Healthcare workers' hand hygiene
- interventions to improve hand hygiene compliance with data from a monitoring system

PhD dissertation

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Preface

The PhD dissertation is based on studies conducted during my enrolment at the Graduate School of Health at Aarhus University and the Department of Oncology at Aarhus University Hospital from 2021 to 2024.

The dissertation is based on the following six papers. The dissertation will refer to the papers by their Roman numerals (I-VI).

Paper I:
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Paper II:
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Paper III:
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Paper IV:
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Hand hygiene compliance in nursing home wards measured with an automated hand hygiene monitoring system – the effect of increased accessibility of alcohol-based hand rub
Submitted to Journal of Hospital Infection, Under review, 2023 [4]

Paper V:
Iversen AM, Hansen MB, Münster M, Kristensen B, and Ellermann-Eriksen S
Hand hygiene compliance in nursing homes measured with an automatic hand hygiene monitoring system – the effects of feedback with lights on alcohol-based hand rub dispensers
Submitted to American Journal of Infection Control, Under review, 2024 [5]

Paper VI:
Iversen AM, Hansen MB, Münster M, Kristensen B, and Ellermann-Eriksen S
Individual feedback on hand hygiene compliance data in nursing homes
Manuscript in preparation [6]

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Competing interests to declare

Marco Bo Hansen MD, PhD, was employed with Konduto ApS, the developer of the Automatic Hand Hygiene Monitoring System, Sani Nudge™. The other authors have no competing interests to declare.

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Anne-Mette Iversen, January 2024

Contents

Abbreviations

Abbreviation	Definition
HAI	Healthcare-acquired infection
HCW	Healthcare worker
HH	Hand hygiene
HHC	Hand hygiene compliance
ABHR	Alcohol-based hand rub
AHHMS	Automatic hand hygiene monitoring system
COVID-19	Coronavirus disease 2019
CI	Confidence interval
PPV	Positive predictive value
IP	Infection preventionist
SSI	Statens Serum Institut (National Centre of Infection Control)
WHO	World Health Organization

1. Introduction

"If you cannot measure it, you cannot improve it"

Lord Kelvin

This thesis is based on original studies completed during my enrolment at the Graduate School of Health at Aarhus University. The research journey began in 2015 when I was employed at the Department of Oncology at Aarhus University Hospital. I worked as a clinical nurse specialist, and one of my tasks was to improve infection prevention in the department. I realized that we needed a better method for data collection to be capable of evaluating interventions to improve hand hygiene in clinical practice. Therefore, I took the initiative to develop an automated hand hygiene monitoring system (AHHMS) in close collaboration with behavioural expert, Morten Münster, and two engineers, Theis Jensen and Morten Egholm, from the Technical University of Denmark. The aim was to develop a system capable of collecting big data 24/7, specifically categorised into room types and staff groups. After the first version and pilot test, we realized that this was something special, and we included one more department, located at Bispebjerg University Hospital, to participate in the development. Infection preventionists (IP), microbiologists and leaders were invited into the process to ensure that we created the best possible system. An overriding purpose of our endeavour was to make the AHHMS fit the clinical workflow instead of having the HCWs change their workflow to make the AHHMS work. Therefore, the AHHMS was developed in close collaboration with clinicians, leaders and IPs.

In 2018, the AHHMS was ready to be implemented in the clinical practice. The AHHMS collects big data. However, the data themselves do not improve hand hygiene. The next step was therefore to investigate how to use the data in real-world clinical practice. Together with Svend Ellermann-Eriksen, Marco Bo Hansen, Morten Münster and Brian Kristensen, we planned this PhD project, investigating the effects of different interventions to improve hand hygiene among healthcare workers (HCWs) in hospitals and nursing homes.

The implementation of the AHHMS began at the beginning of February 2020. Due to the coronavirus disease 2019 (COVID-19) that hit Denmark, the installation was postponed. The implementation resumed in May 2020 and data were collected from the beginning of July 2020. I hope that the readers will keep in mind that hand hygiene compliance data were collected during the COVID-19 pandemic; a special time for HCWs with multiple, continual changes in guidelines and routines, and an extremely high workload.

It must be kept in mind that this project originates from clinical practice and not from a study setup. The PhD study was initiated by an oncology nurse who devised an idea to improve practice.

2. Background

2.1. Healthcare-acquired infections in hospitals and nursing homes

HAIs[1] are infections that patients or residents acquire while being admitted to hospital or other healthcare facilities. HAIs are acknowledged to be one of the most frequent adverse events in healthcare [7, 8]. According to the WHO, the prevalence of HAIs is estimated to be in the range of 3.5-12% in high-income countries and 5.7-19% in low-income countries [9, 10]. Due to the difficulties of collecting and gathering reliable data on HAIs, the global HAI burden remains unknown. Given the likelihood of significant under-reporting, the aforementioned estimates may represent only a small fraction of the actual number of infections [9]. However, compelling evidence indicates that hundreds of millions of patients worldwide are affected by this issue every year [10-17].

The impact of HAIs implies prolonged hospital stays, long-term disabilities, antimicrobial resistance, high costs for patients and relatives, and excess deaths. Furthermore, HAIs impose a substantial additional financial burden on healthcare systems [7, 15, 18].

The risk factors for HAI include length of hospital stay, comorbidities, immunosuppression, frequent visits to healthcare facilities, recent invasive procedures, indwelling devices, mechanical ventilation support and stay in an intensive care unit [19]. The risk depends on the infection control practice at the facility and the prevalence of various pathogens within the community [19]. Furthermore, older age is a risk factor as elderly people are vulnerable to infections due to a weaker immune system, comorbidities and weakness in important infection barriers, including skin thinning, diminished cough reflex and impaired bladder and emptying capacity [20].

In European nursing homes, 50% of the residents are older than 85 years of age [21]. Nursing homes are unique environments for infection transmission due to a homelike environment where microorganisms can easily be transmitted via shared facilities; a situation that is exacerbated by the elderly residents' frailty [22]. According to a point prevalence study from 2017, 3.7% of residents living in European nursing homes have at least one HAI on a given day [21]. For nursing homes in Denmark, the HAI prevalence was reported to be 5.2% [21]. Infection prevention is crucial in these facilities because an increasing number of residents in high-income countries are living in nursing homes owing to a longer life expectancy and as a result of incentives to discharge patients from hospitals sooner [7, 23].

[1] According to the "Report on the Burden of Endemic Health Care-Associated Infection Worldwide, WHO", HAI can be defined as: "An infection occurring in a patient during the process of care in a hospital or other health-care facility which was not present or incubating at the time of admission. This includes infections acquired in the hospital, but appearing after discharge, and also occupational infections among staff of the facility" [7].

For the past few decades, and especially throughout the COVID-19 pandemic, the problem of HAIs has been taken more seriously globally. However, HAIs appear to be a hidden, cross-cutting problem that no country or institution can claim to have solved [7, 8].

2.2. Hand hygiene in infection prevention

HH is considered the cornerstone of infection prevention, and it is widely believed that HAIs are transmitted mainly through the contaminated hands of HCWs as HH disrupts the chain of transmission [9, 17, 24-28]; hence giving rise to strong claims that high HHC among HCWs can drastically reduce HAIs [29, 30]. The persistent underlying message is “the higher HHC, the better”. However, some critical voices argue that little clinical evidence exists to support this claim [25, 30-32]. Critics contend that robust evidence supports the reduction of pathogen carriage through hand decontamination, but strong evidence is lacking that improving HHC reduces HAIs. They claim that the widely held belief that HH is the cornerstone in preventing HAIs is more the result a logical reasoning than being firmly grounded in robust evidence [33]. However, conducting properly designed studies on this topic poses challenges, and more homogeneity in study approaches and a more robust research design are needed. Without a standardized approach to methodology, studies may continue to give different results, hindering the development of evidence-based research [32, 34].

Based on the widely adopted belief that HH is the cornerstone of infection transmission, multiple studies have investigated interventions to improve HH among HCWs in hospitals and other healthcare settings [9, 25-27, 35]. Although HH seems simple, HHC rates remain suboptimal. A review from 2010 reported an average HHC among HCWs of 40% [36]. The review and the reported mean 40% compliance rate are often referenced in studies on this subject [37]. HHC rates may have improved in the ensuing years, although low rates remain a challenge in many facilities [25, 26, 38, 39]. Reported HHC rates vary tremendously, from less than 25% to more than 90%, with numerous factors affecting compliance rates including the healthcare setting (hospital vs. long-term care facility), country, workplace culture, type of procedure, profession, outcome measures and methods for measuring HHC [26, 38, 40-44]. Most interventional studies are conducted in hospital settings. However, with a growing population in high-income countries residing in nursing homes, the problem with HAIs has become clearer within these settings. Only a relatively few studies have reported HHC rates from nursing homes and the reported HHC rates vary considerably (17% to 79%) depending on the nursing home, specific wards and methods for monitoring HHC [40-43, 45].

Factors associated with low HHC encompass time constraints caused by understaffing, overcrowding and high workload, workplace culture, low accessibility to HH supplies, using gloves as a substitute and inconvenient placement of HH supplies. Furthermore, HHC is also evidently higher *before* touching a patient than *after* touching a patient, and among nurses than physicians [9, 26, 37, 38, 44, 46-48]. In nursing homes, an important barrier is reported to be the constant effort to balance competing goals of maintaining HH, preserving social care and a establishing home-like environment [22].

Even during the COVID-19 pandemic, where the level of societal attention devoted to HH was heightened, several studies found no consistent improvements in HHC [48-50]. However, some studies reported temporary improvements in the HHC rates during societal lockdowns but with a subsequent return to baseline rates after a relatively short period [51-53]

This dissertation investigates HHC in Danish nursing homes and hospital wards. To the best of our knowledge, there are no reported HHC rates from nursing homes in Denmark. However, some recent studies from hospital wards in Denmark report HHC rates using the same methodology for data collection, making the overall baseline HHC rates comparable. The reported baseline HHC rates are within the range of 16% to 52% [44, 50, 54-57]. Some of the studies report HHC rates stratified into patient rooms and working rooms, with a significantly lower HHC in patient rooms than in working rooms [44, 54, 57]. This highlights the importance of reporting HHC according to room type rather than merely presenting pooled data.

2.3. Monitoring hand hygiene

A systematic review of systematic reviews of interventions to improve HH identified different methods used to measure HHC: 1) direct observations, 2) video cameras, 3) mobile handheld devices, 4) AHHMS, 5) self-reported data and 6) proxy measures such as ABHR consumption [35]. Direct observation of HCWs by trained observers is considered the golden standard for measuring HHC and is by far the most common method for monitoring HHC [58-61]. Although this method has several unique advantages, it also has some disadvantages [61] (Table 1). These disadvantages have fuelled interest in developing AHHMS as an alternative to, or in combination with, the traditional direct observation methods [59]. AHHMS is primarily used to measure HH in hospitals. Only one study has measured HHC with an AHHMS in nursing homes [41]. However, the study monitored HHC among visitors, patients and HCWs as pooled data because the AHHMS lacked the capability to distinguish between these groups due to its movement-tracking technology. Therefore, this dissertation is the first to report studies on HHC levels of HCWs in nursing homes using an AHHMS technology [62].

Like direct observation, an AHHMS also has advantages and disadvantages, presented in Table 1. In an ideal world, according to Boyce et. al., direct observation and an AHHMS could be used in combination; with direct observation focusing on the qualitative measures (HH technique) and an AHHMS capturing quantitative measures (HH opportunities) [35].

Table 1. Advantages and disadvantages of direct observation and automated hand hygiene monitoring systems as described by John M. Boyce [59]

	Direct observations	AHHMS
Advantages	- Measure all five moments of HH - Evaluate the quality of the HH - Serve as a real-time coach/feedback - Identify causes of non-compliance - Evaluate glove use - Can be used in all facilities around the world	- Measuring HH in all work shifts - Unaffected by the Hawthorne effect - Stores large amounts of data - Sufficient and large sample size - Measures HHC in all room types - Data are automatically analysed
Disadvantages	- Staff time and expenses - Time-consuming and challenging - Captures only a small fraction of the opportunities (insufficient sample size) - Hawthorne effect - Selection bias - Difficult to find observers on night shifts and weekends - Limited to selected room types/situations due to privacy - Many aspects of performing observations vary tremendously, making comparison of HHC difficult	- Expensive - Measures only a few of the WHO's five moments of HH - Staff question the accuracy of the system - Staff feel watched - Only quantity measures, no qualitative measures

Several AHHMS have been developed throughout recent years. Generally, they functions by automatically collecting HH data based on algorithms and presenting data to the HCWs. However, the systems work in different ways, as described by Gould et al. [62] (Table 2), and it is important to be aware of these difference.

Table 2. The function of five types of AHMMS based on the definition from Gould et al. [62].

Type of AHHMS	Measurement function
Type 1	Measures consumption as a proxy for HHC. Opportunities are not measured. Cannot distinguish between HCWs, patients and visitors.
Type 2	Measures the number of people passing certain strategic points in a ward as an indicator of opportunities. Cannot distinguish between HCWs, patients and visitors.
Type 3	Measures HHC using individual badges or other means to identify individuals. Detects movement in and out of rooms as a proxy for HH opportunities. The systems cannot detect movement between beds in the same room, nor repeated need for HH within the same room.
Type 4	Capable of detecting movement between beds by placing beacons on/near the beds to generate bed zones. It can detect presence within these zones but not movement within the zones, nor detect movements outside of the various zones.
Type 5	High-resolution indoor positioning technology that enables continuous detection of movement with arm-length precision throughout the applicable areas of the ward. This allows the system to follow individuals during their workflow and consider the previous work task. The system can measure HHC in different room types in a ward.

2.4. Development of an automated hand hygiene monitoring system

In 2015, the development of a type-five AHHMS began at Aarhus University Hospital in Denmark. A specific objective of the AHHMS was to be capable of measuring HHC in a complex clinical setting by following the HCWs during their workflow and taking their previous work tasks into account. This is important in a clinical setting as HH is conducted within a complex real-life setting encompassing multiple work-related tasks. The system is one of the few type-five systems capable of monitoring individual HCW's HHC [63]. The AHHMS is described in detail in the Method section.

A new AHHMS must be validated in clinical practice to be widely adopted [64-66]. For technical systems, HH actions are less challenging to detect than HH opportunities [60]. A review found that only 20% of the AHHMS included accuracy calculations [67]. In Denmark, the only AHHMS used is the Sani Nudge™ system. The system was previously validated in a German hospital under simulated conditions [68]. A validation under simulated conditions evaluates HH opportunities/actions that the system is developed to take into account. However, an evaluation of whether the AHHMS can capture and measure HHC while taking the clinical workflow and variation into account during real clinical conditions was lacking.

2.5. Interventions to improve hand hygiene

A major challenge in healthcare systems is how to improve and sustain HHC among HCWs. Hundreds of studies have investigated interventions to improve HHC, and multiple reviews have been conducted. To get an overview, a systematic review of systematic reviews was conducted by Price et al. in 2018 [35]. The review concluded that evidence is sufficient to recommend interventions to improve HH but insufficient to make specific recommendations about the specific interventional contents [35]. The review found predominantly low-quality evidence that interventions to improve HH are effective. The wide range of reported HHC rates may be explained by study design heterogeneity which hampers comparison of results [25, 30-32]. Only one of the included reviews had a low risk of bias. This was a Cochrane review of Gould et al. from 2017. They reported an escalating interest in scientific publications on interventions to improve HHC from 2009 to 2017 and found considerable variation in results between studies and within the same study, and between different wards and centres [29]. The Cochrane review found that the most studied interventions for improving HH were [17]:

- Strategic placement of alcohol-based hand hygiene products
- Education of HCWs
- Cues (written and verbal)
- Performance feedback

Most of the interventions were found to increase HHC, but the certainty of evidence varied from very low to moderate. The review concluded that it remains unclear which strategy or combination of strategies is most effective in a given context [17].

2.6. WHO multimodal strategy to improve hand hygiene

According to the WHO's "Guidelines on Hand Hygiene in Health Care", successful and sustained HHC improvement is achieved by implementing multiple actions, suggesting a synergistic effect [16].

The WHO's multimodal strategy recommends five core components to make up an effective strategy for HH (Figure 1) [69]. The five components are: 1) system change, 2) training and education, 3) monitoring and feedback, 4) reminders and communication and 5) safety climate/culture change (Figure 1). Each component is equally important. However, healthcare facilities around the world may have progressed to different levels, and each facility must identify the most relevant component to improve HH [69].

Multimodal combinations of different interventions may have the potential to improve and sustain HHC. However, this combinatorial diversity contributes to diversity in methodological designs, hampering comparison of results. A Cochrane review from 2017 concluded that an urgent need exists to conduct methodologically robust research to explore the effectiveness of multimodal interventions vs simpler interventions in improving HHC [29].

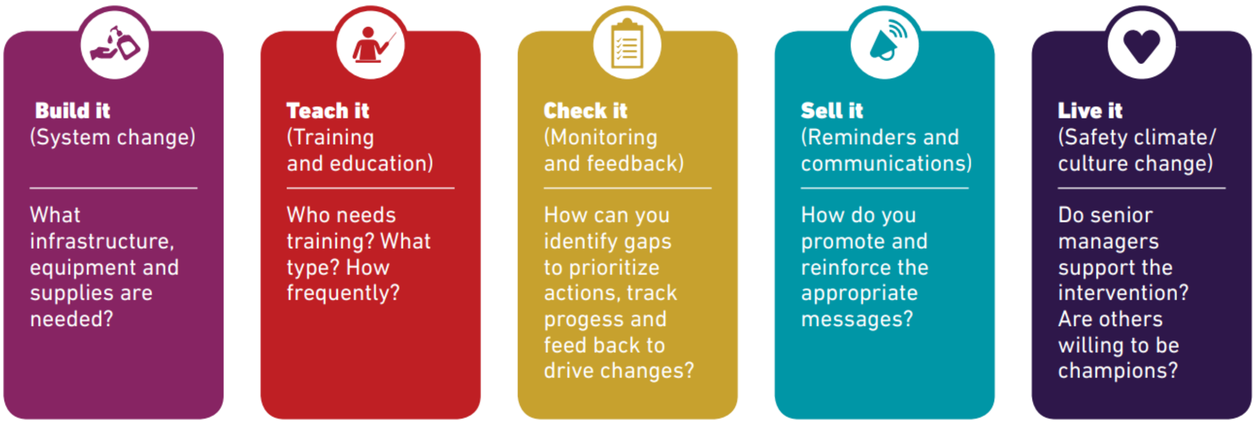


Figure 1. The WHO's multimodal hand hygiene improvement strategy [8].

In this dissertation, we focus on monitoring HHC (element 3) as emerging evidence holds that monitoring HHC with AHHMSs has the potential to improve HHC rates when combined with complementary strategies [54, 70-74]. Furthermore, monitoring HHC is a prerequisite to evaluate the effects of interventions of the other components in the multimodal strategy. Therefore, implementing a monitoring technology to evaluate interventions in clinical practice is an important step towards further improvements. Furthermore, the dissertation focuses on "system change" (element 1), "feedback" (element 3) and "reminders" (element 4) as the dissertation investigates interventions within these elements.

2.7. Hand hygiene guidelines

The WHO's guidelines on "My Five Moments for Hand Hygiene" set out a framework for understanding, training, monitoring and reporting HHC [75]. The five moments are widely adopted and often referred to in the literature. To be effective, HH should be performed at these five specific moments: 1) "before touching a patient", 2) "before clean/aseptic procedure", 3) "after body fluid exposure risk", 4) "after touching a patient" and 5) "after touching patient surroundings" (Figure 2).

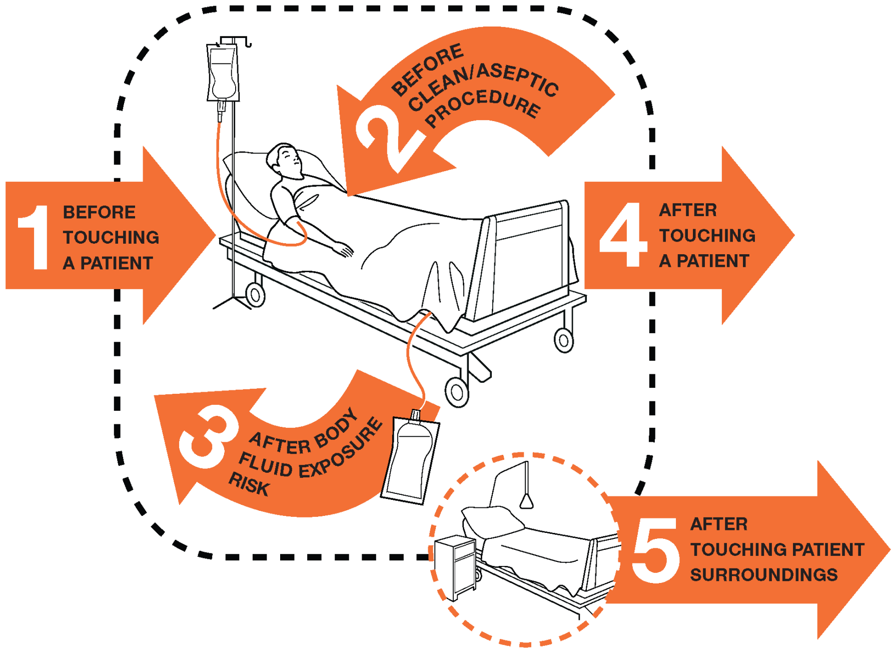


Figure 2. The WHO's 5 moments of hand hygiene. Copyright WHO [76]

2.8. Alcohol-based hand rub over soap and water

Over the past 20 years, a paradigm shift has occurred in HH with the transition from hand washing (soap and water) to using ABHR. Evaluation of ABHR as an alternative to soap and water began in the late 1970s, and evident advantages of ABHR over soap and water resulted in the updated version of the WHO's Guidelines on Hand Hygiene in Health Care from 2009. In the guideline, ABHR was preferred over soap and water. Today, strong evidence underpins that ABHR is (generally) more effective in stopping transmission of pathogens than hand washing with soap and water. Furthermore, performing HH with ABHR is less time-consuming, can be made available at the point of care and is generally better tolerated by skin than soap and water. The shift from soap and water to ABHR is seen as a revolutionary system change in infection control [24, 26] and has been widely adopted in Danish healthcare facilities [77].

Many challenges to HH implementation have been recognised [78]. Few studies have incorporated theoretical underpinning, and the best way of encouraging compliance therefore remains unknown. Behavioural theories may help guide interventions and achieve the desired cultural change in hospitals [79].

2.9. Behavioural science

In *an ideal world*, HCWs would base their decisions (whether to perform HH or not) on best practices, evidence and guidelines [80]. However, in *the real world*, human behaviour is more complex. In clinical practice, HCWs need to make decisions while facing understaffing, cognitively demanding routines and behaviour, high workloads and a myriad of choices and situations, all of which affect their decision-making, especially under stress [9, 81, 82].

The field of behavioural science offers a theoretical underpinning to understand why it is so difficult to make clinicians change their behaviour in a complex *real-world* clinical practice. The traditional approach to behavioural change has largely assumed that people are perfectly rational decision-makers. In other words, providing people with rational information will make them address decision alternatives, calculate the probability of the utility value of different actions and then decide what to do. However, recent behavioural research suggests that in many cases HCWs' decision-making is not perfectly rational [83, 84]. Instead of being perfectly rational, decision-making results from the interaction between two cognitive processes (called "dual process theory") that operate in parallel; one reflective and the other automatic (habits) [84]. This means that our brain has limited capacity (called 'bounded rationality') to process information. People are therefore constantly intellectually challenged because of the large amount of information they must handle. Consequently, they use cognitive shortcuts to simplify the complex task of processing information, which may lead to cognitive biases (systematic and predictable errors in judgement) [82]. This explains why information alone often is not enough to make people change their behaviour [85]. The field of behavioural science has mapped out how people are affected by systematic and predictable cognitive biases. By drawing upon these biases, people may be steered in a certain direction (e.g., following a guideline).

Multiple cognitive biases are reported [84]. Some of the reported cognitive biases that may affect HH are [84, 86, 87]:

- *Overconfidence bias* (the belief that one's abilities surpass quantifiable measures and the median of a group)
- *Salience bias* (focus on information or items that are especially salient in the environment while overlooking other out-of-sight factors)
- *Path of least resistance* (people are hardwired to choose the easy option that requires the least effort)

- *Present bias* (people tend to place disproportionate weight on immediate costs compared to future benefits).

Based on this insight, interventions to change HCWs‘ HH behaviour may benefit by moving beyond a focus on rational strategies (information) towards considering the context within which HCWs act (*the real world*), which is influenced by cognitive limitation and decision errors [88].

Nudging strategies have been suggested as a strategy to influence decision-making by targeting these cognitive biases [88]. Nudging can be defined as subtle changes in how choices are presented that can significantly influence a decision-maker’s behaviour in predictable ways without restricting choices or changing economic incentives [84]. Nudges have increasingly shown promise in promoting adherence to clinical guidelines [80, 89, 90]. In particular, nudging studies targeting HHC have been shown to be successful [80]. Scientific studies have found effective induction of behavioural change in individuals may be achieved by nudging, such as reminding, immediate personalised feedback on behaviour and making it easy for people to do the right thing [91, 92].

3. Aim and Hypotheses

The overall aim of this dissertation was to investigate the effects of behavioural interventions on HCWs' HHC in hospital wards and nursing homes. It was a specific aim to measure HHC with an AHHMS and to use the built-in lights and the collected data for interventions. In other words, we aimed to investigate the effect of using an AHHMS on HCWs' HHC in a real-life practice. This dissertation is based on the specific objectives listed below.

Study I:

The study aimed to evaluate the accuracy of the AHHMS during real-life clinical conditions in different in-patient wards at a hospital. We hypothesised that the system would correctly report HHC in relation to the WHO´s Moments 1, 4, and 5.

Study II:

The study aimed to investigate the effects of reminder and feedback lights on ABHR dispensers on HCWs' HHC. We hypothesised that feedback lights would increase HCWs' HHC and that HHC would decrease when the lights were switched off.

Study III:

The study aimed to investigate the effects of group and individual feedback on HHC in hospital wards. We hypothesised that both group and individual feedback would increase HCWs' HHC, but that the increase would be larger in the group receiving individual feedback in addition to group feedback than in the group receiving only group feedback.

Study IV:

The study aimed to investigate the effect of increased accessibility to ABHR in nursing home wards. We hypothesised that HHC would increase in the residential apartments when implementing one extra ABHR in the hallway of the apartment compared to having only a single ABHR placed in the residential restroom.

Study V:

The study aimed to investigate the effect of feedback light on HCWs' HHC in nursing home wards. We hypothesised that feedback lights would increase HCWs' HHC and that HHC would decrease when the lights were switched off.

Study VI:

The study aimed to investigate the effects of individual feedback on HCWs' HHC in two nursing homes (nine wards). We hypothesised that HHC among HCWs would increase while receiving individual feedback.

4. Methods

This section will present the materials and methods of one validation study and five prospective, interventional studies. Table 3 gives an overview of six studies.

Table 3. Overview of study designs, cohorts, number of HHC opportunities and number of participants included.

Study	Study design and cohort	No. of opportunities	No. of participants
I	A validation study investigating the accuracy of the AHHMS (Sani Nudge™) in hospital in-patient departments	103	25
II	An 11-month prospective, interventional study investigating the effect of reminder and feedback light on HCWs' HHC in hospital departments	231,039	241
III	An 11-month prospective, interventional study investigating the effect of group and individual feedback on HCWs' HHC in hospital departments	231,022	187
IV	An 11-month prospective, interventional study investigating the effect of increased accessibility to ABHR in residential apartments in a nursing home	341,078	159
V	A five-month prospective, interventional study investigating the effect of feedback light on HCWs' HHC at a nursing home	21,042	64
VI	A six-month prospective, interventional study investigating the effect of individual feedback on HCWs' HHC at two nursing homes	144,354	198

4.1. Study subjects

Studies I, II and III collected data from four in-patient wards at two departments at Aarhus University Hospital, Denmark; two haematology in-patient wards and two oncology in-patient wards. Throughout the dissertation, the two departments will be named Department 1 (two-bed wards) and Department 2 (two-bed wards). In total, the four wards had 64 patient rooms (60 single patient rooms and two twin bedrooms). Physicians, nurses and cleaning assistants were included and distributed into staff groups for analysis. The four wards were chosen as patients admitted to the wards have cancer diseases and an impaired immune system. As a result, patients are at increased risk of HAIs [16].

Studies IV, V and VI collected data from nine wards at two nursing homes. Nursing home 1 was a nursing home in Copenhagen. The nursing home consisted of 150 single apartments (one room) distributed into six wards. Each ward had its own local leader. Nursing home 2 was a nursing home near Aarhus. The nursing home consisted of 76 single apartments (two rooms) distributed in three houses/wards. Each ward had its own local leader. Nurses and nurse assistants were included from both nursing homes. The HCWs primarily worked day shift, night shift and evening shift; and the HCWs were distributed into these work shifts (day shift, evening shift, night shifts, and short-term employed) for analysis.

4.2. Data collection

Data were collected in three different ways; 1) direct observation of HHC (Study I), 2) registration of compliance with interventions and placement of patient beds (Study II, III, VI) and 3) the AHHMS collected big data on HHC (Study I-VI).

The following section will describe the AHHMS and the algorithms used to collect HHC data.

4.2.1. Automated hand hygiene monitoring system

Sani Nudge^{TM} was used to collect HHC data. The system is an advanced type-5 AHHMS according to the classification by Gould et al., which is a real-time location system measuring HHC 24/7 [62]. It consists of sensors located on 1) HCW’s name tags, 2) all ABHR dispensers and 3) walls above the patient beds or in working rooms (Figure 3). The sensors create a network that measures HH opportunities and sanitisation in all ward rooms. This sensor network enables the system to track HCWs during their daily workflow and takes situations and behaviour leading up to and after sanitisations into consideration when calculating HHC. The system uses time and distance measures as part of the algorithms to register the occurrence of an HH opportunity. The system is a proxy measure for the WHO´s Moments 1, 4 and 5. It does not qualitatively distinguish between moments 4 and 5. All HHC data can be assessed through an online dashboard. Only project managers (e.g. leaders or hygiene mentors) have access to the dashboard.

1. ID-Tag
All employees wear a small ID-Tag. Once an employee approaches a patient, it´s being registered through a bluetooth signal.

2. Sani Sensor
The sani sensor tracks hand hygiene behaviour among health care workers. It provides them with feedback to improve their hand hygiene compliance.

3. Gateway
A battery-saving gateway transmits the data from the sensor. It runs up to 2 years without battery replacement.

4. Sani Analytics
Leveraging data to gain deeper insights enables the management to identify potential areas of improvement.

Figure 3. The Sani Nudge™ automated hand hygiene monitoring system.

4.2.2. Algorithms

The system measures HHC based on specific time intervals (algorithms), distance and movement behaviour within the detection zone for each room type in the ward; unclean rooms (e.g., staff restrooms, dirty utility rooms), clean rooms (e.g., medication rooms, clean store rooms) and patient rooms/residential apartments. The algorithms were made together with clinicians, IPs and leaders to ensure that the AHHMS aligns with the clinical workflow. Following Sani Nudge™ privacy policy, the details of the algorithms are confidential.

We chose to monitor HHC based on the local guidelines at each study site as the studies aimed to investigate the effects of different interventions in real-life clinical practice and not to change existing guidelines.

HHC was measured only for ABHR in the hospital and Nursing home 2 as it is considered the cornerstone of hand hygiene. However, Nursing home 1 had sensors on both ABHR and soap as the local guideline for HH in all six wards was to perform HH with either soap and water or ABHR.

4.2.3. Algorithms in nursing homes

In nursing homes, HHC was monitored in residential apartments and staff restrooms. In addition, in one of the nursing homes, HHC was monitored in dirty rinsing rooms. In the residential apartments, HHC was measured by entry and exit to the apartments, meaning that the whole apartment was considered a "patient zone". The decision to monitor HHC upon entry and exit to the apartments was based on the existing guidelines for HH in nursing homes.

4.2.4. Algorithms in hospital wards

In the hospital in-patient wards, HHC was monitored in medication rooms, clean rinsing rooms, clean store rooms, dirty rinsing rooms, dirty store rooms, staff restrooms and patient rooms. In the patient room, HHC was measured by an invisible "patient zone" around the patient's bed (created by the wall sensor above the patient's bed). The "patient zone" functioned as a proxy measure for physical contact between the HCW and the patient or the patient-near surroundings. The "patient zone" was created to monitor to which extent the hospital's existing guidelines for HH were followed. The patient zone allows the HCW to enter and exit the patient room without performing HH (e.g. when they give a short message without touching the patient or the nearby surroundings).

To create the correct "patient zone", the patient's bed should be placed correctly under the wall-mounted bed sensor above the bed. To validate the collected HHC data, we monitored the correct placement of patient beds throughout the data collection period. As a measure, the position of all 64 included patient beds was registered on random days, one to two times a week, throughout the data collection period, using a predefined observation sheet (appendix I). This process was implemented to ensure the validity of the collected data. A figure was used to register whether the patient's bed was placed "correctly" or "incorrectly" (Figure 4). The results are reported in the Results section.

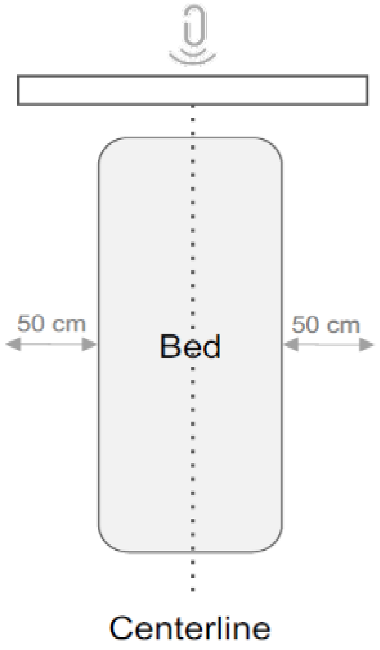


Figure 4. Illustration of the correct placement of the bed.

4.2.5. Data exclusion in hospital wards

During the study periods in the four hospital in-patient wards (Study II and III), the frequency from a hospital bed position system interfered negatively with the AHHMS. This affected the battery status of some sensors, causing the sensor not to send data. To ensure the validity of the data, we made an algorithm allowing us to exclude possibly invalid data from the dataset. Each sensor sends data to "the cloud" in "packages". To avoid invalid data whenever a sensor had not sent a package of data for five consecutive days, we excluded HH opportunities from the affected rooms during the days when no packages had been sent. In total, 43,046 data points from Study II (Table 4) and 35,072 data points from Study III (Table 5) were excluded due to the algorithm for data exclusion.

Table 4. Study II. The number of data points excluded from the study.

Room type	Data points **excluded**	Physicians	Nurses	Cleaning staff
Patient rooms:	31,922	1,672	29,150	1,100
Staff restrooms:	2,107	246	1,566	295
Clean rooms:	1,209	3	722	484
Unclean rooms:	7,808	8	7,150	650
All rooms:	43,046	1,929	38,588	2,529

Table 5. Study III. The number of data points excluded from the study.

Room type	Data points **excluded**	Physicians	Nurses	Cleaning staff
Patient rooms:	18,350	924	15,692	1734
Medication rooms:	10,088	0	9906	182
Restrooms:	1426	115	845	466
Clean rooms:	171	0	164	7
Unclean rooms:	5037	0	3664	1373
All rooms:	35,072	1039	30,271	3762

4.3. Study design and setting

4.3.1. Study I: Clinical evaluation of the AHHMS (Sani Nudge^{TM}) in hospital in-patient wards

On three random days in December 2020 and June 2021, we collected the data from the four in-patient wards at the Department of Oncology and Department of Haematology, Aarhus University Hospital. The study design aimed to compare HH actions and HH opportunities between direct observations and the AHHMS to establish true positive, true negative and false negative events. The study setup did not make it possible to detect true-negative events as a non-event could not be defined in time and place, as described by Limper et al. [93]. Two trained and experienced observers documented HH actions and HH opportunities by direct observation using a predefined and pilot-tested observation sheet (appendix II). The two observers documented each HCW's HH behaviour at the same time. The events were reported in two main categories; (1) HH actions (HCWs' use of ABHR) and (2) HH opportunities (HCWs' physical contact with a patient, patient near surroundings or work zones). In case of discrepancies between the two observers, the event was excluded.

4.3.1.1. Statistics

Direct observation data from the two observers and data from the AHHMS were categorised into three scenarios:

1) True-positive events were defined as actions/opportunities captured by direct observation and the AHHMS.
2) False-positive events were actions/opportunities that were not registered by direct observation but captured by the AHHMS.
3) False-negative events were actions/opportunities registered by direct observation but not captured by the AHHMS.

The truth was defined by the two observers recording the same HH action/opportunity of the HCW. Based on the events, we calculated the sensitivity and PPV. The sensitivity was defined as the probability that a true HH event was captured by the AHHMS. The PPV was defined as the probability that the event captured by the AHHMS occurred. Statistical analyses were conducted using GraphPad Prism (version 9.3.1, GraphPad Inc) and Excel (version 16.47.1, Microsoft).

4.3.2. Study II, III, IV, V, VI: Interventional studies

Five prospective, interventional studies were conducted between July 2020 and May 2022. Each of the five studies had a baseline period and an intervention period. Three studies (Study II, III and V) also had a follow-up period. We considered the need for having a control group that was not subject to interventions to be able to take the effects of other factors into account (e.g. lockdowns during the COVID-19 pandemic). However, it is well established that factors like understaffing, overcrowding, high workload, workplace culture, etc. affect HHC rates in healthcare settings [9, 26, 46, 47]. A control group might therefore not be comparable to the intervention groups. Furthermore, the ward leaders were eager to work with improvements of HHC instead of collecting control data. We therefore decided that the wards should be their own control group.

However, in two of the studies (Study III and VI), we decided to divide HCWs in each ward into two clusters ("No individual feedback" and "Individual feedback") to investigate the effects of individual feedback. The cluster with no individual feedback did not receive the intervention and could be used to monitor tendencies that might affect HHC. However, HCWs from both clusters worked in the same wards. Therefore, we could not isolate the intervention group strictly from the non-intervention group, and the group that received no individual feedback may therefore have been partly exposed to the intervention (e.g. informal discussions in the staff rooms regarding individual HHC rates).

We specifically aimed to investigate interventions that were realistic to implement in clinical practice after the end of this PhD project, pending positive results. Therefore, we had a strong focus on existing guidelines, workflows and routines to make the interventions as easy to comply with in the clinical practice as possible.

Three main interventions were investigated. The interventions are described in three categories in this section; 1) lights on ABHR dispensers, 2) increased accessibility to ABHR and 3) feedback on HHC data (group and individual). For each of the three interventions, the overall intervention will be described. This will be followed by a detailed description of each of the studies investigating the specific intervention. At the end of the section, the statistics will be described for all five interventional studies.

The five interventional studies report HHC rates stratified according to professions (hospitals) and work shifts (nursing homes).

This dissertation will give a brief presentation of the results from patient rooms (hospital) and residential apartments (nursing homes). Results from working rooms are presented in the publications.

4.3.3. Intervention with light on ABHR dispensers (study II and V)

The sensors on ABHR dispensers have built-in lights that were activated during selected intervention periods (Figure 5). The reminder light aimed to increase awareness and consisted of a blue light that appeared on the ABHR dispenser whenever an HCW was close to the ABHR. The feedback light aimed to acknowledge an HCW for using the ABHR. The light consisted of a green smiley that appeared on the ABHR dispenser after the HCW had used it and served as immediate feedback to the HCW to support the desired behaviour.

