ORIGINAL ARTICLE

Monitoring Hand Hygiene via Human Observers: How Should We Be Sampling?

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OBJECTIVE. To explore how hand hygiene observer scheduling influences the number of events and unique individuals observed.

DESIGN. We deployed a mobile sensor network to capture detailed movement data for 6 categories of healthcare workers over a 2-week period.

SETTING. University of Iowa Hospital and Clinic medical intensive care unit (ICU).

METHODS. We recorded 33,721 time-stamped healthcare worker entries to and exits from patient rooms and considered each entry or exit to be an opportunity for hand hygiene. Architectural drawings were used to derive 4 optimal line-of-sight placements for observers. We ran simulations for different observer movement schedules, all with a budget of 1 hour of total observation time. We considered observation times of 1–15, 15–30, 30, and 60 minutes per station. We stochastically generated healthcare worker hand hygiene compliance on the basis of all data and recorded the total unit compliance as it would be reported by each simulated observer.

RESULTS. Considering a 60-minute total observation period, aggregate simulated observers captured 1.7% of the average total number of opportunities per day at best and 0.5% at worst. The 1–15-minute schedule captures, on average, 16% fewer events than does the 60-minute (ie, static) schedule, but it samples 17% more unique individuals. The 1–15-minute schedule also provides the best estimator of compliance for the duration of the shift, with a mean standard deviation of 17%, compared with 23% for the 60-minute schedule.

CONCLUSIONS. Our results show that observations are sensitive to different observers' schedules and suggest the importance of using data-driven approaches to schedule hand hygiene audits.

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Hand hygiene is a critical component of standard infection control precautions that should ideally be practiced by all healthcare workers before and after each patient contact. Although many local, national, and international initiatives have been launched[1-3] to improve hand hygiene practices, high compliance remains an elusive goal,[4] with compliance rates among healthcare workers averaging less than 50%.[1,3,5]

Measurement of hand hygiene compliance is an important component of infection control programs.[1,3,6] Currently, most healthcare facilities measure hand hygiene compliance almost exclusively via direct human observation of healthcare workers. Although it is considered the "gold standard," direct observation is labor intensive and susceptible to observer biases.[5,7,8] Furthermore, the reliability of directly observed hand hygiene audits as a reflection of overall performance can be adversely affected by sporadic or inconsistent sampling.[5] Several new technologies[9-15] offer alternatives to human observation by using technology to measure or approximate hand hygiene compliance, but for the near future, hand hygiene compliance will likely continue to be measured predominantly by human observers in most healthcare settings.

Despite many healthcare organizations' reliance on human observations to monitor hand hygiene compliance in both research and practice, there is little guidance about exactly how many observations to collect, where observations should be made, and when to observe. Because limited resources constrain the time available for observations in healthcare facilities, a streamlined approach for sampling hand hygiene opportunities is needed to maximize the number of opportunities and unique healthcare workers observed. Several key knowledge gaps remain, including the best approaches to the timing, placement, and movement of observers. We conducted a series of computer simulations using real-world healthcare worker movement data from a medical intensive care unit (ICU) to explore how variations in observer schedules and placement influence the number of events observed,

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hand hygiene compliance estimates and their precision, and the diversity of healthcare workers observed by human auditors.

METHODS

We deployed a mobile sensor network to capture detailed movement data for 6 different job categories of healthcare workers at the University of Iowa Hospital and Clinics (UIHC) medical ICU. Our sensor network consists entirely of small, wearable credit card–sized devices called motes. Motes are active, battery-powered, programmable devices that consist of a small processor, flash memory, and an IEEE 802.15.4 compliant wireless radio. Each mote is programmed to broadcast messages to all other motes within a range of approximately 20 meters, while recording any messages received from other motes in memory. From each recorded message, we can extract (1) the identifier of the sending mote, (2) the received signal strength indicator (RSSI), and (3) the time at which the message was received. Motes communicate over unused space in the Wi-Fi spectrum and do not interfere with medical devices. Collectively, the data generated on signal strengths of motes relative to each other can approximate the location of healthcare workers.

