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Observing is influencing: How hand disinfection compliance observations affect hand disinfection rates; specifics derived from an electronic monitoring system

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Abstract

Background

Monitoring hand disinfection (HD) with direct observation is considered the gold standard but is flawed by the Hawthorne effect (HE). In our project in a German university hospital, we quantified the HE and evaluated possible room-specific differences.

Methods

Data were collected on an intensive care unit (ICU), an intermediate care unit (IMC), and a normal ward (NW) each categorized into ‘patient’, ‘utility/waste’ and ‘other’ rooms. While dispensers were monitored by sensors of a full-time active electronic monitoring system (EMS), the infection prevention and control staff performed step-by-step observations according to the WHO ‘5 Moments’. Periods with and without direct observations were compared regarding the number of HDs performed per patient-day (HD/PD) using descriptive evaluation and a linear mixed model.

Results

The HE was detected in ‘patient’ rooms on the NW and ICU (+31.4%, +27.4% HD/PD; both $p < 0.01$) during observation periods. Opposite effects, expressed by significant decreases in HD/PD during observations, occurred in ‘utility/waste’ rooms on the NW (−57.7%), IMC (−99.4%) and ICU (−32.9%).

Discussion & Conclusion

In our setting, the HE varied considerably between wards and room-types. As HE occurred in patient rooms, the usual HD compliance during patient care may be lower than directly observed.

Keywords: hand disinfection, hand hygiene compliance; Hawthorne effect; electronic monitoring system; direct observation

Highlights

- Direct observations for measuring hand disinfection rates are biased by the Hawthorne effect.
- Electronic monitoring systems may help to quantify the Hawthorne effect.
- The Hawthorne effect is present in patient rooms and appears to be dependent on ward- and room-type.
- Depending on the room-type, the number of hand disinfections may increase or decrease during compliance observation periods.

Introduction

Hand disinfection (HD) is considered the most effective single infection prevention measure to protect patients from healthcare-associated infections. It is estimated that the proportion of healthcare-associated infections that could be prevented by implementing infection prevention bundles including HD is 35–55% (1). Indications for hand disinfection during patient care have been defined by the World Health Organization (WHO) in the '5 moments of HD' (2) and were introduced globally in 2009 as part of the global 'Clean care is safer care' campaign (3). The gold standard for determining HD rates of healthcare-workers is direct observation of compliance by trained observers (3). The observation results are used to assess whether the staff's HD compliance is adequate. However, implementing HD-compliance improvement strategies—particularly with sustained impact—is challenging (4–6), partly due to weaknesses in the established compliance monitoring methods (7,8). The validity of compliance observations can be flawed by several factors, such as the observer's expertise and the timing and duration of the observation (9–12). One of the most important confounding factors is known as the Hawthorne effect (HE) and represents a form of observation bias. The HE is based on the fact that healthcare-workers who are aware that they are being observed change their usual behavior (13,14), typically leading to falsely elevated HD-compliance rates. In a systematic review, the HE ranged from −7% to 65%(14). Furthermore, the HE differs between wards, specialties, occupational groups and over time (9,14–16). To monitor HD-compliance without bias from the HE and to obtain more accurate data, electronic monitoring systems (EMSs) have been increasingly used in recent years (31, 34). The main advantages of EMSs include the generation of large datasets around the clock and the ability to provide detailed information on several other factors associated with HD behavior, such as the time- and position-dependent utilization of alcohol-based hand rub dispensers and used volumes of hand rubs (19,20). On the contrary, EMSs are usually not able to correctly assign HD events to all of the '5 moments' or to document information on HD-compliance during complex workflows (21–23), which is why combining an EMS with direct observation appears most promising at the moment (21,23).

So far, little is known about the extent and specifications of the HE in healthcare facilities regarding different room types within the same ward. For example, it is unclear whether, and to which extent, the HE would affect HD rates during direct patient care in patient rooms. We collected data regarding the number of HD from different room types on three wards of a German university hospital using an EMS. The data were obtained and compared with and without parallel direct compliance observations to evaluate and quantify the HE by ward- and room-type specifically.

Materials and Methods

Study design

We conducted a prospective observational project on an 18-bed surgical intensive care unit (ICU), a 12-bed surgical intermediate care unit (IMC), and a 36-bed surgical normal ward (NW) in a university hospital in Germany. The project was favorably evaluated by the Ethics Committee of Witten/Herdecke University, Germany. It took place between February 2022 and May 2023.

