State of the Science Review

Technological innovations in infection control: A rapid review of the acceptance of behavior monitoring systems and their contribution to the improvement of hand hygiene

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Background: Hand hygiene is crucial for preventing nosocomial infections; however, adherence rates need further attention. Prevention of nosocomial infections through regular hand hygiene monitoring and feedback is recommended by the World Health Organization. Technology holds the potential for achieving this goal. The aim of this study was to assess the influence of technological behavior monitoring innovations on hand hygiene adherence and their acceptance by healthcare professionals.
Methods: A rapid review of the literature was conducted. A literature search was performed in electronic databases (Cochrane Library, Scopus, PubMed, CINAHL, PsycINFO, PsycARTICLES, PSYNDEX) and via citation tracking in November 2017. Records were screened for eligibility. Included studies were analyzed and synthesized in a narrative, tabular way.
Results: Overall, 2,426 studies were identified, and 12 were included. Findings indicated that behavior monitoring technology improves hand hygiene adherence, resulting in adherence increases between 6.40%-54.97%. The majority of systems provided real-time feedback. Factors influencing acceptance of technology by healthcare professionals include transparency and confidentiality, user attitude and environment, device function, and device usability.
Conclusions: Recognizing the importance of hand hygiene adherence, active communication between behavior monitoring technology and healthcare workers seems to mediate improvement in sustainable hand hygiene adherence behavior.

Nosocomial infections are classified as a major public health problem, impacting mortality, morbidity, and quality of life in those affected.[1] Recently, the European Centre for Disease Prevention and Control estimated the occurrence of more than 2.6 million new cases of nosocomial infection in the European Union every year.[2] The World Health Organization states that worldwide, 10% of all patients in developing countries and 7% of patients in developed countries will acquire at least 1 nosocomial infection in their lifetime.[1] Considering these statistics, increased efforts are necessary to decrease the occurrence of nosocomial infections across countries.[1]

There are several ways to prevent nosocomial infections, including hand hygiene practices. Proper hand hygiene is crucial and relatively easy to perform.[3,4] However, despite this, hand hygiene compliance rates are still very low.[5,6] Erasmus et al[7] describe in a systematic review a median hand hygiene compliance rate of only 40% across all settings, situations, and professions. Because of the importance of good hand hygiene practices, many researchers try to address the problem of insufficient hand hygiene compliance.[8] As a result of insufficient compliance, the World Health Organization recommends regular hand hygiene monitoring and feedback to control and prevent nosocomial infections.[1]

The term *compliance* has become embedded in the language of healthcare professionals over the years.[9] It is important to note that the terms *compliance* and *adherence* are not synonymous.[9] The main difference involves the recognition of the perspective of patients and healthcare workers. For example, *compliance* represents the extent to which a person's behavior, in terms of taking medications, following a diet, or executing lifestyle changes, follows the recommendations given by a healthcare provider,[10] whereas *adherence* refers to the "extent to which a person's behavior, in terms of taking medications, following a diet, or executing lifestyle changes, corresponds with *agreed* recommendations from a healthcare provider."[11] With respect to the different meanings, this review includes both constructs in its search. The authors strive to use the term *adherence* rather than *compliance* but ultimately use the wording of the respective authors of the included studies in the Results section of this review.

Direct observation is regarded as the gold standard for hand hygiene monitoring.[6] However, direct observation is costly in terms of staff time and resources and may lead to biased adherence rates—for example, because of the influence of complex social interactions between the observer and the observed person (Hawthorne effect).[12] As a result, hand hygiene adherence in observed healthcare workers tends to increase, leading to potentially inaccurate adherence rates.[12]

Subsequently, technological innovations have been developed over the last few years to record and improve hand hygiene adherence.[5,13,14] McGuckin and Govednik[3] differentiate 3 categories of technological innovations for hand hygiene monitoring purposes based on their respective functions: (1) behavior monitoring systems, (2) data management tools, and (3) technique improvement systems. This review focuses on the first category of technological innovations described by McGuckin and Govednik[3] because of their ability to assess and potentially improve hand hygiene adherence rates. Furthermore, the human factor is important in the use of technological innovations, which are increasingly applied in infection control.[15] McGuckin and Govednik[3] describe behavior monitoring systems as electronic sensors that can observe, count, and report hygiene-related actions. These systems provide automated feedback to the user, often through wearable technology.[3] Thus, this review also focuses on such devices.