We designated 2 categories of motes in our experiment: stationary beacon motes, which were placed inside 20 patient rooms and associated hallways and nurses' stations, and portable badge motes, which were distributed to the healthcare workers starting a shift in the area. Badges are housed inside recycled pager bodies and worn by healthcare workers. By examining the message logs of each badge, we derive a time-stamped event log of healthcare worker movement in and out of patient rooms; these "in room" and "out of room" events are widely recognized as practical proxy measures for hand hygiene opportunities. Generating this event log required preexperiment mote calibrations to define RSSI thresholds for identifying the most likely healthcare worker spatial positions for any given timestamp; a more detailed discussion of this approach has been reported elsewhere.[15]

We observed 3 healthcare worker job types (nurses, doctors, and critical support) that were separated into day and night shifts, giving 6 distinct healthcare worker categories. The nurse category included floor nurses assigned to the medical ICU, nursing assistants, and nurse managers; the doctor category included staff physicians, fellows, and residents; and the critical support category included clerks, pharmacists, and respiratory therapists.

Once deployed, our sensor network captured 14 days of healthcare worker movement data. Every morning at 7 AM, we distributed badges to healthcare workers in each of the 3 day categories, and we collected badges at 7 PM the same day while simultaneously handing out badges to the 3 night categories. Although each badge had a unique mote ID number, we did not record the association between mote ID and healthcare worker. In practice, healthcare workers randomly selected badges from a bin of badges designated for their job category. Note that the majority of nurses worked 12-hour shifts. Anyone leaving before 7 PM (days) or 7 AM (nights) deposited their badge in a bin when departing the unit. Physicians who spanned 2 shifts were given a new badge at the beginning of each 12-hour shift.

Using medical ICU architectural drawings, we calculated candidate locations in which human observers should stand. In our experiment, candidate locations are those line-of-sight positions that maximize the total number of visible patient room doorways into mote-equipped rooms, based on a simple model of human visual capabilities in which we assume that an auditor can accurately observe any event taking place within a 33-foot radius of their location. We identified 4 such candidate locations in our medical ICU.

For each logged day of mote data, we stochastically generated a variety of healthcare worker hand hygiene compliance behaviors, which enabled us to simulate each shift under the assumption of different hand hygiene compliance rates but identical healthcare worker movement. This simulation framework enabled us to quantitatively evaluate whether different observation scenarios varied in terms their ability to accurately represent overall hand hygiene compliance within the medical ICU.

For each simulator trial, we created a random synthetic observer. Each observer's schedule was designed to reflect the behavior of a human observer walking to various locations throughout a hospital unit and conducting observations. Each observer's schedule comprised a fixed budget of total observation time, an agenda of candidate observation locations with associated wait times, and a fixed travel time cost for moving between observation points. Wait times corresponded to the actual time spent actively observing hand hygiene opportunities, and travel time corresponded to the time spent walking to a new observation point. For the purposes of this simulation, we assumed that observers did not record any events while transferring between observation positions. We considered a budget of 60 minutes, a travel time cost of 2 minutes, and 4 categories of wait times: the intervals of 1–15 and 15–30 minutes and fixed wait times of 30 and 60 minutes, with the last corresponding to a static observation model (ie, the observer stays at the same candidate location for the entire 1-hour observation period). Each schedule's agenda was created by randomly generating a list of locations to visit and randomly choosing wait times for each location from the wait time category under investigation. Note that we produced each schedule by uniformly sampling within the specified interval, adding a fixed movement time between stations until the 1-hour time budget is exhausted. This random schedule is then evaluated by selecting, with uniform probability, mote data from 1 shift in our data set and assessing the proportion of all opportunities observed, number of unique individuals

