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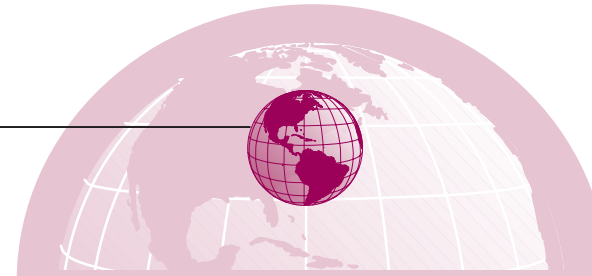
FEATURE ARTICLE



The Effect of Automated Monitoring and Real-Time Prompting on Nurses' Hand Hygiene Performance

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Adequate hand hygiene compliance by healthcare staff is considered an effective method to reduce hospital-acquired infections. The electronic system developed at Toronto Rehabilitation Institute automatically detects hand hygiene opportunities and records hand hygiene actions. It includes an optional visual hand hygiene status indication, generates real-time hand hygiene prompting signals, and enables automated monitoring of individual and aggregated hand hygiene performance. The system was installed on a complex continuous care unit at the entrance to 17 patient rooms and a utility room. A total of 93 alcohol gel and soap dispensers were instrumented and 14 nurses were provided with the personal wearable electronic monitors. The study included three phases with the system operating in three different modes: (1) an inactive mode during the first phase when hand hygiene opportunities and hand hygiene actions were recorded but prompting and visual indication functions were disabled, (2) only hand hygiene status indicators were enabled during the second phase, and (3) both hand hygiene status and real-time hand hygiene prompting signals were enabled during the third phase. Data collection was performed automatically during all of the three phases. The system indicated significantly higher hand hygiene activity rates and compliance during the third phase, with both hand hygiene indication and real-time prompting functions enabled. To increase the efficacy of the technology, its use was supplemented with individual performance reviews of the automatically collected data.

KEY WORDS

Electronic system • Hand hygiene • Monitoring

Inadequate hand hygiene (HH) has been cited as the main reason for increased rates of hospital-acquired infections in healthcare facilities.[1] A systematic review of economic analyses[2] of healthcare-associated infections (HAIs) indicated HAI as one of the most serious patient safety issues in healthcare today. In the US alone, the incidence of HAI has been estimated to be almost 2 million cases annually,[3] resulting in tens of thousands of deaths[2] and significant hospital-related financial burden.[2,4] Despite the knowledge that proper HH could prevent most of these infections, healthcare staff's HH compliance remains unsatisfactory. Although HH monitoring and providing healthcare staff with performance feedback are considered essential for HH promotion programs, a variety of HH interventions have been unable to produce sustainable improvement effects.[5] To date, HH performance is estimated mostly by direct observations,[6,7] self-reporting

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There is a potential conflict of interest because of the anticipated commercialization of the hand hygiene monitoring system. This intellectual property is patent protected. Any future royalties generated will be distributed according to the policy at the Toronto Rehabilitation Institute. Two of the authors who are inventors of the technology may benefit from royalties in the future (Drs Levchenko and Fernie). Dr Fernie has committed to donating his share of royalties to Toronto Rehabilitation Institute.

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by staff,[6] and measurement of gel and soap consumption.[8,9] Along with the currently used methods, educational and HH training programs, electronic technologies appear to be a perspective approach for monitoring and improving health staff's HH performance.

RELATED WORK

The functionality and complexity of electronic technologies used for HH monitoring vary significantly from simple counters[8] measuring the frequency of dispenser activations to specialized monitoring solutions developed to automatically track individual HH performance. Electronic counters are now often offered as an accessory by dispenser manufacturers; some of these devices not only measure consumption of gel or soap[7,8] but also are integrated via a wireless network to transmit time-stamped events[10] of dispenser activations. Although this approach allows tracking HH frequencies over time and locations, it cannot differentiate the use of dispensers among healthcare staff, patients, and visitors; does not allow any judgment on appropriateness of HH actions performed; and does not provide enough data to evaluate individual HH performance.[11,12]