Figure 5. Illustration of reminder and feedback light on ABHR dispensers.

Two studies (Study II and V) investigated the effect of lights on HCWs' HHC. The study design and setting for each study will be presented in the following section.

4.3.3.1. Study II: Intervention with light in hospital wards

An 11-month prospective, interventional study was conducted between July 2020 and May 2021 at Aarhus University Hospital in Denmark. Physicians, nurses and cleaning assistants (n=241) were included from four inpatient wards. The study had four phases (Figure 6). HHC was measured in the patient rooms and working rooms.

Phase 1 constituted the baseline period. In phase 2, the four in-patient wards were randomised into two groups to either receive reminder light or feedback light. During phase 3, all four wards were exposed to both the reminder and the feedback light. Phase 4 was the follow-up phase, which was split into two for analysis: follow-up 1 (immediate effect of a completed intervention phase) and follow-up 2 (long-term effect of a completed intervention phase). This division was made to describe the initial changes and the later steady-state level.

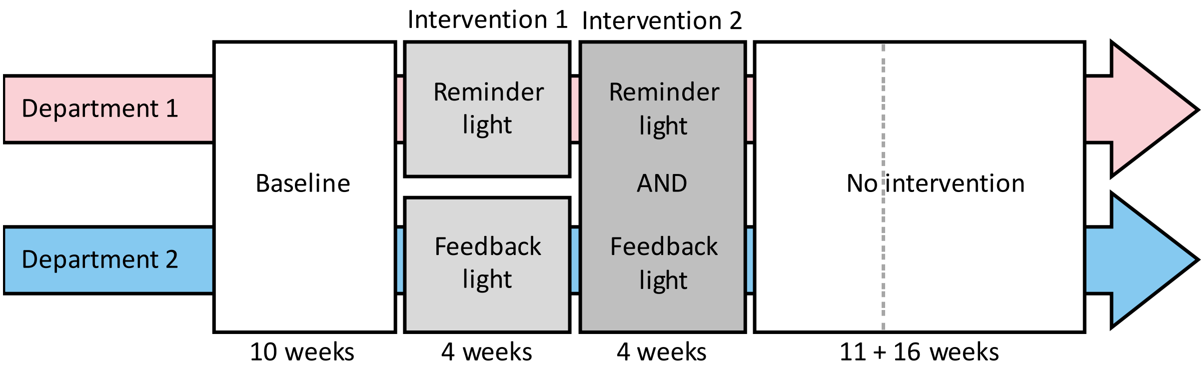


Figure 6. Study overview. Inpatient wards at the Department of Oncology and the Department of Haematology were randomly assigned into two groups (Departments 1 and 2). In the first intervention phase, Department 1 was exposed to the reminder light, and Department 2 was exposed to the feedback light. In the second intervention phase, Departments 1 and 2 were exposed to both the reminder light and the feedback light.

4.3.3.2. Study V: Intervention with light in nursing home wards

A five-month prospective, interventional study was conducted between May 2021 and November 2021 at Nursing home 2. Nurses and nurse assistants (n=64) were included. HHC data from residential apartments and dirty rinsing rooms were included. The study had three phases (Figure 7). Phase 1 was a baseline period without intervention. In phase 2, the HCWs received a feedback symbol that was designed to acknowledge that an HCW had remembered to use the ABHR. The symbol consisted of a green smiley light appearing on the sensor immediately after the HCW had used it. The symbol served as immediate feedback to support the desired behaviour. Phase 3 constituted the follow-up period to investigate if the possible effect of light would be sustained.

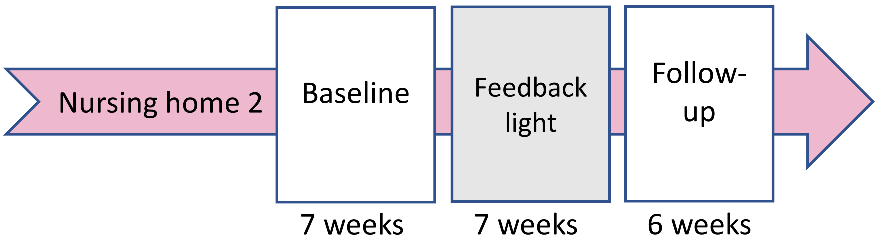


Figure 7. Study overview. Three wards at Nursing Home 2 were selected to investigate the effect of feedback light on ABHR dispensers.

4.3.4. Intervention with increased accessibility to ABHR (study IV)

An 11-month prospective, interventional study was conducted at Nursing home 1 (six wards). Ward 1-3 collected data from October 2020 to September 2021. Wards 4-6 collected data from December 2020 to November 2021. Nurses and nurse assistants (n=159) were included in the study. HHC was measured in the residential apartments.

This study had three phases (Figure 8). Phase 1 constituted the baseline period without any changes to the number of ABHR dispensers in the residential apartments. Only one ABHR dispenser was accessible in the apartments (placed in the restrooms) during the baseline period. Phase 2 constituted the intervention where an extra ABHR dispenser was placed in the hallway (entrance) in all residential apartments to increase accessibility to ABHR (Figure 9). The extra ABHR dispenser was placed in all 150 apartments on the first day of the intervention period and remained in the same position throughout the study period. The hallway was chosen as HCWs always pass the hallway before entering and after exiting residents' living rooms/bedrooms. In other words, the intervention aimed to make it easy for the HCWs to access the ABHR dispenser along their working route. Phase 2 was split into two periods for analysis: "immediate intervention", investigating the immediate effect of increased accessibility to ABHR (23 weeks); and "long-term intervention", investigating the long-term effect of increased accessibility to ABHR (17 weeks).

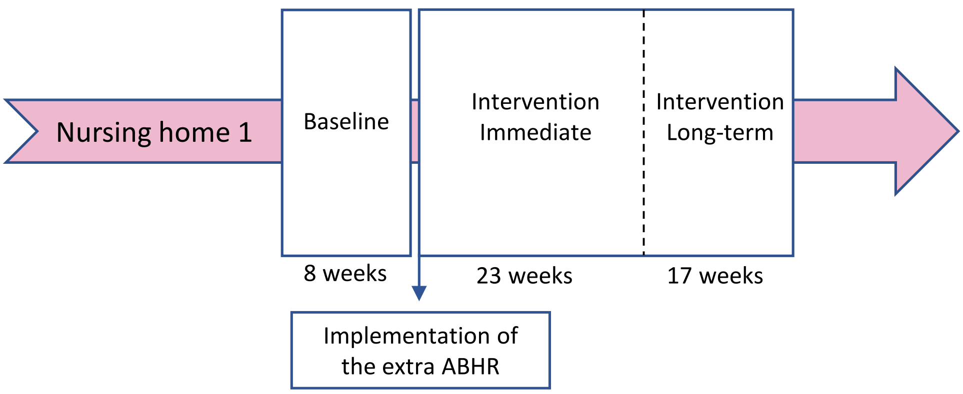


Figure 8. Study overview. Six wards in Nursing home 1 were selected to investigate the effect of increased accessibility to ABHR dispensers in 150 residential apartments.

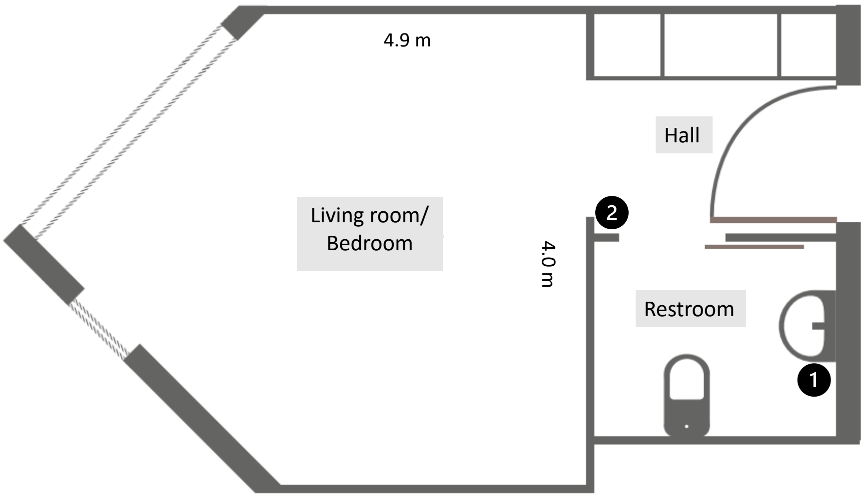


Figure 9: Illustration of a residential apartment and locations of ABHR dispensers. 1: During the baseline period, the ABHR dispenser in the restroom was the only dispenser in the residential apartment. 2: On the first day of the intervention, an extra ABHR dispenser was placed in the hallway/entrance to the living room/bedroom.

4.3.5. Intervention with group and individual feedback on HHC data (study III and VI)

All HHC data are visually illustrated in an online dashboard. Only leaders and the PhD student had access to the dashboard during the data collection period. In the dashboard, aggregated HHC data in room types and staff groups can be accessed for each ward. However, HCWs who signed up to receive individual HHC data had access to their individual data in the dashboard as well, but they could NOT access aggregated HHC data. Leaders and the PhD student with access to the online dashboard could NOT access individual HHC data.

4.3.5.1. Group feedback

Leaders presented and discussed visual graphics with HHC data at regular weekly staff meetings, using 3-10 minutes for feedback provision (Figure 10). Graphics were printed and placed on boards in staff rooms and some leaders provided feedback in newsletters as well. The leaders were free to decide how they wanted to present and work with the aggregated HHC data (e.g., focus on a specific room type or situation). If the leader could not provide feedback due to time constraints or absence, the intervention was skipped. Each leader registered feedback interventions in a predefined sheet to evaluate compliance with the intervention (appendix III). The results of the registrations are presented in the Results section.

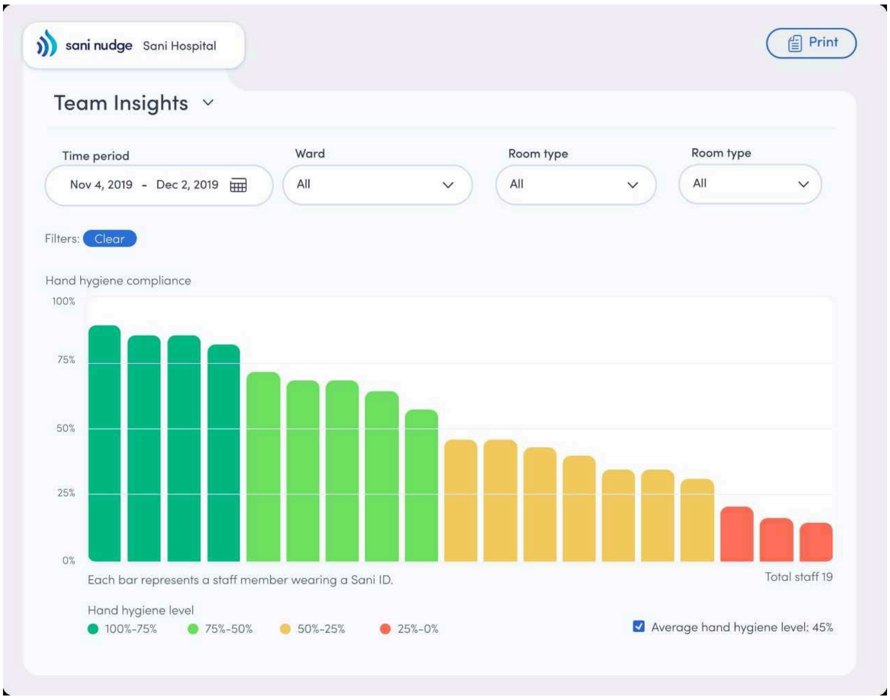


Figure 10. Illustration of aggregated HHC data in the dashboard.

4.3.5.2. individual feedback

HCWs who volunteered to receive individual feedback on HHC data signed up for the weekly email to receive their individual HHC data (Figure 11). The HCWs signed up for the weekly email via an app. To sign up, they had to actively scan their individual sensor on their name badge and write the email address where they wished to receive the weekly email. The weekly email was automatically sent every Monday morning with a link to the individual HHC data. The weekly HHC data were deleted after one week and replaced with new weekly HHC data. If less than five opportunities were collected, no HHC data were shown. The PhD student made weekly registration every Sunday night (at 11 PM) of the total number of opened emails per week to evaluate compliance with the intervention. A predefined observation sheet was used (appendix IV). The results are presented in the Results section.

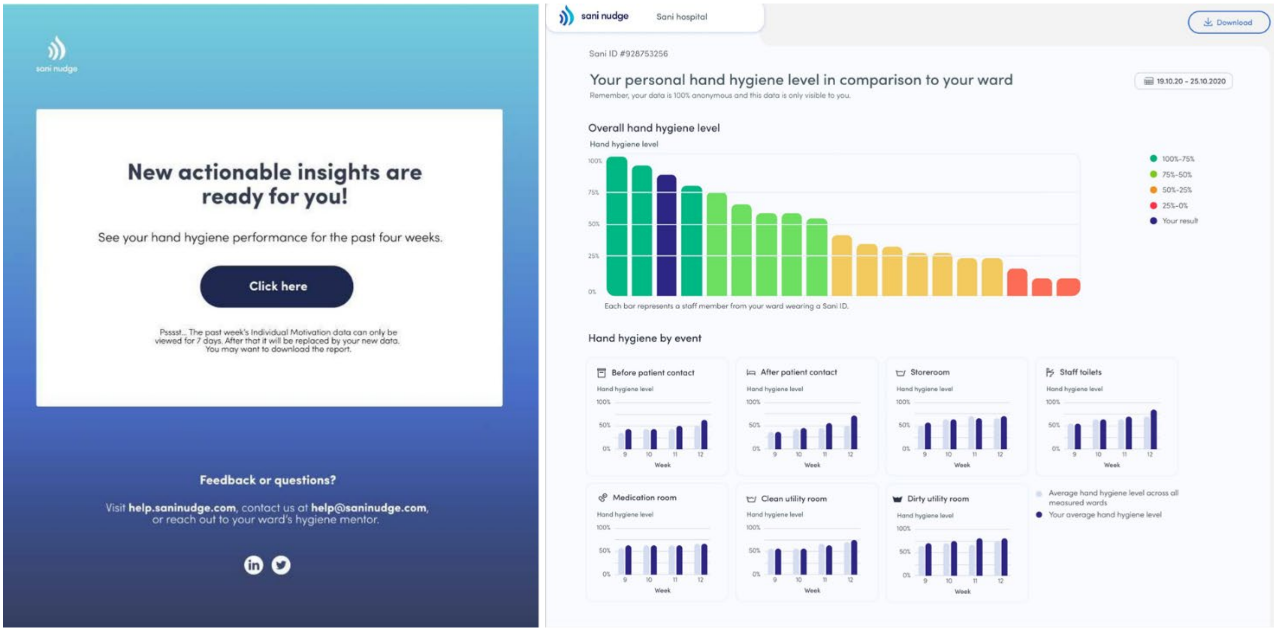


Figure 11. Email with feedback on individual HHC data. The HCWs had to click on the link “Click here” to access the individual data.

Two studies investigated the effects of feedback which will be presented in the following sections.

4.3.5.3. Study III: Group and individual feedback in hospital inpatient wards

An 11-month prospective, interventional study was conducted at four inpatient wards at Aarhus University Hospital between February 2021 and December 2021. Physicians, nurses and cleaning assistants (n=187) received group feedback from their local leader on aggregated HHC data. HCWs (n=104) volunteered to sign up to receive individual feedback on HHC data. HCWs were distributed into two clusters: “Only group feedback” and “Both group AND individual feedback”. All HCWs signing up for individual feedback were distributed into the cluster “Both group AND individual feedback” and stayed in this group for the entire study period, even if they unsubscribed from the weekly emails or did not open their emails.

The study had four phases (Fig.?). Phase 1 constituted the baseline period. Phase 2 was an intervention period with group feedback. In phase 3, the HCWs were split into two clusters. The cluster receiving only group feedback continued group feedback and the cluster receiving both group and individual feedback had individual feedback in addition to the group feedback. Phase 4 was an evaluation phase without interventions.

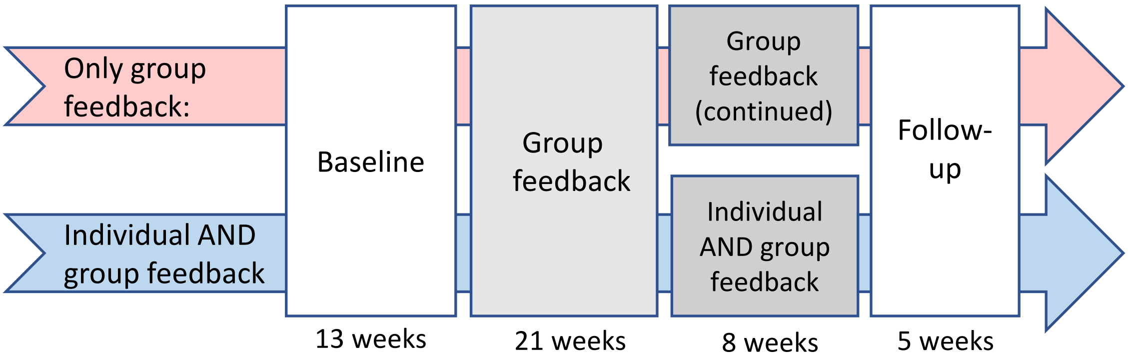


Figure 12. Study overview. Inpatient wards at the Department of Oncology and the Department of Haematology were included. The HCWs were divided into two groups; "Only group feedback" and "Individual AND group feedback", to received group feedback followed by a period with either group feedback (continued) OR individual feedback in addition to the continued group feedback.

4.3.5.4. Study VI: Individual feedback in nursing home wards

A six-month prospective, interventional study was conducted in Nursing Homes 1 and 2. Nursing Home 1 collected data from September 2021 to Marts 2022 and Nursing Home 2 collected data from November 2021 to May 2022. Nurses and nurse assistants (n=198) were included. HCWs (n=67) volunteered to sign up to receive individual feedback on HHC data.

The study had two phases (Figure 13). Phase 1 constituted the baseline period. In phase 2, the HCWs were split into two clusters; "No individual feedback" (control group) and "Individual feedback" (intervention group). HCWs from both clusters worked at the same wards. Therefore, the cluster that received no individual feedback might have been exposed to interventions in the wards. Thus, discussions about HH were prominent features in newsletters, with leaders offering information regarding individual feedback to motivate the intervention group to open the weekly email, among other initiatives.

This study did not have a follow-up phase due to resource constraints associated with the AHHMS, which precluded an extension of the study period.

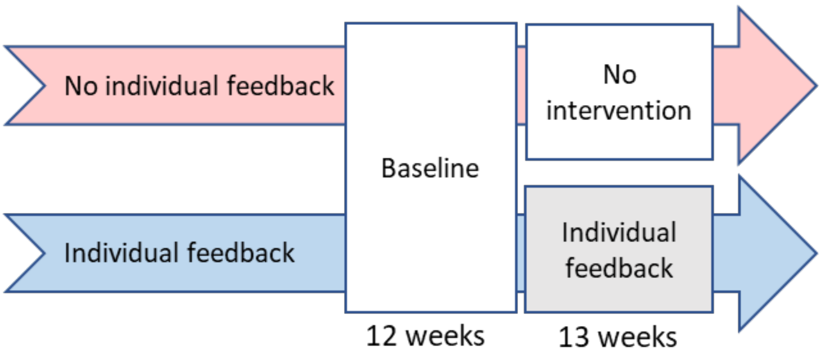


Figure 13. Study overview. After a baseline period both Nursing homes 1 and 2 investigated the effect of individual feedback on HHC data.

4.3.5.5. Statistics for the interventional studies (study II-VI)

Aggregated HHC data were available as total sums (per day) of number of opportunities and ABHR events in patient rooms/residential apartments, staff restrooms, clean rooms (clean utility room and clean store room and unclean rooms (unclean utility room and unclean store room), stratified by staff group and department/nursing home. Individual data for each participant were not available for analysis. Data were provided as HHC rates (0%-100%) with 95% confidence intervals (CIs).

For staff restrooms, clean rooms and unclean rooms, daily and weekly HHC was calculated as the number of compliant visits/total number of visits summed by day or week. For patient rooms and residential apartments, overall daily HHC (sum of both BEFORE entering and AFTER exiting the patient zone) was calculated as "(number of full compliances + 0.5*number of compliances only BEFORE patient visit + 0.5*number of compliances only AFTER patient visit)/total number of visits". Daily HHC was also calculated specifically for compliance BEFORE (or AFTER) patient visits as "(number of full compliances + number of compliances only BEFORE (or AFTER) a patient visit)/total number of visits."

Linear regression models were established for patient rooms and residential apartments (overall, only BEFORE entering the patient zone, and only AFTER exiting the patient zone), staff restrooms, medician rooms, clean rooms and unclean rooms. Daily HHC was used as the outcome and the interaction between department and study phases was used as explanatory variables. The models used the sandwich estimator of variance. Analytical weights (number of daily visits for each HHC) were used in the regression analyses. Coefficients from the models were used to calculate the mean HHC for each department in each study phase and to compare them. Two-sided P values <0.05 were considered statistically significant. Differences were reported as absolute values. All analyses were conducted using STATA (StataCorp LLC, Texas, USA, version 17.0 and 18.0).

Figure 14 and 15 gives an overall overview of data collection periods in hospital departments (Figure 14) and nursing home wards (Figure 15).

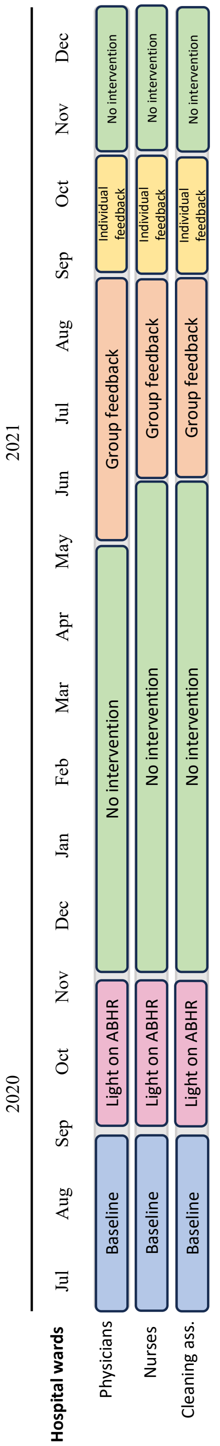


Figure 14. Timeline for studies in hospital wards

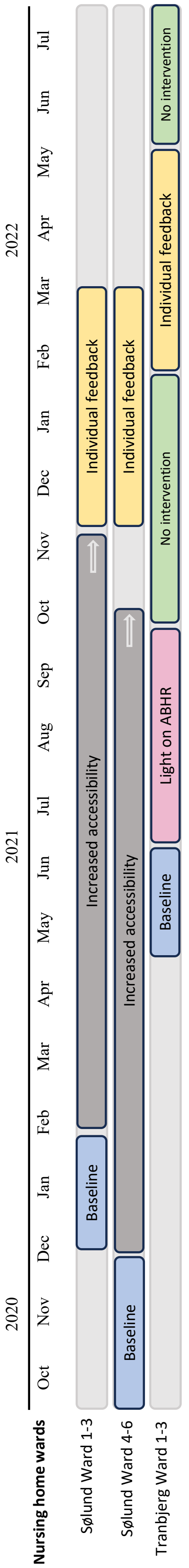


Figure 15. Timeline for studies in nursing home wards

4.4. Ethical considerations

Ethical approval for data collection was sought at the Danish Data Protection Agency (R. no 2019-212-1420) and the Ethics Committee (R. no. 1-10-72-148-19). Both agencies waived requirements of informed consent.

HHC data were anonymised for both investigators and study participants. All HCWs were informed before the installation of the AHHMS. Participation was voluntary, and informed consent was given via the HCWs' active choice to pick up and carry a tag with an anonymous ID number at work. To ensure the participants' anonymity, we obtained information only about their healthcare profession (participants from hospitals) and work shift (participants from nursing homes). Furthermore, HHC rates were accessible only in the online dashboard when data on more than five opportunities in the selected room or staff group had been collected — HCWs who volunteered to receive individual HHC data signed up via an app. When signing up via the app, they scanned their individual sensor (placed on their nametag), wrote the email address where they wished to receive weekly HHC data and then they had to accept the terms and conditions. Participants received a document outlining "terms and conditions" along with short information regarding the weekly feedback. HCWs were informed about the possibility to unsubscribe the weekly emails at any time. Furthermore, HCWs could, at any time, remove the individual sensor from their nametag if they wanted to unsubscribe from the project.

5. Results

This section will present the main results of the six studies.

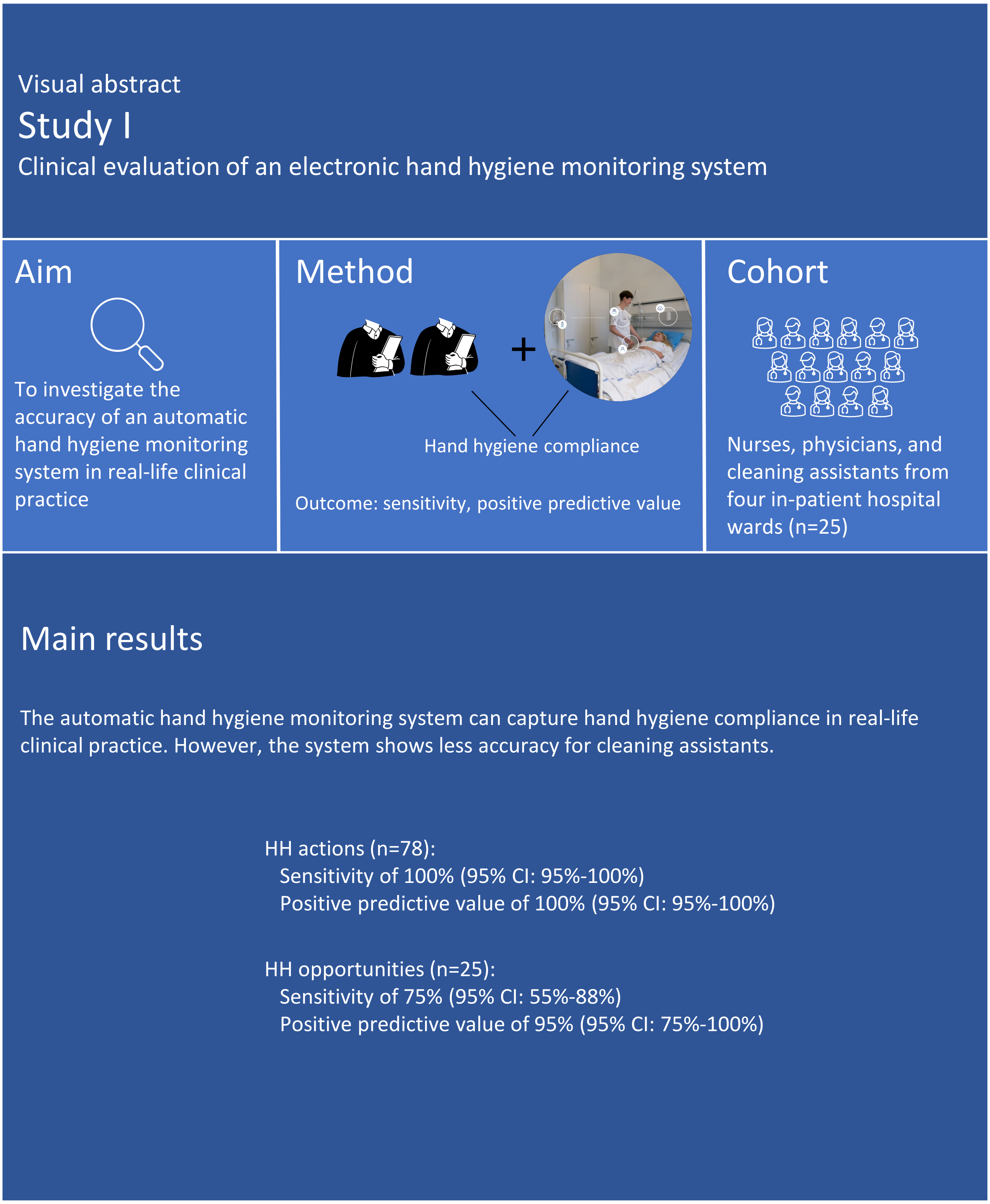


Figure 16. Visual abstract, Study I

5.1. Study I: Clinical evaluation of an electronic hand hygiene monitoring system

The study investigated the accuracy of the AHHMS under real-life clinical conditions in hospital wards (Figure 16) [1]. Overall, 120 events were performed by 25 physicians, nurses and cleaning assistants. Twelve events were excluded as they did not meet the inclusion criteria and five events were excluded due to a discrepancy between the registrations made by the two observers. Thus, 103 events were included in the analyses.

As far as HH actions (n=78) were concerned, the AHHMS detected all HH events with an overall sensitivity of 100% (95% CI: 95, 100) (Table 6).

Table 6. HH actions performed by physicians, nurses and cleaning assistance [1].

	Sanitisations observed	Sanitisation not observed
Detected by the AHHMS	78	0
Not detected by the AHHMS	0	ND

As far as HH opportunities (n=25) were concerned, the overall accuracy shows a sensitivity of 75% (95% CI: 55, 88) and a PPV of 95% (95% CI: 75, 100) (Table 7).

Table 7. HH opportunities performed by physicians, nurses and cleaning assistance [1].

	Contact observed	Contact not observed
Detected by the AHHMS	18	1
Not detected by the AHHMS	6	ND

Eighteen of the 25 HH opportunities were detected by the AHHMS (true-positive). Six of the HH opportunities were not detected by the AHHMS but were detected by the two observers (false-negative). Three of the false-negative events concerned cleaning assistants cleaning the patient's bed or patient surroundings. Two of the false-negative events were physicians examining the patient in a chair close to (approx. 1-2 m) the patient's bed (and the bed-sensor). The last of the false-negative events was a nurse picking up a plate from the patient's table.

One event was observed where the AHHMS registered an opportunity that was not registered by the two observers (false-positive). The event concerned a physician standing near the patient's bed. The AHHMS registered the physician in the patient zone. However, the two observers did not register physical contact between the physician and the patient or the patient-near surroundings.

We concluded that the Sani Nudge^{TM} AHHMS was accurate when tested under real-life clinical conditions. HH opportunities arose that were not registered by the AHHMS. However, the data collected by the AHHMS are deemed valid. Nevertheless, more data points are necessary to determine the validity of the AHHMS during real-life conditions.

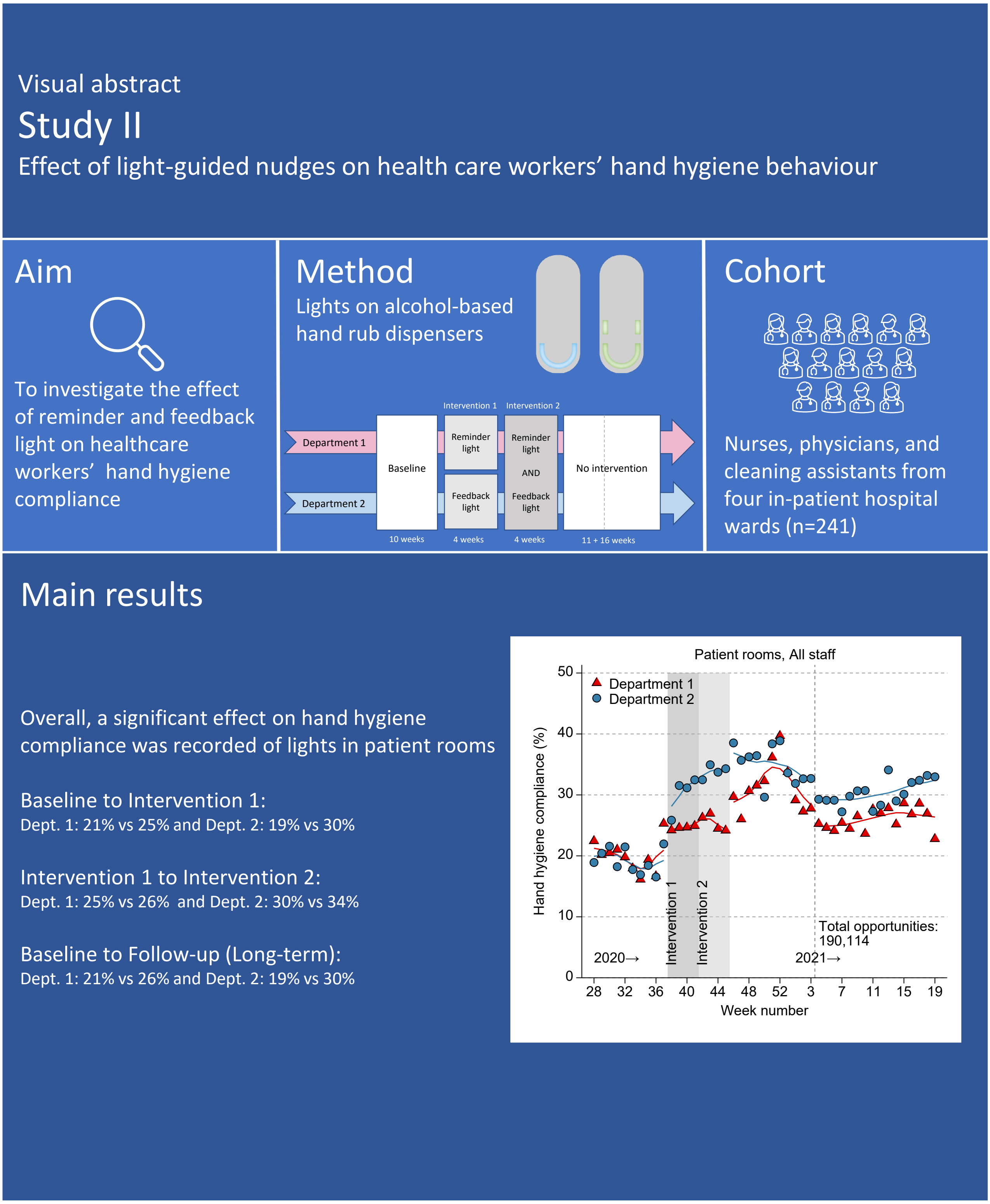


Figure 17. Visual abstract, Study II

5.2. Study II: Light on alcohol-based hand rub dispensers in hospital departments

Publication title: Effect of light-guided nudges on health care workers' hand hygiene behaviour (Figure 17) [2].

An 11-month study investigated the effect of reminder and feedback light on ABHR dispensers in hospital wards. A total of 241 HCWs from four hospital wards (physicians, nurses and cleaning assistants) and 231,039 HH opportunities in patient rooms and working rooms were included in the analyses. HCWs were distributed into Department 1 (two in-patient bed wards) and Department 2 (two in-patient bed wards). At each department, HCWs were distributed into staff categories as physicians, nurses and cleaning assistants.

5.2.1. Patient rooms

A total of 190,114 HH opportunities in patient rooms were included in the analyses.

Overall, a significant immediate effect was achieved in the first intervention period with one light (either reminder or feedback light), with a mean difference from baseline to the intervention with reminder light of +4 percentage points (95% CI: 3, 6. p<0.0001) for Department 1; and from baseline to the intervention with feedback light of +11 percentage points (95% CI: 9, 13. p<0.0001) for Department 2 (Table 8, Figure 18). Furthermore, the two departments had an additional intervention period with both the reminder and feedback light. Only Department 2 found an additional significant effect of the period with two lights (both reminder and feedback), with a mean difference from intervention 1 to intervention 2 of +4 percentage points (95% CI: 1, 6. p=0.004). Both departments demonstrated a long-term sustained effect of light from baseline to the long-term follow-up period of +5 percentage points (95% CI: 4, 7. p<0.0001) for Department 1; and of +11 percentage points (95% CI: 10, 12. p<0.0001) for Department 2.

We found a higher baseline HHC in patient rooms after than before contact with patients or patient-near surroundings, with a mean difference of +6 percentage points (95% CI: 4, 7. p<0.0001) in Department 1 and a mean difference of +6 percentage points (95% CI: 5, 8. p<0.0001) in Department 2 (Table 8, Figure 19).

Furthermore, we found a significantly higher baseline HHC among nurses than among physicians, with a mean difference between nurses and physicians of +6 percentage points (95% CI: 3, 9. p<0.0001) in Department 1 and +4 percentage points (95% CI: 0, 8. p=0.03) in Department 2 (Table 8).

Cleaning assistants had a lower HHC than nurses in Department 1, with a mean difference between nurses and cleaning assistants of +9 percentage points (95% CI: 6, 12. p<0.001). However, in Department 2, cleaning assistants had a higher baseline HHC than nurses and physicians, with a difference between nurses and cleaning assistants of +2 percentage points (95% CI: -3, 6. p=0.4) and a significant difference of +6 percentage points (95% CI: 0, 11. P=0.04) (Table 8) between cleaning assistants and physicians.

Table 8. Study II. HHC in each study phase, specified by staff groups in patient rooms.

		Mean scores (95% CI)									
		Baseline		**Intervention 1†**		**Intervention 2†**		**Follow-up** Immediate		**Follow-up** Long-term	
Department 1	**Patient rooms, HHC**										
	All staff	21%	(20, 21)	25%	(23, 26)	26%	(24, 27)	31%	(30, 33)	26%	(25, 27)
	Physicians	15%	(12, 18)	21%	(18, 24)	26%	(22, 30)	28%	(25, 31)	19%	(17, 22)
	Nurses	21%	(20, 22)	25%	(24, 27)	26%	(24, 28)	32%	(31, 34)	27%	(26, 28)
	Cleaning staff	12%	(10, 15)	13%	(9, 17)	12%	(8, 16)	19%	(17, 22)	15%	(14, 17)
	Overall, before contact	18%	(17, 19)	23%	(21, 25)	24%	(22, 26)	29%	(28, 30)	24%	(24, 25)
	Overall, after contact	23%	(22, 24)	26%	(25, 28)	27%	(25, 29)	34%	(32, 35)	27%	(27, 28)
Department 2	**Patient rooms, HHC**										
	All staff	19%	(18, 21)	30%	(29, 32)	34%	(32, 36)	35%	(34, 36)	30%	(30, 31)
	Physicians	15%	(12, 19)	21%	(17, 25)	20%	(16, 24)	29%	(25, 32)	26%	(23, 30)
	Nurses	20%	(19, 21)	31%	(29, 33)	35%	(33, 37)	36%	(35, 37)	31%	(30, 32)
	Cleaning staff	21%	(17, 26)	22%	(14, 30)	21%	(12, 30)	20%	(17, 24)	17%	(14, 20)
	Overall, before contact	16%	(15, 17)	27%	(25, 29)	31%	(29, 33)	32%	(31, 33)	27%	(26, 28)
	Overall, after contact	23%	(21, 24)	34%	(32, 35)	37%	(35, 39)	38%	(37, 39)	34%	(33, 35)

† Intervention 1 is 'Reminder light' for Department 1 and 'Feedback light' for Department 2. Intervention 2 is a 'Reminder light AND feedback light' for both departments.