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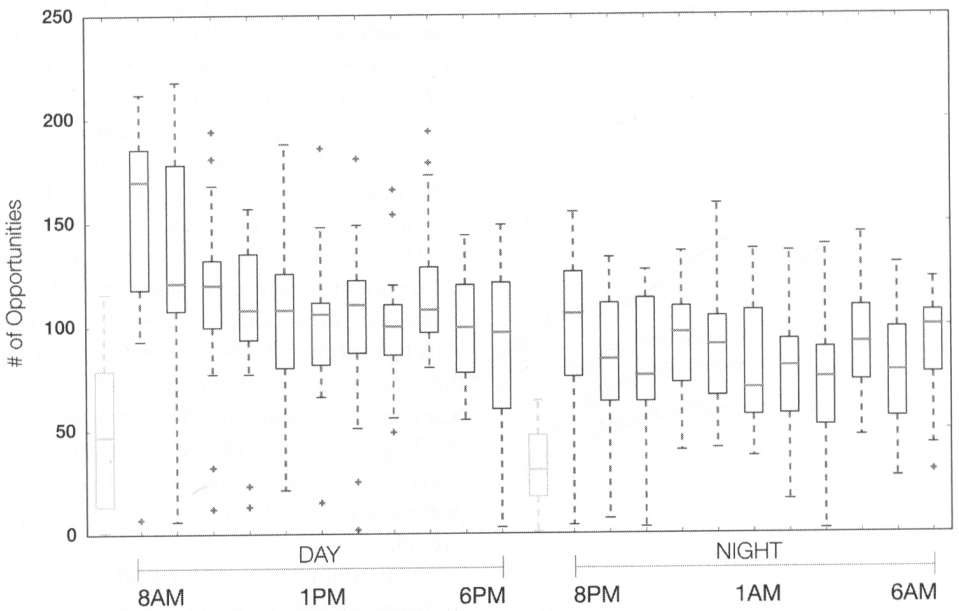


FIGURE 1. A box plot of day and night shift hand hygiene opportunities, by time of day. The gaps at 7 AM and 7 PM correspond to hours in which motes were being collected from and distributed to healthcare workers, and these hours are not used in our analysis.

observed, and hand hygiene compliance rate generated by the observer schedule.

For each trial, the simulator recorded the set of visible opportunities given the current placement of our observer in 1-minute increments. At the conclusion of each trial, we then counted the total number of observed opportunities, calculated the hand hygiene compliance percentage for this set of observations, and calculated the percentage of unique individuals seen. Because our synthetic hand hygiene compliance rates were defined a priori, the global true compliance rate was known for any given shift and could be compared to the rate as measured by our observation schedule. We assigned a fixed average compliance rate and standard deviation to each healthcare worker class (eg, a mean of 60% and standard deviation of 30% for nurses and a mean of 50% and standard deviation of 40% for doctors); adherence for a specific hand hygiene opportunity was then sampled from a normal distribution with this mean and standard deviation. All reported results were based on 200 trials for each data set collected during the 14-day deployment, meaning that each minute in our 2-week deployment data set was sampled 2,800 times. We report the root mean squared error (RMSE), which is equal to the sample standard deviation for these simulations, over the set of replicates. A low RMSE reflects a hand hygiene compliance estimate that is closer to true compliance than that reflected by a high RMSE, because RMSE represents a measure of the difference between the estimated compliance rate and the true compliance rate.

All statistical tests were calculated using R, version 2.12.0. For all tests of multiple comparisons, we used a Dunnett-modified Tukey-Kramer (DTK) test via the R package DTK.

RESULTS

Mote Experiment Data

Overall, we captured 33,721 time-stamped in-room or out-of-room hand hygiene opportunities over 14 consecutive days and nights (Figure 1). For each of these events, healthcare workers were inside a patient room for (ie, had a dwell time of) at least 16 seconds, and the mean (μ) room dwell time was 312 seconds (median no. of seconds, 199; range, 16–3,568). Between 7 AM and 7 PM, 19,321 events (57.3%) occurred, whereas 14,400 events (42.7%) occurred between 7 PM and 7 AM. During the day, each room was associated with a mean of 65 events (median no. of events, 62; range, 2–196) or approximately 33 healthcare worker visits per room per shift (each in-room event necessarily accompanied an out-of-room event). The night shift had a mean of 52 events per room (median events per room, 42; range, 1–320) or approximately 26 healthcare worker visits per room per shift.