More complex HH monitoring solutions usually include a method of detecting and processing HH actions performed by a caregiver combined with some location tracking technology using radio frequency (RF), infrared, or ultrasound sensors with subsequent matching of HH opportunities and HH actions and generation of HH performance reports. Sahud et al[13] conducted a study in a tertiary teaching hospital using an radio frequency identification-based system monitoring the events of entering and exiting patient rooms and relating these events with HH actions performed before entering or after exiting the rooms. Polgreen et al[14] developed a system based on a wireless Zigbee network (Zigbee Alliance, San Ramon, CA) that, depending on location beacons, can achieve higher location precision than radio frequency identification-based solutions do and can track the use of dispensers before caregivers enter or after they exit patient rooms. Cheng et al[15] conducted a trial in a neurosurgical intensive care unit using RF-based technology where the badges worn by caregivers communicated with RF beacons marking monitored areas and dispensers using received signal strength indicator (RSSI) for proximity detection. After analyzing RSSI values recorded by the badges, the system could make a decision on HH actions performed by their wearers and relate them to HH opportunities to evaluate compliance. As the badge records were processed only after uploading data, the system did not generate immediate feedback to prompt a caregiver to perform HH hygiene, if an HH opportunity was detected with no related dispenser activation. Ghosh et al[16] conducted a study using a computerized video observation system that demonstrated a significant increase in HH activity and adherence to HH compliance protocols after activating the HH feedback function.

The system we developed at Toronto Rehabilitation Institute features a distributed embedded architecture,[17,18] with all HH monitoring and prompting functions performed by independently operating personal wearable HH monitors, which are not connected by any network. With HH monitoring algorithms defined in the firmware of these microcontroller-based devices,[17] the performance of the system does not depend on the number of caregivers being monitored, the number of instrumented dispensers, or the number of monitored locations. Personal wearable monitors record the exact time of HH actions performed with instrumented stationary gel or soap dispensers, as well as with optional personal wearable gel dispensers. They also communicate with the sets of infrared beacons defining the areas where HH monitoring is required and detect when a caregiver enters or leaves these areas. Unlike some technologies with centralized architecture, in this distributed system, the personal wearable electronic monitors match HH opportunities and HH actions in real time and can generate immediate HH prompting signals when necessary. When a wearable monitor detects that a caregiver is entering or leaving a monitored location, and no HH action was performed within a programmable time interval prior to this event, the device vibrates (or optionally generates an audible signal), reminding the caregiver to perform HH. If the caregiver responds by activating a dispenser, then the wearable monitor immediately stops generating the reminding signal and records the HH action as performed after prompting. If no HH action is performed while the device is generating a reminding signal, the wearable monitor records that a caregiver decided to ignore it. Every time a caregiver uses a dispenser, the personal wearable monitor flashes green, and if HH action is performed prior to entering or leaving the monitored areas, the device does not generate any reminding signals. Throughout the entire shift, the personal wearable electronic monitors record the exact time when a caregiver enters or leaves monitored areas, identification codes of these areas, HH status at the moment of entering/leaving, the exact time of HH actions performed along with the types of dispensers, and their identification codes. This information is subsequently downloaded via USB to evaluate HH performance and generate individual and aggregated reports.

METHODS

The system was installed on a complex continuing care unit of a larger rehabilitation hospital including eight ward rooms (four beds), six semiprivate rooms (two beds), and four private rooms. Each room was instrumented with

two entrance zones to monitor the events of entering and leaving the room. In addition to patient rooms, the utility room was instrumented with a single entrance zone to implement HH prompting function if HH was not performed before leaving this room. A total of 93 stationary dispensers were instrumented with external controllers, including 22 gel dispensers in the hallways, 47 bedside gel dispensers in the patient rooms, 22 soap dispensers in ensuite patient bathrooms, and one soap and one gel dispenser in the utility room. The floor plan of the instrumented unit is shown in Figure 1.

With the large number of stationary dispensers available on the unit, including the ones installed in individual patient areas, most nursing staff considered personal wearable gel dispensers redundant, so this optional component of technology was not used in this study.

Fourteen nurses employed on the unit delivering direct care to the patients consented to participate in the study. Each participant received an individual introductory and educational session on the importance of HH, HH best practices, the use of the technology, and operation of the devices.