Electronic monitoring system

More than 200 wall-mounted, point-of-care or portable disinfectant dispensers were equipped with the EMS NosoEx® (HYPROS GmbH, Stralsund, Germany) (24,25), which recorded the date, time, and room type of the HDs performed on each of the three wards. Magnetic- or pressure-based sensors facilitated the detection of each HD performed and transmitted the data via Bluetooth Low Energy to local data hubs. After receiving a date and time stamp, the data bundles were passed on to the manufacturers' server for filtering and processing.

Only data on the number of hand disinfections per patient day collected by the electronic system were considered in this project. The electronic system was installed specifically for the purpose of the project. Staff members were informed about the existence, capabilities, and features of the system, but they did not receive any further feedback regarding the collected data. Wearable devices were provided to staff members additionally, enabling the classification by professional groups. Participation in wearing these devices was entirely voluntary, and the data collected were not utilized for the purposes of the present project.

Definition of room types

The rooms of each ward were categorized into ‘patient’ rooms, ‘utility/waste’ rooms, or ‘other’ rooms. While ‘patient’ rooms included all 1- or 2-bedrooms for patient accommodation, ‘utility/waste’ rooms were rooms used for disinfectant dosing devices, bedpan cleaning and disinfection devices, or waste disposal among other things. The category ‘other’ included hallways but also nursing stations, kitchens, common rooms and storage rooms among others.

Direct observation

In addition to the data collected by the EMS, infection prevention and control staff performed open hand disinfection compliance observations according to the WHO’s 5 Moments, using a standardized, paper-based observations sheet. During the compliance observations the infection prevention and control staff used pens and the standardized sheets on clipboards. Healthcare workers were aware of the observation-situation. Six observers we involved, three of which observed on all three project wards and on at least 3 different weekdays. These three observers were responsible for more than 75% of all observations. Compliance observations were not announced in advance and were carried out openly. The vast majority of observations took place in and in front of the patient rooms. Depending on the location and structure of the particular ‘patient’ room, hallways and nursing stations might have been visible for the observers during their observations from locations in and in front of the 'patient' rooms, which was not the case for 'utility/waste' rooms. If processes begun or ended outside the patient rooms the observers followed the healthcare workers. As the EMS did not record data comparable to the compliance observation results, we used the number of hand disinfections per patient day with and without observations for our analysis of the Hawthorne effect. The compliance rates measured during observations are not presented in this project.

Definition of observation periods and shifts

Observations were performed on weekdays during morning shifts (i.e., between 6:00 AM and 2:00 PM) and afternoon shifts (i.e., between 2:00 PM and 10:00 PM). Observation periods were classified according to the time intervals 'before', 'during', or 'after' compliance observation took place. The 'before' period was defined as the time between the shift started and the first observation. It most closely corresponds to usual behavior. The 'during' period was defined as the time between the first and the end of the last observation, and 'after' as the period between the last observation and end of the shift. Assuming that observers entered the ward shortly before the first observation and left shortly after the last observation, the observation period 'during' was extended by 5 minutes at both the beginning and the end.

Statistical modelling

The impact of observation periods on the HD rates, measured in number of HD per patient day (HD/PD), was assessed by a Linear Mixed Model (LMM), including the variables *period* (i.e., before/during/after), *ward*, *shift*, *room type* and whether observations were performed on that day. We included all 2- to 5-way interactions among *time*, *ward*, *observation status* and *room type,* as well as all 2- to 4-way interactions among *time*, *ward*, *observation day,* and *shift*. A random effect for *observation day,* nested within the observer, accounted for daily repetitive observation effects and the respective observer. Unable to estimate a saturated model, we included all relevant terms for subsequent comparisons. If multiple observers were active per day, their IDs were combined into a new one. Due to the unmet assumptions of homoscedasticity and normality of the residuals, evaluated by residual plots and histograms, the target variable HD/PD of LMM was square root-transformed to improve the fit. After the square root-transformation, diagnostic plots showed no violations of model assumptions. This transformation also ensures positive values upon back-transformation, and, unlike e.g., gamma regression, accommodates actual zeros in the target variable, which was crucial for short time intervals without recorded HD.