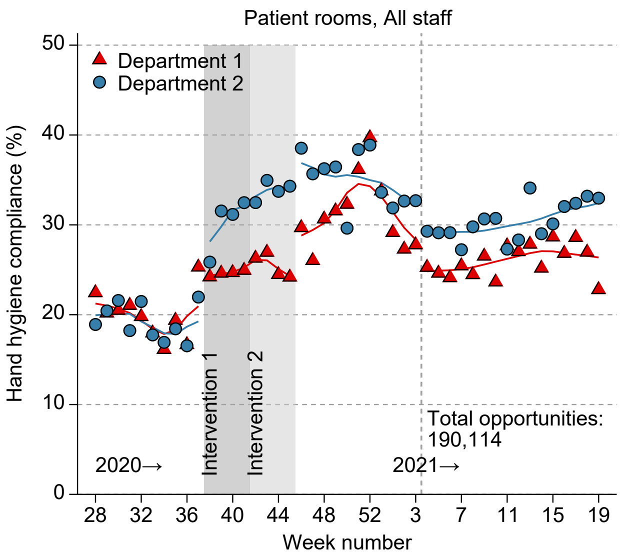


Figure 18. Overall HHC (sum of both BEFORE entering and AFTER exiting the patient zone) in the patient rooms [2].

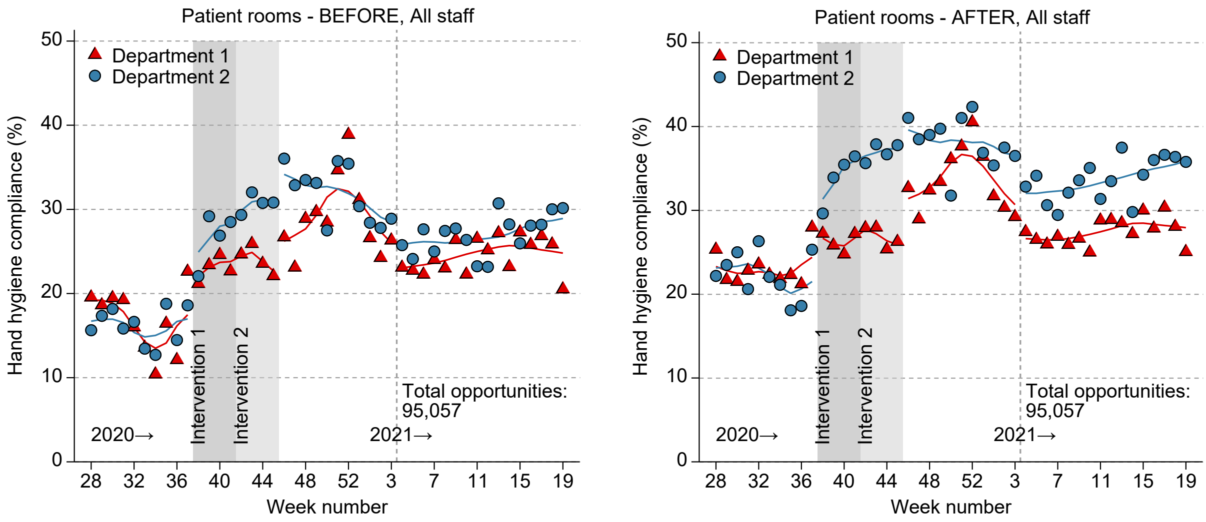


Figure 19. Overall HHC BEFORE entering and AFTER exiting the patient zone in the patient rooms [2].

5.2.2. Validation of placement of patient beds

During the study period, the placement of patient beds (n=64) was registered on random days, one to two times a week. A total of 3,136 observations were collected.

We found that more than 95% of the patient beds were placed correctly in Departments 1 and 2 (Figure 20). However, only 84% of the patient beds were placed correctly in Department 1 during the baseline period. We do not know how this affected HHC. However, the 16% of the patient beds that were placed incorrectly did not result in 16% faulty registrations. It is, however, unknown if and how this affected HHC rates.

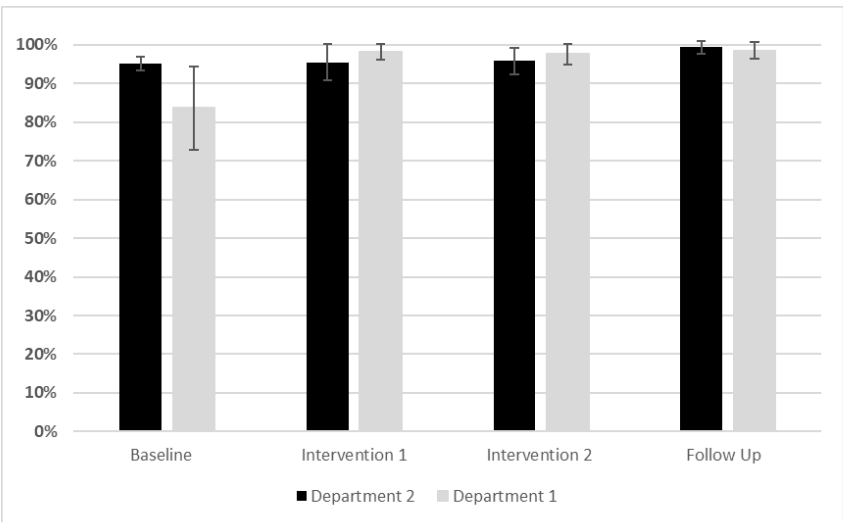


Figure 20. Percentage of patient beds placed correctly under the Sani Nudge™ wall sensor. Error bars represent the standard error of the mean [2].

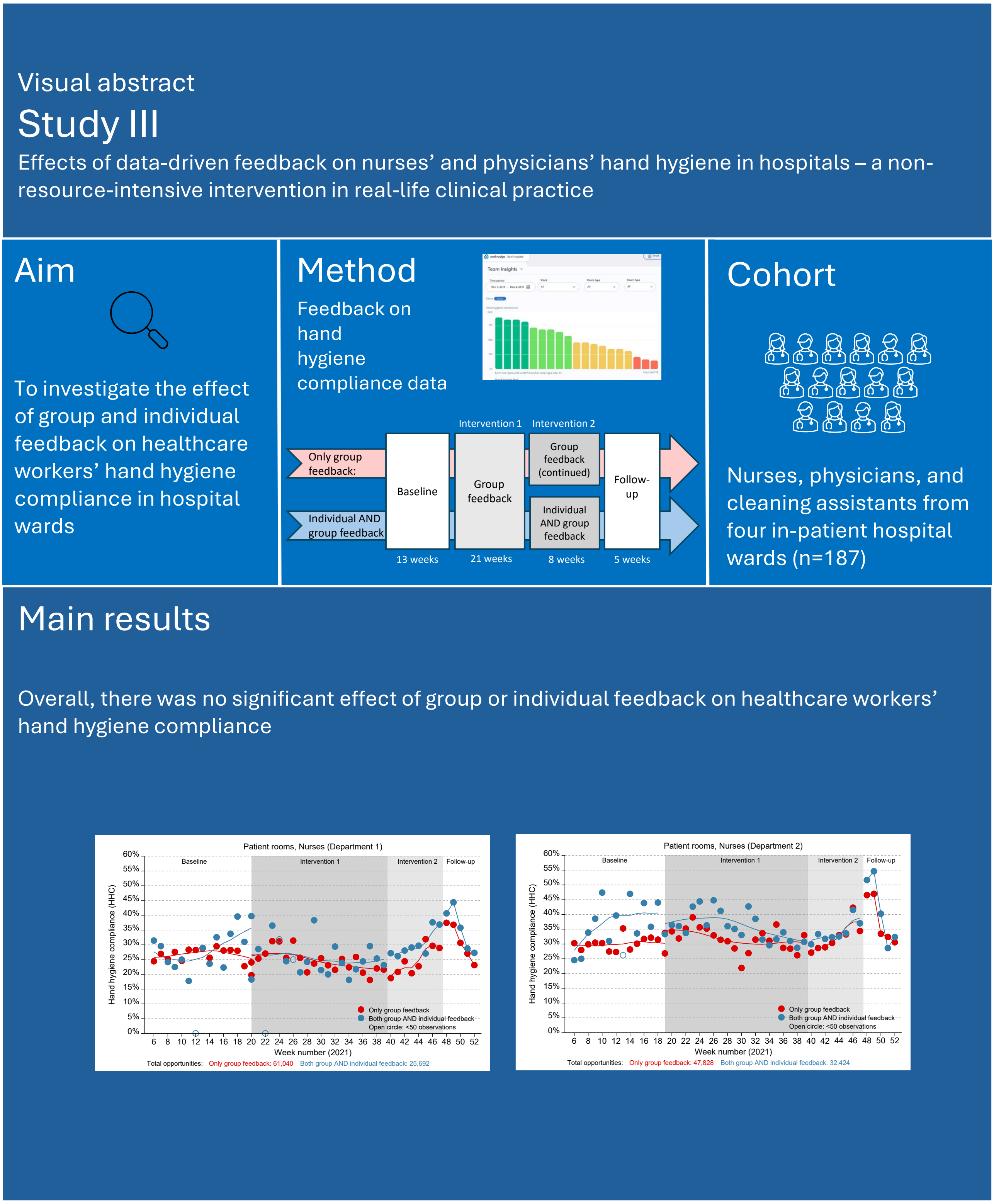


Figure 21. Visual abstract, Study III

5.3. Study III: Group and individual feedback in hospital departments

Publication title: Effects of data-driven feedback on nurses' and physicians' hand hygiene in hospitals – a non-resource-intensive intervention in real-life clinical practice (Figure 21) [3].

An 11-month study investigated the effect of group and individual feedback on HHC rates in hospital wards. A total of 187 HCWs from four hospital wards (physicians, nurses and cleaning assistants) participated. Cleaning assistants (n=13) were excluded from the study as their data could not be analysed anonymously due to a low number of participants signing up to receive individual feedback in each department (n=<4). A total of 231,022 HH opportunities in patient rooms and working rooms were included in the analyses. HCWs (n=174) were distributed into two clusters: "only group feedback" (n=83) and "both group AND individual feedback" (n=91). For each cluster, HCWs were distributed into Department 1 (two in-patient bed wards) and Department 2 (two in-patient bed wards). For each department, HCWs were distributed into physicians and nurses.

5.3.1. Patient rooms

A total of 176,226 HH opportunities in patient rooms were included in the analyses. The study found no effects of the interventions either with group feedback or individual feedback (Figure 22 and Figure 23).

The study found that HCWs in the cluster receiving both group AND individual feedback had a higher baseline HHC than the HCWs in the clustered that received only group feedback (Department 1: +3 percentage points; 95% CI: -1, 6. p=0.1 and Department 2: +6 percentage points; 95% CI: 3, 9. p<0.001) (Table 9). However, the difference in Department 1 was not significant.

We found a higher baseline HHC in the patient rooms after than before contact with patients and patient-near surroundings (Table 9). In Department 1, we found a mean difference of +3 percentage points (95% CI: 2, 4. p<0.0001) in the cluster receiving only group feedback and a mean difference of +4 percentage points (95% CI: -2, 9. p=0.2) in the cluster receiving both group and individual feedback. In Department 2, we found a mean difference of +7 percentage points (95% CI: 6, 9. p<0.0001) in the cluster receiving only group feedback and a mean difference of +3 percentage points (95% CI: -2, 8. p=0.2) in the cluster both group and individual feedback (Table 9).

Furthermore, we found a higher HHC among nurses than physicians (overall HHC for both clusters in both Department 1 and 2), with a mean difference of +8 percentage points (95% CI: 5, 11. p<0.0001) in Department 1 and +6 percentage points (95% CI: 2, 9. p=0.0007) in Department 2 (Table 9, Figure 22 and Figure 23).

Table 9. Study III. HHC in each study phase, specified by staff groups in patient rooms, staff restrooms and medication rooms. HHC is given as the mean score in each phase.

		Cluster "Only group feedback" Mean scores (95% CI)				Cluster "Both group AND individual feedback" Mean scores (95% CI)			
		Baseline	Group feedback	Group feedback (continued)	Follow-up	Baseline	Group feedback	Individual feedback	Follow-up
Department 1	**Patient rooms, HHC**								
	All staff	26 % (26, 27)	24 % (23, 25)	24 % (22, 26)	30 % (27, 33)	29 % (26, 32)	25 % (23, 27)	30 % (28, 31)	35 % (32, 38)
	Physicians	19 % (16, 22)	20 % (17, 23)	21 % (17, 25)	27 % (21, 24)	NA	27 % (23, 30)	29 % (26, 33)	33 % (27, 40)
	Nurses	27 % (26, 28)	24 % (23, 26)	24 % (23, 26)	30 % (27, 33)	29 % (26, 32)	25 % (23, 27)	30 % (28, 31)	35 % (32, 38)
	Overall, before contact	25 % (24, 26)	23 % (21, 24)	22 % (21, 24)	28 % (26, 31)	27 % (24, 31)	24 % (21, 26)	28 % (26, 30)	34 % (31, 37)
	Overall, after contact	28 % (27, 29)	26 % (25, 27)	26 % (24, 27)	31 % (28, 35)	31 % (27, 35)	26 % (24, 28)	31 % (29, 33)	35 % (32, 38)
Department 2	**Patient rooms, HHC**								
	All staff	30 % (29, 31)	32 % (31, 33)	32 % (30, 34)	37 % (33, 42)	36 % (33, 39)	33 % (32, 34)	33 % (32, 35)	40 % (36, 44)
	Physicians	27 % (24, 30)	27 % (24, 30)	30 % (22, 39)	19 % (8, 29)	15 % (10, 20)	29 % (25, 33)	24 % (21, 27)	29 % (21, 38)
	Nurses	30 % (29, 31)	32 % (31, 33)	32 % (30, 34)	38 % (33, 42)	37 % (34, 40)	33 % (32, 34)	34 % (32, 35)	41 % (36, 45)
	Overall, before contact	27 % (26, 27)	28 % (27, 29)	30 % (27, 32)	36 % (32, 40)	34 % (31, 38)	30 % (28, 31)	31 % (29, 32)	38 % (34, 43)
	Overall, after contact	34 % (32, 35)	35 % (34, 36)	34 % (32, 37)	39 % (34, 44)	38 % (34, 41)	36 % (35, 37)	36 % (35, 38)	42 % (37, 46)

NA = Not analysed (< 50 opportunities)

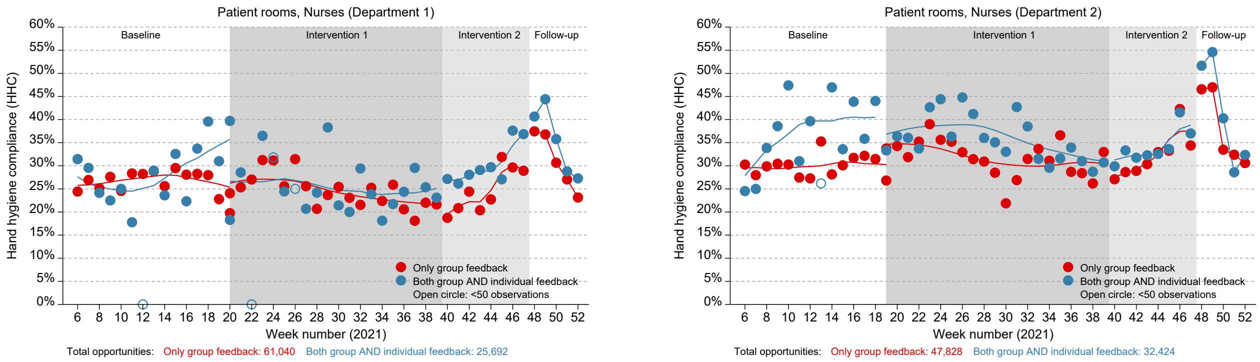


Figure 22. Nurses' hand hygiene compliance in patient rooms. Sum of both before entering and after exiting the patient zone for Department 1 and Department 2 [3].

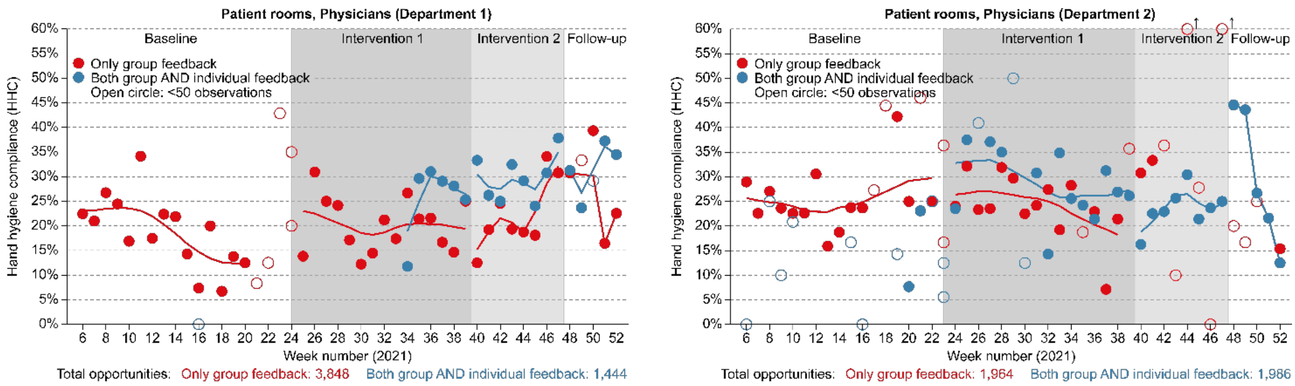


Figure 23. Physicians' hand hygiene compliance in patient rooms. Sum of both before entering and after exiting the patient zone for Department 1 and Department 2 [3].

5.3.2. Validation of placement of patient beds

During the study period, the placement of patient beds (n=64) was registered on random days, one to two times a week. A total of 2,424 observations were collected.

The registrations showed that more than 98% of the patient beds were placed correctly in both departments in all four study periods (Figure 24).

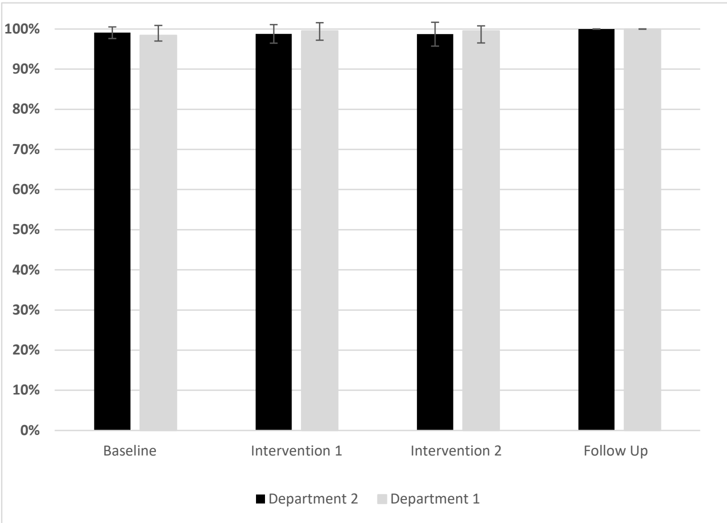


Figure 24. Percentage of patient beds placed correctly under the Sani Nudge™ wall sensor. Error bars represent the standard error of the mean [3].

5.3.3. Compliance with the intervention with weekly group feedback

During intervention periods 1 and 2 (29 weeks), the leaders were supposed to provide their staff group with weekly group feedback. Due to time constraints, the leaders had to skip some of the weekly feedback. However, even when the weekly oral feedback was skipped, an informal focus on HHC data was maintained (e.g., HHC data were printed and placed in staff rooms to initiate reflections and informal discussions, and HHC data were presented in newsletters). This informal focus could not be registered. Each leader registered the number of formalised weekly feedback events to evaluate compliance with the intervention (Table 10). Group feedback among nurses was provided more often in Department 2 (n=16) than in Department 1 (n=4). Group feedback among physicians was provided nearly as often in Department 1 (n=12) as in Department 2 (n=10).

Table 10. The number of provided group feedback sessions in each department and staff group [3].

Group Feedback	Department 1	Department 2
Nurses	4	16
Physicians	12	10

5.3.4. Compliance with the intervention with weekly individual feedback

During the intervention period 2 (8 weeks), the HCWs received a weekly email with their individual HHC data. Nurses and physicians signed up to receive the email during the study period. Table 11 shows the number of nurses and physicians who opened the weekly email.

Table 11. Number of nurses and physicians who signed up to receive the weekly email with individual feedback data and number of HCWs who opened the weekly email in percentage [3].

Study week number	**Nurses** signed up for the email (absolute numbers)	Number of opened reports (in percentage)
1	56	62%
2	57	61%
3	57	41%
4	55	31%
5	55	46%
6	56	41%
7	57	40%
8	57	40%

Study week number	**Physicians** signed up for the email (absolute numbers)	Number of opened reports (in percentage)
1	19	75%
2	27	83%
3	27	50%
4	31	82%
5	31	45%
6	30	38%
7	30	62%
8	30	33%

Visual abstract

Study IV

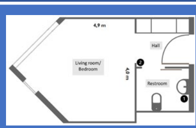
Hand hygiene compliance in nursing home wards measured with an automated hand hygiene monitoring system – the effect of increased accessibility of alcohol-based hand rub.

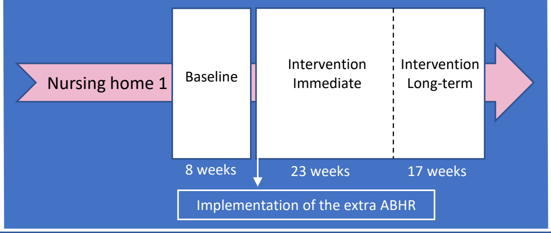
Aim

To investigate the effect of increased accessibility to alcohol-based hand rub on healthcare workers' hand hygiene compliance at nursing home wards

Method

One additional ABHR was placed in the appartments





Cohort

Nurses and nurse assistants from a six-ward nursing home (n=159)

Main results

We found a significant effect of increased accessibility to ABHR by implementing one extra ABHR dispenser in a strategically relevant place according to workflow.

Baseline to immediate intervention: 31% vs 49%

Baseline to long-term intervention: 31% vs 44%

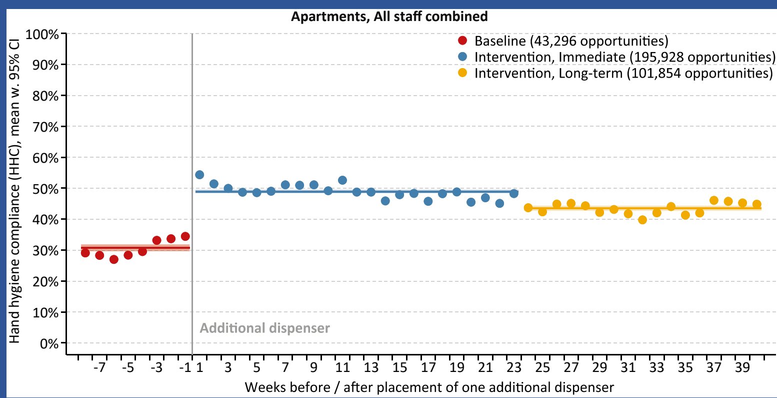


Figure 25. Visual abstract, Study IV

5.4. Study IV: Increased accessibility to alcohol-based hand rub in nursing home wards

Publication title: Hand hygiene compliance in nursing home wards measured with an automated hand hygiene monitoring system – the effect of increased accessibility of alcohol-based hand rub (Figure 25) [4].

An 11-month study investigated the effect of increased accessibility to ABHR when implementing one additional ABHR in residential apartments (hallway) at a nursing home. A total of 159 HCWs (nurses and nurse assistants) were included from six wards at Nursing home 1. HCWs were distributed into day shifts (n=67), evening shifts (n=29), night shifts (n=9) and short-term employees (n=54). A total of 341,078 HH opportunities were collected in residential apartments and included in the analyses.

Overall, HHC increased from 31% (95% CI: 30, 32) in the baseline period to 49% (95% CI: 48, 50) in the immediate intervention period with a mean difference of +18 percentage points (95% CI: 17, 19. p<0.0001). However, during the immediate intervention period to the long-term intervention period, HHC subsequently decreased to 44% (95% CI: 43, 44), with a mean difference of -5 percentage points (95% CI: -5, -6. p<0.0001). Nevertheless, HHC ended up at a higher level than at baseline, with a mean difference from baseline to the long-term intervention period of +13 percentage points (95% CI: 11, 14. p<0.0001) (Table 12 and Figure 26).

We found a higher baseline HHC for HCWs working day shift (33%, 95% CI: 31, 35) than HCWs working evening shifts (27%, 95% CI: 25, 30), with a mean difference of +6 percentage points (95% CI: 3, 8. p<0.001); and HCWs working night shift (27%, 95% CI: 25, 30), with a mean difference of +6 percentage points (95% CI: 2, 9. p<0.001). HCWs working as short-term employees had a baseline HHC of 32%, (95% CI: 30, 34) which was in line with HCWs working day shifts (Table 12).

HHC was higher after exiting the apartments than before entering the apartments in all study periods, with a mean difference in the baseline of +9 percentage points (95% CI: 7, 10. p<0.001); in the immediate intervention period, of +6 percentage points (95% CI: 5, 7. p<0.0001); and in the long-term intervention period, of +7 percentage points (95% CI: 6, 8. p<0.0001) (Table 12 and Figure 27).

Table 12. Study IV. HHC in Nursing home 1 in each study phase, specified by overall HHC, work shifts and "*before* contact with residents or resident-near surrounding", and "*after* contact with residents or residents-near surrounding" in residential apartments.

		Mean scores (95% CI)					
		Baseline		**Intervention Immediate**		**Intervention Long-term**	
Apartments	**Nursing home 1**						
	Overall HHC	31%	(30, 32)	49%	(48, 50)	44%	(43, 44)
	Day shift	33%	(31, 35)	49%	(48, 50)	43%	(42, 44)
	Evening shift	27%	(25, 30)	46%	(45, 48)	38%	(36, 39)
	Night shift	27%	(25, 30)	53%	(51, 55)	55%	(52, 57)
	Short-term employees	32%	(30, 34)	50%	(49, 51)	47%	(46, 49)
	Overall HHC, *before* contact	26%	(25, 28)	46%	(45, 46)	40%	(39, 41)
	Overall HHC, *after* contact	35%	(34, 36)	52%	(51, 53)	47%	(46, 48)

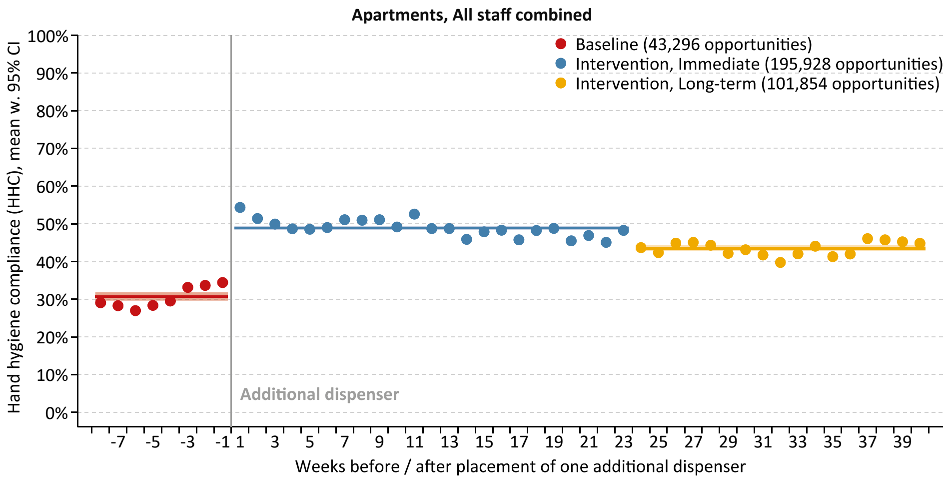


Figure 26. HCWs' HHC in residential apartments. The sum of HHC for both BEFORE entering and AFTER exiting the apartment with 95% CI. The baseline shows the period without intervention. "Intervention, immediate", shows the immediate effect of increased accessibility to ABHR. "Intervention, long-term", shows the long-term effect of the increased accessibility to ABHR. The grey line shows the day one additional ABHR dispenser was installed in each of the 150 apartments [4].

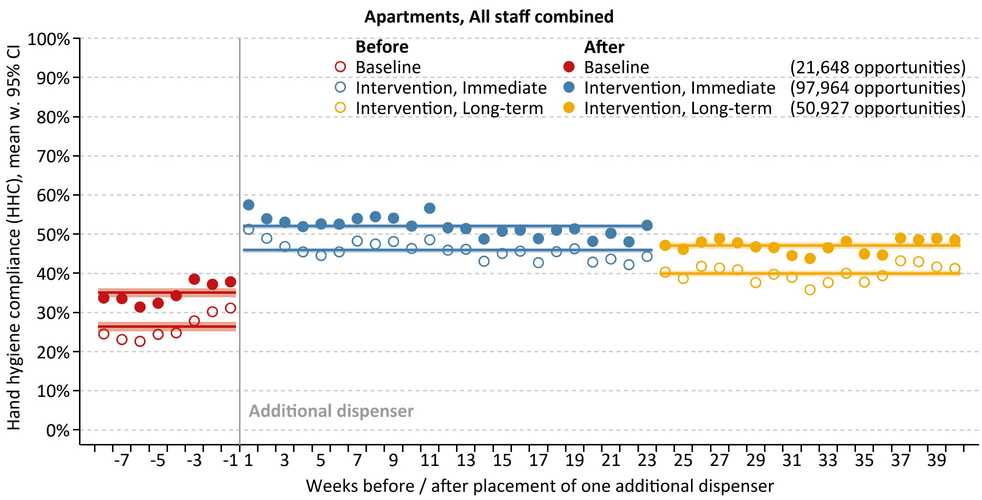


Figure 27. HCWs' HHC in residential apartments BEFORE entering and AFTER exiting the apartment with 95% CI. [4].

Visual abstract

Study V

Hand hygiene compliance in nursing homes measured with an automatic hand hygiene monitoring system – Effects of feedback with lights on alcohol-based hand rub dispensers

Aim

To investigate the effect of feedback light on healthcare workers' hand hygiene compliance in nursing home wards

Method

Nursing home 2 → Baseline (7 weeks) → Feedback light (7 weeks) → Follow-up (6 weeks)

Cohort

Nurses and nurse assistants at three nursing home wards (n=64)

Main results

Overall, a significant effect was recorded of feedback lights in residential apartments. However, the increased hand hygiene compliance was not sustained over time when the light was switched off

Baseline to intervention:
50% vs 56%

Intervention to follow-up:
56% vs 50%

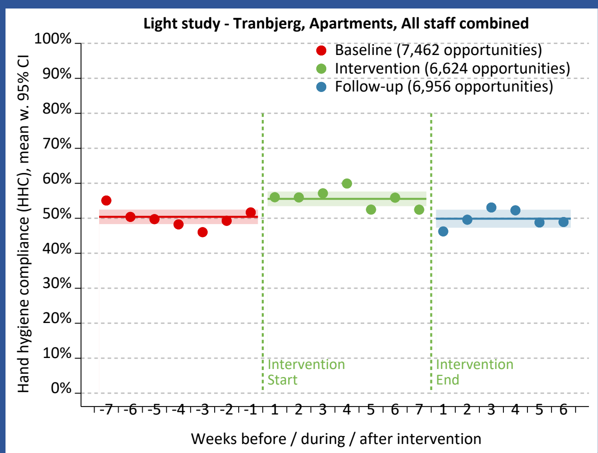


Figure 28. Visual abstract, Study

5.5. Study V: Lights on alcohol-based hand rub dispensers in nursing home wards

Publication title: Hand Hygiene Compliance in Nursing Homes Measured With an Automatic Hand Hygiene Monitoring System – The Effects Of Feedback With Lights on Alcohol-based Hand Rub Dispensers (Figure 28) [5].

A five-month study investigated the effect of feedback light at a nursing home. Nurses and nurse assistants (n=64) were included from three nursing home wards at Nursing home 2. A total of 23,696 HH opportunities were collected in residential apartments and dirty rinsing rooms and included in the analyses.

5.5.1. Residential apartments

A total of 21,042 HH opportunities in residential apartments were included in the analyses. An immediate effect of feedback light was found, with a mean difference from baseline to the intervention period of +5 percentage points (95% CI: 2, 8. p<0.001). However, the increased HHC was not sustained during the follow-up period as HHC declined to 50% in the follow-up period with a mean difference from baseline to follow-up of -0.5 percentage points, 95% CI: -4, 3. p=0.75) (Table 13 and Figure 29).

We found a higher baseline HHC for the HCWs working day shift (52%, 95% CI: 50, 54) than HCWs working evening/night shifts (32%, 95% CI: 27, 38), with a mean difference of +20 percentage points (95% CI: 14, 26. p<0.0001) (Table 13).

HHC was higher after exiting the apartments than before entering the apartments, with a mean difference in the baseline of +3 percentage points (95% CI: -2, 6. p=0.07); in the intervention period, of +3 percentage points (95% CI: -1, 6. p=0.1); and the follow-up period, of +2 percentage points (95% CI: -2, 6. p=0.4). However, the differences were not significant (Table 13 and Figure 30).

Table 13. Study V. HHC in residential apartments in each study phase, specified into work shifts and “before contact with resident” and “after contact with a resident” at Nursing home 2.

		Mean scores (95% CI)					
		Baseline		**Intervention with light**		**Follow-up**	
Apartments	Overall HHC	50%	(48, 53)	56%	(54, 58)	50%	(47, 53)
	Day shift	52%	(50, 54)	58%	(56, 60)	51%	(48, 54)
	Evening/night shift	32%	(27, 38)	27%	(21, 32)	41%	(35, 47)
	Overall HHC, *before* contact	49%	(47, 51)	54%	(52, 57)	49%	(46, 52)
	Overall HHC, *after* contact	52%	(50, 54)	57%	(55, 59)	51%	(48, 53)

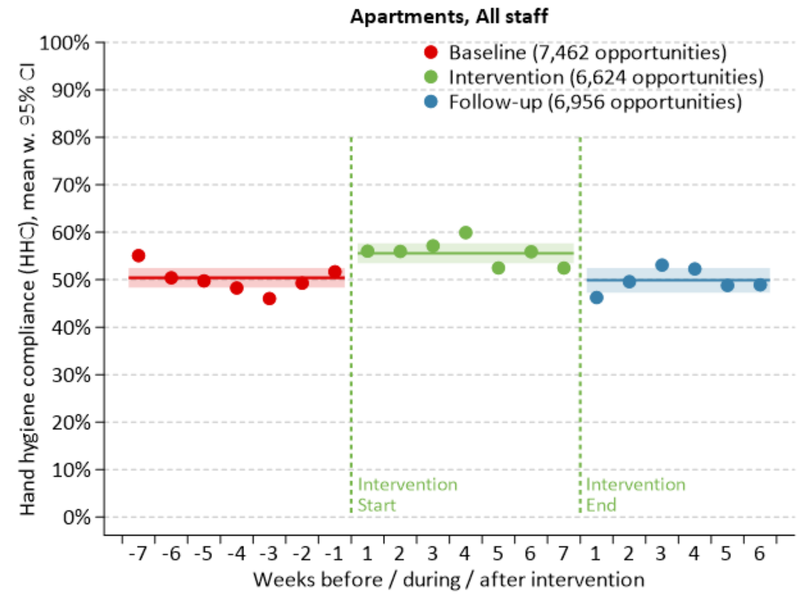


Figure 29. HCWs' HHC in residential apartments. The sum of HHC for both BEFORE entering and AFTER exiting the apartment with 95% CI. The baseline is the period without intervention. The intervention is the period with feedback lights on ABHR dispensers. The follow-up period is the period without interventions [5].

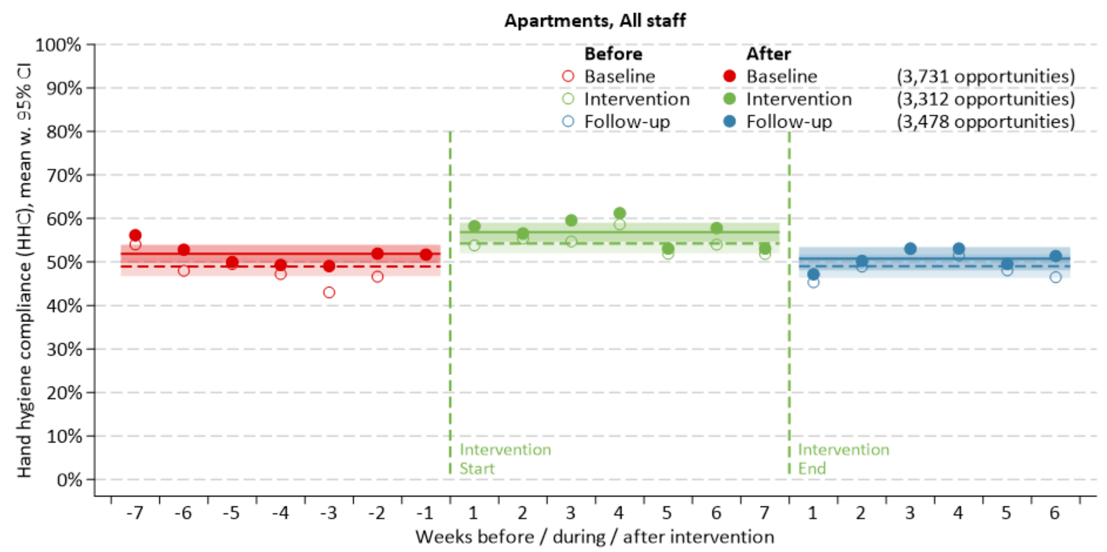


Figure 30. HCWs' HHC in residential apartments BEFORE entering and AFTER exiting the apartment with 95% CI. [5].

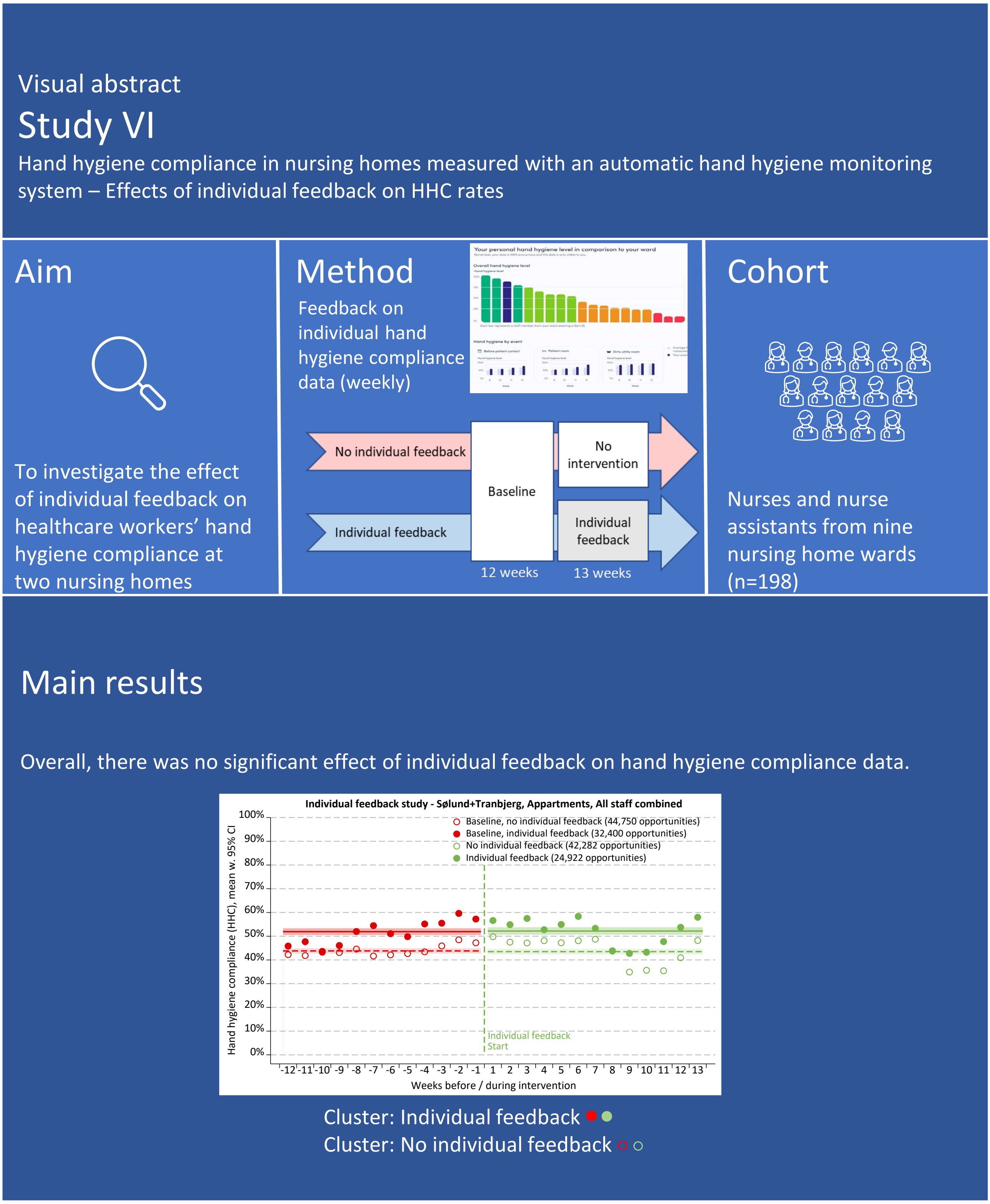


Figure 31. Visual abstract, Study VI

5.6. Study VI: Individual feedback on hand hygiene compliance data in nursing home wards

Publication title: Individual feedback on hand hygiene compliance data in nursing homes (Figure 31) [6].