In contrast to the current gold standard of direct observation for the measurement of hand hygiene adherence rates, most of the technological innovations—for example, behavior monitoring systems—generate data automatically within the work setting (ie, while being worn by the healthcare worker). In addition to assessing adherence rates, these systems have the potential to improve hygiene-related outcomes.[16] The potential improvement is based on usage and, therefore, acceptance of the respective technological innovations.[17] Dawson et al[17] illustrate the importance of technological acceptance in the healthcare sector in an updated version of the *technology acceptance model* from Davis.[18] They describe that attention to end-user acceptance of technological innovations needs to be addressed and is thus potentially as important as the efficacy of decontamination.[17]

Considering the global problem of nosocomial infections, the crucial nature of hand hygiene practices, the very low hand hygiene adherence, in addition to the technological advances in this field, this study focuses on the following questions:

- What influence do technological behavior monitoring innovations have on hand hygiene adherence in healthcare professionals?
- Which factors are relevant with respect to the acceptance of technological behavior monitoring innovations that improve hand hygiene adherence in healthcare professionals?

METHODS

To assess the current state of the art with respect to the influence of new technological behavior monitoring innovations and factors for acceptance, a rapid review of the current research literature has been conducted.

Method of rapid review

Because of the fast-growing body of knowledge in this research field, the rapid review method has been chosen. Rapid reviews can be described as systematically performed reviews of already existing literature. They are required to be explicit in their method but can be conducted in a shorter period of time.[19] Rapid reviews have similar components to systematic reviews but are time-restricted within these components[20] (eg, in the number of electronic databases searched, number of publication years, geographic regions included, or extent of the quality assessment).[21] Additionally, the completeness of the identified literature is determined by time constraints.[19]

The review process in this study was systematically performed based on the 5 steps of systematic reviews described by Khan et al[22]: (1) framing questions for a review, (2) identifying the relevant literature, (3) assessing the quality of the literature, (4) summarizing the evidence, and (5) interpreting the findings.

To achieve transparency in the rapid review process, the streamlined approach is described in the following description of the review process, as Ganann et al[21] recommend.

Search strategy

To identify relevant literature, an electronic database search was conducted. Therefore, a systematic literature search was performed in November 2017 using the electronic databases Scopus, Cochrane Library, PubMed, CINAHL, PsycINFO, PsycARTICLES, and PSYNDEX (last 4 via EBSCOhost). Respecting the restrictions of rapid reviews, no hand search or search for unpublished or gray literature was performed. Forward and backward citation tracking based on the included articles was performed.

Search terms

The search terms were created based on the Eclipse framework.[23] The search terms were created and adapted by an interdisciplinary work group in multiple steps (especially focusing on the adaptation of technical terms) and were adapted for the search interfaces of the Cochrane Library, Scopus, PubMed, and EBSCOhost to search all the databases described above. Table 1 included search terms in 4 categories: technological innovation, hygiene, healthcare, and acceptance. Being consistent with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guideline,[24] search strategy for the Scopus database is presented in Appendix 1.

Eligibility criteria

Studies in English and German were included in this rapid review. There was no predefined range for the publication year. Only peer-reviewed articles were included. Article types to be included were original research, reviews, and peer-reviewed proceedings articles. Inclusion criteria accepted all study designs. There was no geographic limitation. The settings focused on hygiene in hospitals and excluded dental hygiene, nursing homes, and community care services. The target groups were nurses and physicians. The technical innovation needed to fit the definition of *behavior monitoring system* described by McGuckin and Govednik,[3] with elements of observing, counting, and reporting. A key feature of the technological behavior monitoring innovation for inclusion purposes needed to be the ability to communicate with the user to provide feedback. Studies were included when the technologies were wearable and tracked movement

Table 1
Search terms within categories

Technological innovations	Hygiene and infection prevention and control	Healthcare workers	Acceptance of technology
innovation	hygiene	healthcare	acceptance
tracking	infection control	nursing	accepting
technic intervention	hand hygiene	nurse	facilitators
RFID	hand disinfection	physician	facilitator
radio frequency identification	hand wash	medicine	facilitate
technology	handwashing	intensive care unit	facilitating
bluetooth low energy	hand infection	ICU	promoters
BLE		mechanical ventilation	promoting
real time locating system		respirator care	inhibitors
RTLS			inhibitor
smart tracker			inhibiting
			barrier
			adherence
			nonadherence
			non-adherence
			compliance
			noncompliance
			non-compliance

BLE, bluetooth low energy; *ICU*, intensive care unit; *RFID*, radio frequency identification; *RTLS*, real time locating system.

(eg, electronic badges). Nonwearable technologies (eg, systems using light barriers) were excluded from this review.