Quantification of the Hawthorne effect

Instead of using hidden direct observation, the HE was quantified based on HDs performed, continuously recorded by the EMS for each dispenser. The number of HDs recorded for each of the three observation periods (before/during/after) was divided by the period duration and the number of patient days of the respective day to calculate the specific disinfection rate in HD/PD. For each period with observation, a control period without observation but matching in terms of *year*, *month*, *weekday*, *time* and *ward*, was searched for in the system. Additionally, a month was considered only when direct observation took place. For quantification of the HE, the rates of HD/PD were averaged for periods without observation and compared to each period with observation **(Figure 1).** The final dataset included ward (NW, IMC, ICU), room type (‘patient’, ‘utility/waste’, ‘other’), shift (morning, afternoon), observation day (with, without) and the disinfection rate in HD/PD (**Table 1**). Considerations were made for each room type on every ward separately.

Furthermore, the percentage ratios between HD/PD on days with versus without observations were estimated per ward and room type as a separate descriptive evaluation (**Figure 2)**.

Software

Statistical analyses and visualizations were performed using R, version 4.3.3 (26). Additionally, the R packages *lme4*, *lmerTest* and *emmeans* were used for modelling and testing (27–29). The *ggplot2* (30) package was used for visualizations. P-values ≤ 0.05 were regarded as statistically significant.

Results

A total of 476,935 HDs were electronically recorded, comprising 80,351 HDs on the NW (‘patient’: 62836; ‘utility/waste’: 4,817; ‘other’: 12,698), 107,119 HDs on the IMC (‘patient’: 46,926; ‘utility/waste’: 4,772; ‘other’: 55,421), and 289,465 HDs on the ICU (‘patient’: 203,141; ‘utility/waste’: 17,482; ‘other’: 68,842). After processing the data, 194 compliance observation periods on 40 days, carried out during nine of the 16 project months (seven months without observations), were used for the analysis. Of the remaining 15,872 HDs carried out on during the ‘before’, ‘during’ and ‘after’ periods on observation- and matching days, 3,385 HDs were performed on the NW, 2,231 HDs on the IMC, and 10,256 HDs on the ICU. Using the LMM, we investigated the effects of each observation documented by the infection prevention and control staff during three observation periods. At the same time, dispenser-wise monitoring by the EMS allowed conclusions to be drawn about the room-type where HD was performed.

Room type-specific impact of compliance observations

In ‘patient’ rooms, the highest disinfection rate in HD/PD was estimated for the ICU, while the NW showed the lowest rate. Unexpectedly, the number of HD/PD was significantly decreased on observation days in the observation period ‘before’ in ‘other’ and ‘utility/waste’ rooms on the NW ($p \leq 0.05$). The HE was present in ‘patient’ rooms on NW and ICU. Here, significantly more HDs were documented in the observation period ‘during’ on the NW ($p \leq 0.01$) and the ICU ($p \leq 0.001$) compared to periods without observations. The results for ‘utility/waste’ and ‘other’ rooms were less consistent. Here, compliance observations could lead to both, increasing or decreasing disinfection rates or remained unaltered (**Table 1**; **Figure 2**).