In our previous pilot studies,[19] we compared the results automatically generated by the system with the data collected manually during HH observation sessions. The study we present in this article included three phases, with the system operating in three different modes. During the first phase, the system was completely inactive, with HH prompting function and HH status indicator disabled. At this stage, the system was recording only HH actions and the events of entering and leaving monitored locations. Upon completion of this phase, the system was activated, but initially, only the HH status indicator was enabled. During this phase, the personal wearable monitor was flashing green after recording HH actions. The device stayed green for preprogrammed time intervals, which, in this study, were set for 60 seconds in the hallway areas and 20 seconds inside the patient rooms. This partially active phase was of shorter duration and was included mostly for training purposes, so the nurses could observe the logic of device operation and recording of HH actions performed. During the first and the second phases of the study, no feedback and HH performance review sessions were conducted with participating nurses. During the third phase, HH prompting function was enabled. At this stage, if a patient room was entered or left, and the wearable monitor was not flashing green, it started vibrating,

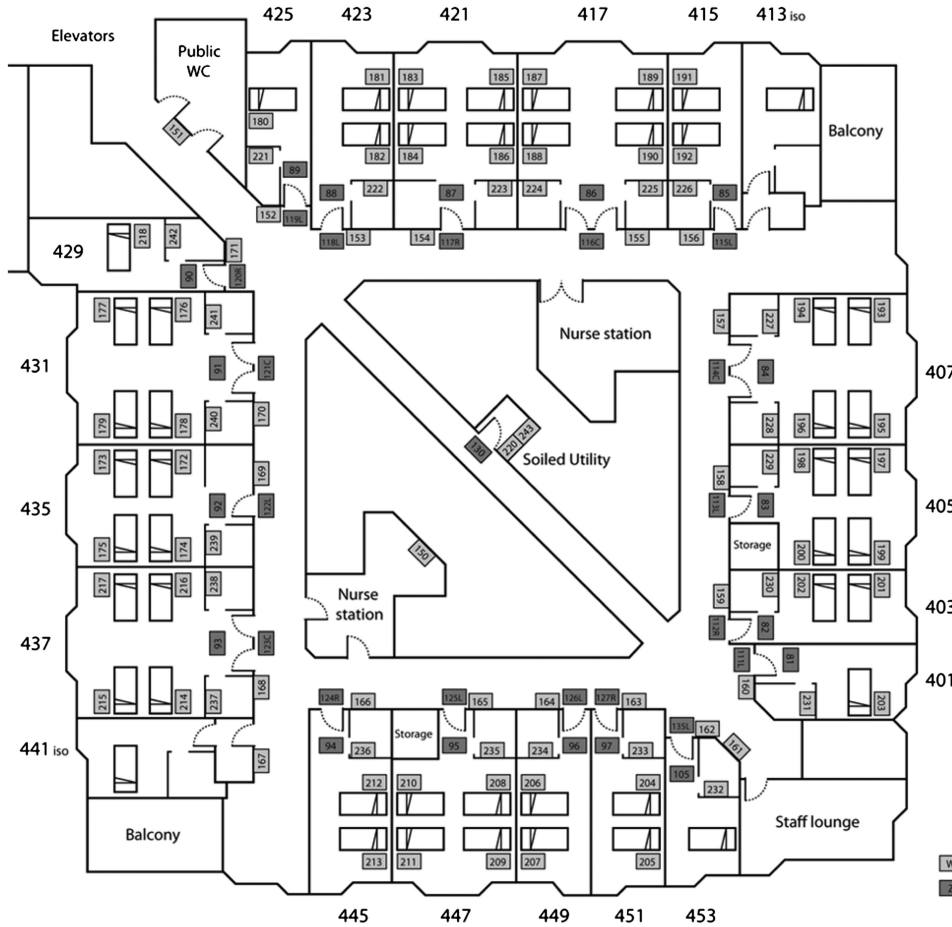

FIGURE 1. Floor plan of the instrumented nursing unit: ■, instrumented gel and soap dispensers; ■, monitored zones to track the events on entering/leaving patient and utility rooms.

reminding that HH needs to be performed. The duration of the reminder was set to 20 seconds, and if a dispenser was used within this time interval, the reminder stopped immediately, the HH status indicator turned green, and the HH action was classified as "performed after prompt." If no HH action was performed within the duration of the prompting signal, the reminder was classified as "ignored." If the personal wearable monitor was green when entering or leaving a patient room, the device did not generate any reminding signal as the HH status variable had already been set to "clean." During this phase, nurses received two individual feedback sessions to review their HH performance and the results recorded by the system.

