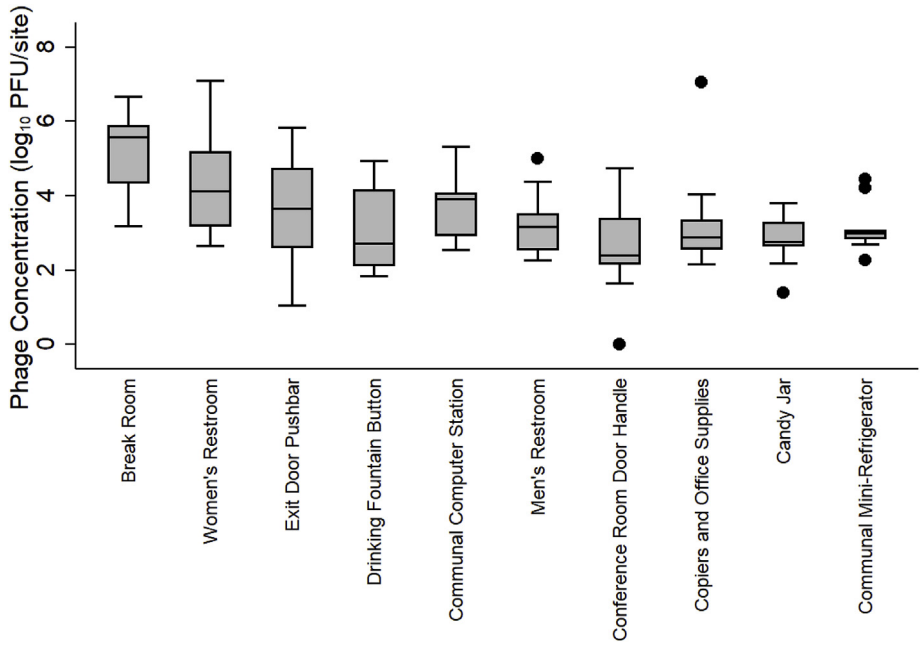

Fig. 3. Comparison of phage concentration by sites across all trials.
Restrooms-door handles, soap dispensers, and faucets
Break room-microwave, refrigerator, coffeepot, faucet handle, soap dispenser, and drawer handles.

illness (Arbogast et al., 2016). When the data in the current study are taken into consideration with previous studies, both high-touch surface disinfection and an HHB should be considered effective hygiene interventions individually but, as this study demonstrates, improved pathogen reduction can be achieved when the high-touch surface disinfection and use of the HHB are paired.

When considering control of viruses on hands and surfaces, disinfection of high-touch fomites after 3.5 h of seeding resulted in a 41.7% average reduction of phage concentrations. When high-touch surfaces were disinfected, and workers also implemented improved hand hygiene, there was a greater reduction of phage concentrations of 85.4%. Therefore, single, mid-day disinfection of high-touch surfaces produced measurable viral load reductions, and even greater reductions were achieved by adding the use of hand hygiene products. The interaction between hands and surfaces likely leads to repeated cross-contamination requiring a bundle of interventions to target multiple routes of transmission. In practice, the greatest public health gain would be to implement a strategy involving more routine surface disinfection and increased hand hygiene practices to significantly reduce the risk of viral transmission in the workplace.

In our study, the concentration of tracer found on hands was similar to sampled fomites, with no statistically significant difference. This further supports our theory that hands and surfaces are in constant interaction and are consistently in a pattern of contamination and recontamination. While the transfer of viruses between hands and fomites has long been studied (Ansari et al., 1988), little is known about how human behaviors and activities contribute to contamination cycles. In addition, the sustainability of the intervention would need to be evaluated to determine long-term changes in viral concentrations.