Influence of compliance observations among periods of observation

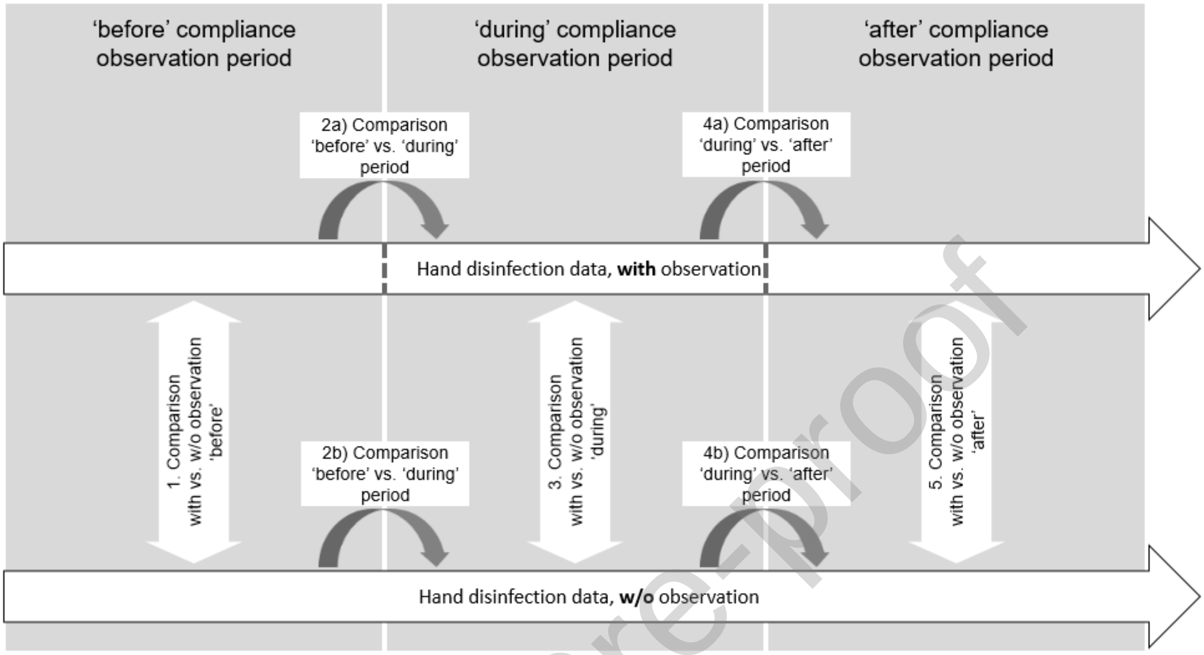
Comparing the ‘before’ with the ‘during’ compliance observation period, the disinfection rates significantly increased on all three ward-types in ‘patient’ rooms and significantly decreased again after the observation ended comparing the ‘during’ with the ‘after’ period (**Table 1**). However, on the IMC, this in- and decrease of HD/PD in ‘patient’ rooms was also observed without compliance observations. Overall, differences in disinfection rates between the periods with observation were less pronounced in ‘other’ and ‘utility/waste’ rooms than in ‘patient’ rooms. We observed a significant decrease in the disinfection rate between the ’before’ and ’during’ periods in the ’utilities/waste’ rooms on the IMC (**Table 1**). The declining disinfection rates between the ‘during’ and ‘after’ periods in ‘other’ rooms on the NW without CO, was statistically significant as well. Apart from the exception in ‘patient’ rooms on the IMC, effects without observation were found comparing the ’during’ and ’after’ periods on the IMC and in ‘utility/waste’ or ‘other’ rooms on the NW.

Table 1: Summarized influence of compliance observation periods onto hand disinfection rates before, during and after observations (please also note Fig. 1 for illustration)

Ward	Room type	1. Comparison with vs. w/o CO	2. Comparison 'before' vs. 'during' period		3. Comparison with vs. w/o CO	4. Comparison 'during' vs. 'after' period		5. Comparison with vs. w/o CO
		in 'before' period	a) with CO	b) w/o CO	in 'during' period	a) with CO	b) w/o CO	in 'after' period
NW	Patient	n. s.	↗ ***	n. s.	↗ **	↘ ***	n. s.	n. s.
	Utility/Waste	↘ *	n. s.	n. s.	↘ **	n. s.	↘ **	n. s.
	Other	↘ *	n. s.	n. s.	↘ ***	n. s.	↘ **	n. s.
IMC	Patient	n. s.	↗ **	↗ **	n. s.	↘ ***	↘ *	n. s.
	Utility/Waste	n. s.	↘ *	n. s.	↘ ***	n. s.	↘ **	n. s.
	Other	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.
ICU	Patient	n. s.	↗ ***	n. s.	↗ ***	↘ ***	n. s.	n. s.
	Utility/Waste	n. s.	n. s.	n. s.	↘ *	n. s.	n. s.	n. s.
	Other	n. s.	n. s.	n. s.	↗ ***	↘ ***	n. s.	n. s.