RESULTS

More than 1270 hours were automatically recorded during the first phase of the study (HH status indicator and HH reminder disabled); the system indicated an average rate of 2.97 HH actions per hour and 8.92 HH opportunities per hour (Figure 2) associated with the events of entering/leaving monitored rooms. Similar results with 2.84 HH actions per hour and 9.43 HH opportunities per hour were obtained during the second phase of the study, which lasted 842 hours, with only the HH status indicator enabled. In the fully active mode, with real-time HH prompting enabled and periodic individual sessions to review automatically collected data, the system indicated an average of 6.61 HH actions and 9.56 HH opportunities per hour obtained over 1269 hours of testing.

The time constants and the operational algorithms of the wearable electronic monitors were identical for all of the phases in the study. Therefore, the system classified some HH opportunities as "performed after prompt" during the first two phases of the study, without generating actual HH prompting signals. This status was automatically assigned to an HH opportunity, if an HH action was performed within the duration of the prompting signal (as if it was set for a fully active mode) after detecting the event of entering or leaving a monitored location. If no HH action was performed after detection of an HH opportunity, the system classified the event as an "ignored HH prompt." Classification of automatically detected HH opportunities according to the HH status of the caregivers is shown in Figure 3 for all three phases of testing.

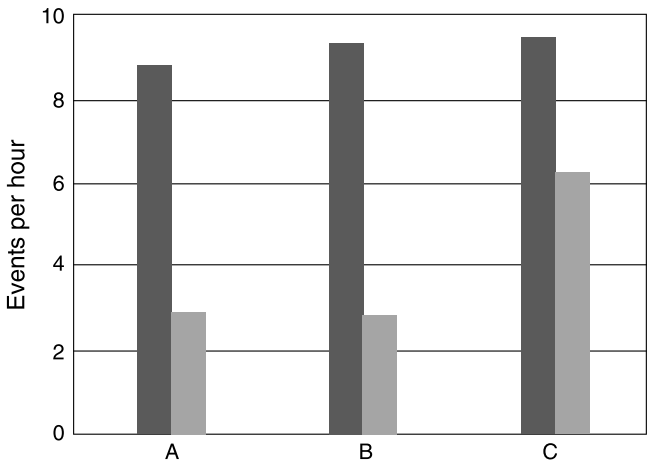

FIGURE 2. Hourly rates of HH opportunities (■) and HH actions (■). A, inactive system; B, HH status indicator only; C, real-time HH prompting signal enabled.

FEEDBACK FROM NURSES

During the third phase of the study, participating nurses received two individual feedback sessions conducted at approximately equally spaced time intervals, upon completion of 30% and 60% of data collection. During the feedback sessions, participants were presented with their individual data recorded by the system and their HH performance was discussed. The feedback provided was tailored to the individual performance. For example, for some participants, the results indicated a drop in compliance at certain times of the day, so the strategies on how the HH compliance could be maintained throughout the entire shift were discussed.

In addition, each session provided the researcher with an opportunity to assess the participants' perception of the effectiveness of the system in improving their personal HH practices. Participants, with support from the researcher, were clearly able to identify those situations where they did not perform HH. At times, they provided a reason why they were unable to perform HH, such as delivering meal trays or carrying supplies, where these were perceived by the staff as legitimate reasons not to perform HH.

Some nurses suggested introducing a short delay before the reminding signal when leaving a patient room. Quite often, they leave a patient room while carrying dirty linens, supplies, or trays and are unable to immediately perform HH when passing through the detectable zone.

Another suggestion was to increase HH expiry time after activation of soap dispensers in ensuite bathrooms, as in this case, handrubbing cannot be done on the way and extra time is needed for rinsing and drying hands after washing with soap and water, so HH action itself takes more time. The system software could be modified so that the wearable monitor adjusts the HH action expiry time for this category of dispensers.

