Why is mock care not a good proxy for predicting hand contamination during patient care?

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SUMMARY

Background: Healthcare worker (HCW) behaviours, such as the sequence of their contacts with surfaces and hand hygiene moments, are important for understanding disease transmission.
Aim: To propose a method for recording sequences of HCW behaviours during mock vs actual procedures, and to evaluate differences for use in infection risk modelling and staff training.
Methods: Procedures for three types of care were observed under mock and actual settings: intravenous (IV) drip care, observational care and doctors' rounds on a respiratory ward in a university teaching hospital. Contacts and hand hygiene behaviours were recorded in real-time using either a handheld tablet or video cameras.
Findings: Actual patient care demonstrated 70% more surface contacts than mock care. It was also 2.4 min longer than mock care, but equal in terms of patient contacts. On average, doctors' rounds took 7.5 min (2.5 min for mock care), whilst auxiliary nurses took 4.9 min for observational care (2.4 min for mock care). Registered nurses took 3.2 min for mock IV care and 3.8 min for actual IV care; this translated into a 44% increase in contacts. In 51% of actual care episodes and 37% of mock care episodes, hand hygiene was performed before patient contact; in comparison, 15% of staff delivering actual care performed hand hygiene after patient contact on leaving the room vs 22% for mock care. The number of overall touches in the patient room was a modest predictor of hand hygiene. Using a model to predict hand contamination from surface contacts for *Staphylococcus aureus*, *Escherichia coli* and norovirus, mock care underestimated micro-organisms on hands by approximately 30%.

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Introduction

Healthcare worker (HCW) behaviours are important for estimating the role of fomite-mediated exposures in the transmission of healthcare-associated infections. Such behaviours include gloved or ungloved hand-to-surface and hand-to-patient contacts, in addition to hand hygiene moments. The frequency and sequence of these activities can be used to inform exposure models that estimate the accretion of pathogens on hands over the course of a care episode [1,2]. These second-by-second behaviours, or 'micro-activities', have been measured within the context of chemical and microbial exposures [3,4], and have been identified as some of the most influential parameters on estimated infection risks in microbial exposure and risk assessment models [5,6]. In a model of fomite-mediated exposures to highly infectious viruses in office settings, hand-to-face contacts were consistently the most important parameters in sensitivity analyses [7]. While hand-to-surface contacts may not have ranked as highly [7], these contacts may drive changes in exposure, or

microbial accumulation on hands over time [8]; as such, it is important to capture accuracy in these behaviours in exposure assessments.

A common method used to collect behavioural data in health care is direct observation [9—14]. Other methods include reported behaviours [15], videography [16,17] and radiofrequency ID sensors [18,19]. A traditional limitation of direct observation in behavioural studies of hand hygiene or other types of behaviour by HCWs has been the Hawthorne effect, which recognizes the change in behaviour of subjects due to being observed [20,21]. While the Hawthorne effect may also affect videography, this type of observation may be less prone to bias compared with direct observation [22,23]. However, there are other concerns related to videography, such as risk of identification and the possibility of multiple or unauthorized people accessing the footage. This may complicate ethical approval when using videographic methods in health care, where patient data must be protected and doctors fear liability [23]. However, as videographic footage can be viewed by many people, this methodology results in more

Figure 1. Example of mock procedure footage from one of two camera angles.

Table I
Pathogen Accretion Model parameters, distributions and sources

Parameter		Distribution	Source
Hand-to-surface or surface-to-hand transfer efficiency (fraction)[a]	*Staphylococcus aureus*	Normal ($\mu=0.60$, $\sigma=0.25$)	[24]
	Escherichia coli	Normal ($\mu=0.49$, $\sigma=0.12$)	[25]
	Norovirus	Normal ($\mu=0.05$, $\sigma=0.09$)	[26]
Fraction of the hand used for hand-to-surface contact		Uniform (0.008, 0.14)	[27]
Concentration on the surface (organisms/cm^2)		Uniform (0.01, 10)	Assumed

[a] All transfer efficiency distributions were left- and right-truncated at 0 and 1, respectively, as transfer efficiency represents the fraction of organisms available for transfer.

robust and accurate translation of captured activities into frequency and sequences of behaviour [9]. One reason why this is particularly true for micro-activities is that their duration may be of the order of milliseconds, making them difficult to observe in real time.