A six-month study investigated the effect of individual feedback on HHC rates in nursing home wards. A total of 198 nurses and nurse assistants from Nursing homes 1 and 2 (nine wards) were included. A total of 67 HCWs signed up and received the intervention with individual feedback with weekly emails. In all, 131 HCWs did not sign up for the weekly email with individual feedback.

HCWs were distributed into two clusters: "No individual feedback" (n=131) and "Individual feedback" (n=67). For each cluster, HCWs were distributed into day shifts (n=106), evening shifts (n=34), night shifts (n=5) and short-term employees (n=53). A total of 144,354 HH opportunities in residential apartments were included in the analyses.

The study found no effects of the intervention with weekly feedback on HHC data (Table 14, Figure 32). The study reported a HHC of 52% (95% CI: 51, 53) in the baseline period and 52% (95% CI: 51, 54) in the intervention period for the cluster receiving individual feedback. The study reported a HHC of 44% (95% CI: 43, 45) in the baseline period and 44% (95% CI: 42, 45) in the intervention period in the cluster receiving no individual feedback.

The study found that HCWs who received individual feedback had a higher baseline HHC than HCWs who received no feedback, with a mean difference of +8 percentage points (95% CI: 6, 10. p<0.0001) (Table 14).

For the cluster "No individual feedback" the study found the highest HHC among HCWs working night shift (58%) and the lowest HHC among HCWs working day shift (40%), with a mean difference of +18 (95% CI: 15, 21. p<0.001). For the cluster "Individual feedback" the study found the highest HHC among HCWs working day shift (57%) and the lowest HHC among HCWs working evening shift (38%), with a mean difference of +19 (95% CI: 15, 23. p<0.0001)

HHC was higher after exiting the apartments than before entering the apartments. The mean difference in the cluster that received no feedback was +7 percentage points (95% CI: 6, 9. p<0.0001) at baseline and +6 percentage points (95% CI: 4, 8. p<0.0001) in the period without intervention. For the cluster that did receive individual feedback, the mean difference was +4 percentage points (95% CI: 2, 6. p<0.001) at baseline and +4 percentage points (95% CI: 1, 6. p<0.002) in the period with individual feedback. (Table 14 and Figure 33).

Table 14. Study VI. HHC in apartments in each study phase, in two clusters: “No individual feedback” and “Individual feedback”. HHC is stratified by work shift and before and after contact with residents. HHC is given as the mean score in each phase.

		Mean scores (95% CI)							
		Cluster “No individual feedback”				Cluster “Individual feedback”			
		Baseline		**No intervention**		**Baseline**		**Intervention with individual feedback**	
	Apartments								
Nursing Homes 1 and 2	Overall HHC	44%	(43, 45)	44%	(43, 45)	52%	(51, 53)	52%	(51, 54)
	Day shift	40%	(39, 41)	41%	(40, 42)	57%	(55, 58)	57%	(55, 59)
	Evening shift	45%	(42, 48)	48%	(44, 51)	38%	(34, 42)	45%	(42, 48)
	Night shift	58%	(55, 61)	52%	(47, 57)	NA		NA	
	Short-term employee	47%	(45, 49)	44%	(42, 46)	51%	(48, 54)	49%	(46, 53)
	Overall HHC, *before* contact	40%	(39, 41)	40%	(39, 42)	50%	(48, 51)	50%	(49, 52)
	Overall HHC, *after* contact	47%	(46, 49)	47%	(45, 48)	54%	(52, 55)	54%	(52, 56)

NA = Not analysed (< 50 opportunities

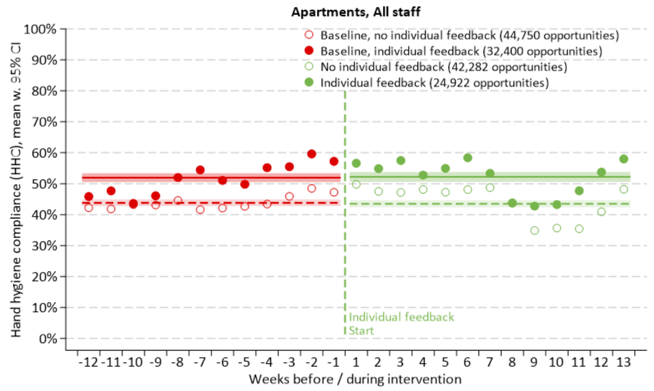


Figure 32. HCWs’ HHC in residential apartments. The sum of HHC for both BEFORE entering and AFTER exiting the apartment with 95% CI. The baseline constitutes a period without intervention. The intervention is the period with individual feedback on HHC data [6].

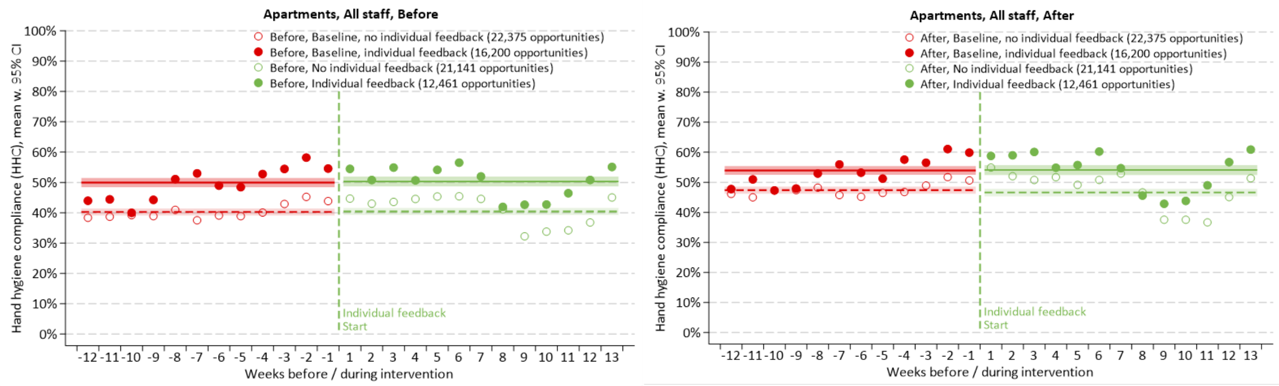


Figure 33. HCWs’ HHC in residential apartments BEFORE entering and AFTER exiting the apartment with 95% CI. [6].

5.6.1. Compliance with the intervention with weekly individual feedback

During the intervention period (13 weeks), the HCWs received a weekly email with their individual HHC data. Nurses and nurse assistants (n=67) signed up to receive the email during the period. Table 15 shows the number of HCWs who opened the weekly email.

Table 15. Number of HCWs who signed up to receive the weekly email with individual feedback data and number of HCWs who opened the weekly email in percentages [6].

Week number	HCWs signed up for the email (absolute numbers)	Number of opened reports (in percentage)
1	60	25%
2	-	-
3	63	37%
4	66	41%
5	66	20%
6	65	31%
7	-	-
8	67	30%
9	67	10%
10	67	31%
11	63	43%
12	60	48%
13	-	-

- Missed value

6. Discussion

6.1. Summary of the main findings

This thesis investigated the accuracy of an AHHMS and the effect of three different interventions to improve HHC in hospital departments and nursing home wards.

Study I evaluated the accuracy of the AHHMS and reported a sensitivity of 100% (95% CI: 95, 100) and a PPV of 100% (95% CI: 95, 100) in relation to HH actions; and a sensitivity of 75% (95% CI: 55, 88) and a PPV of 95% (95% CI: 75, 100) in relation to HH opportunities.

Study II reported a long-term effect of light on ABHR dispensers in hospital wards of +5 percentage points (95% CI: 4, 7. $p<0.0001$) and of +11 percentage points (95% CI: 10, 12. $p<0.0001$) in two different hospital departments.

Study III found no effect of group or individual feedback on HHC data in hospital wards.

Study IV reported an immediate effect of increased accessibility to ABHR in nursing home wards of +18 percentage points (95% CI: 17, 19. $p<0.0001$) and a long-term effect of +13 percentage points (95% CI: 11, 14. $p<0.0001$).

Study V reported an immediate effect of light on ABHR dispensers in nursing home wards of +5 percentage points (95% CI: 2, 8. $p<0.001$). However, the effect was not sustained when the light was turned off.

Study VI found no effect of individual feedback on HHC data in nursing home wards.

6.2. Overall strengths

This thesis has several strengths: 1) It is a large-scale study including more than 968,000 HH opportunities, 2) it evaluates an AHHMS under real-life conditions, 3) it reports data on HCWs' HHC monitored with a type-five AHHMS in nursing home wards and hospital departments, 4) it is the first thesis to report HHC rates from nursing homes in Denmark and 5) it stratifies HHC rates by work shifts and staff groups.

However, the studies from hospital and nursing home wards also had some notable limitations, which will be discussed in the following.

6.3. Discussion of main findings

6.3.1. Evaluation of the AHHMS

HCWs confidence in AHHMS is a key factor for its successful implementation [64, 65, 94, 95], and it has been described that HCWs need to learn to interact with new technology [65]. We experienced that HCWs were interested in understanding the system's technology and algorithms. Many questions were asked regarding its accuracy and about issues related to anonymity (e.g., feeling of being watched), especially during periods where HCWs were being presented with HHC data.

Throughout all the studies, a primary concern was to strike a balance between providing necessary information for the HCWs to adopt the AHHMS and at the same time avoiding undue emphasis on the technology/method for data collection, which could potentially confound the data.

The validation study reported a high sensitivity for detecting nurses' and physicians' HH opportunities, comparable to the findings in a recent German validation study [68]. We chose to include cleaning assistants even though the AHHMS' algorithms were developed to capture events from physicians' and nurses' workflow. The results indicate that cleaning assistants can use the AHHMS, but the system might not register all the cleaning assistants' HH opportunities when cleaning surfaces in patient surroundings and on equipment. However, the missed HH opportunities will not have a negative impact on HHC because they are simply not registered. We concluded that further studies are needed to determine the accuracy in relation to cleaning assistants.

A major limitation of this study is the relatively low number of collected data points. Two observers were observing the same HCWs at the same time, and it turned out to be a time-consuming task. We concluded that a more extensive study with additional data points is needed for a detailed description of the validity of the system under real-life clinical conditions.

6.3.2. Interventions

We chose to investigate the effect of three interventions; 1) light on ABHR dispensers, 2) increased accessibility to ABHR and 3) group and individual feedback. These interventions were chosen based on features from the AHHMS and behavioural theory. The three interventions will be discussed separately in the following sections.

6.3.2.1. Intervention with light:

A cognitive bias called *salience bias* may be a particularly important factor. It refers to the tendency that people focus on information/items that are more prominent or easily accessible, rather than considering all relevant information. People are constantly drawn towards this bias. Salience bias may affect decision-making when people overemphasise the more salient aspects of a situation while neglecting others. When salience bias is at work in the moment of decision-making, people can be nudged by heightening awareness and offering real-time feedback. Light on ABHR dispensers aimed to create such a visual and salient cue to increase awareness and provide real-time feedback [87].

Another important cognitive bias is the *present bias,* which refers to the behavioural tendency to assign greater weight to immediate costs rather than considering future benefits. HH is a situation in which the immediate costs are clear (dry and scratching skin, time consumption, and smell of hand sanitiser), but the benefits are delayed (avoiding HAIs). Accordingly, short-term risk can weigh more heavily than long-term risk in decision-making. Such a cognitive bias may be an impediment to achieving the desired behaviour.

Installing lights to enhance visibility and awareness, acknowledging when an HCW has remembered to perform HH, might help mitigate cognitive biases such as salience and present bias [87, 96].

We found positive results of interventions with light in hospital wards and nursing home wards. However, a long-term effect was found only in the hospital wards. This might be explained by the difference in the intervention design as the hospitals were exposed to two lights (for 8 weeks), while the nursing home was exposed only to one light (for 7 weeks). Interventions with light may be considered a cost-effective intervention that can be used to boost HCWs' HH, especially during periods that demand a strong focus on HH.

Our results were in line with studies reporting significant, immediate effects of visual lights on portable badge or above the patient beds [97-100]. In line with our findings, a study from a Danish hospital reported increased HHC rates following the installation of light on ABHR dispensers (same AHHMS as in this dissertation) in combination with feedback on HHC data [54]. Even though other studies have investigated the effects of light, comparison between studies is hampered by heterogeneity in the intervention designs.

A limitation of the studies with light is that it is impossible to evaluate to which extent the HCWs actually received the intervention because the intervention requires that the HCWs look at the ABHR dispenser when passing and using it. If not, they do not receive the intervention. We speculate whether some of the ABHR dispensers were improperly placed in areas where HCWs might not notice the reminder light when passing the dispenser. Furthermore, HCWs may press the ABHR dispenser very quickly while passing it and therefore do not see the feedback light. Thus, it is unknown to which extent the HCWs actually received the intervention.

6.3.2.2. Intervention with increased accessibility:

The concept of limited cognitive capabilities is well established. Nobel Laureate Daniel Kahneman revolutionised the field of behavioural science by showing the many ways in which our mind chooses the easy option over the more challenging one [84]. As a result, in any given situation, many people will unconsciously try to conserve mental energy for other more demanding work tasks and *default* to the option that requires the least effort (*the path of least resistance*). This is simply a result of the limited cognitive capacity we have available in various situations throughout our lives. Therefore, a lack of compliance with HH is typically not a product of carelessness, misunderstanding or disagreement with the guidelines but rather a product of a cognitive limitation in the specific situation [22, 101]. In other words, people tend to make easy choices, and we therefore need to make the right option easy. Consequently, reducing barriers to the right behaviour may potentially help improve HCWs' HH [102].

In the baseline period at six nursing home wards, only one ABHR dispenser was available in the apartments (in the residential restroom), and HCWs had to walk into the restroom to access the dispenser before contact with the resident. Making it easier for HCWs to access an ABHR dispenser by installing an extra ABHR dispenser in the hallway increased HCWs' HHC. This finding is in line with the theory of behavioural science, arguing that people tend to make easy choices and follow *the path of least resistance* [102]. However, increased accessibility to ABHR might not be the only factor influencing the level of HHC. The new dispenser in the hallway was more visible for HCWs as they passed the dispenser following their work route before and after resident contact. As a result, the visibility of the dispenser may potentially serve as a constant reminder of the need for HH. Additionally, the strategic placement of ABHR may play an important role for HHC. Therefore, *placement* and *visibility* may also impact the effect of the intervention.

Limited accessibility to HH supplies has been identified as one of the important barriers to performing HH [22, 40, 69, 103, 104]. Multiple studies from hospitals have reported that increased access to ABHR enhances HHC rates [105-107]. A recent study found increased ABHR consumption when two dispensers rather than one were made available in the patient room [108], which is in line with our findings. In nursing homes, to the best of our knowledge, the effect of increased accessibility to ABHR has been investigated only in combination with other interventions (e.g. education) [30]. Therefore, this study is the first to assess the effect of increased accessibility to ABHR as a stand-alone intervention on HCWs' HHC in nursing home wards.

We found enhanced HHC rates among HCWs with an additional ABHR in the hallway. We speculate whether further improvements would be possible if we install more ABHR dispensers in the apartments. However, we know from two recent studies [22, 103] that HCWs are constantly challenged by the trade-off between working hygienically and maintaining a homelike environment for residents. Increasing the number of ABHR dispensers in the apartments may compromise the goal of maintaining a homelike atmosphere.

The AHHMS enabled the measurement of HHC during this study. However, measuring consumption may have given comparable results. Nevertheless, if we had pursued this option, we would not have been able to measure opportunities, to stratify HHC data into work shift or to distinguish between residents, visitors and HCWs. The method used to measure HHC is reasonable to consider due to the financial costs of an AHHMS.

6.3.2.3. Intervention with feedback:

Reports indicate that HCWs tend to be overconfident in infection prevention [109]. In particular, HCWs tend to believe that their performance is superior to the median of a group [110]. This overconfidence is not only observed within the realm of infection prevention but is also a general tendency among individuals [111]. The theory posits that on simple tasks (like HH), individuals will, on average, tend to *overplace* their performance relative to others [111]. This may pose a problem as individuals may perceive little need for improvement in their own performance while identifying the shortcomings of their colleagues and recognising their need for improvement [109]. Providing feedback on HHC data might mitigate this overconfidence [112]. However, we found no effect of group feedback as hypothesised. Instead, informal observations and discussions between leaders at the included departments/wards, the PhD student and HCWs revealed that HCWs kept *overplacing* their performance relative to others during the group feedback periods. Furthermore, we hypothesised that providing HCWs with individual feedback would mitigate this overconfidence bias. However, we found no effects of the individual feedback. Instead, we experienced that providing HCWs with feedback on HHC data that significantly differed from the HCWs' own beliefs led to a focus on mistrust of the validity of the AHHMS rather than on improvement. This may be a plausible explanation for the missing effect of the intervention.

Other studies have reported positive results of feedback [54, 57, 113-115]. However, studies have also reported no effects [116-118]. We hypothesised that the intervention with feedback would have a positive effect on HCWs' HHC and that the effect of individual feedback would be greater than the effect of group feedback, based on other studies using the same AHHMS [54-57]. However, our studies (Studies III and VI) found no positive effect of feedback as hypothesised. We chose a non-resource-intensive approach to feedback to explore its feasibility under circumstances where HCWs face time pressure. However, it might have been too low-intensive, indicating that too little time and effort was devoted to the interventions and that improving HHC may demand more allocation of time and energy from leaders. Furthermore, we speculate whether the intervention periods were too short to ensure improvements with this type of intervention and whether immediate feedback, as opposed to the weekly feedback investigated in this dissertation, would have yielded different results. However, this remains unknown.

We might have strengthened the quality of the interventions with group feedback if we had provided more information and education to the leaders regarding HH guidelines, project management and feedback. This would have better equipped them for their leadership roles and facilitated the intervention, aligning with the suggestions by Haenen et al. [119]. It could have been interesting to investigate the leaders' level of knowledge on HH and their experience from working with HHC data and providing feedback to HCWs. However, this aspect remains unknown.

A major limitation of our studies involving feedback is the challenge of assessing whether the HCWs actually received the intervention, posing a challenge in evaluating the interventions.

6.3.2.3.a. Group feedback

During the initial phase of the project, the research group discussed how to provide the HCWs with group feedback. We decided that the leaders should provide feedback during regular weekly meetings to ensure practicality within the clinical practice, considering time constraints. However, when the regular meetings were cancelled, the HCWs did not receive verbal feedback, which was a limitation. Furthermore, if an HCW was not at work on the day the feedback was provided, they did not receive the verbal feedback (they might have received it in a newsletter or from a printed version placed in the staff room, which is unknown).

6.3.2.3.b. Individual feedback

The research group discussed how to provide the HCWs with individual feedback; especially how to do so anonymously. We decided to send the feedback as weekly emails which is a well-known method for providing information, even though we knew that some of the HCWs struggled to find the time to open their emails every week.

We tried to evaluate whether the HCWs received the intervention with feedback by registering the number of provided group feedback instances and the number of opened emails with individual feedback. Based on these registrations, we documented that HCWs were unequally exposed to both group and individual feedback. However, we were not able to register how many HCWs attended the group feedback. Furthermore, we were not able to register if the HCWs who opened the email with individual data actually read and related to the data. In conclusion, even though feedback was provided, the HCWs might not have received it. This is a major limitation of the studies and a plausible explanation for the missing effect of group and individual feedback.

6.4. Secondary findings

This thesis reported some secondary findings, which will be discussed in the following sections.

6.4.1. Overall hand hygiene compliance rates at baseline

All five interventional studies included a baseline period before the introduction of the first intervention (Figure 14 and Figure 15). The highest level of baseline HHC was found in Nursing home 2 with a mean HHC of 50% (95% CI: 48, 53); followed by Nursing home 1, with a mean HHC of 31% (95% CI: 30, 32). The lowest baseline HHC rate was found in the hospitals, with a mean HHC of 19% (95% CI: 18, 21) in Department 2 and a mean HHC of 21% (95% CI: 20, 21) in Department 1.

The baseline rates reported in this dissertation are in line with those reported in other Danish studies using the same AHHMS, reporting baseline HHC rates within the range of 16% to 52% [44, 50, 54-57]. However, the rates are relatively low compared with other international studies reporting HHC rates. However, as HHC rates vary tremendously, from less than 25% to more than 90%, with numerous factors affecting the reported compliance rates, it is hardly feasible to compare the results [25, 26, 38, 40-42].

6.4.2. Hand hygiene compliance in nursing homes stratified according to work shifts

A strength of the studies from Nursing home 1 and Nursing home 2 is that they report baseline HHC data stratified into work shifts. In Nursing home 1, we found a higher baseline HHC among HCWs working day shift (33%, 95% CI: 31, 35) than HCWs working evening shifts (27%, 95% CI: 25, 30), with a mean difference of +6 percentage points ($p<0.001$); and HCWs working night shift (27%, 95% CI: 25, 30), with a mean difference of +6 percentage points ($p<0.001$). HCWs working as short-term employees had a baseline HHC of (32%, 95% CI: 30, 34), which was in line with HCWs working day shifts (Table 12).

These findings are in line with those from Nursing home 2, reporting a higher baseline HHC for HCWs working day shifts (52%, 95% CI: 50, 54) than HCWs working evening/night shifts (32%, 95% CI: 27, 38), with a mean difference of +20 percentage points ($p<0.0001$). We could not report the HHC of short-term employees at Nursing home 2 due to a low number of participants (Table 13).

Our findings from the first baseline periods in nursing homes 1 and 2 (study IV and V) are supported by findings from two studies from hospitals (monitored with AHHMS). The studies reported HHC to be highest during the mornings and subsequently decreasing throughout the day [44, 120]. However, in this dissertation, study VI found a higher HHC among HCWs working night shift than HCWs working day shift, with a mean difference of +18 percentage points (95% CI: 15, 21) in one of the clusters (“No individual feedback”)

(Table 14), which is a conflicting result. To the best of our knowledge, no other studies from nursing homes have stratified HHC data into work shifts and more data are needed on this topic.

We speculate whether the differences between work shifts may be attributed to the characteristics of individuals working each shift, differences in work tasks or the degree of information/discussions regarding infection prevention and HH in each work shift. However, this remains unknown.

6.4.3. Hand hygiene compliance in hospital departments stratified according to profession

In hospital departments, we found a significantly higher baseline HHC among nurses than among physicians in both Study II and Study III (Table 8 and Table 9). Study II found a mean difference of +6 percentage points (95% CI: 3, 9) in Department 1 and +4 percentage points (95% CI: 0, 8) in Department 2. Study III reported a mean difference of +8 percentage points (95% CI: 5, 11) in Department 1 and +6 percentage points (95% CI: 2, 9) in Department 2. This finding is supported by multiple other studies reporting higher HHC among nurses than among physicians [26, 37, 38].

6.4.4. Hand hygiene before vs after contact with patients or residents

At all study sites, we found a higher baseline HHC after contact than before contact with patients/residents or their near surroundings (Table 8, 9, 12, 13, 14). This finding is supported by multiple other studies reporting higher HHC after than before contact with patients/residents or patient-near surroundings [40, 44, 120-123]. In the literature, this has been explained by the need for self-protection [42, 46]. However, another plausible explanation, could be the time inconvenience associated with HHC. Hence, HH supplies are placed at the room entrance before the HCW reaches the patient/resident, precisely when the HCW's focus is on the patient. Performing HH when entering the patient room demands the HCW's attention when his or her mind is absorbing a new and sometimes complex and demanding situation. The HCW's full focus on the patient paradoxically deflects attention from other important tasks such as HH. Exactly because HH is so simple, it is typically allocated neither time nor planning [101]. This may explain why HHC is lower before entering a patient/resident zone/room than after exiting the zone/room.

6.4.5. Hand hygiene among healthcare workers who volunteered to sign up for individual feedback

We found that HCWs who signed up for individual feedback had a higher HHC during the baseline period than HCWs who did not volunteer to receive individual feedback. In hospital departments (Study III), we found a mean difference of +3 percentage points (95% CI: -1, 6. p=0.1) in Department 1 and +6 percentage points (95% CI: 3, 9. p<0.001) in Department 2 (Table 9). In nursing home wards (Study VI), we found a mean difference of +8 percentage points; 95% CI: 6, 10. p<0.0001 (Table 14).

We speculate whether HCWs who volunteer to receive individual HHC data already have a higher focus on HH and therefore have an interest in receiving HHC data. Furthermore, other studies show that time constraints affect HHC rates [9, 22, 26, 47]. HCWs who experience time constraints (and mental overload) possibly have a lower HHC and therefore have little time and energy to engage in the project (individual HHC data). However, the explanation remains unknown. Our finding indicates that stratifying HCWs into intervention groups already from the baseline period may facilitate investigation of potential differences between the groups before an intervention is introduced.

6.5. Methodological considerations

6.5.1. Inclusion of study participants

The author group had some considerations concerning how to include HCWs in this project; the main one being how to balance the need for registration of participants while ensuring the participants that their individual HHC data could not be accessed by their colleagues, leaders or project managers. Each participant should wear a Sani Nudge tag on their name badge with a chip containing a unique anonymous 12-digit ID number. Only a team at Sani Nudge™ had access to the unique ID numbers in the back-end computer program. We considered the HHC data to be pseudo-anonymous as the personal HHC data could be accessed only if the unique ID numbers were paired with work schedules over a longer period.

We decided that informed consent was given when an HCW decided to pick up and carry a tag on their name badge. The tag was easy to put on and also easy to take off if the participant wanted to be excluded from the study. To guarantee the study participants' anonymity, we chose only to obtain information about their healthcare profession. However, it would have been interesting to analyse differences between age, sex and work tenure and to follow individual HHC during the study phases.

6.5.2. Included HCWs and selection bias

The AHHMS collected HHC data when the HCWs wore the Sani Nudge tag on their name badge. To ensure anonymity, the individual ID numbers were not registered. Consequently, we could not assess the individual's HHC data and were therefore unable to determine if all included HCWs participated in the entire data collection period. Some HCWs might have stopped, and others may have been included during the data collection period. Therefore, it remains unknown how many of the included participants participated in the entire study period and if this could have impacted the HHC rates in either direction. This is a limitation of our study design.

Furthermore, study participation was voluntary and selection bias must be considered. We know from the results of Studies III and VI that HCWs who volunteered to sign up for individual feedback had a higher HHC than those who chose not to sign up. Therefore, it may be possible that HCWs who did not participate in the study had a lower HHC than those who did participate.

6.5.3. Interventions – general considerations

All nine wards had positive effects of the first intervention to which they were exposed (lights at hospital wards and Nursing home 2; and increased accessibility to ABHR at Nursing home 1) (Figure 14 and Figure 15). All nine wards investigated the effects of feedback on HHC data after being exposed to other interventions. It is unknown whether we could have seen an effect of the intervention with feedback if HCWs had been exposed to feedback like in the first intervention. However, a relatively long period elapsed between the first intervention and the second intervention in all nine wards, indicating that the second intervention might be considered a new "first" intervention.

Furthermore, we considered the possibility that the effect of the intervention could not be attributed to the specific intervention conducted but instead stemmed from a generally increased focus on the importance of HH. In that case, the specific intervention would be more or less unimportant, and the effect would result from a more general, increased focus on HH. Furthermore, a positive effect of an intervention could also be caused by the project leaders acting as role models rather than resulting from the specific intervention as role models have been suggested to affect the HHC [46, 103].

6.5.4. COVID-19

Immediately after the implementation of the AHHMS in hospital wards, the COVID-19 pandemic hit the country. It is unknown how the pandemic affected the HHC rates. However, other studies have evaluated the effect of COVID-19 on HHC. Some of these studies found no consistent improvements [48-50], while others found temporary improvements during societal lock-downs, followed by a return to baseline after a relatively short period [51-53].

In our Studies II and III (from hospital wards), a short period with increased HHC levels during the follow-up phases was a surprise finding. In both studies, the increased HHC levels correlated with societal lockdowns caused by the COVID-19 pandemic. In Study II, the increased HHC levels were found only in Department 1. In Study III, the increased HHC levels were found in both Departments 1 and 2. We speculate whether a causal relationship exists between societal lockdowns and increased HHC rates (Dec. 2020 - Study II) and (Dec. 2021 - Study III). However, this remains unknown.

It may have been a strength if we had included more departments in the studies to evaluate variations across society (e.g., COVID-19) that could affect HHC levels. However, the studies were planned before COVID-19 struck. Furthermore, the financial costs of the AHHMS barred us from including more departments.

6.6. Is it realistic to adhere to the existing guidelines?

Ensuring clinicians' adherence to guidelines remains a persistent challenge in many organisations, especially within the healthcare system [124]. HH is just one of the guidelines that HCWs find challenging to adhere to. When entering a patient room, HCWs must recall multiple guidelines, and HH guidelines contend for attention among multiple other guidelines that are crucial to patient care and treatment. While HH guidelines might seem relatively simple in isolation, incorporating them into the myriad of other crucial guidelines to remember during patient care renders the overall guidance much more complex. Therefore, it is reasonable to question the feasibility of adhering to HH guidelines in clinical practice, especially with a high workload. For example, the WHO Guidelines For Hand Hygiene in Healthcare recommend that hands be rubbed for 20-30 seconds when using ABHR [16] while the Centers for Disease Control and Prevention recommend rubbing hands until dry for around 20 seconds [125]. The Danish National Infection Prevention Guidelines (NIR) recommend that hands be rubbed for 30 seconds when using ABHR [77]. However, it is reasonable to consider whether it is realistic to rub hands for 30 seconds every time an HH opportunity arises [26, 126]. This consideration is relevant because lack of time is repeatedly identified as a factor that negatively affects HH adherence [9]. If guidelines are excessively time-consuming to follow in clinical practice, high HHC rates might be unattainable. It is crucial that HCWs plan their work activities to limit the number of opportunities and thereby reduce the time spent on performing HH [22]. Furthermore, leaders must allocate time to this task.

This dissertation shows that HCWs can be nudged to enhance HHC by leveraging cognitive biases. However, we must also consider how nudges to improve HH guideline adherence might decrease adherence to other guidelines. Furthermore, if nudges on numerous behaviours became available, their effectiveness would possibly decrease as each nudge may receive less attention than was the case in our studies [87]. However, this consideration remains unexplored in this dissertation.

6.7. Experiences with implementation of an AHHMS in hospital wards and nursing home wards

New AHHMS are being developed these years to accommodate the disadvantages of direct observations [94, 127]. Investigating the effects of technologies in a real-world clinical practice is crucial before investing time and money in the systems. This involves assessing the validity of the data, HCWs' adaption to the systems and how to use big data to improve HHC. The AHHMS themselves do not improve HHC.

The AHHMS enabled assessment of the interventions. However, we found that it was important to be critical to the data collected as another technological system interfered with the AHHMS during data collection. This shows the importance of monitoring performance when implementing such systems into a real-world clinical practice rather than simply adapting knowledge from other AHHMS, countries or departments.

Furthermore, we experienced a relatively high turnover of local leaders during the study period. This presented a challenge, particularly as it was arduous for new leaders to become actively engaged in such a system and project, amid numerous other important projects and tasks. In general, it is important to consider whether the specific clinical managers and employees have the time and motivation to work with the data collected from the AHHMS before implementing such a system as the data themselves will not improve HHC. Challenges with a high staff turnover and cognitive limitations among HCWs may reflect most real-life clinical practices. Therefore, new AHHMS and interventions to improve HHC must take such challenges into account before they are implemented. Otherwise, it may be a time-consuming and expensive solution that fails its intended purpose of improving HHC.

7. Conclusion

The AHHMS enabled assessment of HHC in hospital departments and nursing home wards.

Our study found immediately increased HHC rates following light on ABHR dispensers in hospital and nursing home wards. A long-term effect was seen in the hospital wards. In nursing home wards, however, no long-term effects on HHC rates were achieved when the lights were switched off. This finding is in line with those of two other studies reporting an immediate effect of visual lights on HHC in hospitals decreasing to baseline when the lights were switched off.

The dissertation reported increased HHC rates when accessibility to ABHR was increased in nursing home wards. This finding is in line with other studies reporting positive effects of increased accessibility to ABHR in hospitals. However, to the best of our knowledge, this is the first study to investigate the effect of increased accessibility to ABHR as a single intervention in nursing home settings.

We found no effects of group or individual feedback of HHC data on HCWs' HHC in hospital departments or nursing home wards. This may be attributed to an approach to the interventions with feedback that may have been insufficiently intensive. Our results are in line with those of other studies reporting no effects of feedback on performance status. However, some studies report positive effects of feedback. More robust evidence is therefore needed.

The thesis reported some secondary findings. We found significantly higher HHC among nurses than among physicians in hospital departments, which aligns with emerging evidence. Furthermore, the thesis reported significantly higher HHC among HCWs working day shift than evening/night shifts in nursing homes. To the best of our knowledge, this is the first report on differences in this regard associated with work shifts in nursing homes.

8. Perspectives and Future Research

A constantly challenged healthcare system needs solutions that are not overly resource demanding. An advantage of an AHHMS is its capability to automatically collect and analyse HHC data 24/7. Data can be used to evaluate interventions to improve HH. However, implementing an AHHMS involves major financial costs and requires time and energy from leaders and HCWs to leverage the HHC data collected.

In an ideal world, it would be interesting to implement the AHHMS across hospitals and nursing homes throughout Denmark for continuous monitoring of HHC. Hospital and municipality boards would be able to monitor and evaluate HHC rates and set goals for improvement work. Local leaders would have access to online dashboards where weekly HHC rates would be presented for each room type and profession, which would make improvement work in a more targeted way. Furthermore, researchers would be able to investigate the association between HHC rates and HAIs.

However, some research topics should be investigated in future research to enhance knowledge within this area:

Interventions to improve hand hygiene:

This dissertation found increased HHC rates of interventions with increased accessibility to ABHR and with light on the ABHR. However, more research on the effect of light or other attention-commanding interventions is needed to enhance evidence on how to maximise effect. We found no effect of feedback of HHC data. However, a more intensive approach to feedback of HHC data needs to be investigated.

In this dissertation, we found differences in baseline rates among the study sites. Cultural differences may explain this. It would be interesting to investigate HHC rates at more study sites from hospitals and nursing homes to enhance knowledge of HHC rates in different healthcare settings, e.g. intensive care units, paediatrics, surgical departments and long-term care facilities, to investigate how HHC rates differ among the different facility settings.

HCWs' adaption and perception of the AHHMS:

We evaluated the accuracy of the AHHMS under real clinical conditions in hospital departments. However, it was a small-scale study, and more data are needed to validate the AHHMS in hospital and nursing home settings. Validation of new technologies in clinical practice may be crucial for HCWs' perception and adaption of the system.

Future research should investigate HCWs' adaption and perception of the AHHMS. We experienced from informal observations and discussions that some HCWs requested detailed knowledge about the technology and the algorithms, and that they had considerations regarding anonymity, while others requested no extra information. Lack of acceptance of an AHHMS may inhibit improvements, and further research on this issue is needed.

8.3. Leaders' knowledge regarding the AHHMS and hand hygiene

Monitoring HHC does not inherently improve HH. Local leaders may serve as the bridge linking the collected data with enhanced HHC. However, working with HHC data requires knowledge about the AHHMS, HH guidelines and the connection to HAI to be able to provide HCWs with group feedback and engaging in discussion of data and guidelines with HCWs. Future research should investigate leaders' knowledge of these topics.

8.4. Correlation between improved HHC and HAIs

One of the most important topics to investigate in the future is the correlation between HHC and HAIs. We could not do that in this dissertation due to the COVID-19 pandemic. Future research could use data from the Danish Healthcare-Associated Infections Database (HAIBA) and clinical microbiology departments to follow the number of selected HAIs and outbreaks (e.g. SARS-CoV-2, MRSA, CPO, VRE) to investigate whether they are correlated with HHC. This work would add to the body of knowledge on infection prevention.

This thesis benefits from innovative work in developing an AHHMS capable of monitoring HHC 24/7. The AHHMS was developed due to lack of valid HH data and ensuing difficulties in evaluating initiatives to improve HH. Now we have a fully developed system capable of integrating HHC data with the Danish regions' business intelligence (BI) portals. The next step is to discuss the need for a permanent installation of an AHHMS in clinical practice.

On one hand, hospital and municipality boards request cost-benefit analyses to determine the feasibility of permanently installing an AHHMS. On the other hand, the implementation of an AHHMS is needed to provide the answers required for these requested analyses, posing a challenge for future work with HH.

9. English Summary

Background

Healthcare workers' (HCWs') hand hygiene compliance (HHC) is reported to be one of the most important measures with which to prevent infections in healthcare settings. However, HHC among HCWs remains low and it is a challenge to improve and sustain high compliance rates. We aimed to evaluate the accuracy of an AHHMS (Sani Nudge^{TM}) and assess the effects of interventions to improve HHC among HCWs in hospital and nursing home wards.

Methods

One study evaluated the accuracy of the AHHMS in hospital departments during real-life clinical conditions by comparing HH events registered by two observers in parallel with HH events registered by an automatic hand hygiene monitoring system (AHHMS). A total of 103 HH opportunities were included from nurses, physicians and cleaning assistants (n=25).

Five interventional studies investigated the effects of three different interventions; 1) light on ABHR dispensers, 2) increased accessibility to ABHR dispensers in residential apartments and 3) group and individual feedback on HHC rates. An AHHMS was used to collect HHC data. A total of 968,000 HH opportunities were collected during the five studies. Nurses, nurse assistants, physicians and cleaning assistants from two hospital departments (four wards) and two nursing homes (nine wards) were included. All five studies had a baseline period before introducing an intervention. Three studies had a follow-up phase.

Results

We found the highest baseline in one of the nursing homes with a mean HHC of 50% (95% CI: 48, 53) followed by the other nursing home with a mean HHC of 31% (95% CI: 30, 32). The lowest baseline HHC was found in the hospitals, with a mean HHC of 19% (95% CI: 18, 21) in one of the departments and a mean HHC of 21% (95% CI: 20, 21) in the other department.