Figure 2 demonstrates the distribution of the hand hygiene opportunities by job type. For day shifts, nurses had a mean of 1,058 daily opportunities (median no. of opportunities, 1,065; range, 551–1,459); for night shifts, nurses had a mean of 779 daily opportunities (median no. of opportunities, 815; range, 280–1,088). Overall, nurses averaged 5–10 times more opportunities per day than did the other job types under observation.

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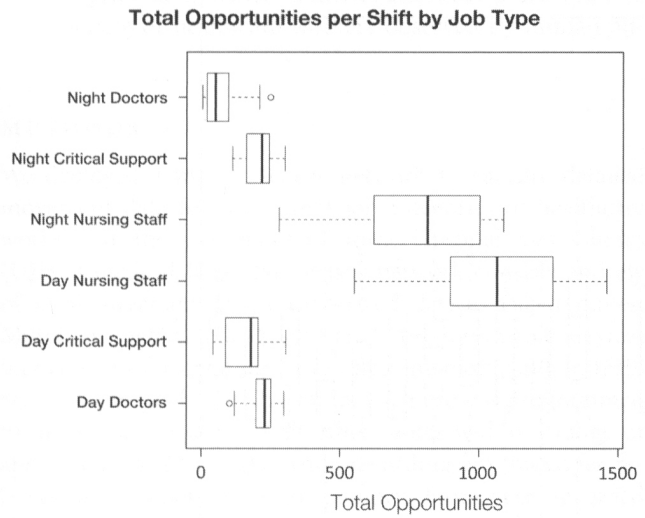


FIGURE 2. A box plot of the number of hand hygiene opportunities, by job type.

Figure 3 shows a distribution of the dwell time for any given visit, broken down by job type. There was a statistically significant difference ($P \leq .05$) between the distribution of dwell times between day critical support staff and both day and night nursing staff.

Simulation Results

Figure 4 demonstrates the relationship between the number of hand hygiene opportunities observed and the percentage of healthcare workers observed. Considering a 60-minute total observation period, aggregate simulated observers captured 1.7% of the average total number of opportunities per day at best and 0.5% at worst. By 12-hour shift, the simulated day shift observers captured 3.0% at best and 1.5% at worst; the simulated night shift observers captured 2.7% at best and 1.2% at worst. The 1–15-minute schedule captured, on average, 16% fewer events than did the 60-minute (ie, static) schedule but sampled 17% more unique individuals. The 1–15-minute schedule also provided the best estimator of compliance for the duration of the shift, with a mean standard deviation of 17% versus 23% for the 60-minute schedule. Finally, Figure 5 shows the RMSE for the different simulated observer schedules.

DISCUSSION

We found that 1 individual observing for 1 hour per day can, at best, capture only a very small proportion of daily observable hand hygiene opportunities. The number of observations captured is highly dependent on when and where observations occur, which are factors that are influenced not only by the workload of the unit under observation but also by the physical structure of the unit itself. Furthermore, we found that the number of unique healthcare workers observed is dependent on the timing and location of human observers. Observers who move more frequently capture a larger sample of unique healthcare workers at the expense of missing hand hygiene opportunities during travel time. In our simulation, the best overall performance during a 1-hour observation period was obtained with many brief (1–15-minute) observation intervals. The 1–15 minute per location schedule necessarily involves more travel time (~25% on average and ~66% at worst) between observation points. In our medical ICU, patient rooms are clustered together into pods; hallways connecting these pods typically do not contain patient rooms. This fact ultimately creates a deficit of observation time, such that capturing the same number of overall events as the other schemes is not possible. This loss, however, is mitigated by the larger diversity of individuals captured, resulting in a lower RMSE and making the 1–15-minute schedule a better performing (ie, more consistent) sampling methodology overall.

The first hour of each day shift (8 AM), corresponding with morning rounds, proved to be the best time to sample hand hygiene opportunities in our medical ICU and typically provided the best overall estimator (ie, the lowest RSME) of compliance for the entire shift. For the evening shift, 8 PM (start of shift), midnight, and 4 AM provided approximately the same RMSE. We can use these results to guide future hand hygiene audits.