While it may not be feasible to collect videographic data in healthcare environments, simulated procedures may be filmed for educational purposes. It is not known if the micro-activities of simulated care are comparable with those of real procedures, or whether this may vary by care type. Comparing the frequency and sequence of micro-activities for different care types will inform future healthcare behaviour research methodology, especially for data collected with the intention of informing exposure and risk assessment models.

The objective of this study was to test the hypothesis that exposure and contamination potential may be driven by care type due to differences in care episode duration and contact frequency. Whether or not these differences are affected by the procedure type (actual or mock) was then evaluated.

Methods

This study was approved by the NHS Health Research Authority Research Ethics Committee (London - Queen Square Research Ethics Committee) (REF: 19/LO/0301). All patients and staff involved in this study signed consent forms.

Observations

Two methods for collecting behavioural data were compared: mock and actual procedures. Mock procedures were conducted by staff in a patient room, while a researcher lay on the bed, and video recorded and directly observed the procedures (Figure 1). Surface contacts were transcribed during care and corrected after watching the videos. Two transcribers compared sequences for accuracies. Care types observed during mock and actual procedures included intravenous (IV) drip insertion (and/or adjustment), doctors' rounds and observational care (blood pressure and temperature monitoring) in single patient bedrooms. During mock care, the mock patient had been prescribed 4.5 mg piperacillin-tazobactam, 400 mg tobramycin and 400 mg teicoplanin via IV drip for a chest infection, and the doctors and nurses performed routine care to evaluate the patient's status.

Observations were performed directly through a web application developed (https://hecoira.thedistance.co.uk) to track and timestamp HCWs' behaviours, including: entrance/ exit from the patient room; donning and doffing of gloves or gowns; use of alcohol hand sanitizer; contact with different

Table II
Summary statistics of contact frequency (contact/min), number of contacts per care episode and care episode duration (min) by procedure type (mock and actual) and by care type [intravenous (IV) drip care, observational care and doctors' rounds]

Contact frequency (contacts/min)						
	IV care		Observational care		Doctors' rounds	
	Mean ± SD (*N*)	Range	Mean ± SD (*N*)	Range	Mean ± SD (*N*)	Range
Mock	9.6 ± 4.3 (*N*=17)	3.3—16.7	10.3 ± 4.2 (*N*=20)	2.3—20.9	7.0 ± 3.6 (*N*=23)	0.8—15.3
Actual	10.3 ± 3.4 (*N*=13)	5.2—15.8	8.8 ± 2.6 (*N*=17)	4.9—14.7	2.4 ± 1.8 (*N*=9)	0.7—6.7
Number of contacts/care episode						
	IV care		Observational care		Doctors' rounds	
	Mean ± SD (*N*)	Range	Mean ± SD (*N*)	Range	Mean ± SD (*N*)	Range
Mock	22.5 ± 9.9 (*N*=17)	9.0—45.0	20.3 ± 6.4 (*N*=20)	9.0—33.0	14.4 ± 7.3 (*N*=23)	4.0—29.0
Actual	32.1 ± 16.3 (*N*=13)	5.0—63.0	40.5 ± 16.7 (*N*=17)	12.0—75.0	15.0 ± 12.2 (*N*=9)	2.0—40.0
Care episode duration (min)						
	IV care		Observational care		Doctors' rounds	
	Mean ± SD (*N*)	Range	Mean ± SD (*N*)	Range	Mean ± SD (*N*)	Range
Mock	3.2 ± 3.2 (*N*=17)	0.6—11.7	2.4 ± 1.2 (*N*=20)	0.8—5.3	2.5 ± 1.5 (*N*=23)	0.6—5.3
Actual	3.8 ± 3.1 (*N*=13)	0.3—12.1	4.9 ± 2.0 (*N*=17)	0.9—8.3	7.5 ± 5.8 (*N*=9)	1.6—19.3

SD, standard deviation.

surface types; and contact with the patient. A picture of the room was taken for the app, and surfaces were added manually before the study commenced. Each time a HCW touched a surface during care, the observer tapped the equivalent surface on the app to build up a sequence of contacts. An observation began when hand hygiene was performed before entering the room or when the room was entered without hand hygiene, and ended when the HCW left the room; as such, observations differed in duration. A contact was recorded when a HCW made contact with a surface, and the contact was considered to be over at the first moment of lack of contact between the hand and the surface. Recruitment was carried out on the respiratory ward at St James' Hospital, Leeds, UK and both care types were performed on this ward. Mock care was conducted in a single side room.