Study selection process

All studies were imported into the literature management program Citavi (Swiss Academic Software, Wädenswil, Switzerland). In a first step, 1 reviewer (M.M.) screened all titles, abstracts, and key words to establish eligibility for inclusion. In step 2, a second reviewer (M.S.) performed a random control of 10% of the included and excluded studies from the title, abstract, and key word screening using exactly the same eligibility criteria. The included studies were retrieved and screened in full text versions in step 3. Step 4 involved a consensus process. In cases where the 2 reviewers disagreed on including or excluding a study without a consensus, a third reviewer (C.K.) rated the study in question. In a final step, the remaining articles were critically appraised by 2 reviewers (M.M., M.S.) independently. Critical appraisal was performed based on the Critical Appraisal Skills Program for the respective study designs.[25]

Data extraction

The relevant information regarding the research questions was extracted in a standardized fashion by 2 reviewers (M.M., M.S.). Extracted information was included in a data extraction sheet. Relevant information was considered the following: authors of the respective studies, year of publication, country where the study was performed, which study question (1 or 2) was addressed, study objectives, research approach, study design, summary of the technological behavior monitoring innovation used, the way communication was performed between the system and the user, and the main findings regarding the respective research questions.

Data analysis and synthesis

With respect to the aim of this review, an in-depth narrative analysis and description were performed. According to the first research question, a narrative and tabular description of the different innovations and their influence on hand hygiene adherence were created. Relevant articles addressing the second research question were imported and analyzed thematically using the data analysis software MAXQDA 12 (VERBI GmbH, Berlin, Germany). Two researchers conducted a line-by-line coding of relevant factors, which were synthesized into core categories according to aspects assessed as important regarding the acceptance of technological behavior monitoring innovations that improve hand hygiene adherence in healthcare professionals.

RESULTS

Overall, 2,426 studies were identified from the electronic databases and citation tracking. After the critical appraisal process, 12 studies were included in this rapid review.[14,16,26-35] Figure 1 shows a flow diagram describing each step of the inclusion and exclusion process.

The 12 studies included in this review are presented in Tables 2 and 3, sorted by publication year. Table 2 provides an overview of each study's research design and major findings regarding the influence of technological behavior monitoring innovations on hand hygiene adherence. Table 3 provides an overview of each study's research design and major findings regarding relevant factors with respect to the acceptance of technological behavior monitoring innovations.

Influence of technological innovations on hand hygiene compliance

Overall, studies using quantitative research methods indicated that new technological behavior monitoring innovations have the potential to improve hand hygiene compliance behavior and result in a hand hygiene compliance increase between 6.40%-54.97%.[16,26,27,30-33] Study results were unclear regarding the sustainability of the effects. One study indicated a large reduction in compliance after removal of the innovation; the average daily dispenser usage was assessed before, during, and after implementation of the technological behavior monitoring innovation.[16] In a subsample, after removal of the innovation, the average daily dispenser usage dropped by 46.60%.[16] Other studies found that technological innovation sustained the effect of improved hand hygiene compliance[27] at a rate that was 1.5 times greater in the postintervention phase—lasting for 63 days— compared with the preintervention baseline.[30]

In contrast to other reviews, this rapid review focused on new technological behavior monitoring innovations that were wearable and able to communicate with the user, as described in detail in the Methods section. Two types of potential communication methods were presented in the included studies with quantitative methods: communication with the user via light, sound, or vibrations transmitted through the wearable device (badge) worn by the healthcare worker[26,30,32,33] or via lights that were installed at the respective
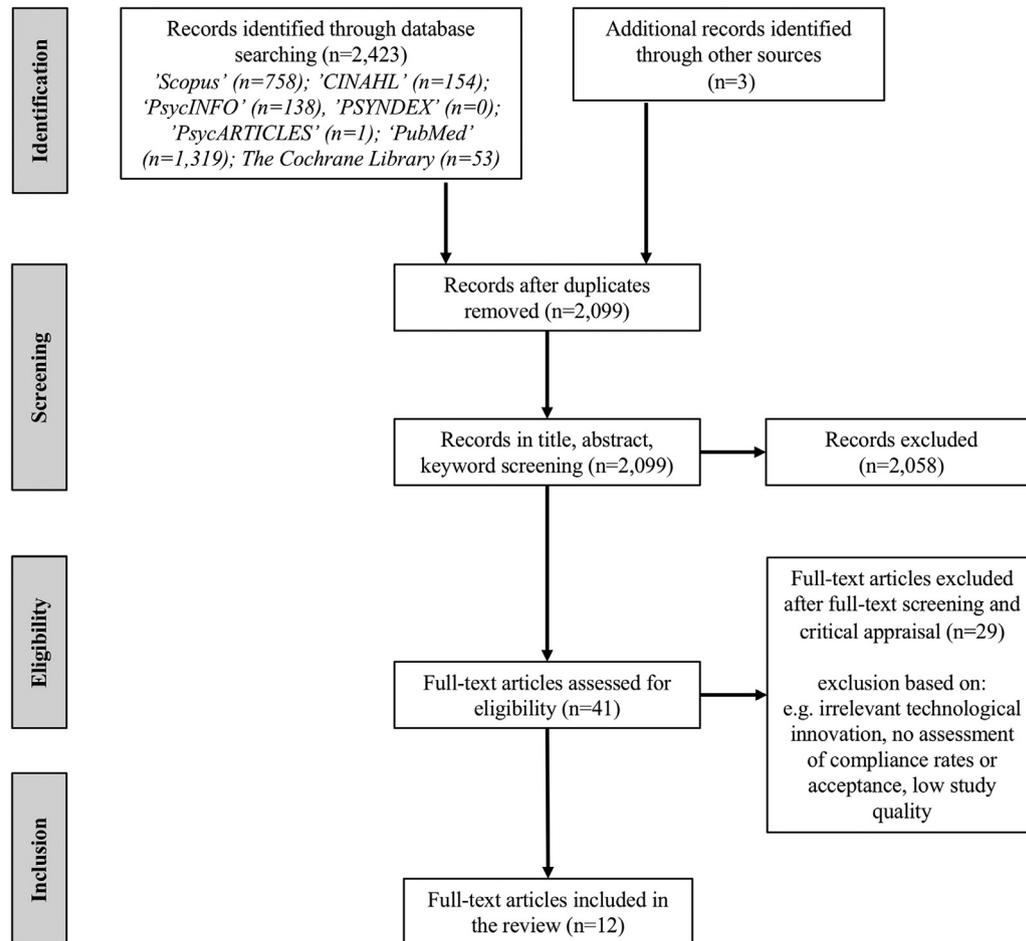
Fig 1. Flow diagram of the screening process based on Moher et al.[24]