Most nurses found the visual HH status indicator (personal wearable monitor flashing green after HH action) to be a useful function that helped them to check their HH status, observe how the device records and processes HH actions, understand the logic of the device

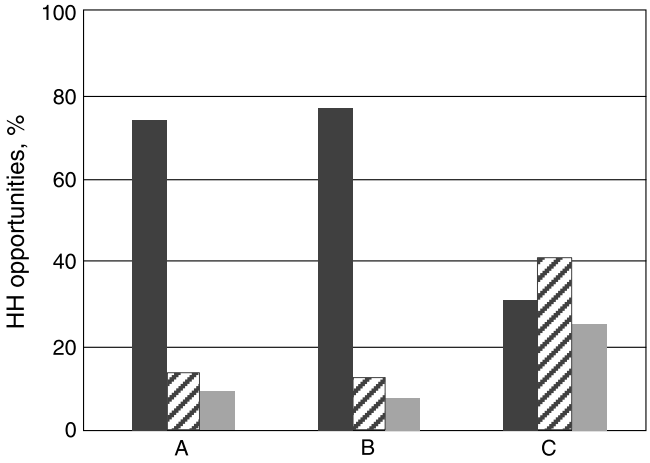

FIGURE 3. HH opportunities with HH status classified as "clean" (▨), "HH after prompt" (▩), and "ignored HH prompt" (■). A, inactive system; B, HH status indicator only; C, real-time HH prompting signal enabled.

operation, and check the status of other nurses at monitored locations.

Overall, participants found HH prompting signals mostly appropriate and indicated that it was an efficient approach to remind them to perform HH. They did not raise any privacy and data confidentiality issues or any concerns about HH monitoring, confirming the results of our previous studies,[19,20] and indicated that the feedback reports were helpful in analyzing their own HH behaviors and practices.

DISCUSSION

Throughout the whole study, data collection was performed automatically, including the baseline phase, when the HH status indicator and reminding signal were disabled. Using the identical experimental setup and data collection procedures for all of the testing phases allows more accurate judgment on the effect of various system functions. Unlike manual HH observations, which are usually organized in 20-minute time slices, the system performed HH monitoring continuously, collecting the same sets of HH-related events for all of the three phases without the effect of observer presence. Overall, results indicate that this technology has great potential to effectively and sustainably enhance HH performance. Data from phase 1 indicate low HH activity rates, despite the convenience sample of participants who were well aware of being monitored for HH. The absence of real improvement in HH performance during the second phase of the study is interesting to note, when only the HH status indicator was enabled but the device did not generate HH reminding signals. However, upon activating the individual prompting signals, the hourly HH activity rates more than doubled (Figure 2) and the ratio between HH opportunities with HH status set to "clean" and "performed after prompt" versus opportunities with HH status "ignored HH prompt" changed significantly (Figure 3).

Although participants found the visual HH status indicator to be a useful function, no improvement in HH was observed in the second phase of the study. During this phase, the HH status indicator was enabled, but the staff were not prompted to perform HH with real-time vibration reminders and had not yet reviewed their individual results, so having the device flashing green after dispenser activation was interesting but had no influence on actual HH practices. This finding corresponds to other studies, indicating that the HH reminding function[16,21] and individualized feedback[22] could be critical for achieving improvement in HH practices. Merely having a light flash when hands are clean is not sufficient to reinforce staff to wash hands, yet actual real-time reminders when hands are not clean does have this effect. The accompanying green light then might function as a positive reward, once the behavior is corrected. It is also important to consider the specific clinical setting of this study: complex continuing care unit. Unfortunately, most patients on the unit are nonresponsive; there is a high patient-staff ratio, resulting in staff mostly working by themselves; and only a limited number of staff participated in the study. Specific features of this clinical setting could result in limited peer pressure, patients not being engaged in the process, and unable to provide feedback based on the visual status of staff's HH monitors. These factors could lead to a contextual devaluing of this specific function of technology. Our previous studies[19] found that clinical staff, as opposed to infection control specialists and managers, focus mostly on immediate feedback to perform HH. The visual HH status indicator might have more significant impact in other clinical settings,[23,24] as a basis for immediate feedback from peers, managers, and patients, along with real-time HH prompting signals generated automatically.

For most nurses, individual HH activity rates increased significantly immediately after activation of the reminding signal, while for others, noticeable improvement was observed only after initial feedback sessions when they could review their individual results. This observation indicates that the generation of individual and aggregated performance reports based on automatically collected data is an essential element of HH monitoring technology.

We previously reported[25] that in the clinical environment where the study was conducted, most of the HH opportunities were associated with the events of entering and leaving patient rooms. This finding was confirmed in this study, as during all three phases of this study, the system recorded significantly higher percentage of HH actions performed with dispensers located in the hallway near the entrances of the patient rooms (Figure 4) compared with HH actions performed with the bedside dispensers in patient rooms.