Statistical analysis

Differences in care episode duration (min), number of contacts per care episode and contact frequency (contacts/min) were compared between care types (IV drip, doctors' rounds and observational care) and between procedure types (mock and actual). Wilcoxon rank sum tests ($\alpha=0.05$) were used to compare mock and actual procedures. Kruskal—Wallis tests ($\alpha=0.05$) with Dunn's post-hoc tests ($\alpha=0.025$) were used for comparisons between care types for mock and actual procedures separately to account for family-wise error rates. Odds ratios (OR) were calculated and given with 95% confidence intervals (CI) for hand hygiene.

Predicting accumulation of micro-organisms on hands

A model for estimating microbial concentrations on hands during patient care — the 'Pathogen Accretion Model' — was used to estimate the microbial concentration on hands (organisms/cm^2) after the mean number of contacts per care episode [1]. Estimated microbial concentrations on hands were used to compare how differences in contacts per episode by care type (IV drip, doctors' rounds and observational care) and procedure type (mock and actual) are anticipated to affect fomite-mediated exposures. Concentrations of *Staphylococcus aureus*, *Escherichia coli* and norovirus on hands were estimated to compare how differences in transfer efficiency of organisms to and from surfaces may affect these accruement differences between care types and procedure types. Peer-reviewed literature was used to inform parameters [24–27], and their descriptions and distributions can be seen in Table I.

A Monte Carlo approach was used to account for variability and uncertainty in transfer efficiencies, fraction of the hand in contact with the surface, and concentration of the organism on the surface. It was assumed that hands started with no contamination. Per contact, the concentration on the hands ($C_{h,k}$) for contact (k) was estimated as:

$$C_{h,k} = C_{h,k} - \lambda S_h C_{h,k-1} + \beta S_h C_s \tag{1}$$

It was assumed that contacts were made with the dominant hand and that a new part of a surface was touched per contact. Ten thousand parameter combinations were run per organism (*S. aureus*, *E. coli*, norovirus). A non-organism-specific distribution of concentrations on the surface (C_s)

Table III
Comparisons of contacts per care episode, contacts per minute and care episode duration among care types for mock and actual procedures[a]

	Mock		Actual	
	Test statistic, df, P-value	Significant differences	Test statistic, df, P-value	Significant differences[a]
Contacts/care episode	$\chi^2 = 10.656$ df=2 P=0.004853	Doctors' rounds and IV care (P=0.0019) Doctors' rounds and observational care (P=0.0042)	$\chi^2 = 12.51$ df=2 P=0.001921	Doctors' rounds and IV care (P=0.0092) Doctors' rounds and observational care (P=0.0002)
Contacts/min	$\chi^2 = 7.9339$ df=2 P=0.01893	Doctors' rounds and IV care (P=0.0241) Doctors' rounds and observational care (P=0.0037)	$\chi^2 = 20.026$ df=2 $P=4.481 \times 10^{-5}$	Doctors' rounds and IV care ($P=8.616 \times 10^{-6}$) Doctors' rounds and observational care ($P=1.322 \times 10^{-4}$)
Care episode duration (min)	$\chi^2 = 0.064148$ df=2 P=0.9684	-	$\chi^2 = 4.7867$ df=2 P=0.09133	-

IV, intravenous.
[a] Kruskal—Wallis tests were used to determine if there were significant differences between care types, and Dunn's tests were used to determine which care types were significantly different from one another.

was used to represent a variety of contamination levels (Table I). Organism-specific transfer efficiencies were used. While the same distribution was used for hand-to-surface (λ) or surface-to-hand (β) transfer, the model allowed for a different value to be used for hand-to-surface or surface-to-hand transfer efficiency for the same contact. The fraction of the hand used for the contact (S_h) was assumed to vary from a single fingertip touch to a 'partial front palm with fingers' configuration, described by AuYeung *et al.* [27]. To estimate the fraction of the hand used for a single fingertip touch, the fraction of the hand used for front partial fingers was divided by 5.