Study I evaluated the accuracy of the AHHMS and reported a sensitivity of 100% (95% CI: 95, 100) and a positive predictive value (PPV) of 100% (95% CI: 95, 100) in relation to HH actions, and a sensitivity of 75% (95% CI: 55, 88) and PPV of 95% (95% CI: 75, 100) in relation to HH opportunities.

Study II reported a long-term effect of light on ABHR dispensers in hospital wards of +5 percentage points (95% CI: 4, 7. p<0.0001) and +11 percentage points (95% CI: 10, 12. p<0.0001) in two different hospital departments.

Study III found no effect of group or individual feedback on HHC in hospital wards.

Study IV reported an immediate effect of increased accessibility to ABHR in nursing home wards of +18 percentage points (95% CI: 17, 19. $p<0.0001$) and a long-term effect of +13 percentage points (95% CI: 11, 14. $p<0.0001$).

Study V reported an immediate effect of light on ABHR dispensers in nursing home wards of +5 percentage points (95% CI: 2, 8. $p<0.001$). However, the effect was not sustained when light was turned off.

Study VI found no effect of individual feedback on HHC in nursing home wards.

Conclusions

The AHHMS can capture HHC among nurses and physicians in a real-life clinical setting but shows less accuracy for cleaning assistants. The AHHMS enabled assessment of HHC during the interventional studies.

Overall, the studies reported increased HHC rates during intervention periods with increased accessibility to ABHR and lights on ABHR dispensers.

Two studies found immediate effects of interventions with lights on ABRH dispensers in nursing homes and hospital departments. A long-term effect of light was reported in hospital departments. Furthermore, a study reported increased HHC rates in nursing home wards when increasing accessibility to ABHR in residential apartments. However, two studies investigated the effects of group and individual feedback on HHC rates and found no effects on HCWs' HHC.

10. Dansk Resume

Baggrund

Sundhedspersonalets håndhygiejne anses for at være en af de vigtigste faktorer i forebyggelsen af sundhedserhvervede infektioner. På trods af dette har personalet på hospitaler og plejehjem en lav efterlevelse af retningslinjer for håndhygiejne. Vi ønskede at evaluere nøjagtigheden af et automatisk monitoreringssystem (Sani Nudge™), som kan indsamle data på personalets håndhygiejne samt undersøge effekten af udvalgte interventioner til at forbedre personalets overholdelse af retningslinjerne for håndhygiejne på hospitalsafdelinger og plejehjem i Danmark

Metode

Vi implementerede et automatisk håndhygiejnesystem, som indsamlede data på personalets håndhygiejne på hospitalsafdelinger og plejehjem. Det første studie evaluerede nøjagtigheden af de data, som systemet indsamlede, ved at sammenligne data fra systemet med observationsdata indsamlet af to observatører. Vi inkluderede 103 håndhygiejnesituationer fra 25 læger, sygeplejersker og serviceassistenter.

Dernæst undersøgte vi effekten af tre forskellige interventioner; 1) lys på spritdispenseren, 2) øget tilgængelighed af håndsprit i plejehjemsboliger og 3) gruppefeedback og individuel feedback på håndhygiejnedata. Sygeplejersker, social og sundhedsassistenter/-hjælpere, læger og serviceassistenter fra to hospitalsafdelinger og to plejehjem blev inkluderet. I alt blev der indsamlet data på mere end 968.000 håndhygiejnesituationer. Disse data blev rapporteret i fem studier. Medarbejdernes eksisterende overholdelse af retningslinjer for håndhygiejne, inden interventionen blev sat i værk (*baseline*), blev undersøgt på begge afdelinger og begge plejehjem.

Resultater

Vi fandt den højeste baseline på det ene plejehjem med en gennemsnitlig overholdelse af retningslinjerne for håndhygiejne på 50% (95% CI: 48, 53) efterfulgt at det andet plejehjem, som have en gennemsnitlig overholdelse af retningslinjerne for håndhygiejne på 31% (95% CI: 30, 32). Det laveste niveau for overholdelse af retningslinjerne for håndhygiejne under baseline-perioden blev fundet på hospitalsafdelinger, hvor gennemsnittet var 19% (95% CI: 18, 21) på den ene afdeling og 21% (95% CI: 20, 21) på den anden.

Studie I evaluerede nøjagtigheden af det automatiske system og fandt en sensitivitet på 100% (95% CI: 95, 100) for brug af håndsprit, en sensitivitet på 75% (95% CI: 55, 88) og en positiv prædiktiv værdi på 95% (95% CI: 75, 100) for situationer, hvor håndhygiejne skulle udføres.

Studie II fandt en langvarig effekt på overholdelse af anvisningerne for håndhygiejne ved interventionen med lys på +5 procentpoint (95% CI: 4, 7. $p<0.0001$) på den ene hospitalsafdeling og +11 procentpoint (95% CI: 10, 12. $p<0.0001$) på den anden hospitalsafdeling.

Studie III fandt ingen effekt af at give hospitalsafdelingernes personale gruppebaseret eller individuel feedback.

Studie IV rapporterede en umiddelbar effekt af at øge tilgængeligheden af håndsprit i plejehjemsboliger på +18 procentpoint (95% CI: 17, 19. $p<0.0001$) og en langvarig effekt på +13 procentpoint (95% CI: 11, 14. $p<0.0001$).

Studie V rapporterede en umiddelbar effekt af feedback med lys på +5 procentpoint (95% CI: 2, 8. $p<0.001$) på et plejehjem. Overholdelsen af retningslinjer for håndhygiejne faldt dog igen, da interventionen med lys på spritdispenserne sluttede.

Studie VI fandt ingen effekt af at give plejehjemspersonalet individuel feedback på deres håndhygiejne-data.

Konklusion

Det automatiske monitoreringssystem kan indsamle nøjagtige data for lægers og sygeplejerskers håndhygiejne på hospitalsafdelinger, men er mindre nøjagtigt, når det måler serviceassistenters overholdelse af retningslinjerne for håndhygiejne. Der er behov for flere datapunkter for at validere systemet i klinisk praksis.

De fem interventionsstudier fandt en positiv effekt af interventioner med lys på spritdispensere og øget tilgængelighed af håndsprit. Studierne fandt ingen effekt af feedback på håndhygiejne-data til personalet.

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Paper I

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Clinical evaluation of an electronic hand hygiene monitoring system

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Major Article

Clinical evaluation of an electronic hand hygiene monitoring system

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Compliance
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A B S T R A C T

Background: We aimed to test the accuracy of an electronic hand hygiene monitoring system (EHHMS) during daily clinical activities in different wards and with varying health care professions.

Methods: The accuracy of an EHHMS (Sani Nudge) was assessed during real clinical conditions by comparing events registered by two observers in parallel with events registered by the EHHMS. The events were categorized as true-positive, false-positive, and false-negative registrations. Sensitivity and positive predictive value (PPV) were calculated.

Results: A total of 103 events performed by 25 health care workers (9 doctors, 11 nurses, and 5 cleaning assistants) were included in the analyses. The EHHMS had a sensitivity of 100% and a PPV of 100% when measuring alcohol-based hand rub. When looking at the hand hygiene opportunities of all health care workers combined taking place in the patient rooms and working rooms, the sensitivity was 75% and the PPV 95%. For doctors' and nurses' taking care of patients in their beds the EHHMS had a sensitivity of 100% and a PPV of 94%.

Conclusions: The objective accuracy measures demonstrate that this EHHMS can capture hand hygiene behavior under clinical conditions in different settings with clinical health care workers but show less accuracy with cleaning assistants.

Health care-associated infections (HAIs) are the most frequent adverse events occurring during patient care and are estimated to cost a 200-bed facility more than $1.7 million per year.[1-4] Inadequate hand hygiene (HH) leads to cross-transmission of microorganisms and HAIs.[5] Even during the Covid-19 pandemic, HH compliance (HHC) among health care workers (HCWs) is a challenge, and hospitals are struggling to find solutions with sustained effect.[6-8]

To evaluate HH interventions and the cost-effectiveness of new initiatives, HHC must be measured reliably. Direct observation by trained observers is the most used method, but it is subject to bias and resource-heavy for the already strained health systems managing the pandemic.[9,10] Health care organizations are starting to use electronic HH monitoring systems (EHHMSs) as part of the World Health Organization's (WHO) multimodal strategy for HH improvement because they require fewer human resources, provide larger and more representative data sets, and are less subject to observation bias. EHHMS measures a proxy for HH. Both direct observations and EHHMSs have pros and cons, and together they can supplement each other.[9-12]

New EHHMSs must be validated in clinical practice to be widely adopted.[13,14] A systematic review of 42 articles mentioning automated measurement systems found that fewer than 20% of the studies included calculations for accuracy.[15] In Denmark, the only EHHMS

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used is Sani Nudge.[16] The system's accuracy was recently validated in a German hospital under simulated conditions, which showed an accuracy rate of 100%.[17] However, EHHMSs also need to be validated during real clinical conditions to assess reliability and generalizability, as suggested by Limper et al.[18,19]

We aimed to test the accuracy of the Sani Nudge system during real clinical conditions in different wards with varying health care professions.

METHODS

Setting

At three randomly selected days in December 2020 and June 2021, we conducted the study at the Department of Oncology (32 beds) and the Department of Hematology (34 beds), Aarhus University Hospital (Denmark) a tertiary care university hospital center with more than 80,000 hospital admissions per year.

Electronic hand hygiene monitoring system

Sani Nudge[6,16,17,20-22] is an advanced type 5 EHHMS according to the classification by Gould et al. A type 5 EHHMS is capable of taking previous workflow into consideration instead of only looking at room entry or patient zones as separate events.[23] This system captures a proxy measure for the WHO's Moments 1, 4, and 5 using three main hardware components (Fig 1): (1) the Sani zone sensor: A sensor placed on the wall above the patient bed and in workrooms (eg, medication rooms) that registers if the HCW was near the sensor; (2) the Sani dispenser sensor: A sensor on soap and alcohol-based hand rub (ABHR) dispensers that measures when the HH action happened. For this study, the sensors were not placed on soap dispensers; (3) the Sani ID: An anonymous Bluetooth tag on the HCW's name badge, key hanger, or clothes which connects a HH action to a HCW and registers if the HH action happened in relation to a HH opportunity.

The system uses time and distance measures as part of the algorithms to register if a HH opportunity takes place. It does not qualitatively distinguish between moments 4 and 5.

Validation approach

The study design aimed to compare HH actions and HH opportunities between direct observations and the EHHMS in order to establish true positive, true negative and false negative events.

We adapted a validation approach described by Limper et al.[18,19] Because the EHHMS had already been validated during real clinical conditions, we focused on the final phase of the validation approach testing how the EHHMS performed under real clinical conditions. HCWs (nurses, doctors, and cleaning assistants) from the two departments (four wards) volunteered to wear a Bluetooth test tag (Sani ID) during their daily clinical activities. The test tag had a known identification number to ensure that each event could be identified in the database retrospectively. The observations were included in the analyses when the following inclusion criteria were met:

1) the observers registered contact between the HCW and the patient/patient surroundings
2) the system registered the HCW in the patient zone in sufficient time for contact with the patient/patients near surroundings
3) the observers registered the HCW's use of ABHR
4) the system registered the HCW's use of ABHR

A prerequisite for the event to be included was that: (1) the HCWs agreed to wear the test tag; (2) the HCWs used an ABHR dispenser with a sensor; and (3) the patient bed was placed correctly under the bed sensor. The prerequisite variables were checked for each event.

Two trained and experienced observers (nurses) documented all HH actions and HH opportunities by direct observation using a predefined observation sheet (Table 1). The two observers documented the behavior of each HCW at the same time. The events are reported in two main categories (1) HH actions (HCWs use of ABHR) and (2) HH opportunities (HCWs physical contact with a patient, patient surroundings, or work zones). In case of discrepancies between the two observers, the event was excluded.

Ethics

This was a substudy to a quality improvement project. According to the Danish law, approval was queried and evaluated as not needed by both the Ethics Committee (J. no. 1-10-72-148-19) and the Danish Data Protection Agency (J. no. 2019-212-1420). After approval from department management, all the observed HCWs were verbally informed of the aim of the study and agreed to use a test sensor while they were being observed. Patients were also verbally informed of the purpose of the observers' presence in the patient room.

Statistical analysis

We used an independent-event approach treating each device encounter as an independent event to allow identification of

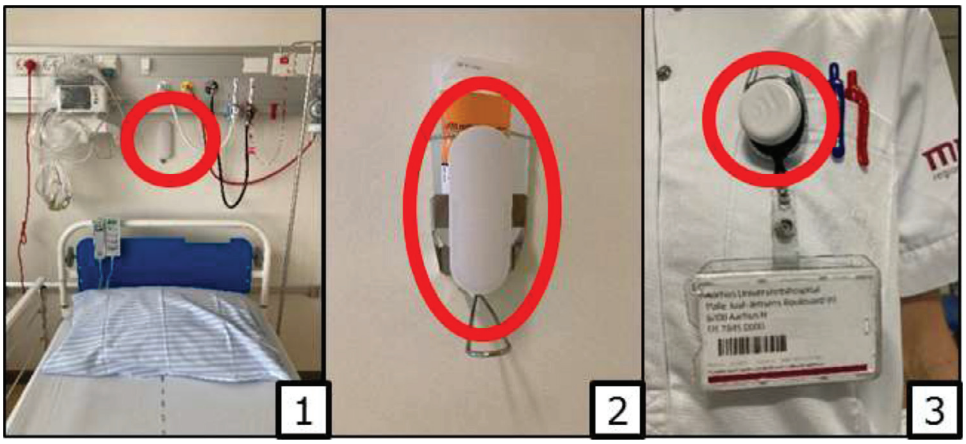

Fig 1. Three hardware components of Sani Nudge: (1) the Sani zone sensor, (2) the Sani dispenser sensor, (3) the Sani ID (individual Bluetooth tag).

Table 1
Example of registration of observation data

Time (HH:MM)	Procedure/behavior	Use of ABHR
08.36	Hand hygiene	x
08.37	Touch the patient bed	
08.41	Take a notebook from the uniform pocket and write a note	
08.43	Hand hygiene	x
08.43	Put on gloves	
08.44	Touch patient leg and stomach	
08.55	Hand hygiene	x

Table 2
Hand hygiene actions performed by doctors, nurses, and cleaning assistants

	Sanitizations observed	Sanitizations not observed
Detected by the EHHMS	78	0
Not detected by the EHHMS	0	ND

Comparisons of results between the direct observers and the electronic hand hygiene monitoring system for nurses, doctors, and cleaning staff.

Table 3
Hand hygiene opportunities performed by doctors, nurses, and cleaning assistants

	Contact observed	Contact not observed
Detected by the EHHMS	18	1
Not detected by the EHHMS	6	ND

Comparison of results between the direct observers and the electronic hand hygiene monitoring system.

inaccuracies during the observations. The direct observation data from the two observers and data from the EHHMS were categorized into three scenarios as suggested by Limper et al[18]: (1) True-positive events were defined as actions/opportunities captured by the direct observers and the EHHMS. (2) False-positive events were actions/ opportunities that were not registered by the direct observers but captured by the EHHMS. (3) False-negative events were actions/ opportunities registered by the observers but not captured by the EHHMS. The truth was defined by the two observers recording the same HH action and HH opportunity of the HCW. Based on the events, we calculated the sensitivity and positive predictive value (PPV). The sensitivity was defined as the probability that a true HH event was captured by the EHHMS. The PPV was defined as the probability that the event captured by the EHHMS really occurred. True-negative events (events not captured by the observers or the EMHHS) were not possible to report in this study because these events could not be identified.

Statistical analyses were conducted using GraphPad Prism (version 9.3.1, GraphPad Inc) and Excel (version 16.47.1, Microsoft).

RESULTS

Overall, 120 events were performed by 25 HCWs (doctors, n=9; nurses, n=11; cleaning assistants, n=5). Twelve events did not meet the inclusion criteria. Of the remaining events, we found a discrepancy between the registrations of the two observers in five cases (percentage of agreement between observers of 95%). Thus, 103 events were included in the accuracy analyses, of which 78 were HH actions and 25 were HH opportunities. The nurses accounted for 45 (44%) of the registrations, doctors 35 (34%), and the cleaning assistants 22 (21%).

When looking at HH actions, the overall accuracy analyses show a sensitivity of 100% (95% CI: 95%-100%), meaning that all HH events were detected by the EHHMS. The PPV was 100% (95% CI: 95%-100%) (Table 2).

Table 4
Hand hygiene opportunities performed by doctors and nurses

	Contact observed	Contact not observed
Detected by the EHHMS	16	1
Not detected by the EHHMS	0	ND

Comparisons of results between the direct observers and the electronic hand hygiene monitoring system.

When looking at HH opportunities of all HCWs (doctors, nurses, cleaning assistants), the overall accuracy of the EHHMS shows a sensitivity of 75% (95% CI: 55%-88%) and a PPV of 95% (95% CI: 75%-100%) (Table 3). Three of the six false-negative events concerned cleaning activities of the patient bed or patient surroundings by the cleaning assistants, which were not registered by the system. Two false-negative events were doctors examining the patient in a chair close (approx. 1-2 m) to the bed and the sensor. The last false-negative event was a nurse picking up a plate from the patient table in the patient room, which the EHHMS did not detect. The nurse did not touch the patient. The one false-positive event concerned a doctor standing near the patient's bed talking to the patient for a longer period. The doctor did not have patient contact and did not touch the near surroundings, but the EHHMS registered the doctor in the patient zone. So, the system detected all HH opportunities of nurses and doctors with the patient in bed, but also one event without contact.

The system was developed to detect HH events related to workflow of nurses and doctors, who have patient contact while the patient is in bed or while they perform work in the medication room, rinsing rooms, storerooms, and staff toilets. When looking into these events only, the sensitivity was 100% (95% CI: 81%-100%) and the PPV 94% (95% CI: 73%-100%) (Table 4). When looking at the cleaning assistants for whom the system was not intended, the observers only registered three events with contact between a cleaning assistant and a patient or patient near surroundings which the system did not capture.

The median length of the patient contacts registered by the EHHMS was 63 seconds (95% CI: 23%-215%). The patient contact with the shortest length of duration was 15 seconds. The patient contact with the longest length of duration was 587 seconds.

DISCUSSION

In this validation study, we investigated the accuracy of an EHHMS during real clinical conditions in different wards and with varying types of health care professionals. We found a high sensitivity for detecting HH opportunities by nurses and doctors, which was comparable to the findings in a previous validation study of the EHHMS under simulated conditions.[17]

It is the first time cleaning assistants has used the EHHMS and is, to the best of our knowledge, the first study to publish data for this group. The EHHMS calculates HHC based on algorithms designed for the workflow of nurses and doctors. We found it interesting to investigate if the EHHMS and the algorithms could be used on the cleaning assistant's workflow. The results indicate that this staff group can use the EHHMS, but the system might not register all HH opportunities of the cleaning assistants when cleaning equipment and surfaces of patient surroundings. Importantly, the missed HH opportunities will not have a negative impact on their HHC because they are simply not registered. Further studies are necessary to determine if the EHHMS can be used to measure the HHC of cleaning assistants.

Two false-negative cases were in relation to doctors examining patients in a chair next to the bed, and one false-negative case was a nurse picking up a plate from the patient room while the patient was sitting in a chair. We decided to include HH opportunities in the patient chairs nearby the bed to investigate the possibility of false-positive events. However, we did not detect any false-positive events with patients sitting in chairs. The chairs were placed randomly in each patient room with a distance between 1 and 2 meters from the patient bed. If we only include patient contacts occurring when in bed, the system registered all HH opportunities.

Only a few studies have tested the accuracy of an EHHMS using a methodology like this study, which was suggested by Limper et al.[18] One EHHMS study found a sensitivity of 88.7% with a PPV of 99.2% under simulated conditions and 92.7% and 84.4%, respectively, under real clinical conditions (GOJO/Purell SMARTLINK system).[19] A second study found that the accuracy of measuring HH events decreased from 88.5% under simulated conditions to 52.4% under real clinical conditions (nGage system).[24] A third study found an 84% agreement between an EHHMS and the manual observations (Tork Vision Hand Hygiene System).[23] Post hoc analyses of the study with the Tork Vision Hand Hygiene System by Cawthorne et al showed a sensitivity of 75%, specificity of 97%, PPV of 97%, and NPV of 72%.[25] Our data suggest that Sani Nudge may be as or more accurate than other EHHMSs when assessing the HH behavior of doctors and nurses.

When implementing an EHHMS, the algorithms can be adjusted to the setting. This study found a median length of the patient contacts of 63 seconds with the shortest contact of 15 seconds, which is relevant knowledge when optimizing EHHMSs because the time parameter is often part of the algorithms used. The threshold needed for estimation of patient contact might differ in other settings and types of professions. However, a strength of the study is that we used different wards and different health care professions, which increases the reliability and generalizability.

A strength of this study is that the EHMMS was compared to human evaluation of the HCWs' HH behavior by two observers. Human evaluation depends on the observer's experience. We overcame this challenge by using two trained observers documenting the behavior of each participating HCW at the same time. We found a percentage of agreement between observers of 95%, highlighting the importance of having two observers present when conducting EHHMS validation studies to minimize the risk of wrongly classified events. However, having two observers collecting the same observation data by following the HCWs through different room types and tasks resulted in relatively few data points, which is a major limitation of this study.

We could have collected more data points if we only looked at room entry and exits, but the strength of this type 5 EHHMS is that it measures HHC by following the HCW around in the different rooms in the ward, and therefore the observers also did that. Continued study with more data points is necessary to determine the validity under real clinical conditions. A limitation of the study is that the study setup did not make it possible to detect true-negative events. This is not possible because a nonevent could not be defined in time and place as described by Limper et al.[18] Without true-negative events, we cannot calculate specificity and negative predictive values.

CONCLUSIONS

We found the Sani Nudge system to be accurate when tested during real clinical conditions. The EHHMS captured WHO's Moments 1, 4, and 5 of varying health care professions in different settings with high objective accuracy. The findings indicate that the EHHMS can be used as a supporting tool to provide reliable data for some of the key elements of infection prevention and control.

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Paper II

Iversen AM, Hansen MB, Alsner J, Kristensen B, and Ellermann-Eriksen S

Effects of light-guided nudges on health care workers' hand hygiene behavior

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Major Article

Effects of light-guided nudges on health care workers' hand hygiene behavior

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Key Words:
Compliance
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Hospital-acquired infection
Infection prevention
Electronic monitoring systems

Background: Hospital-acquired infections are the most frequent adverse events in health care and can be reduced by improving the hand hygiene compliance (HHC) of health care workers (HCWs). We aimed to investigate the effect of nudging with sensor lights on HCWs' HHC.
Methods: An 11-month intervention study was conducted in 2 inpatient departments at a university hospital. An automated monitoring system (Sani Nudge^{TM}) measured the HHC. Reminder and feedback nudges with lights were displayed on alcohol-based hand rub dispensers. We compared the baseline HHC with HHC during periods of nudging and used the follow-up data to establish if a sustained effect had been achieved.
Results: A total of 91 physicians, 135 nurses, and 15 cleaning staff were enrolled in the study. The system registered 274,085 hand hygiene opportunities in patient rooms, staff restrooms, clean rooms, and unclean rooms. Overall, a significant, sustained effect was achieved by nudging with lights in relation to contact with patients and patient-near surroundings for both nurses and physicians. Furthermore, a significant effect was observed on nurses' HHC in restrooms and clean rooms. No significant effect was found for the cleaning staff.
Conclusions: Reminder or feedback nudges with light improved and sustained physicians' and nurses' HHC, and constitute a new way of changing HCWs' hand hygiene behavior.

BACKGROUND

Hospital aquired infections (HAIs) are the most frequent adverse events in health care delivery, affecting more than 7% of all hospitalized patients in European countries. HAIs increase mortality, morbidity, length of stay, and costs.[1] Hand hygiene (HH) is considered the most important factor in preventing HAIs.[2] Even though hospitals have standardized HH guidelines, noncompliance among health care workers (HCWs) remains a universal problem.[2,3] Research suggests that noncompliance is typically not caused by a lack of knowledge or will, but may be explained by a reflection of our cognitive and emotional biases,[4] described in the theoretical field of behavioral science.[5]

Behavioral science

In an ideal world, HCWs base their decisions on scientific evidence and best practice.[6] However, in clinical practice, human behavior is more complex, and cognitive and emotional biases often affect decisions, especially when decisions are made under stress.[7,8] To better understand these biases and learn how to overcome them, the field of behavioral science, especially behavioral economics, has emerged as a way to describe and identify how people behave irrationally.[5,9,10] In the case of HH, at least 14 biases have been identified as contributors to noncompliance.[10] "Present bias" is a particularly important factor and refers to the behavioral tendency to overweight immediate costs relative to future benefits. The immediate costs of HH are clear (time consumption, dry and scratching skin, hand sanitizer smell), but the benefits are delayed (avoiding HAIs), which may impede achieving the desired behavior. Nudging

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0196-6553/

to modify a person's behavior toward the desired end point is a way to address these biases.[5,10]

Reminder and feedback nudges

Behavioral scientists Thaler and Sunstein have described nudging as "any aspect of the choice architecture that alters people's behavior predictably without forbidding any options or significantly changing their economic incentives."[5,11] In other words, subtle changes to the design of the environment or framing of choices without restrictions encourage a given behavior. Nudge strategies are often easy to scale and implement at a low cost, making nudging a practical approach to behavior change.[6,8,11–13] This is especially important within health care. Several reviews have recently shown that nudges can successfully change HCWs' behavior.[4,6,8,11] Only a few studies have investigated the effect of reminder and feedback nudges,[4] and nudging has been criticized for offering a limited platform for long-lasting behavioral change.[14] Thus, more interventional studies of nudging are warranted to understand the temporal dimensions of interventions targeting HH, including how long the effect lasts.[15]

Overall aim

This study aimed to examine the effect of nudging with 2 lights (reminder and feedback) on HCWs' HH compliance (HHC). We hypothesized that nudging with light would increase HCWs' HHC and that HCWs would fall back into old HH habits once the nudges were switched off. Furthermore, we hypothesized that the combined effect of reminder and feedback nudges would be superior to nudging only with 1 light.

METHODS

Study design and setting

An 11-month prospective, interventional study was conducted between July 2020 and May 2021 at the Aarhus University Hospital in Denmark. In total, 241 HCWs from the Departments of Oncology and Haematology (4 inpatient wards) were included. The departments had 64 patient beds for patients with malignant diseases and were chosen because these patients have an impaired immune system and a higher risk of HAIs.[2]

Data were collected during the COVID-19 pandemic, during which HH and societal distancing were stressed nationwide. By the end of December 2020 (week 51), a lockdown was imposed in Denmark during which schools, restaurants, shops, and malls were closed; and people were encouraged to work from home if possible. The society was gradually reopened in the following months and fully reopened by May 2021.[16]

Study subjects and data collection

Physicians, nurses, and cleaning staff were included in the study. Data were anonymized for both study participants and investigators. Before study initiation, all participants were informed of the study's purpose and the automated HH monitoring system (AHHMS). Informed consent was given via the participants' active choice to pick up and carry a tag with an anonymous ID number at work. To guarantee the anonymity of the study participants, we only obtained information about their health care profession.

We focused on the alcohol-based hand rub (ABHR) recommended in the World Health Organization's (WHO) "My 5 Moments for Hand Hygiene."[2] We used an AHHMS (Sani Nudge™)[17] to collect the HHC data. Individual tags were placed on the HCWs' name badges to detect their HH behavior. Sensors were placed on ABHR dispensers to register when HCWs used the dispensers. Sensors were also placed on the walls above the patients' beds to establish an invisible patient zone around the patient bed (a proxy measure for contact with a patient or patient-near surroundings), as defined by the WHO guidelines.[2] Furthermore, sensors were placed on workroom walls (eg, utility rooms and staff restrooms) to detect HH opportunities. Weekly registrations of correct patient bed placements under the wall sensors were made in the course of the study phases (for more details, see the Supplementary Material). The AHHMS has previously been described in detail[18,19] and validated.[18,20]

Participants and investigators were blinded to the HHC data to minimize any risk of performance and observer biases. Data were collected in patient rooms, staff restrooms, clean rooms (clean store rooms and clean utility rooms), and unclean rooms (unclean store rooms and unclean utility rooms). HHC was measured based on the algorithms for correct HH. In the patient rooms, HHC was measured as both (1) "overall" (both BEFORE entering and AFTER exiting the patient zone, (2) "BEFORE entering the patient zone," and (3) "AFTER exiting the patient zone." In clean rooms, HHC was measured as "BEFORE (or when) entering the clean room." In unclean rooms and staff restrooms, HHC was measured as "After (or when) exiting the unclean room."

During the study period, the frequency of a signal from a hospital bed position system interfered negatively with the AHHMS, which affected some of the sensors. Therefore, data were excluded from rooms with a sensor that had not sent a data package for 5 consecutive days. In total, 43,046 data points were excluded from the dataset using an algorithm for data exclusion (for more details, see the Supplementary Material).

Intervention

The sensors on the ABHR dispensers have built-in nudging features and discrete light symbols that were activated during selected phases of the study (Fig 1).

Inpatient wards from the Department of Oncology and the Department of Haematology were randomly assigned to 2 groups (groups 1 and 2). The study had 4 phases (Fig 2). Phase 1 constituted the control phase, during which the baseline HHC was obtained. In phase 2, the inpatient wards were randomly assigned to receive either reminder nudges (group 1) or feedback nudges (group 2). The reminder nudge aimed to increase awareness and consisted of a blue light displayed on the ABHR sensors that appeared when an HCW was close to the ABHR dispensers (Fig 1). The feedback nudge was designed to acknowledge that an HCW had remembered to use the ABHR. It consisted of a green smiley light that was shown on the ABHR sensors after the HCW used it and served as immediate feedback to support the desired behavior (Fig 1). During phase 3, both groups 1 and 2 were exposed to both types of nudges, creating a habit loop of reminder and feedback. Phase 4 was an evaluation period without any interventions. Data from this follow-up phase were split into 2 periods for analysis: follow-up 1 (immediate effect of a completed nudging period) and follow-up 2 (long-term effect of a previous nudging period). This division was made to describe the initial decrease and the later steady-state level.

Ethics

Under Danish law, approval was sought, but the requirement was waived by both the Ethics Committee (R. no. 1-10-72-148-19) and the Danish Data Protection Agency (R. no. 2019-212-1420).

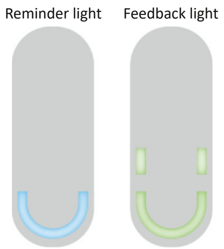

Fig. 1. Sensors with a blue reminder light and a green feedback light. The sensors were placed on the ABHR dispensers. The blue light was activated when an HCW was close to the ABHR dispenser (reminder), and the green light was displayed when the HCW used the dispenser (feedback). ABHR, alcohol-based hand rub; HCW, health care worker.

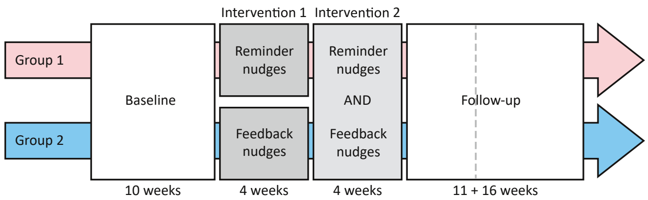

Fig. 2. Study overview. Inpatient wards at the Department of Oncology and the Department of Haematology were randomly assigned to 1 of 2 groups. In the first intervention phase, group 1 received nudges with reminder light, and group 2 received nudges with feedback lights. In the second intervention phase, groups 1 and 2 received nudges with both lights.

Statistical analysis

Aggregated HHC data were available as the total sum (per day) of the number of opportunities and ABHR events in patient rooms, staff restrooms, clean rooms (clean utility room and clean store room), and unclean rooms (unclean utility room and unclean store room), stratified by staff group and the department. Individual data for each participant were not available for analysis. Data were provided as HHC rates (0%-100%) with 95% confidence intervals (CIs).

For staff restrooms, clean rooms, and unclean rooms, daily and weekly HHC were calculated as the number of compliant visits/total number of visits summed by day or week. For patient rooms, overall (sum of both BEFORE entering and AFTER exiting the patient zone) daily HHC was calculated as "(number of full compliances + 0.5 × number of compliances only BEFORE patient visit + 0.5 × number of compliances only AFTER patient visit)/total number of visits." Daily HHC was also calculated specifically for compliance BEFORE (or AFTER) patient visits as "(number of full compliances + number of compliances only BEFORE [or AFTER] a patient visit)/total number of visits."

Six linear regression models were established for patient rooms (overall, only BEFORE entering the patient zone, only AFTER exiting the patient zone), staff restrooms, clean rooms, and unclean rooms. Daily HHC was used as the outcome, and the interaction between the department and study phases was used as explanatory variables. The models used the sandwich estimator of variance. Analytical weights (number of daily visits for each HHC) were used in the regression analyses. Coefficients from the models were used to calculate the mean HHC for each department in each study phase and to compare them. Two-sided P values < .05 were considered statistically significant. Differences were reported as absolute values. All analyses were conducted using STATA (StataCorp LLC, version 17.0).

RESULTS

A total of 91 physicians, 135 nurses, and 15 cleaning staff were enrolled in the study. The AHHMS registered 274,085 HH opportunities in patient rooms, staff restrooms, clean rooms, and unclean rooms. In total, 231,039 HH opportunities were included in the analysis (physicians = 9,813, nurses = 206,733, and cleaning staff = 14,493).

HHC in patient rooms

In total, 190,114 HH opportunities were collected and included in the analysis in patient rooms (physicians = 8,346, nurses = 175,060, and cleaning staff = 6,708) (Fig 3).

In both groups, the overall HHC for all HCWs increased significantly in patient rooms in both phases with nudging (Fig 3A, Table 1). In group 1, the HHC increased from 21% at baseline (95% CI: 20%-21%) to 25% during the first intervention with reminder nudges (95% CI: 23%-26%) (mean diff. +4 percentage points; P < .0001). The improved HHC level was sustained during the second intervention with both reminder and feedback nudges (26%, 95% CI: 24%-27%). Similarly, group 2 HCC increased from 19% at baseline (95% CI: 18%-21%) to 30% during the first intervention with feedback nudges (95% CI: 29%-32%) (mean diff. +11 percentage points; P < .0001) and further increased during the second intervention with both reminder and feedback nudges (34%, 95% CI: 32%-36%) (mean diff. +4 percentage points; P < .004) (Fig 3A). The analyses of the specific staff groups showed that the increased HHC levels in both groups

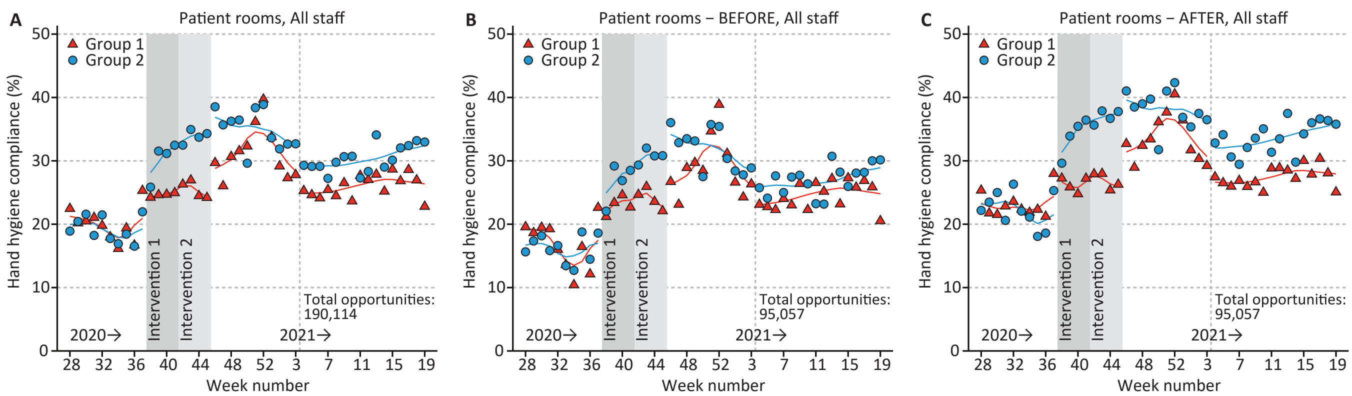

Fig. 3. HHC for physicians, nurses, and cleaning staff in patient rooms. (A) HHC in patient rooms: sum of HHC for both BEFORE entering and AFTER exiting the patient zone. (B) Hand hygiene compliance in patient rooms: BEFORE entering the patient zone (WHO moment 1). (C) Hand hygiene compliance in patient rooms: AFTER exiting the patient zone (WHO moments 4 and 5). HHC, hand hygiene compliance.

Table 1
HHC in each study phase, specified by staff groups in patient rooms and staff restrooms

		Mean scores (95% CI)					Difference in mean scores (95% CI)			
		Baseline	Intervention 1*	Intervention 2*	Follow-up period 1	Follow-up period 2	Baseline vs intervention 1*	Intervention 1* vs 2*	Intervention 2* vs follow-up 1	Baseline vs follow-up 2
Group 1	Patient rooms									
	All staff	21% (20, 21)	25% (23, 26)	26% (24, 27)	31% (30, 33)	26% (25, 27)	+4 (3, 6)	+1 (−1, 3)†	+6 (4, 8)	+5 (4, 7)
	Physicians	15% (12, 18)	21% (18, 24)	26% (22, 30)	28% (25, 31)	19% (17, 22)	+6 (2, 10)	+5 (0, 10)†	+2 (−3, 7)†	+5 (1, 8)
	Nurses	21% (20, 22)	25% (24, 27)	26% (24, 28)	32% (31, 34)	27% (26, 28)	+4 (2, 6)	+1 (−2, 3)†	+6 (4, 9)	+6 (4, 7)
	Cleaning staff	12% (10, 15)	13% (9, 17)	12% (8, 16)	19% (17, 22)	15% (14, 17)	+1 (−4, 6)†	−1 (−7, 4)†	+7 (3, 12)	+3 (0, 6)†
	Staff restrooms									
	All staff	51% (48, 54)	54% (51, 58)	53% (50, 56)	55% (52, 58)	47% (45, 49)	+3 (−1, 8)†	−1 (−6, 3)†	+2 (−2, 6)†	−4 (−7, −1)
	Physicians	57% (49, 65)	57% (49, 64)	49% (42, 57)	59% (52, 66)	52% (46, 59)	0 (−11, 11)†	−8 (−18, 3)†	+10 (−1, 20)†	−4 (−15, 6)†
	Nurses	51% (48, 54)	55% (51, 59)	55% (51, 58)	56% (53, 59)	49% (46, 51)	+4 (−1, 9)†	−1 (−6, 5)†	+2 (−3, 6)†	−3 (−6, 1)†
	Cleaning staff	44% (35, 54)	48% (40, 55)	48% (41, 56)	45% (40, 50)	36% (32, 40)	+3 (−9, 16)†	+1 (−10, 11)†	−3 (−13, 6)†	−8 (−19, 2)†
Group 2	Patient rooms									
	All staff	19% (18, 21)	30% (29, 32)	34% (32, 36)	35% (34, 36)	30% (30, 31)	+11 (9, 13)	+4 (1, 6)	+1 (−1, 3)†	+11 (10, 12)
	Physicians	15% (12, 19)	21% (17, 25)	20% (16, 24)	29% (25, 32)	26% (23, 30)	+6 (1, 11)	−1 (−7, 5)†	+9 (3, 14)	+11 (6, 16)
	Nurses	20% (19, 21)	31% (29, 33)	35% (33, 37)	36% (35, 37)	31% (30, 32)	+11 (9, 13)	+4 (2, 7)	+1 (−1, 3)†	+11 (10, 13)
	Cleaning staff	21% (17, 26)	22% (14, 30)	21% (12, 30)	20% (17, 24)	17% (14, 20)	+1 (−8, 9)†	−1 (−13, 11)†	−1 (−10, 9)†	−4 (−9, 1)†
	Staff restrooms									
	All staff	55% (52, 58)	57% (53, 61)	62% (58, 66)	65% (62, 67)	67% (65, 69)	+1 (−4, 6)†	+6 (0, 11)	+3 (-2, 7)†	+12 (8, 15)
	Physicians	46% (37, 55)	58% (45, 71)	54% (37, 72)	55% (44, 67)	46% (34, 57)	+12 (−4, 28)†	−4 (−25, 19)†	+1 (−20, 23)†	0 (−15, 15)†
	Nurses	57% (54, 60)	57% (53, 61)	64% (60, 68)	65% (62, 67)	67% (65, 69)	0 (−5, 6)†	+7 (1, 12)	+1 (−4, 6)†	+11 (7, 14)
	Cleaning staff	50% (42, 58)	39% (18, 61)	52% (40, 65)	66% (59, 74)	68% (64, 72)	−11 (−33, 12)†	+13 (−12, 38)†	+14 (−1, 29)†	+18 (9, 27)

NOTE. HHC is given as mean score in each phase and as a difference in mean score between selected phases: baseline vs intervention 1, intervention 1 vs 2, intervention 2 vs follow-up period 1, and baseline vs follow-up period 2. CI, confidence interval.
*Intervention 1 is “Reminder nudge” for group 1 and “Feedback nudge” for group 2. Intervention 2 is “Reminder nudge AND Feedback nudge” for both groups.
†Not significant.

were driven by the physicians and nurses. In contrast, the nudges had no effect on the cleaning staff HHC (Table 1).