To prevent the spread of nosocomial infections, a great deal of research has been devoted to increasing compliance via hand hygiene intervention strategies. Guidance for human observation of hand hygiene tends to focus on overall goals for compliance rates and broad recommendations for the number of observations to conduct. The Joint Commission, for example, recommends maintaining a 90% compliance rate and cites the World Health Organization (WHO) figure of

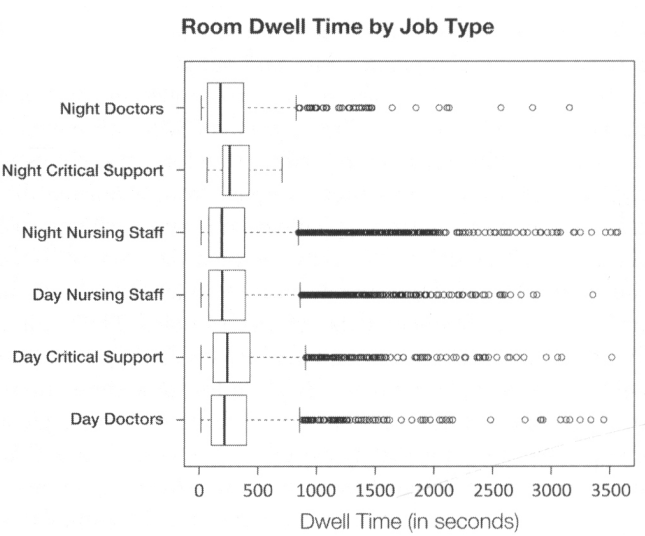


FIGURE 3. A box plot of the total time spent in a patient room (ie, dwell time) for any given visit, by job type.

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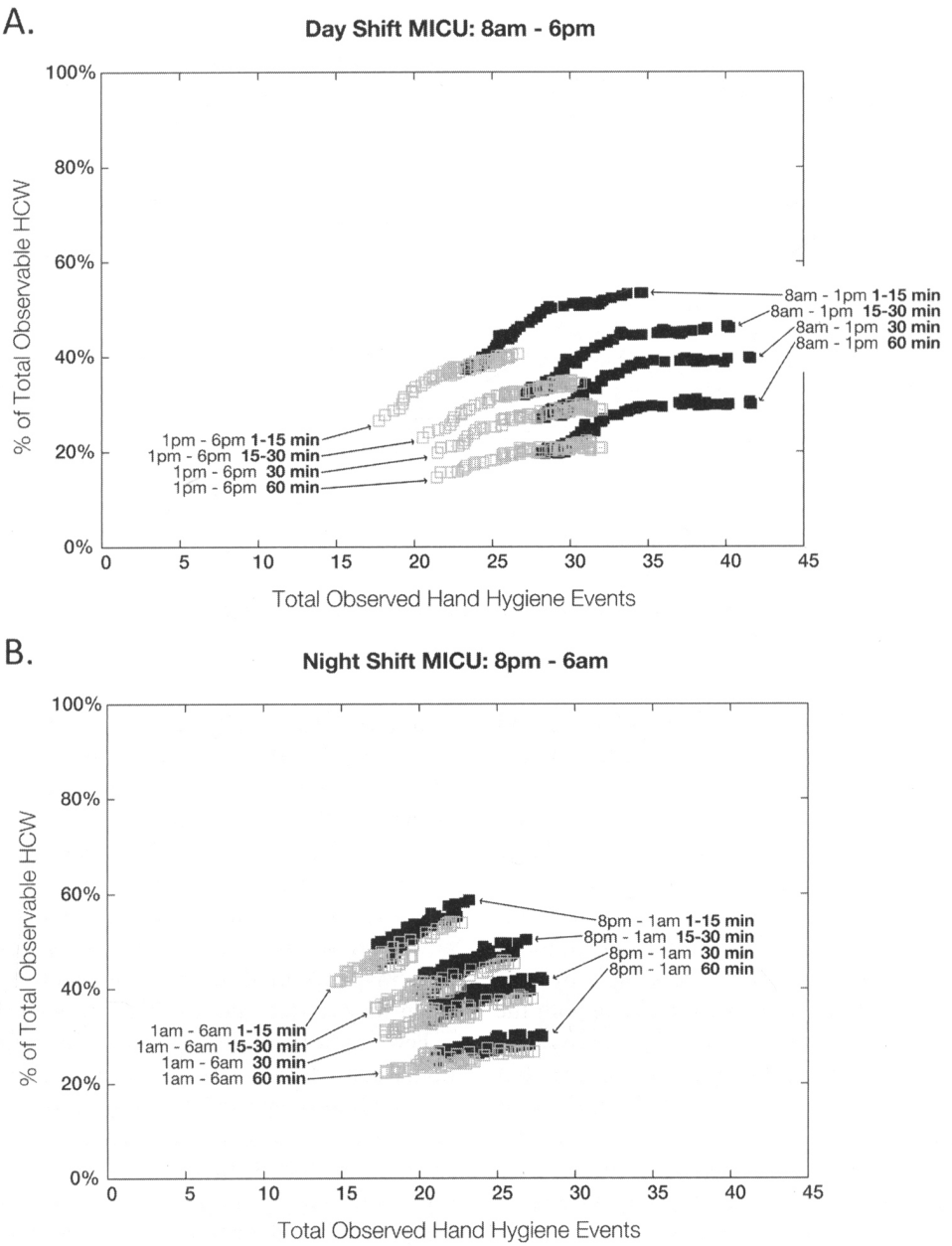