*Results from the estimation of disinfection rates [HD/PD] all derived by the EMS by the linear mixed model. Days with observations were compared to those without (w/o). Change of the disinfection rate from one period to the following (1. before to during; 2. during to after). Significantly increasing rates = ↗; decreasing rates = ↘, with asterisks marking the level of significance: ≤ 0.05 = *; ≤ 0.01 = **; ≤ 0.001 = ***. n. s. = not significant. CO= compliance observation; ICU= intensive care unit; IMC= intermediate care unit; NW= normal ward.*

Figure 1: Illustration of the comparisons presented in Table 1 with explanation for each column (please note consecutive numbers in table and illustration)

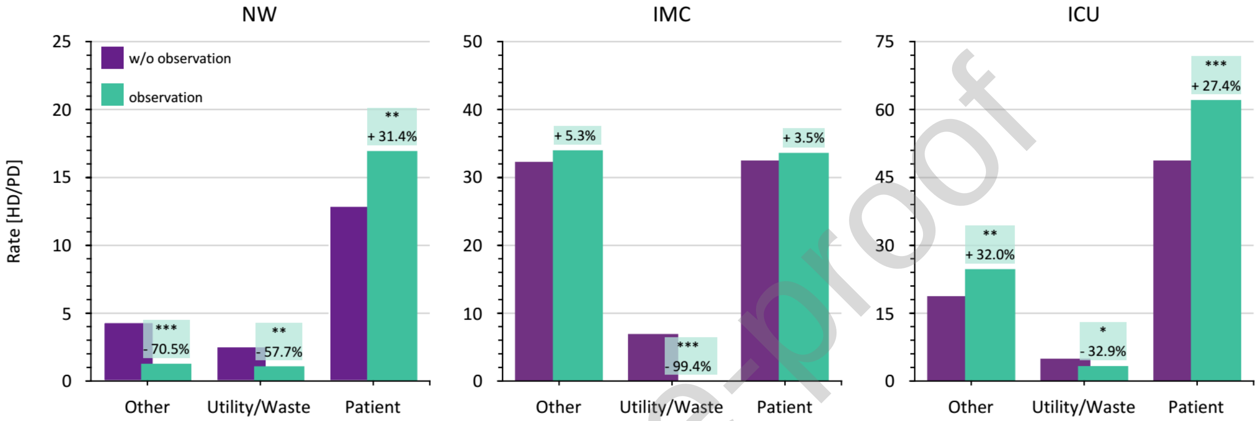


Vertical dashed lines marking the beginning and end of compliance observations; CO= compliance observation; w/o= without

Quantification of the Hawthorne effect

Alterations of the number HD/PD in the 'during' observation period with actual CO compared to the number without CO most closely corresponds to the presence of the HE. As specified in **Figure 2**, the comparison between days without and with observation showed increased disinfection rates in 'other' rooms on the IMC (+5.3%; LMM: not significant) and ICU (+32%; LMM: $p < 0.01$), whereas the disinfection rate decreased on the NW (−70.5%; LMM: $p < 0.0001$). The HE was also detected in 'patient' rooms on all three wards, with significance in the observation period 'during' on the NW (+31.4%; LMM: $p < 0.01$) and ICU (+27.4%; LMM: $p < 0.001$), while the disinfection rate on the IMC remained unchanged (+3.5%; LMM: not significant). In addition, significant decreases in disinfection rates were noticed in 'utility/waste' rooms on the NW (−57.7%; LMM: $p < 0.01$), the IMC (−99.4%; LMM: $p < 0.001$), and the ICU (−32.9%; LMM: $p < 0.05$).

Figure 2: Extent of the Hawthorne effect during compliance observation periods determined by an electronic monitoring system



*Estimation of the hand disinfection rates [HD/PD] exclusively for the observation period 'during', differentiated by ward and room type ('other'; 'utility/waste'; 'patient'). Purple bars = days without (w/o) observation; green bars = days with observation. Numbers above the green columns indicate differences between days w/o and with observation in %. Asterisks mark the level of significance: ≤ 0.05 = *; ≤ 0.01 = **; ≤ 0.001 = ***. Estimations based on the linear mixed model. HD/PD, hand disinfections per patient day; ICU, intensive care unit; IMC, intermediate care unit; NW, normal ward.*

Discussion

The positive Hawthorne effect is strongest in patient rooms

In our project, direct compliance observations significantly increased the number of HDs per patient day on the NW and the ICU in the observation period 'during' in 'patient' rooms, where HD is most critical for infection prevention. On the IMC, in contrast, the number of HDs did not change significantly in 'patient' rooms during observation compared to the number without. It was also obvious that HD rates decreased significantly in 'utility/waste' rooms, where no direct patient care takes place, on all three wards during CO. These results base on 194 compliance observation periods on 40 days and 15,872 HDs used for the analysis. The Hawthorne effect depended on the observed ward type in our setting. To the best of our knowledge, we showed for the first time that the Hawthorne effect might also depend on the observed room type. It was pronounced in 'patient' rooms and we recorded a decrease of the number of hand disinfections per patient day in 'utility/waste' rooms, which is remarkable, because usually the number of hand disinfections rises during compliance observations. Thus, healthcare workers behavior under observation might be more complex than presumed.