Results

For mock procedures, 17 (13 actual), 20 (17 actual) and 23 (nine actual) observations were made for IV care, observational care and doctors' rounds, respectively (see Table II). IV care involved siting, adjustment, injecting something into the port, manipulation in order to adjust the flow, and pressing controls on the flow rate apparatus on the drip stand. Parity between observation counts could not be obtained due to the coronavirus disease 2019 (COVID-19) pandemic. A strong effect size was found in terms of total surface contacts (0.93), suggesting that sufficient cases had already been obtained. Overall, actual patient care exhibited 70% more surface contacts than mock care (32 ± 18 vs 19 ± 8; $P=1.075\times10^{-4}$) and took 2.4 min longer (5.12 vs 2.7 min; $P=4.008\times10^{-5}$) (Figure 2). However, no difference was seen in terms of the number of patient contacts ($P=0.68$). On average, doctors' rounds took 7.5 ± 5.8 min (vs 2.5 ± 1.5 min for mock care) ($P=0.01421$), whilst auxiliary nurses took 4.9 ± 2 min for observational care (vs 2.4 ± 1.2 for mock care) ($P=0.000157$). Registered nurses took 3.2 ± 3.1 min for mock IV care and 3.8 ± 3.2 min for actual IV care ($P=0.4387$). Figure 2 shows violin plots which also show pairwise comparisons (Table III).

For contacts per minute, there were no significant differences between mock and actual procedures for IV care and observational care, as opposed to doctors' rounds ($P=2.6 \times 10^{-4}$) (Figure 2). For doctors' rounds, a greater number of
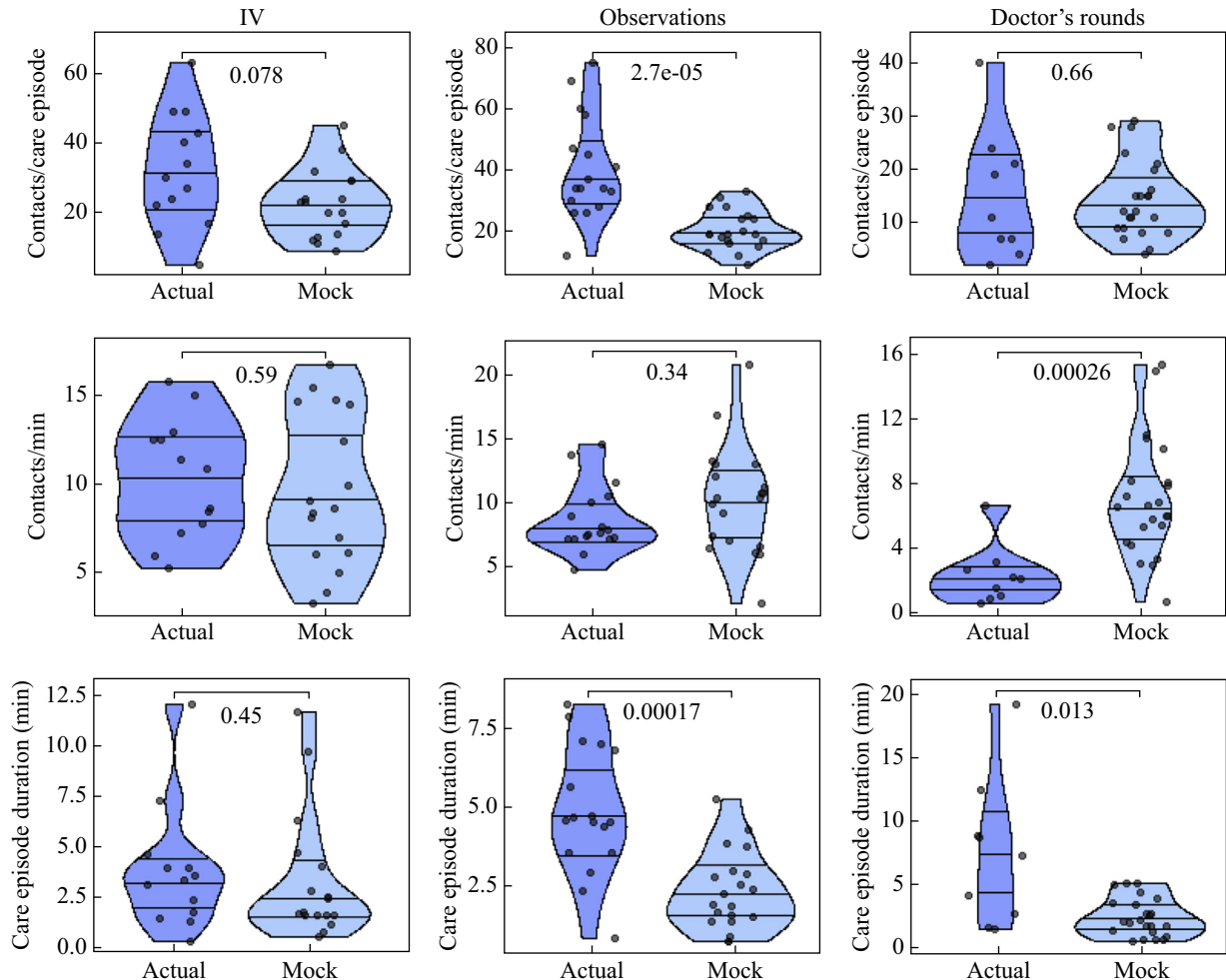