dispensers or above the patient's bed.[27,31] In 1 case, a liquid crystal display was installed at a dispenser to potentially communicate with healthcare workers.[16] It is important to note that the majority of systems presented in the empirical studies provided real-time feedback.[26,27,30-33]

Three reviews were identified supporting the statement that behavior monitoring systems potentially improve hand hygiene compliance behavior.[14,28,29] However, the review by Srigley et al[29] indicated that 1 study with a minimal potential for bias—being a randomized controlled trial (RCT)—presented the smallest effect for hand hygiene compliance.[32]

Acceptance of technological behavior monitoring innovations

Only 2 qualitative studies focusing on the second research question have been identified in this rapid review. Both studies described factors that might influence the later acceptance of a technological behavior monitoring innovation.[34,35] In the synthesis of these studies, 4 key elements have been described as potentially influencing the acceptance of specific technologies by healthcare professionals: transparency and confidentiality, user attitude and environment, device function, and device usability.

Transparency and confidentiality

Transparency and confidentiality at implementation of a new technological behavior monitoring innovation seem to be key elements for acceptance.[34,35] Within the context of confidentiality,

participants of 1 study stated that the availability of recorded data and clear data policies were important.[35] Regarding transparency, the need for information about the technological innovation seems to be crucial.[34,35] Specifically, the "need for information" can be described as information about (1) how feedback of the data collected is accessible to the user,[35] (2) how the collected data are used,[34,35] (3) who has access to the data,[32,33] and (4) how the data are measured with respect to individual or group measurement, time intervals of measurement, and frequencies of measurement.[35]

User attitude and environment

User attitude toward the technological innovation seems to play an important role in device acceptance.[34,35] Focus group results demonstrated different user attitudes about being monitored by technology.[34,35] One possible factor influencing later acceptability is described as "perceived positive external perception of patients" when the user is wearing the badge, which represents a form of professional responsibility.[35] Another factor may also lead to more positive attitudes about the technology in question: technology perceived as supportive is potentially more accepted.[34,35]

Device function

Device function and features seem to be important as well.[34,35] Both studies focusing on device function described the accuracy of the measurement as a potentially important aspect.[34,35] This can be divided into the assessment of accuracy regarding patient zones

Table 2
Studies presenting the influence of technological behavior monitoring innovations on hand hygiene adherence, sorted by publication year