FIGURE 4. The relationship between the number of hand hygiene opportunities witnessed and the percentage of healthcare workers (HCWs) seen for each simulated observation schedule (*A*, day shift; *B*, night shift). Note the pronounced differences between the first half and the second half of the day shifts, which can be partially explained by morning rounds, and how observed behavior is more uniform throughout the night. Similar trends were observed over weekend shifts, although reduced staffing levels result in a less pronounced difference between day shifts and night shifts (detail not shown).

200 observations per time period for each unit or ward under observation.[16] This number, however, only speaks to the power to detect differences when comparing compliance within 2 observation periods and does not consider how representative the sample of observations is. Sampling guidelines that follow Lloyd[17] take the form of probabilistic approaches (ie, various random sampling schemes) or nonprobability schemes (ie, convenience sampling, quota sampling, and judgment sampling) and are typically borne out of resource-limited circumstances. Although there may be a consensus that the number of observations currently performed in most facilities is too low, much less attention is focused on how methodological approaches to observation can affect the diversity of a sample population in healthcare facilities. Our mote deployment allowed us to focus on not only quantity but also diversity by capturing a large consecutive number

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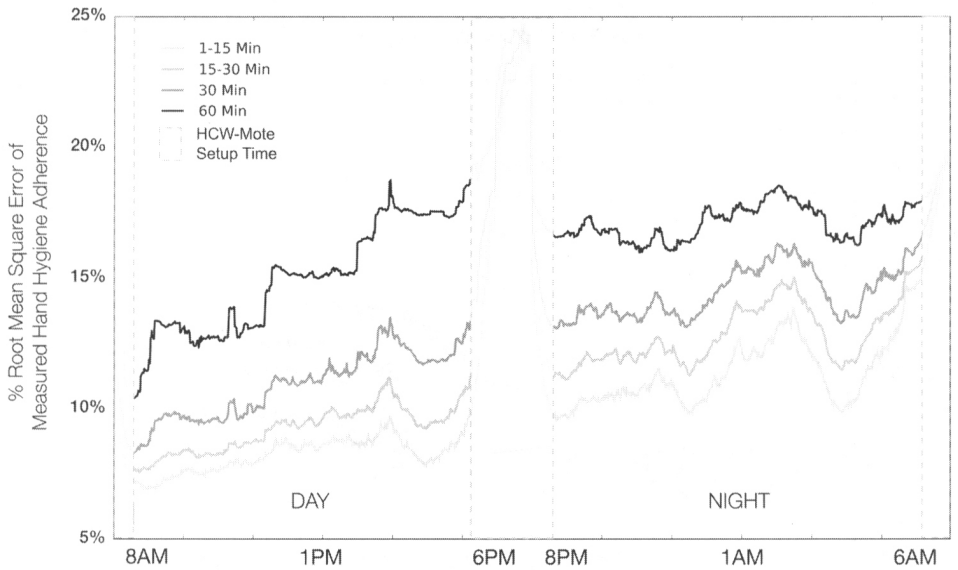