Figure 2. Comparison of number of contacts/min, number of contacts/care episode and duration of exposure (min) for mock and actual procedures: intravenous (IV) care, observational care and doctors' rounds. Horizontal lines on the violin plots represent the 25th, 50th and 75th quantiles. Values are *P*-values that reflect Wilcoxon rank sum test results.

contacts per minute was generally observed for mock procedures than for actual procedures. For care episode duration, significant differences in mock and actual procedures were observed for observational care ($P=1.7 \times 10^{-4}$) and doctors' rounds ($P=0.013$), where actual procedures took longer than mock procedures (Figure 2).

Significant differences in contacts per care episode were observed between doctors' rounds and IV care for mock procedures ($P=0.0019$) and actual procedures ($P=0.0092$) (Table II). Significant differences in contacts per care episode were also observed between doctors' rounds and observational care for mock procedures ($P=0.0042$) and actual procedures ($P=0.0002$) (Table II). Significant differences between these care types (doctors' rounds and IV care, and doctors' rounds and observational care) were also observed for number of contacts per minute (Table II). For care episode duration, no significant differences between care types were observed for mock or actual procedures (Table II).

Hand hygiene

HCWs performed hand hygiene at some point in 79% of actual procedures vs 62% of mock procedures. In 51% of actual procedures and 37% of mock procedures, hygiene was performed before patient contact ($OR=0.55$, 95% CI 0.23–1.35). Comparatively, 15% of HCWs performed hygiene on leaving the room after actual procedures vs 22% for mock procedures ($OR=0.66$, 95% CI 0.23–1.91). Logistic regression shows that

the number of overall surface touches in the patient room was a modest predictor of hygiene (95% CI -0.001 to 0.05; $P=0.06$).

Exposure model comparison

On average, actual care predicted 30% higher hand contamination than mock care. The smallest accruement on hands was estimated for doctors' rounds for both mock and actual procedures, and for scenarios involving contact with norovirus-contaminated fomites (Figure 3). Greater accruement was seen for *S. aureus* and *E. coli*, likely due to larger transfer efficiencies for these organisms compared with norovirus (Table I).