Author	Year (location)	Aim of the study	Research approach	Study design	Description of behavior monitoring system innovation	System−human communication	Main findings regarding the influence on hand hygiene adherence
Staats et al[16]	2017 (United States)	To investigate the effect of electronic monitoring on hand hygiene compliance	Quantitative	Longitudinal observational study (3 y)	Wearable RFID badges; RFID sensors installed throughout the monitored area and hand hygiene dispenser	Hand hygiene dispensers being able to communicate with an LCD display to provide personalized messages (potential communication)	Electronic monitoring of individual hand hygiene compliance increased compliance by 54.97% (average daily dispenser usage per unit bed); compliance initially increased and gradually declined; removal of innovation led to decrease in compliance below preactivation levels
Al Salman et al[26]	2015 (Kingdom of Bahrain)	To evaluate the impact of technology on improving healthcare workers' hand hygiene compliance	Quantitative (alongside semistructured interviews)	Longitudinal observational study (28 d)	Wearable badges with sensing and recording abilities, sensing beacon that defines the patient area, and dispenser monitor that monitors dispensing	Wearable badges with active communication function when hand hygiene is not performed (red light, vibration)	Steady increase in hand hygiene compliance (60%-82%); technology could improve hand hygiene compliance; many concerns about the new technology were expressed, mainly during the first phase of the study, leading to reduced cooperation
Radhakrishna et al[27]	2015 (India)	To increase hand sanitizer usage using RFID technology with real-time feedback	Quantitative	Interventional, quasi-experimental	Wearable RFID readers, without communication function, for the healthcare workers; RFID tags combined with motion sensors that define the patient area; hand sanitizer with pressure sensor and transmitter	Hand sanitizer able to communicate actively with a flashing LED light	Hand sanitizer usage (median, in mL) was higher in the intervention group (9,250 mL) than the control group (7,035 mL) ($P < .05$); the effect of the intervention was sustainable over time (4-mo postintervention period after 6-mo intervention phase); technical interventions (eg, automated systems) can monitor and increase compliance; stated their study costs were approximately US $20,000
Jarrin Tejada, Bearman et al[28]	2015 (United States)	To describe 4 modalities for hand hygiene compliance monitoring	Review	Review	(Modalities: (1) direct observation, (2) measuring product consumption, (3) electronic surveillance and alerts, (4) video surveillance and feedback) (this review focuses on the third category)	-//-	Electronic surveillance and alerts: Studies showed that visual or audible feedback increased hand hygiene compliance; 1 study demonstrated an increase in hand hygiene compliance from 66%-92% using alcohol-sensing badges and room entry and exit sensors; costs were described as a significant limitation in the implementation of these technologies; costs can vary significantly
Srigley et al[29]	2015 (Canada)	To assess the efficacy of electronic and video monitoring systems in improving hand hygiene	Review	Systematic review	Electronic monitoring systems with either individualized feedback or real-time reminders and electronic monitoring systems with both feedback and reminders (this review focuses on the second condition)	-//-	Overall poor study quality; the study with the least risk of bias showed the smallest effect of electronic monitoring systems in improving hand hygiene; 1 study showed an increase in hand hygiene compliance of 25%-65%; another showed an increase in hand hygiene compliance of 6.8% between intervention and control group
Levchenko et al[30]	2014 (Canada)	To assess the efficacy of electronic reminder and monitoring systems on hand hygiene performance	Quantitative	Longitudinal observational study (403 days)	Wearable badges that record the entry and exit of a specific area and the usage of dispensers; infrared beacons defining the area, hand hygiene needs to be performed; dispensers that can communicate with the wearable badges	Wearable badges with active communication function when hand hygiene is not performed when entering or exiting a room (not flashing green and vibrating as a prompt to perform hand hygiene)	Increase in hourly hand hygiene activity rates between baseline (no prompting to perform hand hygiene or visual status indicator) and intervention phase (enabled prompting and status indicator) ($P < .004$); sustainability: in the postintervention phase, a hand hygiene activity rate of 4.39 per h was assessed compared with a rate of 2.78 in the preintervention phase (in both the preintervention and postintervention phases, a visual status indicator was enabled, but the prompting feature was disabled)

Table 2 (*Continued*)