The experimental setup allowed for differentiation of office hot spots, or locations where a greater concentration of the phage accumulated. It was observed that the exit door push bar, the women's restroom, the break room, the drinking fountain button, and the communal computer station were consistently areas of high concentration of the tracer throughout the study (Fig. 3). Based on these findings, a change in cleaning protocols to increase the frequency of disinfection activities at these sites in conjunction with an increase in hand hygiene activities is recommended to decrease contamination and reduce the

risks of infection from pathogens that could aggregate in these locations. Similarly, extra precautions are recommended relative to contact with communal surfaces, such as refrigerators, coffeepots, door knobs, and other objects shared by many people. An additional assessment was performed utilizing the 95th percentile as the cutoff to determine which were the most contaminated surfaces, but this method was deemed inappropriate due to outliers in the data that pushed certain fomites to the top of the list due to results from one trial, such as the office supplies, but were not representative of the overall results from all trials.

Another interesting result is that shared fomites had significantly higher phage concentrations compared to personal office fomites. The interaction between personal and communal spaces and the potential for cross-contamination of pathogens between these general areas needs more study. Understanding these behaviors can help to inform best practices for targeting critical control points for reducing pathogen transmission. The women's restroom had consistently higher MS2 counts than the men's restroom, but this could be due to the much higher ratio of women to men in the office. Because there are more female workers, the women's restroom is used more often, which likely contributes to the higher numbers of phage in that location compared to the men's restroom.

When implementing a new cleaning regimen, a potential concern is whether daily high-touch surface cleaning is safe for employees who may be handling the chemical prior to eating and in some cases, their food may even have direct contact with these surfaces (e.g., break room tables, desks). In this study, a novel surface disinfectant was used for high-touch point cleaning that contains 29.4% ethanol, about half as much as other similar products, and is classified with the EPA's lowest possible toxicity rating (Category IV). Since this product contains only ingredients that are safe for food contact surfaces, it is ideal for sanitization in an office setting where it can be used on desks, kitchen surfaces and conference room tables where employees frequently prepare and consume food without requiring a subsequent cleaning step.

A limitation of the study was that no data on individual compliance with use of the hand hygiene products was collected. Without this information, it is difficult to conclude if phage reduction was driven by increased hand hygiene practices from a few individuals, versus a collective effort from everyone in the office slightly increasing their amount of hand hygiene events. Another limitation is that the MS2 tracer is used as a surrogate for respiratory and enteric viruses, but there could still be differences between survivability of various organisms based on the disinfectants and sanitizers used. The product used to disinfect surfaces in Arms 2 and 3 has been EPA certified as a disinfectant, with efficacy claims against bacteria, non-enveloped viruses, influenza, and fungi when used according to manufacturer instructions.

5. Conclusions

Implementation of a targeted risk reduction program, with surface disinfection of commonly touched shared objects and hand hygiene, including hand sanitizer at the desk and simple employee education (i.e., intervention instructions, promotional signage, and emails), resulted in a significant reduction of virus transmission in an office setting. By reducing exposure, this advanced hygiene program is also expected to minimize the risk of infections from common enteric and respiratory pathogens. Given the difficulties in conducting epidemiological studies (i.e., controlling confounding factors such as unanticipated seasonal illness, outbreaks, and changes in disinfection or hand hygiene protocols that may happen over time), tracer studies offer an effective approach for evaluating real-time infection prevention and control practices in a variety of settings. While clinical consequences were not determined in this study, these results can be used to inform quantitative microbial risk assessment (QMRA) models aimed at determining the relationship between exposure and the probability of disease that contributes to high healthcare costs, absenteeism, presenteeism, and loss of productivity in the workplace. Future QMRA models could also simulate variable behaviors and product use scenarios (e.g., intervention frequency, formulation and contact time) to quantify their impact on the probability of exposure or the sequence of contamination and exposure events.

Authors contributions

K.A.R., J.D.S., C.P.G., R.A.L., and S.L.E. conceived and designed the study approach; E.K.K., J.D.S., F.G., A.R., and R.C. performed the experiments; E.K.K. and F.G. analyzed the data; E.K.K., F.G, J.D.S. and K.A.R. drafted the paper and all co-authors reviewed and revised the final manuscript.

Conflicts of interest

This study was partially funded by GOJO Industries, whose researchers participated in the study design. The conduct of the study, analysis and presentation of the results as well as the decision to publish were solely determined by the academic authors without influence from any funding source.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2019.01.001.

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