Another finding relates to the appropriateness of HH actions. Along with significantly higher HH rates during phase 3, when real-time HH prompting function was enabled, almost three quarters of the HH actions were associated with automatically detected HH opportunities (Figure 5); that is, dispensers were used before or immediately after entering or leaving monitored areas, while during phases 1 and 2, only half of HH actions were in this category.

Although the study demonstrated the possibility to improve HH performance using the electronic system with real-time prompting function, a longer trial is needed to evaluate the sustainability of the observed results and accurately measure the degree of sustainable improvement that could be achieved with automated HH monitoring technology.

During all of the three phases, HH opportunities with HH status set to "clean" were mostly associated with the events of entering monitored locations, while most of HH opportunities with HH status "performed after prompt" were related to the events of leaving monitored rooms. This does not necessarily indicate that nurses forget to perform HH after completing the task and might result from the fact that the dispensers at room entrance areas were located on the side of the hallway, so that the event of leaving the room was detected just before a nurse could reach a dispenser. Further research is required to make a more accurate judgment on nurses' awareness to perform HH before and after completing the tasks.

LIMITATIONS

The study unit used for testing the technology was a complex continuing care unit, with extended length of stay for patients. As most of the patients have chronic conditions, the pace with which staff carry out their assignments might be more organized and predictable compared with other clinical environments, and although we expect similar functionality of the technology, the frequencies of HH opportunities and HH actions might not be generalizable to other healthcare settings.

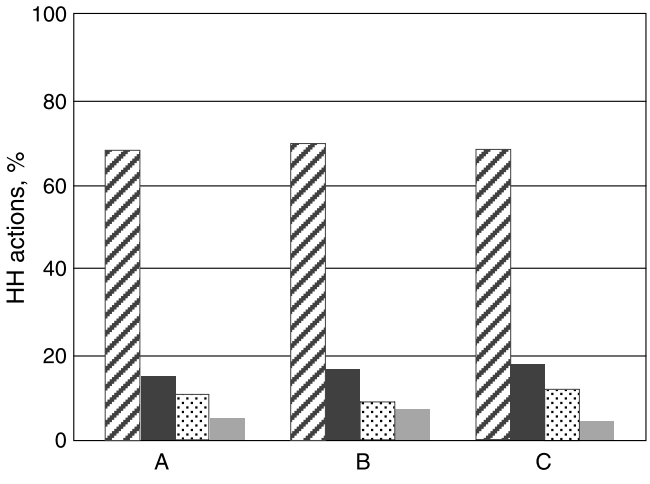

FIGURE 4. HH actions performed with dispensers installed in hallways (▨), soap dispensers in ensuite bathrooms (■), bedside dispensers in patient rooms (▩), and dispensers in soiled utility room (■). A, inactive system; B, only HH status indicator enabled; C, real-time HH prompting signal enabled.

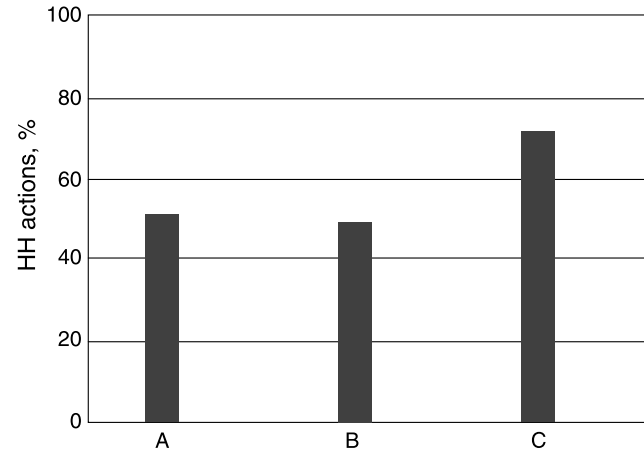

FIGURE 5. Percentage of HH actions associated with the events of entering and leaving monitored locations. A, inactive system; B, only HH status indicator enabled; C, real-time HH prompting signal enabled.

CONCLUSION

The electronic monitoring system demonstrated the capability of improving nurses' HH performance when tested in a complex continuing care setting. The ability of the system to generate real-time HH prompting signals appears to be an important function for increasing HH activity and compliance. To maximize the efficiency of automated HH monitoring, the technological component should be supplemented with periodic individual performance review sessions to analyze automatically generated data and develop individual educational and training strategies when required.

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