Overall, both groups 1 and 2 had a higher HHC after exiting the patient zone than before entering the patient zone (Fig 3B and C). However, when studying the data generated for each staff group, we found that physicians had a lower HHC after exiting the patient zone than before entering the patient zone (Table 1).

HHC in staff restrooms

In total, 19,208 HH opportunities (physicians n = 1,428, nurses n = 15,512, cleaning staff n = 2,268) were collected and included in the analysis in staff restrooms (Fig 4). Overall, the HHC baseline in staff restrooms was higher than in the patient rooms. The group 1 baseline was 51% (95% CI: 48%-54%) in staff restrooms compared with 21% (95% CI: 20%-21%) in patient rooms. Similarly, the group 2 HHC baseline was 55% (95% CI: 52%-58%) in staff restrooms and 19% (95% CI: 18%-21%) in patient rooms (Table 1). In group 1, nudging with lights in staff restrooms did not have a significant effect (Table 1). In group 2, overall HHC increased from 55% at baseline (95% CI: 52%-58%) to 57% during the first intervention phase (95% CI: 53%-61%) when the HCWs received feedback nudges (mean diff. +1 percentage point; $P < .59$). However, during the second intervention, HHC increased significantly to 62% when HCWs received both reminder and feedback nudges (95% CI: 58%-66%) (mean diff. +6 percentage points; $P < .049$).

HHC in clean and unclean rooms

Data from clean rooms are only presented for group 2 (see the Methods section for a detailed description of data exclusion).

A total of 8,258 HH opportunities were collected and included in the analysis in clean rooms (clean utility rooms and clean store rooms) and 13,459 HH opportunities in unclean rooms (unclean utility room and unclean store room). Only a few HH opportunities were collected for physicians in clean and unclean rooms (n = 39), as they usually do not access these room types.

In clean rooms, the group 2 HHC increased for nurses from baseline (36%, 95% CI: 33%-39%) throughout the first intervention with feedback nudges (56%, 95% CI: 49%-62%) (mean diff. +20 percentage points; $P < .0001$). However, HHC seemed to decrease again in the second intervention when they received reminder and feedback nudges (48%, 95% CI: 42%-53%) (mean diff. −8 percentage points; $P < .073$). HHC increased to 51% in the first follow-up phase (95% CI: 47%-55%) and decreased to a sustained level of 42% (39%-45%) in the second follow-up phase. The mean difference from the baseline to the second follow-up phase was +6 percentage points; $P < .007$. Nudging did not increase HHC in clean rooms among cleaning staff. In unclean rooms, nudging did not change HHC among nurses and cleaning staff. Both groups 1 and 2 had a relatively high baseline HHC in unclean rooms (group 1: 74%, 95% CI: 68%-79% and group 2: 65%, 95% CI: 62%-68%) compared with patient rooms and clean rooms. In unclean rooms, HHC decreased through both intervention phases. The mean difference from baseline to the second follow-up phase was −23 percentage points; $P < .0001$ in group 1 and −11 percentage points; $P < .0001$ in group 2.

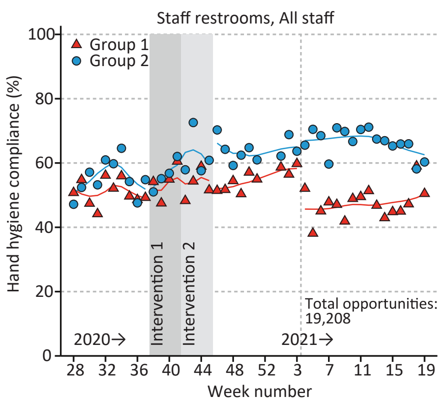

Fig. 4. Overall hand hygiene compliance in staff restrooms for all HCWs. HCWs, health care workers.

The effect of reminder nudges versus feedback nudges

The greatest significant effect of nudging was recorded in the first intervention phase (Table 1) when both groups were exposed to single nudges with light. Nudging with both reminder and feedback nudges in the second intervention phase only generated a marginal further improvement. Group 2 (feedback nudges) had a greater absolute significant effect in the patient rooms (+11 percentage points, 95% CI: 9%-13%) than group 1 (reminder nudges) (+5 percentage points, 95% CI: 3%-6%). During the second intervention phase, HHC in group 2 increased only in the staff restrooms. Two nudges increased HHC +6 percentage points (95% CI: 0%-11%), whereas this intervention did not increase HHC during the first intervention phase (+1 percentage points, 95% CI: −4; +6%).

The long-term effect of nudging with light

Overall, HHC increased in both groups from baseline and throughout the intervention phases in patient rooms, staff restrooms, and clean rooms. In patient rooms and clean rooms, HHC was higher during the second follow-up phase than during the baseline phase (Table 1).

In patient rooms, the absolute difference in HHC increased +11 percentage points ($P < .0001$) in group 1 and +16 percentage points ($P < .0001$) in group 2 from baseline to the first follow-up phase. HHC decreased from the first follow-up phase to the second follow-up phase and stabilized. However, HHC was higher in the second follow-up phase than at baseline for both group 1 (mean diff. +5 percentage points; $P < .0001$) and group 2 (mean dif. +11 percentage points, $P < .0001$).

In staff restrooms, HHC increased significantly from baseline to the first follow-up phase with a mean absolute difference of +4 percentage points ($P < .034$) in group 1 and +9 percentage points ($P < .0001$) in group 2. HHC continued to increase in group 2, with an overall increase of +12 percentage points ($P < .0001$) by the end of the second follow-up phase. However, HHC decreased significantly −4 percentage points ($P < .021$) in group 1.

In clean rooms, HHC among nurses in group 2 increased significantly, with an absolute difference from baseline to the first follow-up phase of +15 percentage points ($P < .0001$). HHC decreased from the first to the second follow-up phase and then stabilized, yielding a significant difference of +6 percentage points ($P < .007$) from baseline to the second follow-up phase.

DISCUSSION

This study investigated the effect of reminder and feedback nudges on HCWs' HHC. Overall, a significant effect was recorded of nudging with lights in relation to contact with patients and patient-near surroundings for both nurses and physicians. Furthermore, a significant effect was recorded for nurses' HHC in staff restrooms and clean rooms. No significant effect was seen for the cleaning staff.

HHC in clean versus unclean rooms and situations

A trend was seen that the HHC was higher in unclean rooms than in clean rooms. Similarly, we recorded a higher HHC after patient contact than before patient contact. Other studies support this finding, which is most likely explained by a tendency to self-protect in situations where your hands feel soiled.[21]

One or two nudges

We hypothesized that the combined effect of both reminder and feedback nudges would be superior to nudging with only 1 type of nudge. However, we found the greatest effect of the nudges during the first intervention phase, where the groups received a single nudge (either reminder or feedback nudges), and, generally, 2 nudges (both reminder and feedback nudges) did not have a synergistic effect. This finding may be explained by the fact that the HCWs went from nothing (no nudges) at baseline to a change (nudging) in the first intervention phase. Thus, the same effect would possibly have been observed if the combination of nudges had been introduced as the first intervention. However, HHC increased further in some of the rooms during the second intervention phase when HCWs were exposed to the combination of both nudges. A recent review found several studies that used more than 1 nudging technique in their intervention.[6] They describe that the combination of the nudges seemed to increase the possibility of behavior change. On the other hand, using several different nudges makes it more challenging to determine which elements make the intervention significant.

Interestingly, we found a more significant effect in group 2, which received feedback nudges, suggesting that the positive nudging approach (feedback on behavior) may be more effective than the reminders of correct behavior. Cultural differences between departments may help explain the greater effect of nudges in group 2, but it seems less likely because their HHC was the same at baseline.

Temporal effects of nudging

Few studies have administered and measured the effects of an intervention implemented more than once, making it hard to know how long the effects of nudges are likely to persist.[22] It has been speculated that people's responses to the same stimuli wane as time passes ("poster blindness") when, for example, seeing the same sticker repeatedly. The decrease in attention paid to the nudges limits their ability to change our behavior in the long term. On the other hand, repeated exposure to the same nudges may help strengthen the desired associations.[23] We decided to employ short intervention phases to avoid poster blindness. Thus, more studies are warranted to investigate how long a nudge may be applied before HCWs experience poster blindness.

While more work is needed on the temporal effects of nudging, our work provides some initial key insights. We hypothesized that nudges would affect HHC while the HCWs received the nudge and that HHC would decrease after the nudges were turned off. We found that HHC decreased over time when nudging was not in place. Even so, in the patient rooms, staff restrooms, and clean rooms, HHC was higher during the second follow-up phase than before nudging was initiated, suggesting light nudges may help remind HCWs to do HH at appropriate times.

Data collection during the COVID-19 pandemic

This study investigated the effect of nudging with light during the COVID-19 pandemic. As a result of the pandemic, the level of attention devoted to HH in society, in general, was heightened, which we expected to improve HHC. However, the baseline HHC was low, indicating that the pandemic did not affect the HCWs' HHC as much as one could expect. This conclusion is supported by other studies that did not find consistent improvements in HCWs' HHC during the pandemic.[24-26] Some studies found temporarily increased HHC levels during pandemic lockdowns and a subsequent return to baseline levels after a relatively short period.[27-29] During part of this study, a societal lockdown was introduced in December 2020 that coincided with the first follow-up phase. It may have affected the results and the evaluation of the sustained effects. Having a simultaneous control group without any interventions would have been useful. However, we were unaware of the societal lockdown when planning the study. Therefore, we chose the departments to be their own control group.

Data collection with an AHHMS

A strength of this study is that the AHHMS collected data on more HH opportunities than studies using the direct observation method. Nudging with light was associated with a significant increase in HHC among both physicians and nurses but not among cleaning staff. A recent study found that AHHMS's measurements of physicians' and nurses' HHC were highly accurate but lower for cleaning staff. However, few cleaning staff participated in that study, and the authors concluded that more data are needed. Moreover, the cleaning staff's workflow differs from those of physicians and nurses, and the data collected with this AHHMS, which is designed to detect clinical behavior, may therefore have been less accurate for the cleaning staff.[18]

The AHHMS collected HHC when the 241 participating HCWs wore a tag with an anonymous ID number. To ensure anonymity, we did not register the tag ID numbers worn by specific HCWs. Thus, we could not assess the individual's HHC and determine if all 241 HCWs participated in the entire data collection period. The AHMMS was installed in the hospital wards 2 months before we initiated the baseline recordings to ensure that most participants had become comfortable with the AHHMS. Some participants (nurses) in group 2 were present during the initial development and testing of the AHHMS during 2018-2019. They, therefore, understood the AHHMS from the onset, which may have affected their culture for improvement and may help explain why the intervention had the greatest effect among group 2 nurses. However, their baseline HHC level was similar to that of group 1.

The interventions were based on theory from behavioral science. The study investigated if nudging with light modifies a person's behavior toward the desired end point, thereby overcoming cognitive and emotional biases, such as the "present bias." The results indicate that HCWs' HH behavior can be modified by nudges. However, although nudging with light improved HCWs' HHC, the HHC level was low, especially in patient rooms. According to a systematic review,[30] even a small increase in the HHC might have an impact on the incidence of HAIs.[30]

Nudging with light might not improve HHC sufficiently if provided as an isolated intervention, but nudging may be used in conjunction with other interventions, as suggested by the WHO in their multimodal strategy.[31] Future studies are warranted to investigate how other behavioral nudge interventions affect the HCWs' HHC and for how long an effect may be sustained.

CONCLUSIONS

Nudging with light can be used to improve physicians' and nurses' HHC. We found a significant effect in relation to contact with patients and patient-near surroundings, in clean rooms and in staff restrooms. The cleaning staff's HHC did not improve.

The results indicate that receiving a single reminder or feedback nudge was as effective as, or better than, the combined effect of both nudges. The nudging effect decreased with time once the lights were switched off. Despite the decrease, HCWs' HHC in the patient rooms was higher during the second follow-up phase than during the baseline. HHC was higher in unclean rooms than in clean rooms, and after contact with patients and the patient-near surroundings than before contact with patients.

Acknowledgments

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ajic.2023.05.006.

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Supplementary material:

Effects of light-guided nudges on health care workers' hand hygiene behavior

Authors: Anne-Mette Iversen, Marco Bo Hansen, Jan Alsner, Brian Kristensen and Svend Ellermann-Eriksen

Table of Content:

1. Automated hand hygiene monitoring system

In the study **"Effects of light-guided nudges on health care workers' hand hygiene behavior",** an automated hand hygiene monitoring system (Sani Nudge™) was used to collect hand hygiene compliance (HHC) data. The system is a real-time location system measuring HHC 24/7. It consists of sensors on all alcohol-based hand rub dispensers, workrooms' walls (e.g., utility rooms and staff restrooms), and above patient beds. Individual tags were placed on healthcare workers' (HCWs') name badges. The sensors and individual tags create a network that measures hand hygiene opportunities and sanitizations in all rooms of the wards. The network of sensors allows the system to track HCWs' workflow and considers situations and behaviors in the period leading up to and after sanitizations when calculating HHC (Figure 1).

Supplementary Figure 1. The automated hand hygiene monitoring system (Sani Nudge™)

Patient rooms

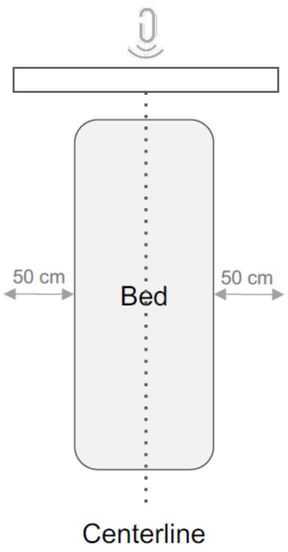
In patient rooms, an invisible "patient zone" around the bed is established by a bed sensor placed on the wall above the patient bed. The "patient zone" is used to register proxy measures for physical contact between an HCW and a patient or the patient-near surroundings. In patient rooms, the system measures HHC when the HCW is registered in the “patient zone”.

For each room type (patient rooms, clean rooms, and unclean rooms), HHC measurement was based on algorithms. The algorithms were based on specific time intervals for each room type. Following Sani Nudge privacy policy, the algorithms are confidential. Researchers interested in replicating the study may contact the first author for more information regarding the specific time intervals used.

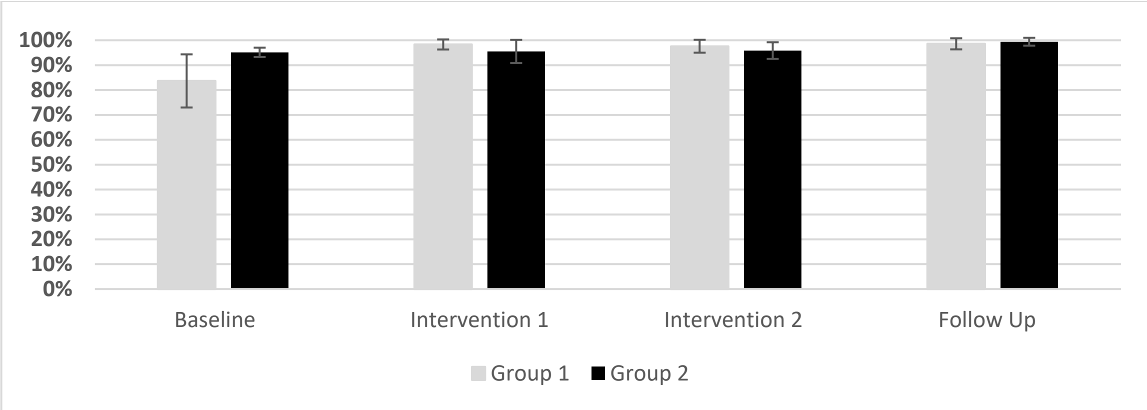
2. Bed placements under the sensors

In patient rooms, the invisible “patient zone” functions as a proxy measure for physical contact between the HCW and the patient or the patient-near surroundings. To create the correct “patient zone”, the patient bed must be placed correctly under the wall-mounted bed sensor above the patient bed. Therefore, the placement of 64 patient beds was registered on random days, one to two times a week, throughout the study period. A figure was used to register whether the patient’s bed was placed “correctly” or “incorrectly” (Figures 2 and 3).

Supplementary Figure 2. Illustration of the correct placement of the bed.



Supplementary Figure 3. Percentage of patient beds placed correctly under the Sani Nudge wall sensor. The total number of observations = 3,136. Error bars represent the standard error of the mean.



3. Data exclusion

In total, 274,085 data points were collected in the study. During the study period, the frequency from a hospital bed position system interfered negatively with the automated hand hygiene monitoring system, affecting some sensors. The interference affected the battery status of some sensors causing the sensor not to send data. To ensure the validity of the data, we made an algorithm allowing us to exclude possibly invalid data from the dataset. Each sensor sends data to "the cloud" in "packages". To avoid invalid data whenever a sensor had not sent a package of data for five consecutive days, we excluded hand hygiene opportunities from the affected room during the days when no packages had been sent. In total, 43,046 data points were excluded by the algorithm (Table 1).

Supplementary Table 1. Number of data points included and excluded:

Room type	Data points included	Physicians	Nurses	Cleaning staff
Patient rooms:	190,114	8,346	175,060	6,708
Staff restrooms:	19,208	1,428	15,512	2,268
Clean rooms:	8,258	12	5,515	2,731
Unclean rooms:	13,459	27	10,646	2,786
All rooms:	231,039	9,813	206,733	14,493

Room type	Data points excluded	Physicians	Nurses	Cleaning staff
Patient rooms:	31,922	1,672	29,150	1,100
Staff restrooms:	2,107	246	1,566	295
Clean rooms:	1,209	3	722	484
Unclean rooms:	7,808	8	7,150	650
All rooms:	43,046	1,929	38,588	2,529

Paper III

Iversen AM, Hansen MB, and Ellermann-Eriksen S

Effects of data-driven feedback on nurses' and physicians' hand hygiene in hospitals – a non-resource-intensive intervention in real-life clinical practice

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Effects of data-driven feedback on nurses' and physicians' hand hygiene in hospitals — a non-resource-intensive intervention in real-life clinical practice

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SUMMARY

Background: Hand hygiene (HH) by healthcare workers (HCWs) is one of the most important measures to prevent hospital-acquired infections. However, HCWs struggle to adhere to HH guidelines. We aimed to investigate the effect of a non-resource intensive intervention with group and individual feedback on HCWs HH in a real-life clinical practice during the COVID-19 pandemic.

Methods: In 2021, an 11-month prospective, interventional study was conducted in two inpatient departments at a Danish university hospital. An automated hand hygiene monitoring system (Sani Nudge™) was used to collect data. HH opportunities and alcohol-based hand rub events were measured. Data were provided as HH compliance (HHC) rates. We compared HHC across 1) a baseline period, 2) an intervention period with weekly feedback in groups, followed by 3) an intervention period with weekly individual feedback on emails, and 4) a follow-up period.

Results: We analyzed data from physicians (N=65) and nurses (N=109). In total, 231,022 hygiene opportunities were analyzed. Overall, we observed no significant effect of feedback, regardless of whether it was provided to the group or individuals. We found a trend toward a higher HHC in staff restrooms than in medication rooms and patient rooms. The lowest HHC was found in patient rooms.

Conclusions: The automated hand hygiene monitoring system enabled assessment of the interventions. We found no significant effect of group or individual feedback at the two departments. However, other factors may have influenced the results during the pandemic, such as time constraints, workplace culture, and the degree of leadership support.

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Introduction

Multiple studies have investigated hand hygiene (HH) throughout recent decades, building a substantial body of knowledge. It is widely acknowledged that HH by healthcare workers (HCWs) is a critical measure for preventing hospital-acquired infections (HAIs) [1]. Although HH seems simple, HCWs struggle to adhere to guidelines. Even during the COVID-19 pandemic, with increased societal attention devoted to HH, effective strategies were needed to improve and sustain HH compliance (HHC). Reported HHC rates vary tremendously from less than 25% to more than 90%, with numerous factors affecting HHC rates, including culture, outcome measures, and methods used to estimate HHC rates (direct observation vs automated monitoring systems) [1]. A recent study by our author group found low mean HHC among physicians and nurses (*N*=241) in two cancer departments in Denmark during the COVID-19 pandemic: less than 21% (95% CI; 20–21) in patient rooms and less than 55% (95% CI; 52–58) in staff restrooms [2]. This finding is supported by other comparable Danish studies reporting low adherence to HH guidelines, with varying baseline HHC rates depending on room type (e.g., patient room or staff restroom), staff group, and departments [3–5].

Factors associated with low HHC include understaffing, overcrowding, high workload, workplace culture, limited access to HH supplies, and using gloves as a substitute. HHC is also evidently higher among nurses than among doctors, after patient contact than before patient contact, and higher during daytime than during night shifts [1,6–10].

Multiple studies have investigated the effect of interventions to improve HHC among HCWs. A Cochrane review from 2017 found that performance feedback, education, cues (written and verbal), and placement of alcohol-based hand rub (ABHR) may improve HHC [11]. The authors called for robust research to explore the effectiveness of interventions and address the variability in the certainty of evidence, interventions and methods.

The World Health Organization (WHO) recommends a multimodal strategy to improve HHC in healthcare that includes five major components; 1) ensuring availability of HH supplies, 2) education of HCWs, 3) monitoring and providing feedback, 4) reminders at the point of care, and 5) promoting a culture change [1,12]. This study aimed to investigate the effects of monitoring HH and providing HCWs with group and individual feedback. Even though some studies have reported positive results of feedback [3,13–15], other studies have reported no effect [16–19]. In other words, more robust evidence is needed, and we believe, that this study can add to the body of knowledge. We specifically aimed to investigate a non-resource-intensive intervention to make the intervention feasible in real-life clinical practices as the HHC data were collected during the COVID-19 pandemic with HCWs facing time pressure. We hypothesized that both group and individual feedback would increase HCWs' HHC compared to baseline, with larger improvements observed with individual feedback.

Methods

Study design and setting

An 11-month prospective, interventional study was conducted between February 2021 and December 2021 at the Aarhus University Hospital in Denmark. In total, 187 HCWs from the Department of Hematology and the Department of Oncology (four inpatient wards) were included. These two departments had 64 beds for inpatients with cancer diseases and were chosen because their patients have an impaired immune system and are therefore at increased risk of HAIs [20].

Data were collected during the COVID-19 pandemic; a period generally characterized by a high focus on HH, use of facemasks, and societal distancing requirements. By the end of this study in November and December 2021, the number of registered persons with a positive COVID-19 test in Denmark was on the rise, leading to additional requirements such as the closing of theatres and museums in week 50 [21].

Study subjects and data collection

Physicians (*N*=65), nurses (*N*=109), and cleaning staff (*N*=13) were included in the study. Data were anonymized for both investigators and study participants. Participants were informed about the study's purpose and use of an automated HH monitoring system (AHHMS). Informed consent was obtained indirectly by the participants choosing to pick up and carry an individual tag on their name badge. To ensure participant anonymity, we only obtained information about their profession. Investigators and participants were blinded to HHC data during the baseline period to minimize any risk of observer or performance biases.

Data were collected using an AHHMS (Sani Nudge™) [22]. The AHHMS is an advanced sensor system capable of considering the previous workflow rather than solely considering room entry and exit as separate events. The AHHMS has been described in detail in a recent publication [6] and evaluated in two recent studies [23,24].

Data were collected in patient rooms, medication rooms, staff restrooms, unclean rooms (unclean storerooms and unclean utility rooms), and clean rooms (clean storerooms and clean utility rooms). HHC was measured using alcohol-based hand rub (ABHR), which is considered the cornerstone of infection prevention and possibly the single most effective measure to reduce HAIs [8]. HHC was calculated based on the WHO's "My 5 Moments for Hand Hygiene" [25]. The system measured a proxy of moment 1 (before touching a patient), 4 (after touching a patient), and 5 (after touching the patient's surroundings). In the patient rooms, HHC was measured as the sum of both BEFORE entering the patient zone and AFTER exiting the patient zone. In staff restrooms and unclean rooms, HHC was measured as "AFTER (or when) exiting the unclean room". In medication rooms and clean rooms, HHC was measured as "BEFORE (or when) entering the room".

Weekly registrations of placements of patient beds under the wall sensor were made during the entire study to investigate if an incorrect placement of beds could impact HHC (see supplementary).

During the study period, signal interference from a hospital bed position system negatively affected some of the AHHMS sensors, interrupting the signal. Therefore, data were excluded from rooms with a sensor that had not sent a data package for five consecutive days (the algorithm is presented in a recent publication [2]). In total, 35,072 data points were excluded from the dataset using an algorithm for data exclusion (see supplementary).

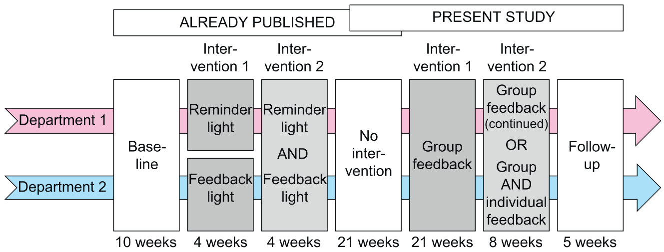

Figure 1. Overview of the multimodal project. Inpatient wards at the Department of Oncology and the Department of Hematology. In the first two intervention phases, both groups received nudges with lights (reminders and feedback). After a period without interventions, both departments received feedback in groups followed by a period with group feedback (continued) OR group AND individual feedback.

The HHC data for cleaning staff during the individual period could not be analyzed anonymously because only a small number of participants in each department ($N=<4$) signed up to receive the weekly individual HHC feedback via email. Therefore, all data points ($N=26,407$) for cleaning staff ($N=13$) were excluded from this study. Furthermore, 10,292 data points were excluded from rooms/HCWs due to a low number of data points (see supplementary).

Interventions

This study is part of a multimodal intervention strategy, which is divided into two parts for analysis and publications (Figure 1). The first part of the multimodal project investigated the effect of light on ABHR dispensers (recently published) [2]. The second part of the multimodal project consists of the present study, investigating the effect of performance feedback.

The present study had four phases (Figure 1). Phase one was the baseline period in which no interventions were conducted. Phase two was the intervention period. All HCWs ($N=174$) received weekly group-based feedback on aggregated HHC data. Leaders ($N=6$) presented and discussed the HHC data at regular weekly staff meetings, using 3–10 minutes for feedback provision. The leaders accessed the HHC data via an online dashboard. Graphics with aggregated HHC data were printed and placed on boards in staff rooms (see supplementary). If the leader could not provide feedback due to time constraints, the weekly intervention was skipped (see supplementary). Each leader registered feedback in a predefined sheet to evaluate compliance with the weekly feedback. Phase three was also an intervention period. HCWs who volunteered to receive individual feedback signed up for the weekly email to receive their individual HHC data (see supplementary). The first author made weekly registrations of the number of opened emails per week (see supplementary). Phase four was an evaluation period without interventions.

Ethics

Ethical approval was sought in accordance with Danish law. The requirement of informed consent was waived by both the Danish Data Protection Agency (R. no. 2019-212-1420) and the Ethics Committee (R. no. 1-10-72-148-19).

Statistical analysis

Analysis was done as in the first reported part of the multimodal project [2]. Aggregated HHC data were available as total daily sums of the number of HHC opportunities and ABHR events in patient rooms, medication rooms, and staff restrooms. Data were stratified by staff group and department. Individual participant data were not available for analysis. Data were provided as HHC rates (0%–100%) with 95% confidence intervals (CIs).

For staff restrooms and medication rooms, we calculated daily and weekly HHC as the number of compliant visits/total number of visits summed by day or week. For patient rooms, we calculated overall (sum of both BEFORE entering and AFTER exiting the patient zone) daily HHC as "(number of full compliances + 0.5*number of compliances only BEFORE patient visit + 0.5*number of only compliances only AFTER patient visit)/total number of visits".

Linear regression models were established. Daily HHC was used as the outcome, and the interaction between department and study phases was used as an explanatory variable. The models used the sandwich estimator of variance. Analytical weights (number of daily visits for each HHC) were used in the regression analyses. Model coefficients were used to calculate the mean HHC for each department in each study phase and to compare them. Two-sided P values <0.05 were considered statistically significant. Differences were reported as absolute values. All analyses were conducted using STATA (StataCorp LLC, Texas, USA, version 17.0).

Results

Nurses' HHC in patient rooms

In total, 166,984 HH opportunities were included in the analysis of nurses' HHC in patient rooms (Figure 2).

In general, we observed no significant increase in nurses' HHC throughout the intervention periods, except for a small significant increase (mean dif. +2 percentage points; $P<0.01$) from baseline to the first intervention period for the group receiving only group feedback at Department 2 (Figure 2B, red line). For Department 1 (Figure 2A), the group receiving both individual AND group feedback (blue line) had a marginally higher baseline HHC than the group receiving only group feedback (red line) (29% vs 27%; $P<0.15$) (Table I). For Department 2 (Figure 2B), the group receiving both individual AND group feedback (blue line) had a significantly higher baseline HHC than the group receiving only group feedback (red line) (36% vs 30%; $P<0.0001$) (Table I).

For both departments, HHC increased significantly from the second intervention period to the follow-up period. For Department 1 (Figure 2A), the group receiving only group feedback (red line) had a mean difference of +6 percentage points ($P<0.001$). The group receiving both group AND individual feedback (blue line) had a mean difference of +5 percentage points ($P<0.005$). For Department 2 (Figure 2B), the

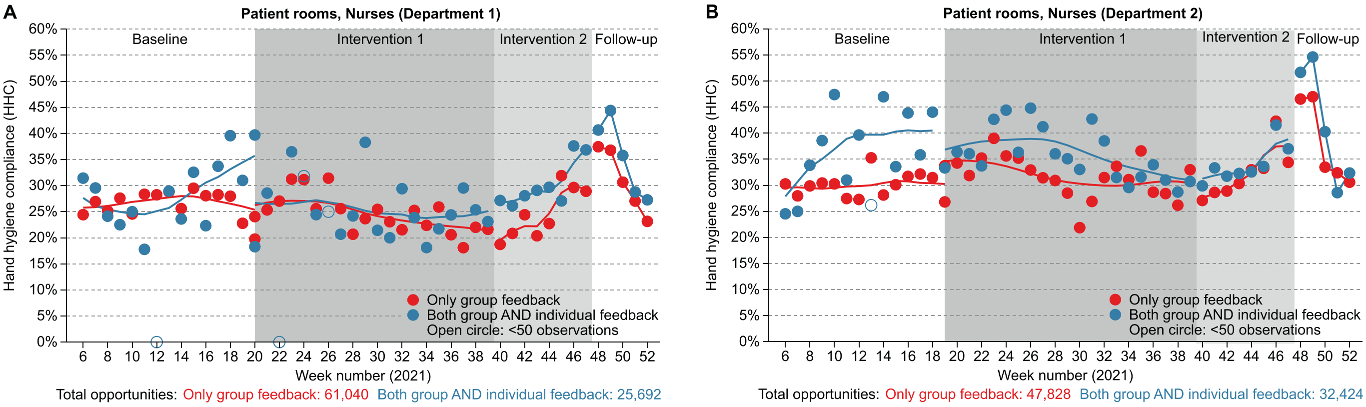

Figure 2. Nurses' hand hygiene compliance in patient rooms. Sum of both BEFORE entering and AFTER exiting the patient zone. A) Hand hygiene compliance in Department 1. B) Hand hygiene compliance in Department 2.

group receiving only group feedback (red line) had a mean difference of +6 percentage points; $P<0.02$, and the group receiving both group AND individual feedback had a mean difference of +7 percentage points; $P<0.004$.

Physicians' HHC in patient rooms

In total, 9,242 HH opportunities were included in the analysis of physicians' HHC in patient rooms.

In general, we observed no significant increase in physicians' HHC throughout the intervention periods. However, we observed an increase from the second intervention to the follow-up in Department 1 (Figure 3A) with a mean dif. of +7 percentage points ($P<0.1$) in the group only receiving group feedback (red line) and a mean dif. of +4 percentage points ($P<0.3$) in the group receiving both group AND individual feedback (blue line). Furthermore, for Department 2 (Figure 3B), we observed an increase from the second intervention period to follow-up with a mean dif. of +5 percentage points ($P<0.2$) in the group receiving both group AND individual feedback (blue line).

In general, we observed a trend towards higher HHC levels in staff restrooms than in both medication rooms and patient rooms. The lowest HHC levels were found in patient rooms (Table I).

For Department 1, we observed no significant increase throughout the study periods. For Department 2, HHC increased (mean dif. +4 percentage points; $P<0.01$) from baseline to the first intervention period among participants in the group receiving only group feedback. However, HHC decreased in the second intervention period, and the increase from baseline to follow-up ended up being non-significant (mean dif. +4 percentage points; $P<0.3$). The group receiving both group AND individual feedback did not improve in terms of HHC from baseline throughout the intervention periods to the follow-up period. The group receiving both individual AND group feedback had a significantly higher baseline HHC than the group receiving only group feedback (76% vs 66%; $P<0.001$) (Table I).

Doctors' HHC in staff restrooms was not included in the analysis due to a low number of data points (see supplementary).

Nurses' HHC in staff restrooms

In total, 16,615 HH opportunities were collected in staff restrooms and included in the analysis.

Nurses' HHC in medication rooms

In total, 38,181 HH opportunities were collected in medication rooms and included in the analysis.

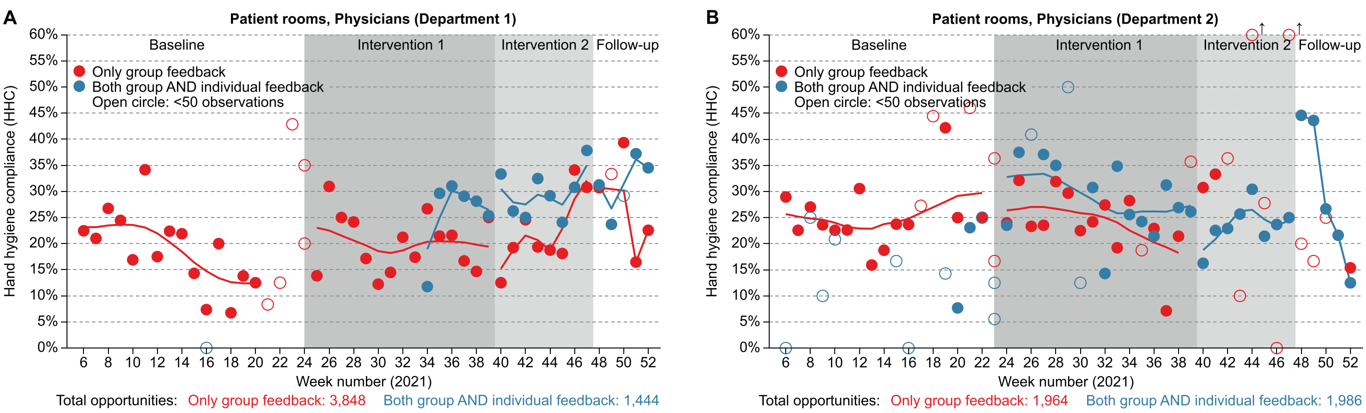

Figure 3. Physicians' hand hygiene compliance in patient rooms. Sum of both BEFORE entering and AFTER exiting the patient zone. A) Hand hygiene compliance in Department 1. B) Hand hygiene compliance in Department 2.

Table I
HHC in each study phase, specified by staff groups in patient rooms, staff restrooms, and medication rooms. HHC is given as the mean score in each phase

	Cluster "only group feedback" mean scores (95% CI)								Cluster "both group and individual feedback" mean scores (95% CI)							
	Baseline		Group feedback		Group feedback (continued)		Follow-up		Baseline		Group feedback		Individual feedback		Follow-up	
DEPARTMENT 1																
Patient rooms																
All staff	26 %	(26, 27)	24 %	(23, 25)	24 %	(22, 26)	30 %	(27, 33)	29 %	(26, 32)	25 %	(23, 27)	30 %	(28, 31)	35 %	(32, 38)
Doctors	19 %	(16, 22)	20 %	(17, 23)	21 %	(17, 25)	27 %	(21, 24)	-	-	27 %	(23, 30)	29 %	(26, 33)	33 %	(27, 40)
Nurses	27 %	(26, 28)	24 %	(23, 26)	24 %	(23, 26)	30 %	(27, 33)	29 %	(26, 32)	25 %	(23, 27)	30 %	(28, 31)	35 %	(32, 38)
Staff restrooms																
Nurses	49 %	(47, 51)	50 %	(47, 53)	42 %	(38, 47)	43 %	(37, 50)	51 %	(43, 60)	57 %	(54, 61)	55 %	(51, 58)	54 %	(49, 60)
Medication rooms																
Nurses	42 %	(40, 44)	31 %	(28, 33)	43 %	(40, 46)	41 %	(37, 44)	51 %	(46, 56)	35 %	(32, 38)	49 %	(46, 51)	47 %	(44, 51)
DEPARTMENT 2																
Patient rooms																
All staff	30 %	(29, 31)	32 %	(31, 33)	32 %	(30, 34)	37 %	(33, 42)	36 %	(33, 39)	33 %	(32, 34)	33 %	(32, 35)	40 %	(36, 44)
Doctors	27 %	(24, 30)	27 %	(24, 30)	30 %	(22, 39)	19 %	(8, 29)	15 %	(10, 20)	29 %	(25, 33)	24 %	(21, 27)	29 %	(21, 38)
Nurses	30 %	(29, 31)	32 %	(31, 33)	32 %	(30, 34)	38 %	(33,42)	37 %	(34, 40)	33 %	(32, 34)	34 %	(32, 35)	41 %	(36, 45)
Staff restrooms																
Nurses	66 %	(64, 68)	71 %	(68, 73)	66 %	61, 72)	70 %	(63, 77)	76 %	(71, 81)	69 %	(66, 71)	72 %	(68, 75)	75 %	(72, 79)
Medication rooms																
Nurses	62 %	(61, 64)	64 %	(62, 66)	64 %	(61, 67)	68 %	(63, 72)	72 %	(68, 75)	67 %	(64, 80)	66 %	(64, 68)	66 %	(64, 68)

- = Not analyzed (<50 opportunities).