Discussion

This study found that consistency in behaviours between mock and actual procedures depends upon care type. Therefore, behaviour observations in mock procedures should be used with caution for representation of actual procedures in terms of frequency of surface contacts or care episode duration. For example, while there were significant differences in contacts per care episode for observational care ($P=2.7 \times 10^{-5}$), this was not the case for IV care ($P=0.078$) or doctors' rounds ($P=0.66$) (Figure 2). One explanation for this may be due, in part, to differences between the care episode durations of different care types. Doctors' rounds tended to be longer for actual procedures than mock procedures (Figure 2), but more contacts per minute were made during mock doctors' rounds
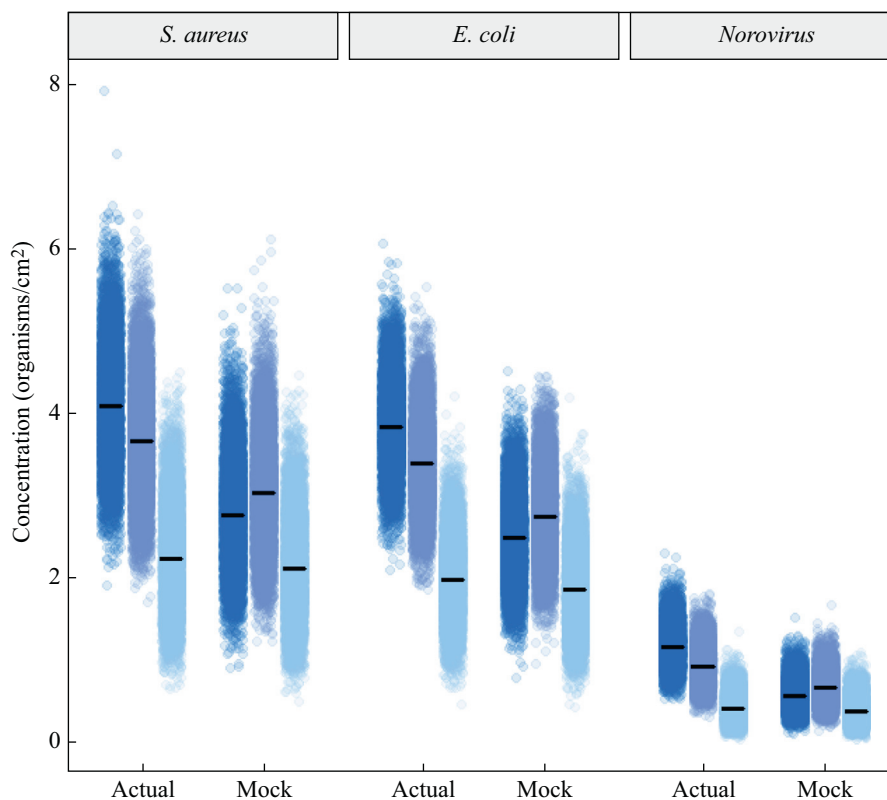

Figure 3. Comparison of estimated concentrations of *Staphylococcus aureus*, *Escherichia coli* and norovirus on hands after the average number of contacts per care episode observed for mock or actual behaviours during observational care (dark blue), intravenous drip care (mid blue) and doctors' rounds (light blue). Horizontal bars indicate the median.

than actual doctors' rounds (Figure 2). With a greater number of contacts but a shorter care episode duration for mock doctors' rounds, and a smaller number of contacts but a larger care episode duration for actual doctors' rounds, the contacts per care episode appeared similar (Figure 2). This suggests that doctors spend more time conversing with the patient without touching anything. Procedural care, such as IV care, can be performed more quickly in actual care than in mock care, whilst not changing the number or sequence of surface contacts.

There were significant differences between doctors' rounds and IV care, and between doctors' rounds and observational care in contacts per care episode and contacts per minute for mock and actual procedures (Table II). Among care types, the highest contact frequency was observed for observational care in mock procedures, while IV care had the highest contact frequency for actual procedures (Table II). Doctors' rounds consistently had the lowest average contact frequency and number of contacts per care episode for mock and actual procedures (Table II). Doctors' rounds also had the longest average care episode duration for actual procedures. This indicates that care episode duration may not necessarily imply a greater number of surface contacts, but may depend on the care type itself. However, in a separate study [9], time spent in the room correlated positively with the frequency of hand hygiene, which reinforces a gain in subconscious hygiene requirements the longer a HCW is in the room.

Consistent differences between IV care and observational care with doctors' rounds may be due, in part, to who was conducting the care. While doctors' rounds were performed by physicians, IV care and observational care were performed by nurses. Differences in training and approaches to patient interactions may drive some of the differences observed here, in addition to differences in the procedures themselves. This may also be altered by level of work experience. For example, it is possible that more experienced HCWs may have more consistent behaviours, resulting in smaller differences between their mock and actual behaviours (it was not possible to do a paired comparison). It is also possible that less-experienced HCWs may have been trained more recently in specific procedures, resulting in more consistency than their more-experienced peers who have altered their behaviours due to real-world experience. Other factors that have been recognized as confounders in human behaviour studies include age, education level, gender and skill set [28]. While these parameters and their effects on human systems in industrial contexts have been explored, the effects of these parameters on micro-activity behaviours have not been addressed in health care. Future research should evaluate whether these factors influence differences between mock and actual procedures.