Overall, our results are in line with other studies, which also determined a relevant HE during HD compliance observations (9,13–15,17,32). The fact that the HE was most evident in 'patient' rooms in our project suggests that HD-compliance according to the WHO's '5 Moments' in everyday practice is lower than assumed when relying solely on compliance observations. These findings indicate that the HE is particularly relevant during direct patient care. One reason for these results might be, that the vast majority of observations took place openly in or in front of the 'patient' rooms. This might have pronounced the effect in this room type. Nevertheless, the usual compliance observations also concentrate on activities in patient rooms, where most procedures are carried out, which makes our results comparable. Additionally, we recorded significant changes in 'other' rooms and 'utility/waste' rooms as well.

A negative Hawthorne effect may occur in segregated rooms unrelated to direct patient care

To our knowledge, this is the first project providing detailed information on the specifications of the HE with regard to different room-types on three different wards. Interestingly, while we observed a 'typical' HE, i.e., an increase of HDs during observation, in 'patient' rooms on the ICU and NW, we recorded an 'atypical' HE, i.e., a decrease, in 'utility/waste' rooms on each of the observed wards (ICU, IMC, and NW). With −99.4%, this effect was strongest and also highly significant for the IMC. One explanation may be that 'utility/waste' rooms were separate rooms of limited size in our setting. Therefore, healthcare-workers were fully aware of whether they were being observed while working in this type of room. Situations were often less clear for the healthcare-workers in ‘patient’ and ‘other’ rooms because compliance observers may have observed them without their awareness. The knowledge of being observed is stressful, which may have led to reactance among the healthcare-workers in a usually unobserved, controlled and ‘private’ situation in ‘utility/waste’ rooms. On the other hand, these results are surprising because HDs after body fluid exposure are frequently carried out in these room types. Since this indication is an important self-protection measure, it usually achieves high HD-compliance rates during observations and showed the highest rates (79%) among the WHO’s ‘5 Moments’, according to the NRZ data in 2023 (31).

At the same time the negative HE has to be interpreted with caution, as the number of HDs in ‘utility/waste’ rooms was generally limited compared to the other room types.

Reactance effects may also have played a role in the recorded decrease of HD/PD during observations in the ‘before’ period in ´utility/waste´ and ´other´ rooms on the NW, at least if the healthcare-workers would have been aware of the impending observations. Nevertheless, this awareness of healthcare-workers is unlikely, the level of significance was low and the effect should be interpreted with caution.

The Hawthorne effect differs between ward types

The HE in our project also appeared to be ward dependent, as it was not observed in ‘patient’ and ‘other’ rooms on the IMC with statistical significance. Others have also reported varying HEs depending on the ward type. For example, Wu *et al*. observed a moderate HE on the ICU, while it was almost three times higher in the outpatient clinic (16). Likewise, McLaws and Kwok found the HE to be stronger on the medical ward than on the surgical ward (9). Reasons for these differences could be, e.g., a different degree of standardization of infection prevention-relevant processes on the observed wards, different levels of self-confidence and self-perception of the observed staff, and differences in the interaction of the observed staff with the observers.

To put our results into context and compare them with representative data from other German hospitals and wards, we used data from the National Reference Center for Surveillance of Nosocomial Infections (NRZ). The comparison with the reference data from the surveillance surveys of 2022 and 2023 (31) revealed that our NW (9 ± 3 HD/PD) achieved an overall disinfection rate similar to the NRZ data from normal wards for 2022 (9 HD/PD) and 2023 (8 HD/PD). On average, the HD/PD on our NW was 5.9% higher than the average performance of other NWs between 2022 and 2023. More pronounced than the data for the NW, our IMC (47 ± 13 HD/PD) showed a disinfection rate nearly twice as high as the NRZ IMC standards for 2022 (26 HD/PD) and 2023 (25 HD/PD). The HD performance on our IMC exceeded the averaged standards by 84.3%. The ICU also reached a higher disinfection rate (57 ± 10 HD/PD) than the NRZ ICU standards for 2022 (50 HD/PD) and 2023 (47 HD/PD). In this case, the overall HD performance was 17.5% higher than the averaged NRZ ICU standard. Thus, with an increase of 84.3%, the number of HDs per patient day on our IMC was considerably higher than the German standard values evaluated by the NRZ for 2022 and 2023, while the HD rates on our NW and ICU exceeded the standard to a lesser but notable extent. As the disinfection rate for the IMC was already very high, the HE may have been reduced as there were likely only few additional indications for further HDs.