Author	Year (location)	Aim of the study	Research approach	Study design	Description of behavior monitoring system innovation	System–human communication	Main findings regarding the influence on hand hygiene adherence
Marra et al[31]	2014 (Brazil)	To evaluate the effectiveness of real-time feedback in improving hand hygiene compliance	Quantitative	Quasi-experimental, case-control	Wireless identification device without communication function (badge); electronic dispensers capable of detecting the badge; wall-mounted sensor to create a radiofrequency safety zone (where hand hygiene needs to be performed)	Red or green light above patient bed, indicating if the healthcare worker performed hand hygiene before entering the patient zone	Intervention group: increase in hand sanitizer usage per patient d between baseline (68.9 mL) and intervention (103.1 mL) (P = .04); intervention phase: no significant increase in hand sanitizer usage per patient d between intervention group (103.1 mL) and control group (80.7 mL; increase in mean number of dispensing episodes per patient d between control (89.9) and intervention phase in intervention unit (105.5) (P = .030); increase in mean number of dispensing episodes per patient d between control unit (89.22) and intervention unit after implementing the innovation (105.5) (P = .002); described that costs were seen as a major barrier in the expansion of using this kind of technology; stated their study-related costs were about US \$50,000
Marra, Edmond[14]	2014 (Brazil)	To discuss new technologies for monitoring hand hygiene compliance (our review focuses on electronic systems for monitoring hand hygiene)	Review	Review	-//-	-//-	One study described an increase in hand hygiene compliance of 6.8% between intervention and control group; these technologies were limited in use because they were expensive and generated high maintenance costs; these costs potentially decrease over time
Fisher et al[32]	2013 (Singapore)	To validate an electronic monitoring system for measuring hand hygiene compliance	Quantitative	Randomized controlled trial	Ultrasound protection zone transmitter; wireless tags (badges that register entry/exit of a patient room and dispenser usage); electronic hand rub dispensers; wireless reader unit (badges that transmit data to the unit, which transmits data to a server)	Wireless tags (badges) are able to emit a beep sound if hand hygiene is not performed	Increase in compliance at "entry" of 6.4% (P = .001) between control and intervention group*; increase in compliance at "exit" of 6.4% (P = .002) between control and intervention group*
Levchenko et al[33]	2013 (Canada)	To assess the efficacy of electronic reminder and monitoring systems on hand hygiene performance	Quantitative	Longitudinal observational study (141 d)	Wearable badges that record the entry and exit of a specific area and the usage of dispensers; infrared beacons that define the area where hand hygiene needs to be performed; dispensers that can communicate with the wearable badges	Wearable badges with active communication function when hand hygiene is not performed when entering or exiting a room (not flashing green and vibrating as a prompt to perform hand hygiene)	Real-time hand hygiene prompting and a status indicator (light) seem to be important factors in increasing hand hygiene compliance; increase in hand hygiene actions per h when real-time hand hygiene prompting is activated: 2.97-6.61

NOTE. Research question 1: What influence do new technological behavior monitoring innovations have on hand hygiene adherence in healthcare professionals? Research question 2: Which factors are relevant with respect to the acceptance of technological behavior monitoring innovations that improve hand hygiene adherence in healthcare professionals?
LCD, liquid crystal display; *LED*, light emitting diode; *RFID*, radio frequency identification.
*Both analyses excluded the multivariate analysis baseline; the authors strove for wording similar to that used by the original authors.

Table 3
Studies presenting relevant factors with respect to the acceptance of technological behavior monitoring innovations, sorted by publication year

Author	Year (location)	Aim of the study	Research approach	Study design	Description of behavior monitoring system innovation	System−human communication	Main findings regarding the acceptance of technological behavior monitoring innovations that improve hand hygiene adherence
Ellingson et al[34]	2011 (United States)	To assess familiarity and comfort level with and perceived impact of sensor-based hand hygiene adherence monitoring	Mixed methods	Structured focus group interviews (qualitative and quantitative)	Focus group participants should imagine a hypothetical, small, wearable device that can track entry and exit of a patient care area and record hand hygiene actions and is able to perform user feedback	–/–	Potentially negatively influencing factors regarding comfort with new oversight technology innovation are the accuracy of data produced by the device, how data are used in a later process, and a potential lack of information about the innovation; frontline healthcare personnel in particular stated that transparency in the implementation phase would potentially lead to more acceptance of the device
Boscart et al[35]	2008 (Canada)	To assess the acceptability and usability of a wearable electronic device in a clinical setting	Qualitative	Structured focus group interviews (qualitative and quantitative)	Questioning based on a wearable electronic monitor that can track entry and exit of a defined patient zone and is able to communicate with dispensers and track their activation	System is able to prompt a signal if required	The authors suggest that healthcare workers should be asked to wear the device voluntarily for a couple of weeks, prior to any tracking and recording, to increase their level of habituation; the way in which collected data are used needs to be transparent before introducing a device; reports of performance should be personal and confidential; accessibility and confidentiality of collected data need to be focused and communicated to the user

NOTE. Research question 1: What influence do new technological behavior monitoring innovations have on hand hygiene adherence in healthcare professionals? Research question 2: Which factors are relevant with respect to the acceptance of technological behavior monitoring innovations that improve hand hygiene adherence in healthcare professionals? The authors strove for wording similar to that used by the original authors.

and the assessment of accuracy regarding indications relevant to hand hygiene.[35] Other potentially important factors are (1) when and whether reminders are provided, (2) how many reminders are given by the device after a hand hygiene action is missed, (3) how many signal prompts are provided at a specific event, and (4) what kind of signal prompt is given.[35] In light of this, different forms of signals—light, sound, and vibrations—were discussed according to their advantages and disadvantages.[35] One option participants mentioned as very important was the ability to turn off the signals for specific situations (eg, a palliative condition).[35]

Device usability

Usability and ease of use may contribute to sustained implementation of new technological innovations.[35] Specifically, usefulness, as perceived by healthcare providers, was described as an important aspect.[35] Other factors with the potential to influence the usability of devices include size and weight (small and light, respectively) as well as design (ie, devices that are not perceived as obstacles while providing direct patient care).[35]

DISCUSSION

Overall, included studies found technological behavior monitoring innovations to have a potentially positive effect on hand hygiene compliance. Study results were unclear with respect to sustainability of technological behavior monitoring innovations. Communication between the healthcare worker and the technological device—through behavior monitoring systems and real-time feedback—is important for improving hand hygiene adherence. Transparency and confidentiality, user attitude and environment, device function, and device usability were described as key elements in the continued acceptance of technological behavior monitoring innovations.