While mock procedures consistently resulted in smaller predicted microbial accruement on hands than actual procedures, contacts per care episode were being compared. Significant differences in care episode duration were seen for observational care and doctors' rounds (Figure 2), meaning it is possible that different patterns in accretion on hands could be seen over the course of an entire shift compared with comparisons per care episode. It must also be noted that this model assumes that each surface is contaminated homogeneously with the pathogen in question, and hence is shown here as an example of how the differences between mock and actual care can be presented in quantitative terms. However, it should be noted that this is a method framework, and hence absolute risks may be thought of as worst-case scenarios.

Limitations

One of the limitations of this study is a lack of comparison of videographic vs direct observation methods. As videography and direct observation were conducted for the mock procedures but not for the actual procedures, small differences in care episode duration, contact frequency and contacts per care episode between procedure type (mock vs actual) or care type could be due to differences in observational methods as opposed to differences in procedure type (mock vs actual). However, it is likely that videographic methods would be used for collection of mock procedure behaviour data. Therefore, the differences observed in behaviours between mock and actual procedures in this study represent anticipated differences due to changes in behaviour as a function of being videotaped, and as a function of conducting a mock vs an actual procedure.

This study also evaluated the frequency of hand-to-surface contacts for incorporation into exposure assessment modelling. However, it is unknown whether these contacts are errors in procedures, required by the procedure or contacts unrelated to the procedure itself. Comparing error rates in procedures among procedure types and for mock vs actual procedures would provide insights into the representativeness of mock behaviours for actual procedures in terms of quality of care, and would require observation by a trained HCW.

In conclusion, this study found that the use of mock procedures in place of actual procedures for behavioural studies of micro-activities, such as contacts with surfaces, could introduce errors into subsequent applications of these behavioural data, such as in exposure and risk assessment modelling. Differences between mock and actual procedures were observed for care episode duration, number of surface contacts per minute and number of contacts per care episode. For both mock procedures and actual procedures (separately), differences in contacts per minute and contacts per episode were observed between care types, specifically between doctors' rounds and IV care, and between doctors' rounds and observational care. This led to a 30% higher exposure prediction using actual vs mock data.

Future research should evaluate differences in hand-to-face contact frequency in mock vs actual procedures, so that microbial risk assessments could be conducted using specific doses, dependent upon adherence of the pathogen to skin following contact. Additionally, it is likely that outbreaks and pandemics, such as COVID-19, affect contact frequencies and other behaviours due to changes in training, personal protective equipment protocols, perceived risk for the patient and the HCW, and increases in workload and stress. More work is needed to evaluate behavioural change under these conditions, and the implications that these changes have for occupational risks for HCWs and risks for patients.

Acknowledgements

References

[1] King M-F, Noakes CJ, Sleigh P. Modelling environmental contamination in hospital single and four-bed rooms. Indoor Air 2015;25:694–707.

[2] Wilson AM, Reynolds KA, Sexton JD, Canales RA. Modeling surface disinfection needs to meet microbial risk reduction targets. Appl Environ Microbiol 2018;84:1–9.

[3] Beamer P, Canales RA, Leckie JO. Developing probability distributions for transfer efficiencies for dermal exposure. J Expo Sci Environ Epidemiol 2009;19:274–83.

[4] Nicas M, Sun G. An integrated model of infection risk in a healthcare environment. Risk Anal 2006;26:1085–96.

[5] Zhang N, Li Y. Transmission of influenza A in a student office based on realistic person-to-person contact and surface touch behaviour. Int J Environ Res Public Health 2018;15:1699.

[6] Wilson AM, King MF, López-García M, Weir M, Sexton JD, Canales RA, et al. Evaluating a transfer gradient assumption in a fomite-mediated microbial transmission model using an experimental and Bayesian approach. R Soc Interface 2020;17:20200121.

[7] Contreras RD, Wilson AM, Garavito F, Sexton JD, Reynolds KA, Canales RA. Assessing virus infection probability in an office setting using stochastic simulation. J Occup Environ Hyg 2020;17:30–7.

[8] Lai X, Wang M, Qin C, Tan L, Ran L, Chen D, et al. Coronavirus disease 2019 (COVID-2019) infection among health care workers and implications for prevention measures in a tertiary hospital in Wuhan, China. JAMA Netw Open 2020;3:e209666.