For Department 1, we observed no significant increase in HHC throughout the study periods. The group receiving both individual AND group feedback had a significantly higher baseline HHC than the group receiving only group feedback (51% vs 42%; $P<0.001$). For Department 2, we observed a significant increase from baseline to follow-up in the group receiving only group feedback (mean dif. +5 percentage points; $P<0.02$). The group receiving both individual AND group feedback had a significantly higher baseline HHC than the group receiving only group feedback (62% vs 72%; $P<0.0001$).

Discussion

This study investigated the effect of a non-resource-intensive intervention with group feedback and individual feedback on HCWs' HHC. We hypothesized that weekly feedback would increase HCWs' HHC compared to baseline. However, the results showed no effect of either group or individual feedback.

Several studies have shown the effects of feedback on HCWs' HHC [3,5,26–28]. However, comparison of such studies is hampered by multiple factors, including the combination of feedback with other interventions and the use of a variety of outcome measures, types and durations of feedback, workplace cultures, role models, and methods used for estimating HHC. In the present study, we specifically aimed to investigate a non-resource-intensive intervention in a real-life clinical practice to explore its feasibility under circumstances where HCWs were facing time pressure. No time-consuming formalized training or education was provided. Furthermore, the intervention period with individual feedback was relatively short (N=8 weeks). We therefore speculate that the missing effect may be explained by the fact that too little time and effort was put into the interventions and that obtaining improvements in HHC demands allocation of more time and energy as well as active support from leaders and local role models.

A strength of the present study is that it includes four inpatient wards from two different departments and six leaders each with their respective staff groups. This allowed us to compare the results across departments and staff groups. In general, for both Departments 1 and 2, baseline HHC was higher in the groups receiving both group AND individual feedback than in the groups receiving only group feedback (Table I). This indicates that HCWs who willingly opted for individual feedback already possessed a heightened awareness of the importance of HH, which likely contributed to their increased motivation for improvement. However, in general, the groups receiving both group AND individual feedback did not respond better to feedback than did the groups not signing up for individual feedback.

Another strength of the study is that we can report HHC rates in different room types. We found that HHC rates varied profoundly with room types, with HHC being lowest in patient rooms (Table I). This highlights the importance of reporting HHC according to room type rather than as pooled data because a meta-analysis will not provide a sufficiently nuanced picture. Specifying HHC data according to room type requires multiple data points to be able to evaluate the effects of the interventions. In the present study, we therefore had to exclude several data points because of a too low number of data points in some of the rooms (see supplementary).

The study has some notable limitations. First, HCWs were not exposed to the interventions to the same extent, which is a major limitation. Not all HCWs were equally exposed to the group feedback as attendance at feedback meetings depended on the individual's work hours and workload. Furthermore, the leaders could not provide all the weekly interventions as intended due to time constraints. Therefore, the frequency of the intervention was reduced to every other week or less. While weekly feedback was not consistently provided, occasional data printouts were posted in staff rooms and informal discussions about the feedback took place throughout the week. We cannot report the informal discussions as it was not possible to register these discussions. However, the formal weekly feedback was registered by the leaders (see supplementary). The nurses in Department 2 (N=16) received formal weekly feedback from their leader more often than the nurses in Department 1 (N=4) did. This may indicate that Department 1 suffered from time constraints during the intervention period. It may also explain the trend towards a higher HHC in Department 2 than in Department 1 during the entire study period. However, the same difference was found in the previous study in the same departments [2]. This indicates that cultural differences between the departments may also explain the differences in HHC. Similarly, HCWs who volunteered to receive an email with individual feedback were also unequally exposed to the individual feedback as only 31–83% of the emails were opened each week (see supplementary).

To ensure feasibility in real-life practice, we opted for a non-resource-intensive intervention. Despite that, due to constraints, the leaders were unable to provide weekly feedback consistently, and HCWs did not always open the weekly emails as intended. Consequently, not all participating HCWs received the intervention as planned, posing a challenge in evaluating its effectiveness, which is a significant limitation of the present study.

Another limitation of the study is that data were collected during the COVID-19 pandemic. The increased HHC in the follow-up period was associated with an increased number of patients hospitalized with COVID-19 in Denmark (see supplementary). While this association may provide an explanation for the increased HHC, the existence of a causal relation remains uncertain.

This study was the last part of a multimodal project (Figure 1). In the first part, the study participants increased HHC through interventions with lights (reminder and feedback) on ABHR dispensers (Figure 1). The light intervention was followed by a 21-week gap before the feedback intervention began. HHC rates decreased after the light intervention and stabilized before the feedback intervention began, as described in a previous publication [2]. However, in this present study, we observed a trend toward decreased HHC throughout the intervention periods. The potential impact of the previous increase in HHC from the light intervention on the subsequent decrease in this study remains unknown.

The AHHMS collected the HHC data when the HCWs wore a tag with an anonymous ID number. To ensure anonymity, the individual ID numbers were not registered. We were therefore unable to assess the individual's HHC data and could not determine if all 174 HCWs participated in the entire data collection period. Some HCWs might have stopped, and new ones were included during the study period. It is therefore unknown whether this could have impacted the overall HHC levels in either direction.

This study adds important insights strategies for enhancing HHC among HCWs. Our data suggest that implementing an AHHMS in clinical practice and providing HCWs with a non-resource-intensive intervention with feedback did not increase HHC among HCWs. We therefore speculate that obtaining improvements in HHC demands allocation of more resource-intensive interventions.

Conclusion

In conclusion, the AHHMS provided HHC data on physicians' and nurses' HHC in various room types and inpatient wards. However, the study showed no effect of providing HCWs with verbal group feedback from leaders or with written individual feedback via email.

Acknowledgments

As authors, we express our gratitude to the HCWs who participated in the study and to all the leaders who provided weekly feedback. Furthermore, the authors want to thank Senior Consultant Jan Alsner for statistical assistance and enriching discussions.

Author contribution

Iversen, AM: Conceptualization, Methodology, Investigation, Writing – Original Draft, Visualization, Project administration, Funding acquisition. **Hansen, MB:** Conceptualization, Methodology, Writing – Review & Editing, Supervision. **Ellermann-Eriksen, S:** Conceptualization, Methodology, Writing – Review & Editing, Supervision, Funding acquisition.

Conflicts of interest

MBH is employed with Konduto ApS; the developer of Sani Nudge™. The other authors have no competing interests to declare. All authors approved the final article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.infpip.2023.100321.

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Supplementary material:

Effects of Data-driven Feedback on Nurses' and Physicians' Hand Hygiene in Hospitals – a Non-resource-intensive Intervention in Real-life Clinical Practice

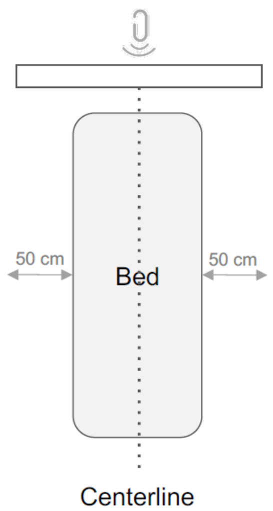
Authors: Anne-Mette Iversen, RN, MSc, Marco Bo Hansen, MD, PhD, Svend Ellermann-Eriksen, MD, PhD, DMSc

Table of Content:

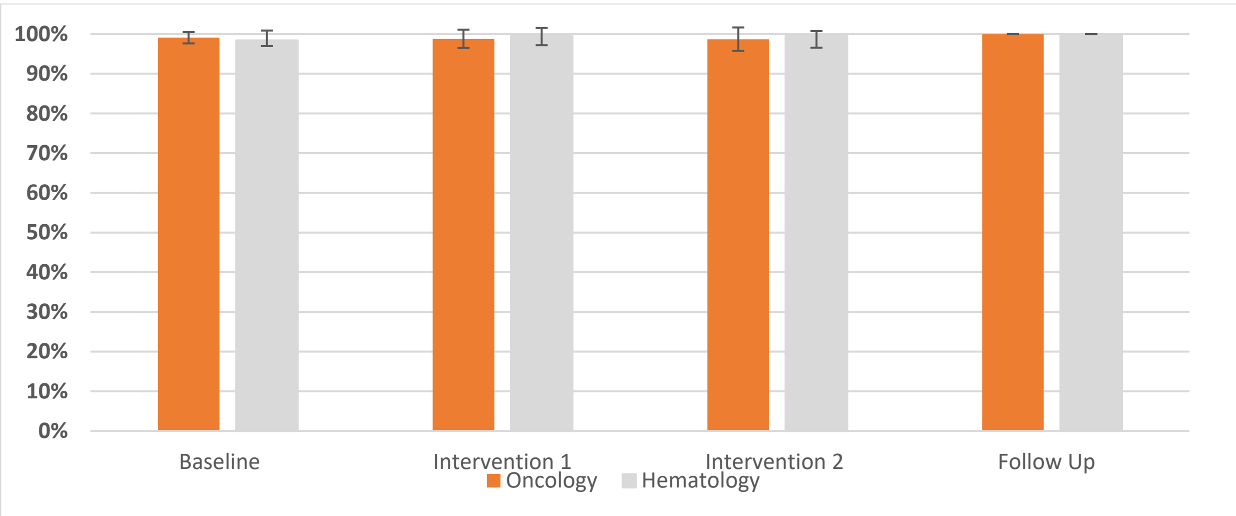
1. Bed placements under the sensors

In patient rooms, the AHMMS creates an invisible "patient zone". The "patient zone" functions as a proxy measure for physical contact between the healthcare worker (HCW) and the patient or the patient-near surroundings. To ensure data validity, it is crucial that the patient bed is placed correctly under the wall-mounted bed sensor above the patient bed. Therefore, the placement of the patient beds (n=64) was registered on random days, approximately one time a week, throughout the study period. A figure was used to register whether the patient bed was placed "incorrectly" or "correctly" (Figure 1). The registrations showed that more than 98% of the patient beds were placed correctly in both departments in all the four study periods (Figure 2).

Supplementary Figure A1. The figure, used to register the correct placement of the bed.



Supplementary Figure A2. Percentage of patient beds placed correctly under the Sani Nudge wall sensor. Error bars represent the standard error of the mean. Total number of observations = 2424.



2. Data exclusion

In total, 272,624 data points were collected in the study. During the study period, the frequency with which a hospital bed position system interfered negatively with the automated hand hygiene monitoring system affected some sensors. To ensure the validity of the data, we made an algorithm for data exclusion. The algorithm is described in a recent publication (1). In total, 31,310 data points were excluded by the algorithm. Furthermore, 10,292 data points were excluded from the analysis due to low data points in the specific room for a specific staff group (Table I).

Supplementary Table A I. The number of data points 1) included in the study, 2) excluded from the study due to the algorithm for data exclusion, and 3) excluded from the study due to a low number of data points in a specific room for a specific staff group.

Room type	Data points **included**	Physicians	Nurses	Cleaning staff
Patient rooms:	176,226	9242	166,984	0
Medication rooms:	38,181	0	38,181	0
Restrooms:	16,615	0	16,615	0
Clean rooms:	0	0	0	0
Unclean rooms:	0	0	0	0
All rooms:	231,022	9242	221,780	0

Room type	Data points **excluded** (due to **the algorithm**)	Physicians	Nurses	Cleaning staff
Patient rooms:	18,350	924	15,692	1734
Medication rooms:	10,088	0	9906	182
Restrooms:	1426	115	845	466
Clean rooms:	171	0	164	7
Unclean rooms:	5037	0	3664	1373
All rooms:	35,072	1039	30,271	3762

Room type	Data points **excluded** (due to a **low number of data points**)	Physicians	Nurses	Cleaning staff
Patient rooms:	14,924	0	0	14,924
Medication rooms:	453	0	0	453
Restrooms:	5443	1459	0	3984
Clean rooms:	5473	0	3189	2284
Unclean rooms:	10,406	0	5644	4762
All rooms:	36,699	1459	8833	26,407

3. Aggregated and Individual HHC data

Graphics with aggregated HHC data were printed and placed on boards in staff rooms. Furthermore, HCWs who volunteered to receive individual feedback signed up for the weekly email to see their individual HHC data (Figure A3).

Supplementary Figure A3. Graphics of aggregated group HHC data printed from an online dashboard (Figure A3.1) and graphics with individual HHC data sent to the HCW in a weekly email (Figure A3.2).

4. Group feedback –number of times each staff group received feedback in groups

During intervention periods one and two, the leaders were supposed to provide their staff group with group feedback once a week. Due to time constraints, the leaders sometimes had to skip the formalized group feedback (Table II). However, even when the group feedback was skipped, there was a focus on the weekly HHC data that were not registered (e.g., the data were printed and placed in staff rooms to stimulate informalized talks in small groups or between a leader and one of the HCWs).

Supplementary Table A II. Number of times leaders provided feedback in groups.

Group Feedback	Department 1	Department 2
Nurses	4	16
Physicians	12	10

5. Individual feedback – number of opened emails

During the intervention period with individual feedback, the HCWs received a weekly email (every Monday) with their individual HHC data. The number of HCWs signed up to receive the weekly email was registered together with the number of nurses and physicians who actually opened the weekly email within one week.

Supplementary Table A III. Number of HCWs who signed up to receive the weekly email with individual feedback data and number of HCWs who opened the weekly email in percentage and absolute numbers.

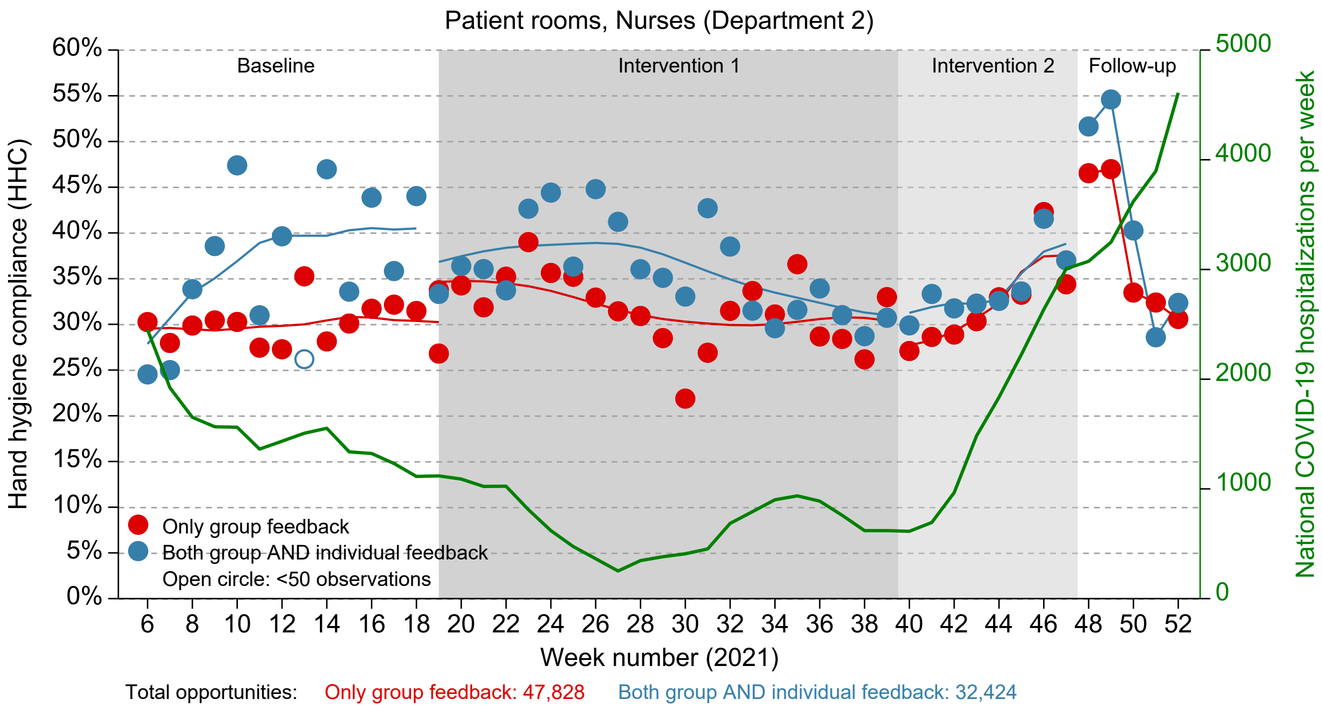
Week number	**Nurses** signed up for the email (absolute numbers)	Opened reports %	Opened reports Absolut numbers
40	56	62 %	35
41	57	61 %	35
42	57	41 %	23
43	55	31 %	17
44	55	46 %	25
45	56	41 %	23
46	57	40 %	23
47	57	40 %	23

Week number	**Physicians** signed up for the email (absolute numbers)	Opened reports %	Opened reports Absolut numbers
40	19	75 %	14
41	27	83 %	22
42	27	50 %	14
43	31	82 %	25
44	31	45 %	14
45	30	38 %	11
46	30	62 %	19
47	30	33 %	10

6. Impact of COVID-19 on HHC

HHC data were collected during the COVID-19 pandemic during which restrictions on HH and social distancing were stressed nationwide. The restrictions may possibly have impacted the HHC level. An association is seen between the increased level of HHC for nurses in patient rooms in the follow-up period and the number of hospitalized patients with COVID-19 in Denmark (Figure 3). However, we do not know if there is a correlation.

Supplementary Figure A4. Association between nurses' HHC in patient rooms and number of patients hospitalized with a COVID-19 diagnosis in Denmark.



7. Reference

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Paper IV

Iversen AM, Hansen MB, Münster M, Kristensen B, and Ellermann-Eriksen S

Hand hygiene compliance in nursing home wards measured with an automated hand hygiene monitoring system – the effect of increased accessibility of alcohol-based hand rub

Submitted to Journal of Hospital Infection, Under review, 2023

Hand hygiene compliance in nursing home wards measured with an automated hand hygiene monitoring system – the effect of increased accessibility of alcohol-based hand rub.

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Conflicts of interest:

MBH was employed with Konduto ApS; the developer of Sani Nudge^{TM}, during the data collection period. The other authors have no competing interests to declare. All authors approved the final article.

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Summary

Background

Elderly nursing home (NH) residents are vulnerable to infections due to age, weakened immune system and comorbidities. Furthermore, microorganisms are easily transmitted in shared facilities. Hand hygiene (HH) is considered the single most important measure to prevent transmission. We monitored HH compliance (HHC) among healthcare workers (HCWs) using an automatic hand hygiene monitoring system (AHHMS) and determined the effect of increased accessibility to alcohol-based hand rub (ABHR) in NH wards.

Methods

An 11-month intervention study was conducted in a Danish six-ward NH. After a baseline period, one extra ABHR dispenser was placed in each of the 150 apartments. We compared baseline HHC with the HHC during an immediate intervention period and a long-term intervention period.

Results

We included 159 HCWs. Data were collected with a type-five AHHMS, and 341,078 HH opportunities were registered. Overall baseline HHC was 31% (95% CI: 30-32). A significant +18% absolute immediate effect (first five months) (95% CI: 17-19; p<0.0001) and +13 percentage points (95% CI: 11, 14; p<0.0001) long-term effect (another four months) were recorded. HCWs working day shifts and short-term employees had a higher baseline HHC than HCWs working evening/night shifts. However, HCWs working night shifts achieved the greatest long-term effect with a mean +27 percentage point difference (p<0.0001).

Conclusions

Placing an additional ABHR dispenser strategically within staff workflow significantly increased HHC among HCWs, showcasing a noteworthy effect. The study is the first to report the effect on NH dispenser placement and demonstrate a significant unmet potential.

Key-words: visibility; placement; availability, infection prevention; nudging, long-term care

Introduction

The connection between low hand hygiene compliance (HHC) and healthcare-associated infections (HAIs) is well established. Nevertheless, low HHC remains an urgent problem in hospitals and nursing homes (NH) globally [1, 2]. Multiple interventional studies have been conducted to improve HH, but most were conducted in hospitals and strong evidence from NHs is lacking [1, 3].

Nursing homes

An increasing number of residents in high-income countries are living in NHs owing to a longer life expectancy and as a result of incentives to discharge patients from hospital sooner [4]. In European NHs, 50% of the residents are older than 85 years of age [5]. In general, elderly people are vulnerable to infections due to a weaker immune system, comorbidities and weakness in important infection barriers, including skin thinning, diminished cough reflex and impaired bladder and emptying capacity [6]. According to a point prevalence study, 3.7% of residents living in European NHs have at least one HAI [5]. For NHs in Denmark, the HAI prevalence was reported to be 5.2% [5].

NHs are unique environments for infection transmission due to a homelike environment where microorganisms can easily be transmitted via shared facilities. This vulnerability is compounded by frailty of the elderly residents [7]. Therefore, NH infection prevention is crucial for prevention of HAIs.

Monitoring hand hygiene compliance in nursing homes

HCWs' HH is considered the single most important factor in preventing HAIs [8]. Only a few studies have reported HHC rates from NHs with reported HHC rates varying considerably (17% to 79%) depending on the NH, wards and methods used to monitor HHC [9-13]. Most NH studies have measured HHC using direct observations. This method has several advantages such as the possibility to measure the quality of HH performance and all of the World Health Organization's (WHO) "Five moments of hand hygiene" [14].Conversely, direct observations capture only a small fraction of the total hand hygiene opportunities while being time-consuming and subject to bias (observer, observation and selection bias) [15]. Due to the disadvantages of direct observations, recent years have seen the development of automated hand hygiene monitoring systems (AHHMS) capable of collecting far more HH opportunities while being less time-consuming and less prone to bias. AHHMS are mostly used to measure HHC in hospitals and, to the best of our knowledge, only one study has measured HHC with an AHHMS in NHs [10]. The previous study monitored HHC among visitors, patients and HCWs as pooled data because the AHHMS lacked the capability to distinguish between these groups due its movement-tracking technology. Therefore, the present study is the first to report HHC levels of HCWs from six wards at a NH using a type-five AHHMS technology capable of considering the previous workflow, according to the definition by Gould et al [16].

Behavioural science and ABHR accessibility

In *an ideal world*, HCWs would base their decisions (whether to perform HH or not) on best practices, evidence and guidelines [17]. However, in *the real world*, human behaviour is more complex. In clinical practice, HCWs face understaffing, cognitively demanding routines and behaviour, high workloads and a myriad of choices and situations all of which affect their decision-making [18, 19]. Many HCWs will therefore unconsciously try to conserve mental energy for the demanding environment and default to the option that requires the least effort (*the path of least resistance*), which is doing nothing. This is simply a result of the limited cognitive energy we have available in various situations throughout our lives. The idea of limited cognitive capabilities is well established. Nobel Laureate Daniel Kahneman revolutionised the field of behavioural science by showing the many ways in which our mind chooses the easy option over the hard one [20]. Therefore, a lack of compliance with HH is typically not a product of disagreement with the guidelines but rather a product of cognitive limitation in the specific situation [15]. In other words, people tend to make easy choices, and we therefore need to make the right option easy. It follows that decreasing barriers to the right behaviour may potentially help improve HCWs' HH [21].
Low accessibility to HH supplies was reported to be one of the important barriers to performing HH [7, 9, 22-24]. Multiple studies have reported that increased access to ABHR enhances the HCWs' HHC rate in hospitals [25-27]. A recent study found an increased ABHR consumption when two dispensers instead of one dispenser were made available in the patient room [28]. In NHs, to the best of our knowledge, the effect of HCWs' increased accessibility to ABHR on HHC was investigated only in combination with other interventions (e.g. education) [3]. Therefore, this study is the first to assess the effect of increased accessibility as a single intervention on HCWs' HHC in NHs.

This study aimed to investigate the effect of increased ABHR accessibility on HCWs' HHC. It was a specific aim to access HHC rates and evaluate the effect of the intervention with an AHHMS. We hypothesised that HHC among HCWs increases in residential apartments when implementing one extra ABHR dispenser in the hallway of the residential apartments where HCWs pass when entering and exiting compared to having only one ABHR dispenser in the restroom.

METHODS

Study design and setting

An 11-month prospective, interventional study was conducted in a NH in Denmark. The NH consists of 150 single apartments distributed in six wards. Wards 1-3 collected data from October 2020 to September 2021. Wards 4-6 collected data from December 2020 to November 2021.

The NH provides healthcare to residents who cannot manage their needs independently in their homes. Residents have an extensive, lasting and constant (24 hours/day, 7 days/week) need for care and practical help. The residents and HCWs use shared facilities such as hallways, living rooms and dining rooms.
Data were collected during the COVID-19 pandemic; a period generally characterized by a high focus on HH, use of facemasks and social distancing requirements. Especially, by the end of December 2020, a societal lockdown was imposed in Denmark during which restaurants, shops, schools and malls were closed; and people were encouraged to work from home if possible. The society was gradually reopened in the following months and by May 2021, all restrictions had been lifted [29].

Study subjects and data collection

Nurses and nurse assistants (n=159) from six wards were included in the study. Participants were informed about the use of the AHHMS and the study purpose. To ensure participant anonymity, the only information obtained was the HCWs' primary work shift: 1) day shift, 2) evening shift, 3) night shift, and 4) short-term employees/hourly paid.
Data were collected using an AHHMS (Sani Nudge™) [30]. The AHHMS is an advanced type-five sensor system that enables continuous detection of movement with arm-length precision throughout the ward [16]. In this study, the AHHMS monitored HCWs compliance with HH before entering and after exiting residential apartments. The AHHMS has been described in detail in a recent publication [31] and evaluated in two recent studies [32, 33].

Interventions

This study investigated the effects of increased accessibility to ABHR in residential apartments in three periods. Period one served as baseline period without any changes to the number of ABHR dispensers in the residential apartments. During the baseline period, only one ABHR dispenser was accessible in the apartments (placed in the restrooms) (Figure 1). The baseline period was followed by an intervention period. On the first day of the intervention, one extra ABHR dispenser was placed in the hallway (entrance) in all residential apartments to increase ABHR accessibility (Figure 1). The extra dispenser remained in the same position throughout the entire study period. In this study, we define *accessibility* in terms of physical distance. The hallway was chosen as the HCWs always pass the hallway before entering and after exiting the resident's living room/bedroom. In other words, the intervention aimed to make it easy for the HCWs to access the ABHR dispenser along their working route. HHC was monitored during a nine-month period during which no further changes were made in the placements of ABHR dispensers. The period was split into two periods for analysis: “immediate intervention” lasted five months and captured the immediate effect of the increased accessibility to ABHR; “long-term intervention” lasted four months and measured the long-term effect of the increased accessibility to ABHR.

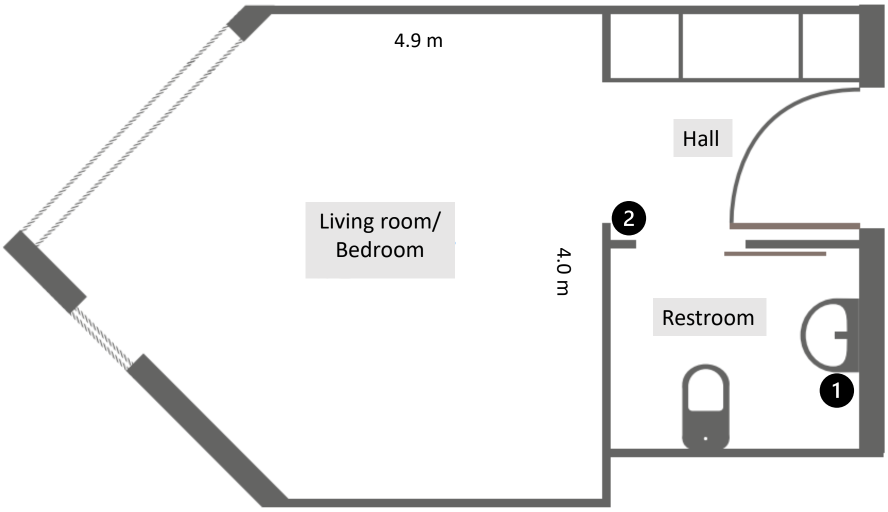

Figure 1. Illustration of a residential apartment and locations of ABHR dispensers. 1: During the baseline period, the ABHR dispenser in the restroom was the only dispenser in the residential apartment. 2: On the first day of the intervention, an extra ABHR dispenser was placed in the hallway/entrance to the living room/bedroom.

Ethics

Ethical approval was sought in accordance with Danish law. The requirement of informed consent was waived by both the Danish Data Protection Agency (R. no. 2019-212-1420) and the Ethics Committee (R. no. 1-10-72-148-19).

Statistical analysis

Aggregated HHC data were available as total daily sums of the number of HHC opportunities and ABHR events in the apartments. Data were stratified by work shift. Individual participant data were not available for analysis.

We calculated the overall (sum of both BEFORE entering and AFTER exiting the apartment) daily HHC as "(number of full compliances + 0.5*number of only compliances BEFORE entering + 0.5*number of only compliances AFTER exiting)/total number of visits".

Linear regression models were established. Daily HHC was used as the outcome and the differences between the study phases and staff groups were used as an explanatory variable. The models used the sandwich estimator of variance. Analytical weights (number of daily visits for each HHC percentage) were used in the regression analyses. Model coefficients were used to calculate the mean HHC in each study phase and to compare them. Two-sided P values <0.05 were considered statistically significant. Differences were reported as absolute values. All analyses were conducted using STATA (StataCorp LLC, Texas, USA, version 18.0).

RESULTS

A total of 159 nurses and nurse assistants were included in the study. The AHHMS registered 341,078 HH opportunities in the residential apartments (day shift=166,588, evening shift=74,338, night shift=13,976, and short-term employee=86,176).

The effect of increased accessibility to ABHR in residential apartments

Overall HHC increased from 31% (95% confidence interval (CI): 30-32) in the baseline period to 49% (95% CI: 48-50) in the immediate intervention period with a mean difference of +18 percentage points (p; <0.0001) (Figure 2). HHC subsequently decreased during the long-term intervention to 44% (95% CI: 43-44) with a mean difference of -5 percentage points (p; <0.0001). However, HHC ended up at a higher level than recorded during the baseline period with a mean difference from baseline to long-term intervention of +13 percentage points (p; <0.0001) (Table I).

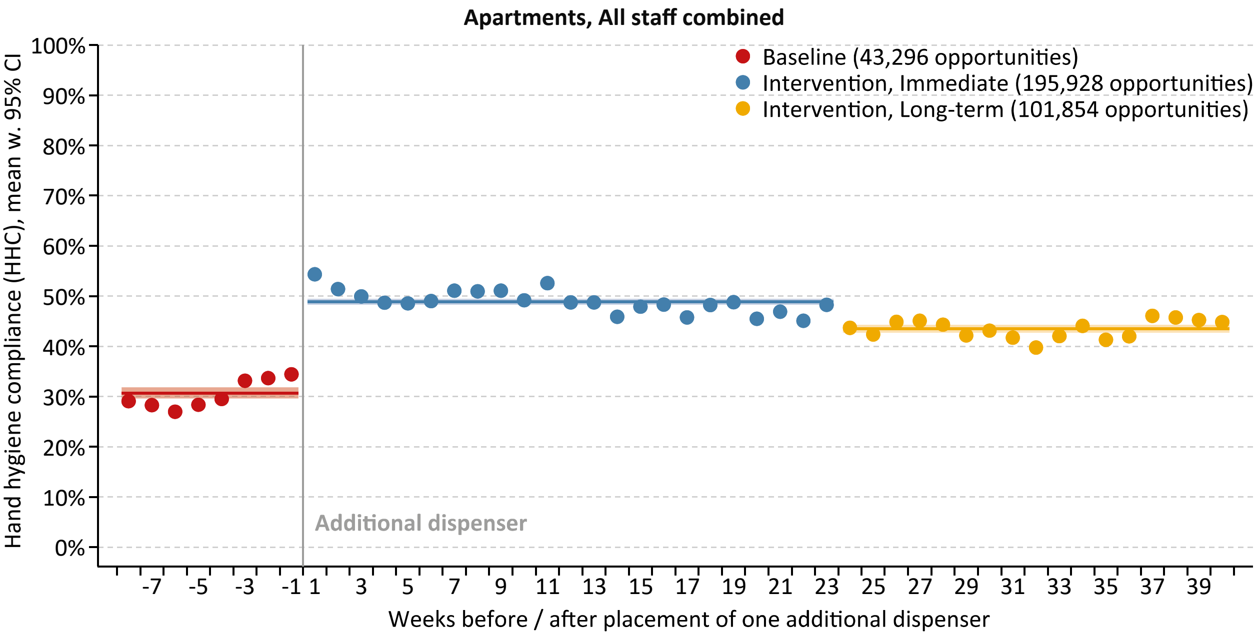

Figure 2. Healthcare workers' hand hygiene compliance in residential apartments. The sum of HHC for both BEFORE entering and AFTER exiting the apartment with 95% CI. The baseline constitutes a period without intervention. "Immediate intervention" shows the immediate effect of the increased accessibility to ABHR. "Long-term intervention" shows the long-term effect of increased ABHR accessibility. The grey line marks the day when one additional ABHR dispenser was placed in each of the 150 apartments.

Table 1. HHC in each study period, by staff groups. HHC is given as a mean score in each period and as difference in mean score between selected periods: Baseline vs. Immediate intervention, Baseline vs. Long-term intervention, and Immediate intervention vs Long-term intervention.

	Mean scores (95% CI)			**Difference in mean scores (95% CI)**		
	Baseline *(2 Months)*	**Immediate intervention** *(5 Months)*	**Long-term intervention** *(4 Months)*	**Baseline vs. Immediate intervention**	**Baseline vs Long-term intervention**	**Immediate vs Long-term intervention**
Staff group						
All staff	31% (30, 32)	49% (48, 50)	44% (43, 44)	+18 (17, 19)	+13 (11, 14)	-5 (-6, -5)
Day shift	33% (31, 35)	49% (48, 50)	43% (42, 44)	+16 (15, 18)	+10 (8, 12)	-6 (-7, -5)
Evening shift	27% (25, 30)	46% (45, 48)	38% (36, 39)	+19 (16, 22)	+10 (7, 13)	-8 (-11, -7)
Night shift	27% (25, 30)	53% (51, 55)	55% (52, 57)	+26 (22, 29)	+27 (24, 31)	+2 (-1, 5)*
Short-term employee	32% (30, 34)	50% (49, 51)	47% (46, 49)	+18 (16, 21)	+15 (13, 18)	-3 (-5, -1)

* Not significant

HHC between the workgroups

HCWs primarily working day shifts had the highest baseline HHC (33%, 95% CI: 31-35) followed by HCWs hired as short-term employees (32%, 95% CI: 30-34). HCWs working evening shift (27%, 95% CI: 25-30) and HCWs doing night shifts (27%, 95% CI: 25-30) had the lowest baseline HHC (Table I). However, HCWs working night shifts had the greatest effect of the intervention with a mean difference from baseline to the long-term intervention period of +27 percentage points (p<0.0001). Furthermore, this group had higher HHC in both intervention periods (Immediate intervention: 53%, 95% CI: 51-55 and Long-term intervention: 55%, 95% CI: 52-57) than the other work groups (Table I).

HHC before and after resident contact

Overall, we observed a significantly higher HHC *after exiting* the apartments than *before entering* the apartments in all three study periods (Figure 3). Overall baseline HHC *after exiting* the apartments was 35% (95% CI: 34-36) compared with 26 % (95% CI: 25-28) *before entering* the apartments, yielding a mean difference of +9 percentage points (p<0.0001). HCWs working night shifts had the greatest difference in HHC between *before entering* and *after exiting* the apartments with a mean difference in the baseline period of +19 percentage points (p<0.0001), a mean difference in the Immediate intervention period of +15 percentage points (p<0.0001) and a mean difference in the Long-term intervention period of +20 percentage points (p<0.0001) (data not shown).

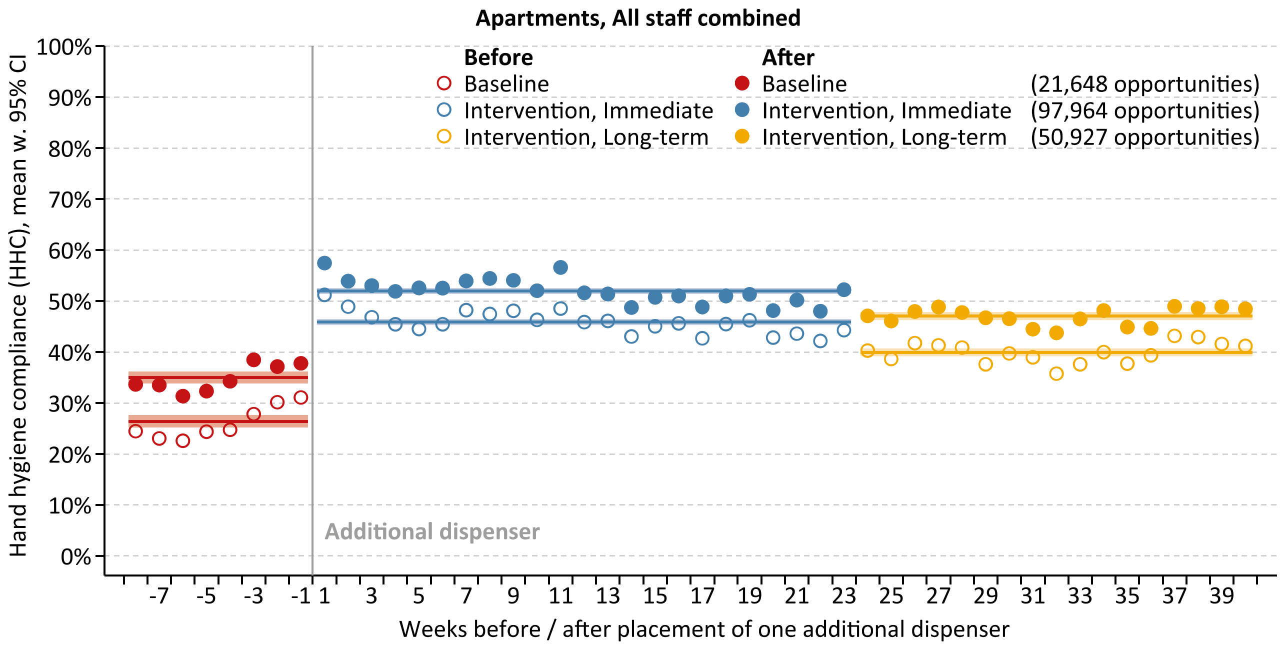

Figure 3. Healthcare workers' hand hygiene compliance in residential apartments *before entering* (empty circle) and *after exiting* (full circle) the apartment with 95% CI.

DISCUSSION

This study investigated the effect of increased accessibility to ABHR on HCWs' HHC in NHs. Overall, a significant +18 percentage point (p<0.0001) effect was recorded in the period immediately after baseline and a +13 percentage point (p< 0.0001) long-term effect was recorded. The precise impact of the increased HHC rate on infection risk remains unknown. A review from 2015 examined the impact of HAIs in NHs and found that 63% of the reviewed studies suggested that HH helped decrease infection risk in NHs. However, the review also demonstrated that the precise impact of HH on infectious risk in NHs remains poorly documented [3].

This study found an overall baseline HHC of 31% (95% CI: 3032). Other studies have reported HHC rates from NHs. However, due to the wide range of HHC rates reported from NH (17-79%) and the heterogeneity of the studies [9-13], it is not possible to compare the overall HHC rates reported in this study with HHCs reported in other studies from NHs. However, studies of HHC rates in hospitals measured with the same AHHMS have reported baseline HHC rates from patient rooms to fall in the 20-44% range [34-38]. It was claimed that HHC rates in NHs are lower than in hospitals [39, 40]. However, in the present study, we showed that baseline HHC rates from an NH were in line with baseline HHC rates from comparable studies in hospitals.