FIGURE 5. Root mean square error (RMSE) for all 4 schedule types, by time of day. A lower RMSE reflects a better estimator of hand hygiene compliance. HCW, healthcare worker.

of hand hygiene opportunities across time and space and playing back these observations over and over with different observers.

One way to insure that the observations are more representative is to increase the number of different healthcare workers observed. Because healthcare workers tend to work within small clusters of rooms assigned to specific patients, observational schedules that limit the number of locations where observations take place can bias the sample by capturing fewer distinct healthcare workers. Increasing both the number of events seen and the number of unique individuals observed is the best strategy for reducing sampling error, but in practice, a trade-off exists between these 2 objectives. Our results suggest that frequent observer placement change is a better methodology for sampling a diversity of job types and individuals in an ICU setting. Thus, more unique observations are captured without sacrificing the number of observations. Moreover, the cost associated with this change is quite minimal. For example, Figure 2 indicates that the percentage of unique healthcare workers observed can change from 20% to 40% by implementing the 1–15-minute wait time, compared with the 60-minute wait time. This clearly indicates that moving facilitates observation of more opportunities, although none of the strategies led to more than 55% of the healthcare workers being directly observed during any given shift.

Several studies have demonstrated that improving hand hygiene can decrease healthcare-associated infections. Failure of healthcare workers to perform hand hygiene is cited as one of the leading preventable causes of healthcare-associated infections. Not all studies, however, have consistently shown that increasing hand hygiene rates will decrease healthcare-associated infections.[18] Our simulations highlight one potential reason for these counter-intuitive results: examples in which an increase in hand hygiene rates may not decrease nosocomial infections may easily be an artifact of sampling at most 1%–2% of all hand hygiene opportunities. Clearly, healthcare workers' hands can harbor and transmit infectious agents to patients under their care. Our simulations highlight how even attentive observers who are diligently recording rates may capture different versions of reality depending on when they started and finished and who they sampled.

Few studies have investigated the difference in observational approaches in terms of performance. An Australian ICU study also reported that conventional observation schedules detect only a small proportion of hand hygiene opportunities.[19] However, they were only able to estimate opportunities for radiograph technicians using patient visit logs as a measure of opportunities; they estimated that observers captured 3.4% of opportunities, compared with our best-case estimate of 1.7%. Although human observers capture only a small percentage of opportunities, this rate compares favorably with that for quality control samples in manufacturing outside of healthcare. In addition, observations may be associated with positive externalities, such as increasing awareness of hand hygiene, administrator support, and possible increasing compliance as the result of an observational effect.

Our study has several limitations. First, we define opportunities as in-room or out-of-room opportunities; this is easy for us to measure, but it is an under-representation of what is happening in patient rooms and does not capture the WHO 5 moments of hand hygiene. Second, there was a brief 20–40-minute period between 12 shifts during badge mote distribution during which we did not capture opportunities. Thus,

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we did not have a complete 24-hour, 7-day sample for the entire period. However, we think that report was being given during most of this period, and this period was one of communication between healthcare workers and thus involved fewer patient contacts. Third, we did not distribute motes to healthcare workers who visited the unit to see patients in the medical ICU (eg, consulting physicians). This is an important group of healthcare workers to consider. Finally, our study was performed in a single unit in a single medical center, and the results may not be generalizable to other healthcare settings.

In conclusion, we show how sensitive hand hygiene observations are to different observers' schedules and demonstrate the importance of data-driven approaches to schedule hand hygiene audits. Furthermore, even simple interventions in focusing audits toward peak flow times may dramatically improve the yield of audits in terms of the number and diversity of observations.