[9] King M-F, Noakes CJ, Sleigh PA, Bale S, Waters L. Relationship between healthcare worker surface contacts, care type and hand hygiene: an observational study in a single-bed hospital ward. J Hosp Infect 2016;94:48–51.

[10] Smith SJ, Young V, Robertson C, Dancer SJ. Where do hands go? An audit of sequential hand-touch events on a hospital ward. J Hosp Infect 2012;80:206–11.

[11] Huslage K, Rutala WA, Sickbert-Bennett E, Weber DJ. A quantitative approach to defining 'high-touch' surfaces in hospitals. Infect Control Hosp Epidemiol 2010;31:850–3.

[12] Smith J, Adams CE, King MF, Noakes CJ, Robertson C, Dancer SJ. Is there an association between airborne and surface microbes in the critical care environment? J Hosp Infect 2018;100:123–9.

[13] Jinadatha C, Villamaria FC, Coppin JD, Dale CR, Williams MD, Whitworth R, et al. Interaction of healthcare worker hands and portable medical equipment: a sequence analysis to show potential transmission opportunities. BMC Infect Dis 2017;17:1–10.

[14] Hyman SR, Cohen B, Rosenberg L, Larson E. Frequency, level and duration of patient contacts: an observational study and survey of physicians, nurses, clinical staff, non-clinical staff and visitors. Am J Infect Control 2011;39:E178–9.

[15] Port CL, Hebel JR, Gruber-Baldini AL, Baumgarten M, Burton L, Zimmerman S, et al. Measuring the frequency of contact between nursing home residents and their family and friends. Nurs Res 2003;52:52–6.

[16] Su YM, Phan L, Edomwande O, Weber R, Bleasdale SC, Brosseau LM, et al. Contact patterns during cleaning of vomitus: a simulation study. Am J Infect Control 2017;45:1312–7.

[17] Ahmad N, Hussein AA, Cavuoto L, Sharif M, Allers JC, Hinata N, et al. Ambulatory movements, team dynamics and interactions during robot-assisted surgery. BJU Int 2016;118:132–9.

[18] Dedesko S, Stephens B, Gilbert JA, Siegel JA. Methods to assess human occupancy and occupant activity in hospital patient rooms. Build Environ 2015;90:136–45.

[19] Vanhems P, Barrat A, Cattuto C, Pinton JF, Khanafer N, Régis C, et al. Estimating potential infection transmission routes in hospital wards using wearable proximity sensors. PLoS One 2013;8.

[20] Goodwin MA, Stange KC, Zyzanski SJ, Crabtree BF, Borawski EA, Flocke SA. The Hawthorne effect in direct observation research with physicians and patients. J Eval Clin Pract 2017;23:1322–8.

[21] Niles M, Johnson N. Hawthorne effect in hand hygiene compliance rates. Am J Infect Control 2016;44:S28–9.

[22] Pringle M, Stewart-Evans C. Does awareness of being video recorded affect doctors' consultation behaviour? Br J Gen Pract 1990;40:455–8.

[23] Asan O, Montague E. Using video-based observation research methods in primary care health encounters to evaluate complex interactions. Inform Prim Care 2014;21:161–70.

[24] Lopez GU, Gerba CP, Tamimi AH, Kitajima M, Maxwell SL, Rose JB. Transfer efficiency of bacteria and viruses from porous and nonporous fomites to fingers under different relative humidity conditions. Appl Environ Microbiol 2013;79:5728–34.

[25] King MF, López-García M, Atedoghu K, Zhang N, Wilson AM, Weterings M, et al. Bacterial transfer to fingertips during sequential surface contacts with and without gloves. Indoor Air 2020;30:993–1004.

[26] Kraay ANM, Hayashi MAL, Hernandez-Ceron N, Spicknall IH, Eisenberg MC, Meza R, et al. Fomite-mediated transmission as a sufficient pathway: a comparative analysis across three viral pathogens. BMC Infect Dis 2018;18:540.

[27] AuYeung W, Canales RA, Leckie JO. The fraction of total hand surface area involved in young children's outdoor hand-to-object contacts. Environ Res 2008;108:294–9.

[28] Khandan M, Vosoughi S, Azrah K, Poursadeghiyan M, Khammar A. Decision making models and human factors: TOPSIS and ergonomic behaviors (TOPSIS-EB). Manag Sci Lett 2017;7:111–8.