Compliance observations appear to have weaknesses in determining daily HD rates. We found a ward- and room-type-dependent HE, which most likely led to an overestimation of HD rates especially in ‘patient’ rooms and thus during patient care on two out of three wards in our project. Monitoring instruments such as EMSs or hand disinfectant consumption may be more suitable for assessing daily HD rates (18,33–34). Covert observation is another option but is not recommended by the WHO as it could encourage mistrust between healthcare-workers and covert observers if the healthcare-workers become aware of the observation (3).

Although direct observations may lead to a systematic overestimation of HD-compliance, the results may be helpful. They allow a sophisticated determination of compliance rates for each indication and the observer may get an impression of possible reasons for non-compliance (knowledge deficit, infrastructure etc.). Thus, compliance observations serve as the basis for process optimization and differentiated education programs.

The HE on HD-compliance during compliance observations has been detected all over the world in studies from North and South America, Asia, Australia, and Europe (13,14). Therefore, it should not be considered as an individual misconduct of the observed healthcare-workers but as a general, culture-independent phenomenon of human behavior.

Limitations

Our project had several strengths but also some limitations. One of the limitations was that there tended to be more HDs during the observation periods compared to other periods, regardless of whether an observation actually took place. An unlikely reason for this is that observed healthcare-workers might have expected an observer to appear at the corresponding times. However, it is more reasonable to assume the observers chose observing periods when many procedures were carried out by ward staff, to maximize the number of HD opportunities observed per time. Therefore, we had to separately compare periods ‘before’, ‘during’, and ‘after’ observations on days with and without observations of the same periods to reliably determine the HE.

Another limitation of our project is that compliance observations were exclusively conducted during morning and afternoon shifts and on weekdays, excluding night shifts and weekends. However, since fewer patients are admitted on weekends and during night shifts and therefore fewer procedures, rounds, etc. take place, we assume that concentrating the observations on the morning and afternoon shifts is unlikely to have caused significant bias. As the EMS did not record data comparable to the compliance observation results, compliance results were not analyzed for this project or included in the results. Instead, we used the number of hand disinfections per patient day with and without observations for our analysis of the Hawthorne effect. An EMS which offers reliable compliance observation results for WHO`s '5 Moments' would have provided a more detailed analysis of the Hawthorne effect but is currently not available. Additionally, it was not possible to exclude HD of visitors from the data set. However, the number of HD performed by visitors should be very low compared to the number of HD carried out by hospital staff so the impact is most likely negligible.

Based on the collected data, we were only able to make statements regarding the number of hand disinfections per patient day, but not about their quality. Although the EMS used in our project is, in principle, capable of measuring the amount of alcohol-based disinfectant dispensed per hand disinfection, this analysis was not possible in our project due to technical reasons. Future studies should also assess the coverage of the entire hand surface with the alcohol-based disinfectant, the duration of hand disinfection, and similar quality-related parameters.

There were also limitations associated with the use of the LMM. In some cases, the extrapolation to determine the HD/PD rate may have been subject to large variance due to very short observation periods. To address this, we analyzed the periods with a slack time of 5 min before the first and after the last observation.

Regarding the differences in HD between different ward types, the specific behavior of the wards` medical teams and its team composition may have played an additional role. Since we collected our EMS data on the ward- and not on an individual level and we did not for example use questionnaires to evaluate the attitude towards HD of different medical teams, we are unable to provide additional information on this matter.

Conclusions

In this work, we found a ward- and room-type-specific Hawthorne effect with alterations between -99.4% to +31.4% hand disinfections per patient day during compliance observations. Further scientific evidence is needed to verify our observations and to improve and specify the reliability of HD-compliance measurement tools.

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