Seven quantitative studies were identified. Of these, 1 was an RCT, 2 were quasi-experimental studies, and 4 were observational studies.[16,26,27,30-33] The RCT presented the smallest positive effect on improvement in hand hygiene compliance (6.4%) using technological innovations.[32] Furthermore, it was the only study identified that presented a gold standard study design for testing interventions. Both quasi-experimental studies described a significant increase in hand sanitizer usage after implementing the technological innovation.[27,31] One study described a significant ($P < .05$) increase in median hand sanitizer usage in a 6-month intervention period (9,250 mL in the intervention vs 7,035 mL in the control group).[27] Marra et al[31] indicated a significant ($P = .04$) increase in hand sanitizer usage per patient day between baseline (68.9 mL) and intervention (103.1 mL) in the intervention group but no significant ($P = .15$) increase in hand sanitizer usage per patient day between intervention (103.1 mL) and control (80.7 mL) group after implementation of the technological innovation. Four observational studies were identified with observation periods ranging between 28 days and 3 years.[16,26,30,33] The study with the shortest observation period showed the largest increase in hand hygiene compliance (60%-82%).[26] In contrast, the study with the longest observation period showed an increase in hand hygiene compliance of 55%.[16] The 2 studies (141 and 403 days) between the total observation period range (28 days to 3 years) described hand hygiene actions per hour.[30,33] One study presented an increase in hourly hand hygiene actions between a baseline phase (deactivated technological innovation, 2.97 actions) and an experimental phase (fully activated technological innovation, 6.61 actions).[33] The authors described these changes with descriptive statistics only.[33] The observation period was 141 days.[33] Levchenko et al[30] indicated a significant ($P < .004$) increase in hourly hand hygiene actions between baseline and intervention, with 403 observation days.

Overall, the quantitative studies discussed the positive effects of technological behavior monitoring innovations on hand hygiene adherence; however, studies with more controlled methodological approaches are needed. Of importance is the method of communication between end users and behavior monitoring technology. One factor contributing to the effectiveness of behavior monitoring systems may be the mere presence of the device itself which tends to increase the effect potentially more if the respective device actively communicates nonadherence.[16] Active communication in the form of direct personal feedback between the device and the healthcare worker may improve hand hygiene adherence through the process of *achievement motivation.* If the personal accomplishment is noticeable to others, this type of motivation potentially leads to an increase in intrinsic motivation.[36]

The type of communication may also be an indicator for improvements in hand hygiene adherence sustainability. As stated above, study results were unclear regarding sustainability. The only study not able to confirm sustainability of the effect of improved hand hygiene adherence after removing the innovation used elective communication functions.[16] This means that system−human communication through the technological innovation was possible but optional. This leads to the hypothesis that active communication between technology and the healthcare worker through the technological behavior monitoring innovation results in a more sustainable improvement in hand hygiene adherence.

Direct observation is perceived as the gold standard for assessing hand hygiene adherence.[6] However, the studies included in this review indicate that technology can monitor and improve—possibly through the ability to communicate with the user—hand hygiene adherence.[14,16,26-33] By improving adherence, technology holds the potential for better patient outcomes.[3] Thus, new technological behavior monitoring innovations may affect hand hygiene adherence rates; therefore, these innovations should be further developed, sustainably implemented, and evaluated for their infection prevention purposes. In this context, the potential Hawthorne effect needs to be addressed, as the awareness of being directly observed may potentially lead to better hand hygiene behaviors in healthcare workers.[12] However, technological behavior monitoring innovations have demonstrated the ability to monitor hand hygiene without the involvement of another human being.[14,16,26-33] Therefore, in the context of observing hand hygiene adherence, these innovations may have the potential to reduce the bias caused by the Hawthorne effect.

The results presented regarding the second research question (ie, relevant factors with respect to acceptance) identify key aspects that can be discussed in the context of the adapted technology acceptance model as it relates to hand hygiene.[17] This model describes 5 factors leading to the acceptance of technology, namely the perceived ease of use, confidence of use, perceived usefulness, satisfaction of use, and behavioral intention.[17] This review identified 4 factors as potentially important in the acceptance of technological behavior monitoring innovation: transparency and confidentiality, user attitude and environment, device function, and device usability. The technology acceptance model and the identified factors of this rapid review have certain similarities, further supporting the significance of the results presented. Yet, in assessing acceptance, a major difference between the 2 involves when behavior monitoring is stressed—prior to technological implementation (eg, transparency and confidentiality) in this rapid review and after implementation in the technology acceptance model.