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REFERENCES

1. Boyce JM, Pittet D. Guidelines for hand hygiene in health-care settings: recommendations of the healthcare infection control practices advisory committee and the HICPAC/SHEA/APIC/IDSA hand hygiene task force. *Infect Control Hosp Epidemiol* 2002;23:S3–S41.
2. Allegranzi B, Sax H, Bengaly L, et al. Successful implementation of the World Health Organization hand hygiene improvement strategy in a referral hospital in Mali, Africa. *Infect Control Hosp Epidemiol* 2010;31:133–141.
3. Pittet D, Allegranzi B, Boyce JM; World Health Organization World Alliance for Patient Safety First Global Patient Safety Challenge Core Group of Experts. The World Health Organization guidelines on hand hygiene in health care and their consensus recommendations. *Infect Control Hosp Epidemiol* 2009; 30:611–622.
4. Maskerine C, Loeb M. Improving compliance to hand hygiene among health care workers. *J Contin Edu Health Prof* 2006;26: 244–251.
5. Haas JP, Larson EL. Measurement of compliance with hand hygiene. *J Hosp Infect* 2007;66:6–14.
6. Joint Commission on Accreditation of Healthcare Organizations. Patient safety goals. http://www.jcaho.org/accredited+organizations/patient+safety/npsg.htm. Accessed December 2, 2009.
7. Adair JG. The Hawthorne effect: a reconsideration of the methodological artifact. *J Appl Psychol* 1984;69:334–345.
8. Eckmanns T, Bessert J, Behnke M, Gastmeier P, Ruden H. Compliance with antiseptic hand rub use in intensive care units: the Hawthorne effect. *Infect Control Hosp Epidemiol* 2006;27: 931–934.
9. Boscart VM, McGilton KS, Levchenko A, Hufton G, Holliday P, Fernie GR. Acceptability of a wearable hand hygiene device with monitoring capabilities. *J Hosp Infect* 2008;70:216–222.
10. Boyce JM, Cooper T, Dolan MJ. Evaluation of an electronic device for real-time measurement of alcohol-based hand rub use. *Infect Control Hosp Epidemiol* 2009;30:1090–1095.
11. Kinsella G, Thomas AN, Taylor RJ. Electronic surveillance of wall-mounted soap and alcohol gel dispensers in an intensive care unit. *J Hosp Infect* 2007;66:34–39.
12. Larson EL, Albrecht S, O'Keefe M. Hand hygiene behavior in a pediatric emergency department and a pediatric intensive care unit: comparison of use of 2 dispenser systems. *Am J Crit Care* 2005;14:304–311.
13. Swoboda SM, Earsing K, Strauss K, Lane S, Lipsett PA. Isolation status and voice prompts improve hand hygiene. *Am J Infect Control* 2007;35:470–476.
14. Venkatesh AK, Lankford MG, Rooney DM, Blachford T, Watts CM, Noskin GA. Use of electronic alerts to enhance hand hygiene compliance and decrease transmission of vancomycin-resistant *Enterococcus* in a hematology unit. *Am J Infect Control* 2008;35:199–205.
15. Polgreen PM, Hlady CS, Severson MA, Segre AM, Herman T. Method for automated monitoring of hand hygiene compliance without radio-frequency identification. *Infect Control Hosp Epidemiol* 2010;31:1294–1297.
16. Sax H, Allegranzi B, Chraïti MN, Boyce J, Larson E, Pittet D. The World Health Organization hand hygiene observation method. *Am J Infect Control* 2009;37(10):827–834.
17. Lloyd RC. The search for a few good indicators. In: Ransom SC, Joshi MS, Nash DN, eds. *The Healthcare Quality Book: Vision Strategy and Tools.* Chicago: Health Administration Press, 2005: 103–110.
18. Rupp ME, Fitzgerald T, Puumala S, et al. Prospective, controlled, cross-over trial of alcohol-based hand gel in critical care units. *Infect Control Hosp Epidemiol* 2008;29(1):8–15.
19. van de Mortel T, Murgo M. An examination of covert observation and solution audit as tools to measure the success of hand hygiene interventions. *Am J Infect Control* 2006;34:95–96.

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