The identified literature mainly used the term *compliance* rather than *adherence.* With respect to the acceptance of technological behavior monitoring innovations, the use of these terms seems to be crucial. This review identified 4 categories with the potential to improve later acceptance of the technology: transparency and confidentiality, user attitude and environment, device function, and

device usability. Therefore, the term *adherence* seems to be the appropriate 1, as it includes an educational process.[9] This educational process potentially results in healthcare workers' understanding of the importance of the action asked to perform (eg. performing hand hygiene), as part of a bilateral process of negotiation.

LIMITATIONS

This study has several limitations. Despite an extensive search strategy, because of the methodology of a rapid review and the rapidly expanding field of research, all relevant literature may not have been found. This poses a risk for the publication bias of rapid reviews, as described by Ganann et al[21] In addition, only electronically-published publications written in English and German were found, possibly leading to a language publication bias.[21] Despite these potential limitations, the rapid review methodology has been demonstrated to be appropriate for evidence synthesis, in limited timeframes, within the context of the speed of current healthcare technology development. Kaltenthaler et al[37] and Khangura et al[38] have also stated that rapid reviews are especially important in the field of health technology assessment for supporting informed decision-making in a short period of time. Overall, rapid reviews are not limited to the field of health technology assessment but to situations in which timely decisions regarding new healthcare technologies are required[37]; this was the main goal of this rapid review.

In the review process, we used an inclusive approach that involved the inclusion of different study designs. This led to heterogeneity of the included studies. Because of this procedure, no meta-analysis was performed. Instead, an in-depth analysis and description of the included studies were presented. We followed the rapid review method, but we did not limit publication years, geographic regions, or number of databases. However, the completeness of identified studies is potentially determined by the time constraints inherent in this rapid review. Neither a hand search nor a search for unpublished and gray literature was performed. Overall, the identified studies point to a developing field that needs to be addressed in future research using high-quality research designs.

CONCLUSIONS

The included studies demonstrated the potential for better patient outcomes via improvement in hand hygiene adherence through technological innovations. However, prior to implementation, understanding the critical key elements identified (transparency and confidentiality, user attitude and environment, device function, and device usability) regarding the acceptance of technological behavior monitoring innovations is crucial for success.

APPENDIX 1

Search term used in Scopus:
((TITLE-ABS-KEY(innovation) OR TITLE-ABS-KEY(tracking) OR TITLE-ABS-KEY(technic intervention) OR TITLE-ABS-KEY(rfid) OR TITLE-ABS-KEY(radio frequency identification) OR TITLE-ABS-KEY(ble) OR TITLE-ABS-KEY(bluetooth low energy) OR TITLE-ABS-KEY(rtls) OR TITLE-ABS-KEY(real time locating system) OR TITLE-ABS-KEY(smart tracker) OR TITLE-ABS-KEY(technology)))
AND
((TITLE-ABS-KEY(acceptance) OR TITLE-ABS-KEY(facilitators) OR TITLE-ABS-KEY(facilitator) OR TITLE-ABS-KEY(facilitate) OR TITLE-ABS-KEY(promoters) OR TITLE-ABS-KEY(adherence) OR TITLE-ABS-KEY(inhibitors) OR TITLE-ABS-KEY(inhibitor) OR TITLE-ABS-KEY(non-adherence) OR TITLE-ABS-KEY(non-adherence) OR TITLE-ABS-KEY(compliance) OR TITLE-ABS-KEY(noncompliance) OR TITLE-ABS-KEY(barrier) OR TITLE-ABS-KEY(non-compliance) OR TITLE-ABS-KEY

(promoting) OR TITLE-ABS-KEY(facilitating) OR TITLE-ABS-KEY(inhibiting) OR TITLE-ABS-KEY(accepting)))
AND
((TITLE-ABS-KEY(hygiene) OR TITLE-ABS-KEY(infection control) OR TITLE-ABS-KEY(hand hygiene) OR TITLE-ABS-KEY(hand disinfection) OR TITLE-ABS-KEY(hand wash) OR TITLE-ABS-KEY(hand washing) OR TITLE-ABS-KEY(hand infection)))
AND
((TITLE-ABS-KEY(healthcare) OR TITLE-ABS-KEY(nursing) OR TITLE-ABS-KEY(nurse) OR TITLE-ABS-KEY(physician) OR TITLE-ABS-KEY(medicine) OR TITLE-ABS-KEY(icu) OR TITLE-ABS-KEY(intensive care unit) OR TITLE-ABS-KEY(mechanical ventilation) OR TITLE-ABS-KEY(respirator care)))
AND
(LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "German"))

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