This study had several strengths: 1) It was the first study to investigate the effect of increased accessibility (as a single intervention) on HCWs HHC in NHs, 2) it was the first to report data on HCWs HHC monitored with a type-five AHHMS in an NH [16], 3) it was the first study to report HHC data from an NH stratified by work shift, 4) it was a large-scale study comprising more than 340,000 HH opportunities and, finally, 5) the study reported the long-term effect of the intervention.

HHC rates across work shifts and WHO moments 1, 4 and 5

We found a significantly higher HHC after exiting than before entering the apartments. This finding echoes those in studies from NHs, reporting higher HHC rates after than before contact with a resident [9, 11, 41, 42]. Furthermore, we found baseline HHC to be higher for HCWs working day shifts and among short-term employees than among HCWs working evening shifts and night shifts. A similar result was found in a study from a hospital in Denmark (monitored with the same AHHMS), reporting the highest HHC during the mornings and subsequently decreasing HHC rates throughout the day, reaching the lowest levels during night shifts [31]. However, in the present study, HCWs working night shifts had the greatest effect of the intervention and ended up with higher HHC rates than HCWs working other shifts.

AHHMS vs. direct observations

We specifically aimed to evaluate the effect of the intervention with an AHHMS. Direct observations are still considered the gold standard when monitoring HHC in healthcare given the unique abilities to provide HHC rates for all 5 HH Moments, to assess the HH quality and glove use, to provide real-time feedback, and the fact that the direct observations can be conducted in healthcare settings with widely ranging resources [15]. However, AHMMS has become more commonly used in hospitals to overcome the methodologic issues associated with direct observations (time-consuming, small sample sizes and the Hawthorne effect). To the best of our knowledge, only one study by Starrett et al. has previously reported HHC data from NHs in the USA monitored by AHHMS [10]. Their study monitored HHC among visitors, patients/residents and HCWs as pooled data, making the HHC rates impossible to compare to our findings. Furthermore, to the best of our knowledge, no HHC data have been published from NHs in Denmark; either with direct observations or AHHMS. Future studies are warranted to investigate HHC rates in NHs.

The AHHMS enabled the measurement of HHC during this study. However, measuring consumption may have given comparable results. Nevertheless, if we had pursued this option, we would not have been able to measure opportunities, to stratify HHC data into work shift or to distinguish between residents, visitors and HCWs. Furthermore, a strength of the type-five AHHMS is that it takes situations and behaviour leading up to and after sanitisations into consideration when calculating HHC (e.g. if the HCW use an ABHR on the way to the apartment, the system will take this action into account when calculating HHC in the apartment). The method used to measure HHC is reasonable to consider due to the financial costs of an AHHMS.

The visibility of ABRH dispensers in the apartments

In the baseline period, only one ABHR dispenser was available in the apartments (in the residential restroom). As a result, HCWs had to walk into the restroom (Figure 1) to access the dispenser before entering the living/bedroom to the resident. Making it easier for HCWs to access an ABHR dispenser by implementing an extra ABHR dispenser in the hallway increased HHC. This finding is in line with the theory of behavioural science arguing that people tend to make easy choices and as a result follow *the path of least resistance* [21]. However, increased accessibility to ABHR might not be the only factor influencing HHC level. The new dispenser in the hallway was more visible for the HCWs as they passed the dispenser following their work route before and after resident contact. As a result, the visibility of the dispenser may potentially serve as a constant reminder of the need for HH. Furthermore, increased accessibility might not be the only factor impacting HHC level. Additionally, the strategic placement of ABHR may play an important role for HHC. Therefore, *placement* and *visibility* may also impact the effect of the intervention.

The number of ABRH dispensers in the apartments

We found improved HHC among HCWs with an additional ABHR in the hallway. We speculate whether further improvements would be possible if we implement more ABHR dispensers in the apartments. However, an important consideration is the balance between maintaining a homelike environment and establishing the best possible architecture to achieve good hygiene in the residential apartments. We know from a recent study by Lescure et al. that HCWs are constantly challenged by the trade-off between working hygienically and maintaining a homelike environment for the residents [7]. Increasing ABHR availability in the apartments may compromise the goal of maintaining a homelike atmosphere.

This study has some potential limitations. First, selection biases should be considered as participation was voluntary. Second, the AHHMS collected HHC when the 159 HCWs wore a tag with an anonymous ID number. To ensure anonymity, we did not register the specific tag ID number. Thus, we were unable to determine if all 159 HCWs participated in the entire study period. Some might have stopped, and others may have been included during the data collection period. Therefore, it remains unknown how many of the included participants participated in the entire study period and if this could have impacted the HHC rates in either direction.

Furthermore, HHC data were collected during the COVID-19 pandemic. We began data collection in October 2020 when the pandemic was on the rise. As a result, the level of attention devoted to HH in society was heightened. HCWs' HHC rates might have been affected by the high level of attention devoted to HH in society during the pandemic. However, studies on the impact of COVID-19 on HHC show either no effects [37, 43, 44] or temporarily increased HHC rates during societal lockdowns, followed by a return to baseline rates after a relatively short period [45-47]. Based on these studies, a long-term impact of COVID-19 in the present study is considered less likely.

Future aspects

This study adds important insights to the literature as the first to report HHC monitoring of HCWs in an HN using a type-five AHHMS. However, more studies on HHC rates from NHs measured with an AHHMS are needed. As suggested by John M. Boyce, direct observations and AHHMS could be used in combination. Direct observations may be considered the primary qualitative measure of HHC, and AHHMS may become the main quantitative approach for accessing HHC rates [15].

Conclusion

The AHHMS enabled continuous assessment of HHC in a six-ward NH. We found that improved ABHR accessibility in residential NH apartments significantly increased the HCWs' HHC rates. The improvements are deemed clinically relevant and emphasize the importance of having strategies for ABHR dispenser placement in NHs.

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Author contribution

Iversen, AM: Conceptualisation, Methodology, Investigation, Writing - Original Draft, Visualisation, Project administration, Funding acquisition.

Hansen, MB: Conceptualisation, Methodology, Writing - Review & Editing, Supervision.

Münster, M: Conceptualisation, Methodology, Writing - Review & Editing, Supervision.

Kristensen, B: Conceptualisation, Methodology, Writing - Review & Editing, Supervision.

Ellermann-Eriksen, S: Conceptualisation, Methodology, Writing - Review & Editing, Supervision, Funding acquisition.

Conflicts of interest

MBH was employed with Konduto ApS, the developer of Sani Nudge™, during the data collection period. The other authors have no competing interests to declare.

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Paper V

Iversen AM, Hansen MB, Münster M, Kristensen B, and Ellermann-Eriksen S

Hand hygiene compliance in nursing homes measured with an automatic hand hygiene monitoring system – the effects of feedback with lights on alcohol-based hand rub dispensers

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Hand Hygiene Compliance in Nursing Homes Measured With an Automatic Hand Hygiene Monitoring System – The Effects Of Feedback With Lights on Alcohol-based Hand Rub Dispensers

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Conflicts of interest:

MBH was employed with Konduto ApS, the developer of Sani Nudge™, when the study data were collected and analyzed. The other authors have no competing interests to declare. All authors approved the final article.

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This study was funded by the Municipality of Aarhus and the Health Research Foundation of the Central Denmark Region (R. no. A3099).

Background:

Hand hygiene (HH) among healthcare workers (HCWs) is crucial in preventing infections in nursing homes. However, HH compliance (HHC) among HCWs remains low. This study aimed to investigate the effect of feedback lights on HCWs' HHC.

Methods:

A five-month interventional study was conducted in three wards in a nursing home in Denmark. During the intervention period, a green light with a smiley appeared on the alcohol-based hand rub (ABHR) dispensers when HCWs used the ABHR, acknowledging HCWs for using the ABHR. HHC was monitored using an automatic hand hygiene monitoring system (AHHMS).

Results:

A total of 64 HCWs were enrolled. The AHHMS collected 23,696 HH opportunities in apartments and dirty rinsing rooms. Overall, HHC in the apartments increased from 50% at baseline (95% CI: 48, 53) to 56% (95% CI: 54, 58) during the intervention. However, the increased HHC level was not sustained during follow-up.

Conclusions:

The AHHMS enabled assessment of the intervention. We found a significant effect of light-guided feedback in the apartments. However, the increased HHC was not sustained after the light had been switched off.

Key-words: feedback; light-guided nudge; infection prevention; electronic monitoring systems; long-term care

Highlights:

- Feedback with light on alcohol-based hand rub dispensers was investigated in nursing home wards
- Hand hygiene compliance was measured using an automatic hand hygiene system
- Use of light had an immediate, significant effect on healthcare workers' hand hygiene compliance
- The increased hand hygiene compliance level was not sustained over time
- No effect was recorded of light on healthcare workers' hand hygiene compliance in dirty rinsing rooms

Introduction

Nursing Homes

Nursing homes (NHs) are unique environments for infection transmission. This is due to shared facilities such as dining rooms and living rooms, where microorganisms can easily be transmitted, in combination with the elderly residents' frailty [1-3]. A total of 3.7% of residents living in European NHs have at least one healthcare-acquired infection (HAI) at any time [2]. For NHs in Denmark, the HAI prevalence was found to be 5.2% [2].

Due to the increasing proportion of elderly in the population, a growing number of residents in high-income countries are living in NHs [4]. Therefore, studies to prevent infections in NHs are warranted.

Hand Hygiene in Nursing Homes

Hand hygiene (HH) is crucial for prevention of infection transmission in healthcare [5]. However, despite the COVID-19 pandemic, HH compliance (HHC) among healthcare workers (HCWs) remains low in NH settings [6-8]. The reported HHC rates vary widely (from 17% to 79%) depending on the method used to monitor HHC, profession, culture, use of gloves as a substitute, and the specific HH action (e.g., *after* versus *before* contact with residents/procedures) [1, 6, 9]. Only relatively few interventional studies have been conducted in NH settings [7, 10-15]. However, there are considerable variations in data collection methodologies and a diverse range of interventions. To the best of our knowledge, this author group is the first to report HHC data from Danish NHs.

Barriers to HH in NHs have been reported to include individual risk perception, lack of role models, understaffing, high workload, low access to HH supplies, skin reactions, lack of knowledge, and a constant trade-off between the competing goals of HH, preserving social care and maintaining a home-like environment [1, 6-9, 13, 15, 16].

Monitoring Hand Hygiene Compliance

Monitoring HHC in clinical practice is crucial for evaluating the interventions investigated. In NHs, the three methods used to monitor HCWs' HHC are direct observations, self-reporting by questionnaires, and indirect measurement using HH product usage data [17]. To the best of our knowledge, only one study has used an automatic HH monitoring system (AHHMS) to measure HHC in NHs. However, the AHHMS used a movement technology that pooled all HH opportunities from HCWs, patients, and visitors. Therefore, this author group is, in all likelihood, the first to report HHC data of HCWs collected with an AHHMS. The AHHMS is capable of following HCWs throughout their daily workflow and taking previous work tasks into account when calculating HHC.

Providing feedback with a light on alcohol-based hand rub dispensers

The multimodal strategy of the WHO suggests five core components to consider when working with improvement strategies [18]. One of the five components is to monitor HHC and provide feedback to HCWs. This study aimed to monitor HHC with an AHHMS and to provide immediate feedback on HH with light on the ABHR dispensers. The purpose of adding light feedback was to acknowledge the HCW for using the ABHR. To the best of our knowledge, this study is the first to report data on the effect of lights on ABHR dispensers used to provide immediate feedback to the HCWs in NH settings. However, in hospitals, immediate feedback with light has recently been investigated by this author group. The study found an overall significant long-term effect of lights on ABHR dispensers on HCWs' (n=241) HHC with a mean difference of +5 percentage points (95% CI; 4, 7) in one of the departments and +11 percentage points (95% CI; 10, 12) in another department.

METHODS

Study design and setting

A five-month prospective, interventional study was conducted between May 2021 and November 2021 at an NH in Denmark. The NH consisted of 76 single apartments distributed in three wards. Each ward had its own local leader. The residents and HCWs used shared facilities in living rooms, hallways, and dining rooms. NHs in Denmark provide healthcare to residents who have an extensive and lasting need for care and practical help and are therefore unable to manage independently in their own homes.

Data were collected during the COVID-19 pandemic, a period generally characterized by a high societal focus on HH. However, during the five-month data collection period, no societal lockdowns were implemented [19].

Study subjects and data collection

Nurses and nurse assistants (n=64) from three wards were included in the study. Participants were informed about the use of the AHHMS and the study purpose. The only information obtained about the participants was work shifts; 1) day shift (n=50), 2) evening shift (n=7), 3) night shift (n=3), and 4) short-term employees (n=4). To ensure anonymity, HHC data are reported in the following groups: "overall staff" (n=64), "day shifts" (n=50), and "evening/night shifts" (n=7). Short-term employees are included only in the category "overall staff" as they may have worked in all three work shifts. Furthermore, due to a low number of participants in this group, we could not report data as a separate category.

Data were collected using an AHHMS (Sani Nudge™) [20]. The AHHMS is an advanced sensor system capable of considering the preceding workflow. In this study, the AHHMS monitored entry to and exit from residential apartments and exit from dirty rinsing rooms. The AHHMS used has been described in detail [21] and evaluated in recent studies [22, 23].

Interventions

Sensors on ABHR dispensers have discrete built-in lights with a feedback symbol that was activated during the intervention period (Figure 1).

Figure 1. Illustration of the light-guided feedback on ABHR dispensers.

The study comprised three phases. Phase 1 was a baseline period without any intervention. In phase 2, the HCWs received a feedback symbol that was designed to acknowledge that an HCW had remembered to use the ABHR. The symbol consisted of a green smiley light appearing on the sensor immediately after the HCW had used it. The symbol served as immediate feedback to support the desired behavior. Phase 3 was a follow-up period without light on the dispensers to establish if the effect of light (if any) would be sustained.

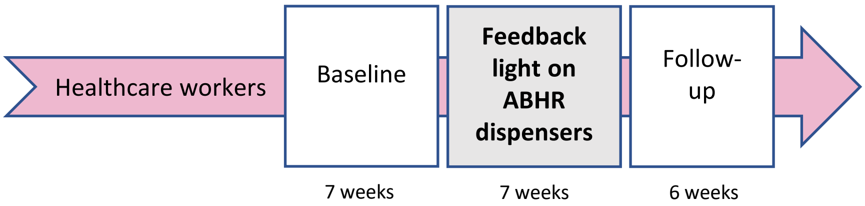

Figure 2. Study overview.

Ethics

Ethical approval was sought in pursuance of Danish law. The requirement of informed consent was waived by both the Danish Data Protection Agency (R. no. 2019-212-1420) and the Ethics Committee (R. no. 1-10-72-148-19).

Statistical analysis

Aggregated HHC data were available as total daily sums of the number of HHC opportunities and ABHR events in the apartments and dirty rinsing rooms. Data were stratified by work shifts. Individual participant data were not available for analysis.

For apartments, we calculated overall (sum of both BEFORE entering and AFTER exiting the apartment) daily HHC as "(number of full compliances + 0.5*number of compliances only BEFORE entering + 0.5*number of only compliances only AFTER exiting)/total number of visits". For dirty rinsing rooms, we calculated daily and weekly HHC as the number of compliant visits/total number of visits summed by day or week.

Linear regression models were established. Daily HHC was used as the outcome, and the interaction between the study phases and staff groups was used as an explanatory variable. The models used the sandwich estimator of variance. Analytical weights (number of daily visits for each HHC) were used in the regression analyses. Model coefficients were employed to calculate the mean HHC for each NH in each study phase and to compare them. Two-sided P values <0.05 were considered statistically significant. Differences were reported as absolute values. All analyses were conducted using STATA (StataCorp LLC, Texas, USA, version 18.0).

RESULTS

The effect of feedback light in nursing homes

A total of 64 nurses and nurse assistants were enrolled from three NH wards. The AHHMS registered 21,042 HH opportunities in the apartments and 2,654 HH opportunities in dirty rinsing rooms.

HHC in residential apartments

The overall HHC in the residential apartments increased from 50% at baseline (95% CI: 48, 53) to 56% (95% CI: 54, 58) during the intervention with feedback light (mean difference +5 percentage points; p<0.001) (Figure 3). However, the increased HHC level was not sustained as HHC decreased during the follow-up period to 50% over time when the light was switched off (mean difference from baseline to follow-up; -1 percentage points; p=0.75) (Table 1).

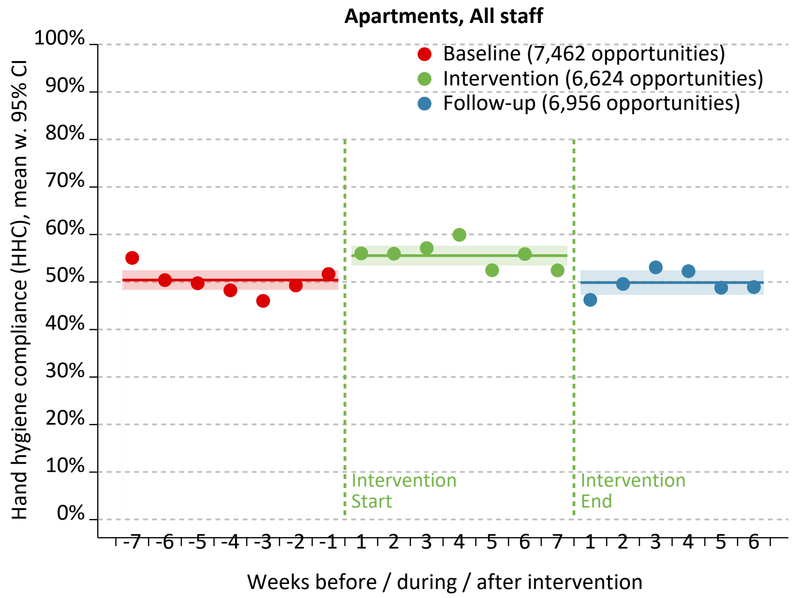

Figure 3. Overall HHC for nurses and nurse assistants in the residential apartments throughout the three study periods. Sum of both BEFORE entering and AFTER exiting the apartments. HHC is reported as weekly means with 95% CI.

The analysis of the specific work shifts showed that the highest baseline HHC was recorded for HCWs working the day shift at 52% (95% CI: 50, 54). Furthermore, the analysis of the specific work shifts revealed that the increased HHC level from baseline to the intervention period was driven mainly by HCWs working day shifts (mean difference from baseline to intervention; +6 percentage points; p<0.0001). In contrast, HCWs working evening/night shifts had a baseline HHC of 32% (95% CI: 27, 38). The intervention with light did not affect HCWs working evening/night shifts (mean difference from baseline to intervention; -6 percentage points; p=0.2).

HHC in dirty rinsing rooms

The overall baseline HHC in dirty rinsing rooms was 34% (95% CI; 31-38). There was no effect of the intervention with light in dirty rinsing rooms (Figure 4). Due to a relatively low number of HH opportunities collected in dirty rinsing rooms, it was not possible to report HHC stratified into work shifts (Table 1).

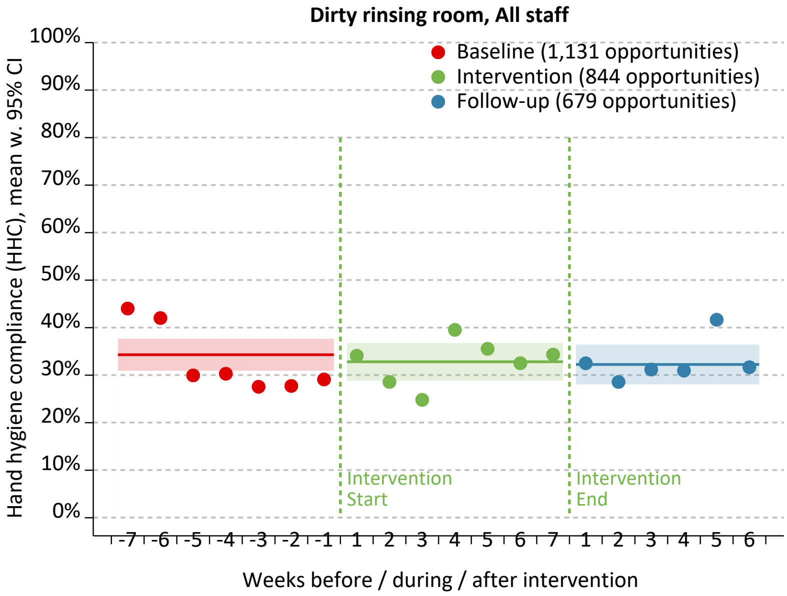

Figure 4. Overall HHC for nurses and nurse assistants in dirty rinsing rooms throughout the three study periods. HHC is reported as weekly means with 95% CI.

Table 1. HHC in each study phase, specified by apartments and dirty rinsing rooms. HHC is given as a mean score with 95% CI in each study phase and as a difference in mean score with 95% CI between selected phases: Baseline versus intervention, baseline versus follow-up, and intervention versus follow-up.

	Mean scores (95% CI)			Difference in mean score (95% CI)		
	Baseline **Compliance**	Intervention **Compliance**	Follow-up **Compliance**	Baseline→ Intervention **Difference**	Baseline→ Follow-up **Difference**	Intervention→ Follow-up **Difference**
Apartments						
All staff	50% (48, 53)	56% (54, 58)	50% (47, 53)	5 (2, 8) p<0.001	-1 (-4, 3) p=0.75	-6 (-9, -2) p<0.001
Day shift	52% (50, 54)	58% (56, 60)	51% (48, 54)	6 (3, 9) p<0.0001	-1 (-5, 3) p=0.61	-7 (-11, -4) p<0.001
Evening/night shift	32% (27, 38)	27% (21, 32)	41% (35, 47)	-6 (-14, 2) p=0.16	8 (0, 17) p=0.05	14 (6, 22) p<0.001
Dirty rinsing rooms						
All staff	34% (31, 38)	33% (29, 37)	32% (28, 36)	-2 (-7, 4) p=0.58	-2 (-7, 3) p=0.45	-1 (-6, 5) p=0.85

DISCUSSION

In this study, we investigated the effect of immediate light-guided feedback on ABHR dispensers. Overall, a significant effect was found in residential apartments with a mean difference of +5 percentage points (p<0.001). However, the improvement was not sustained when the light was subsequently switched off. We found no effect of the intervention in the dirty rinsing rooms.

To the best of our knowledge, no studies have investigated the effects of immediate light-guided feedback on HCWs' HHC in NH settings. However, this author group has previously investigated a similar intervention with two different lights in hospital in-patient wards [24]. The previous study reported a mean difference of +11 percentage points from baseline to the intervention period for the group receiving feedback light. However, the group had a lower baseline HHC (29%) than the baseline HHC in the present study conducted in an NH (50%), which may explain the higher effect of the previous intervention. The hospital study found a long-term effect of the light-based intervention. However, the long-term effects are not comparable between the two studies as the hospital study investigated the long-term effects of two lights in combination: a reminder and a feedback light. Furthermore, a study by Zwicker et al. [25] reported significant, immediate effects of a portable badge that provided HCWs with visual light and vibration. The improved HHC rates were not sustained when the lights/vibrations were switched off which is in line with our results.

A strength of this study is that it is one of the first studies to report HHC rates measured with an AHHMS in NHs. The study reports an overall baseline HHC of 50% (95% CI: 48, 53). Other studies have investigated HHC rates in NHs [7, 10, 13-15]. However, the reported rates vary considerably from 17% to 79%. Due to the wide range, differences in methods for data collection, and the diversity of the interventions, it is not possible to compare the HHC rates.

Another strength of this study is that it reports HHC data stratified into day and evening/night shifts. We found a higher baseline HHC for the HCWs working day shifts (52%, 95% CI: 50, 54) than HCWs working evening/night shifts (32%, 95% CI: 27, 38), with a mean +20 percentage point difference, $p<0.0001$. This finding is supported by a study from another NH in Denmark reporting a higher baseline HHC for HCWs working the day shift (33%, 95% CI: 31, 35) than HCWs working evening shift and night shifts (27%, 95% CI: 25, 30) (pending study by this author group). Furthermore, our findings from nursing home wards are supported by findings from two studies from hospitals (monitored with AHHMS'). The studies reported HHC to be highest during the mornings whereafter it decreased throughout the day [21, 26]. To the best of our knowledge, no other studies from NHs have presented HHC data by work shifts.

Although HHC improved, it remained suboptimal. This indicates that using light-guided feedback as an isolated intervention is not sufficient to sustain the improved HHC. However, it remains unknown whether the feedback light may be used as a short-term booster to increase awareness in periods with low HHC. A Danish study has reported effects of the combined effect of feedback light on ABHR dispensers and feedback on performance HHC rates and found significant improvements among physicians (16% versus 42%) and for nurses (27% versus 43%) [27]. However, the reported baseline HHC from hospitals was lower than the baseline HHC from the NH in this study, which may make the absolute improvement rates difficult to compare. Nevertheless, the findings indicate that combining feedback lights with other interventions may potentially be more effective, as also suggested by the WHO in their multimodal strategy [18]. Future studies are warranted to investigate the effects of feedback lights.

This study has several potential limitations. First, Out of approximately 80 HCWs, only 64 were included. Furthermore, selection biases should be considered as participation was voluntary. Finally, the AHHMS collected HHC when the 64 HCWs wore a tag with an anonymous ID number. To ensure anonymity, we did not register the specific tag ID number. Thus, we were unable to determine if all 64 HCWs participated in the entire study period.

CONCLUSION

Light-guided feedback on ABHR dispensers can improve HCWs' HHC in residential apartments within NH wards. However, the improvements were not sustained subsequently when the lights were no longer used to provide feedback.

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Conflicts of interest

MBH was employed with Konduto ApS, the developer of Sani Nudge™, during the data collection period. The other authors have no competing interests to declare.

Source of funding

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Paper VI

Iversen AM, Hansen MB, Münster M, Kristensen B, and Ellermann-Eriksen S

Individual feedback on hand hygiene compliance data in nursing homes

Manuscript in preparation

Individual feedback on hand hygiene compliance data in nursing homes

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Conflicts of interest:

MBH was employed with Konduto ApS; the developer of Sani Nudge™, when data were collected and analyzed. The other authors have no competing interests to declare. All authors approved the final article.

Source of funding:

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Summary

Background:

Hand hygiene (HH) among healthcare workers (HCWs) is an important measure to prevent infections in Nursing homes. However, only relatively few studies from nursing home settings have been published. This study aimed to investigate the effect of providing HCWs with weekly feedback on individual hand hygiene compliance (HHC) data.

Methods:

A six-month interventional study was conducted in two Nursing homes (nine wards) in Denmark. During the intervention period, a weekly email with individual HHC data was sent to all HCWs who volunteered to receive individual feedback. HHC was monitored with an automatic hand hygiene monitoring system (AHHMS).

Results:

In total, 198 HCWs were included in the study. 67 HCWs volunteered to receive weekly feedback on individual HHC data. The AHHMS collected more than 144,000 HH opportunities from residential apartments. Overall, the study found no improvements in HHC from baseline to the intervention period in the cluster receiving individual feedback (52% vs 52%, p=0.8) or in the cluster receiving no individual feedback (44% vs 44%, p=0.7). The study found a mean difference in baseline HHC between the two clusters of +8 percentage points (95% CI: 6, 10).

Conclusions:

The AHHMS enabled the assessment of the intervention. There was no effect of individual feedback on hand hygiene compliance data in nursing homes. A too low-intensive approach to feedback may explain this.

Key-words: Feedback; health-care workers; infection prevention; electronic monitoring systems; long-term care

Highlights:

- Individual feedback on hand hygiene compliance was investigated in nursing home wards
- Hand hygiene compliance was measured with an automatic hand hygiene system
- More than 144,000 hand hygiene opportunities were included in the study
- A mean compliance (baseline) of 44% and 52% were reported from two clusters
- There was no effect of feedback on healthcare workers' hand hygiene compliance

Introduction

(Introduction in preparation)

This study aimed to investigate the effects of individual feedback on healthcare workers' (HCW) hand hygiene compliance (HHC) in two nursing homes (nine wards). We hypothesized that HHC among HCWs would increase while receiving individual feedback.

METHODS

Study design and setting

A six-month prospective, interventional study was conducted in two nursing homes (nine wards) in Denmark.

Nursing home 1 was a six-ward nursing home with 150 single apartments. The nursing home collected data from September 2021 to March 2022. Nursing home 2 was a three-ward nursing home with 76 single apartments. The nursing home collected data from November 2021 to May 2022. All included nursing home wards (n=9) had their own leader.

Data were collected during the COVID-19 pandemic; a period generally characterized by a high focus on HH, use of facemasks and social distancing requirements. Especially, by the end of December 2021, a partly societal lockdown was imposed in Denmark during which for example theatres and museums were closed; and social distancing requirements in malls were imposed. The society was gradually reopened in the following months and by February 2022, all restrictions had been lifted [1].

Study subjects and data collection

Data were collected with an automatic hand hygiene monitoring system (AHHMS) (Sani Nudge™) capable of monitoring HHC 24/7. The system is a high-resolution sensor system capable of taking previous work task into account when calculating HHC. The AHHMS is described in detail in a recent study [2] and evaluated in two recent publications [3, 4]. Data were collected in residential apartments, dirty rinsing rooms (only Nursing Home 2), and staff restrooms. However, due to a low number of HH opportunities in staff restrooms and dirty rinsing rooms, we had to exclude data from these working rooms. Therefore, all presented data in this publication is from residential apartments.

HHC was calculated based on WHOs "My 5 Moments for Hand Hygiene" [5]. The AHHMS measures a proxy of Moment 1 (before contact with a resident), which is measured by the AHHMS when the HCW enter the apartment and Moments 4 and 5 (after contact with a resident and resident surroundings) which are measured by the AHHMS when the HCW exit the apartment.

Nurses and nurse assistants (n=198) were informed about the study's purpose and the AHHMS. The HCWs were included when they volunteered to pick up and carry a Sani Nudge tag on their name tag. To ensure anonymity the only information obtained was the HCWs primarily work shift stratified into; 1) day shift, 2) evening shift, 3) night shifts, and 4) short-term employees.

Intervention

This study is a part of a multimodal intervention strategy which is divided into three parts for analysis and publications (Figure 1). The first part of the multimodal project investigated the effect of increased accessibility to ABHR in Nursing home 1. Part two investigated the effect of feedback with lights on ABHR-dispensers in Nursing home 2. The last part of the multimodal project consists of the present study, investigating the effects of weekly individual feedback on HHC data in both Nursing homes 1 and 2.

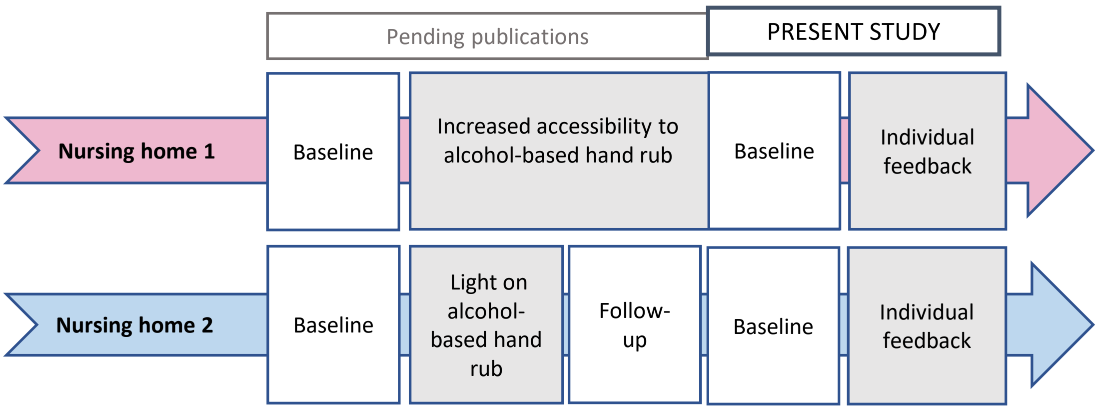

Figure 1. Overview of the multimodal project in Nursing home 1 and Nursing home 2. In the first part of the multimodal project Nursing home 1 investigated the effect of increased accessibility to ABHR by implementing one extra ABHR in the hallway of the apartments. The extra ABHR was implemented the first day of the intervention period, and remained at the same position throughout the entire multimodal project. Nursing home 2 investigated the effect of feedback with light on ABHR dispensers as their first intervention. After a new baseline period both Nursing homes 1 and 2 investigated the effect of individual feedback on HHC data (present study).

The present study had two phases (Figure 1). Phase one was a new baseline period (12 weeks) in which no interventions were conducted. Phase two was an intervention period (13 weeks). During the intervention phase a weekly email was sent to the HCWs that signed up for the individual feedback. The email was sent every Monday morning (Figure 2). All HCWs (n=198) were encourage to sign-up to receive the weekly email. HCWs signed up via an app by actively scan their individual sensor on their name badge and chose the email address where they wanted to receive the weekly email. The email consisted of a text “New actionable insights are ready for you!". HCWs had to press a link "Click here" to enter the individual HHC data. The email consisted of individual HHC data from the past week (in columns) where the HCW could compare themselves to colleagues (Figure 2). Furthermore, HHC data were stratified into room type for the past four weeks. If less than five HH opportunities were collected in a week, no HHC data were shown.

To evaluate compliance with the intervention, weekly registration of the total number of opened emails were made every Sunday evening (at 11. p.m.).

After the data collection period, all HCWs were divided into two clusters for analysis 1) "No individual feedback" (n=131) and "Individual feedback" (n=67) and each cluster were stratified into work shifts.

Figure 2. Email with feedback on individual HHC data. The HCWs had to click on the link "Click here" to access the individual data.

Ethics

Ethical approval was sought in accordance with Danish law. The requirement of informed consent was waived by both the Danish Data Protection Agency (R. no. 2019-212-1420) and the Ethics Committee (R. no. 1-10-72-148-19).

Statistical analysis

Aggregated HHC data were available as total daily sums of the number of HHC opportunities and ABHR events in the apartments. Data were stratified by work shifts. Individual participant data were not available for analysis.

We calculated overall (sum of both BEFORE entering and AFTER exiting the apartment) daily HHC as "(number of full compliances + 0.5*number of compliances only BEFORE entering + 0.5*number of only compliances only AFTER exiting)/total number of visits".

Linear regression models were established. Daily HHC was used as the outcome, and the interaction between the study phases and work shifts was used as an explanatory variable. The models used the sandwich estimator of variance. Analytical weights (number of daily visits for each HHC) were used in the regression analyses. Model coefficients were used to calculate the mean HHC for each nursing home in each study phase and to compare them. Two-sided p-values <0.05 were considered statistically significant. Differences were reported as absolute values. All analyses were conducted using STATA (StataCorp LLC, Texas, USA, version 18.0).

RESULTS

A total of 198 nurses and nurse assistants were enrolled from nine wards in two nursing homes. A total of 67 nurses and nurse assistants signed up and received the weekly email with individual HHC data (“Individual feedback”) and 131 HCWs did not sign up for the intervention with weekly feedback (“No individual feedback”). HCWs were stratified into work shifts: day shift (n=106), evening shift (n=34), night shifts (n=5), and short-term employees (n=53). Due to a low number of HH opportunities in the cluster receiving individual feedback in staff restrooms (n=642) and dirty rinsing rooms (n=768), we had to exclude all data from these working rooms.

The AHHMS registered 144.354 HH opportunities in residential apartments during the study period which was included in the analyses.

The study found no effects of the intervention with weekly feedback on HHC data (Figure 3 and Table 1). The study reported a HHC of 52% (95% CI: 51, 53) in the baseline period and 52% (95% CI: 51, 54) in the intervention period for the cluster receiving individual feedback. The study reported a HHC of 44% (95% CI: 43, 45) in the baseline period and 44% (95% CI: 42, 45) in the intervention period in the cluster receiving no individual feedback.

Baseline hand hygiene compliance in the two clusters

The study found that HCWs who received individual feedback had a higher baseline HHC (52%, 95% CI: 51, 53) than HCWs who received no individual feedback (44%, 95% CI: 43, 45), with a mean difference of +8 percentage points (95% CI: 6, 10. p<0.0001) (Table 1).

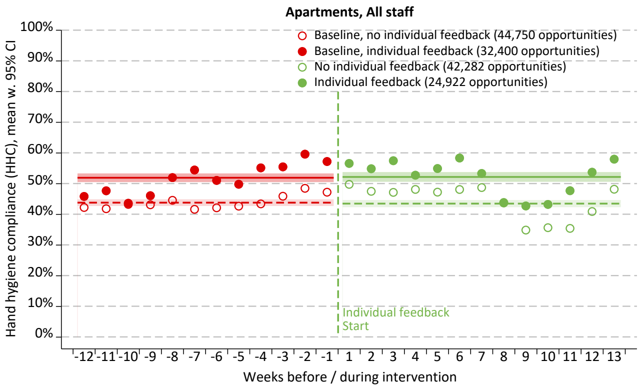

Figure 3. HCWs HHC in residential apartments stratified into two clusters “Individual feedback” and “No individual feedback”. The sum of HHC for both BEFORE entering and AFTER exiting the apartment with 95% CI. The baseline constitutes a period without intervention. The intervention constitutes a period with individual feedback on HHC data for the cluster “Individual feedback” and a period without intervention for the cluster “No individual feedback”.

Table 1. HHC in residential apartments stratified in clusters (“No individual feedback” and “Individual feedback”), study phases and work shifts. HHC is given as the mean score in each phase.

		Mean scores (95% CI)			
		Cluster “No individual feedback”		**Cluster “Individual feedback”**	
		Baseline	**No intervention**	**Baseline**	**Intervention with individual feedback**
Nursing homes 1 and 2	**Apartments**				
	Overall HHC	44% (43, 45)	44% (43, 45)	52% (51, 53)	52% (51, 54)
	Day shift	40% (39, 41)	41% (40, 42)	57% (55, 58)	57% (55, 59)
	Evening shift	45% (42, 48)	48% (44, 51)	38% (34, 42)	45% (42, 48)
	Night shift	58% (55, 61)	52% (47, 57)	NA	NA
	Short-term employee	47% (45, 49)	44% (42, 46)	51% (48, 54)	49% (46, 53)

NA = not analyzed (< 50 opportunities)

Hand hygiene compliance stratified into work shifts

For the cluster “No individual feedback” the study found the highest HHC among HCWs working night shift (58%) and the lowest HHC among HCWs working day shift (40%), with a mean difference of +18 (95% CI: 15, 21. p<0.001) (Table 1). For the cluster “Individual feedback” the study found the highest HHC among HCWs working day shift (57%) and the lowest HHC among HCWs working evening shift (38%), with a mean difference of +19 (95% CI: 15, 23. p<0.0001) (Table 1).

Hand hygiene compliance stratified into WHO's 5 moments of hand hygiene

The study found that HHC was higher after exiting the apartments (WHO; Moments 4 and 5) than before entering the apartments (WHO; Moment 1). For the cluster "Individual feedback", the mean difference was +4 percentage points (95% CI: 2, 6. p<0.001) at baseline and +4 percentage points (95% CI: 1, 6. p<0.002) in the period with individual feedback. The mean difference in the cluster "No individual feedback" was +7 percentage points (95% CI: 6, 9. p<0.0001) at baseline and +6 percentage points (95% CI: 4, 8. p<0.0001) in the following period without intervention (Figure 4).

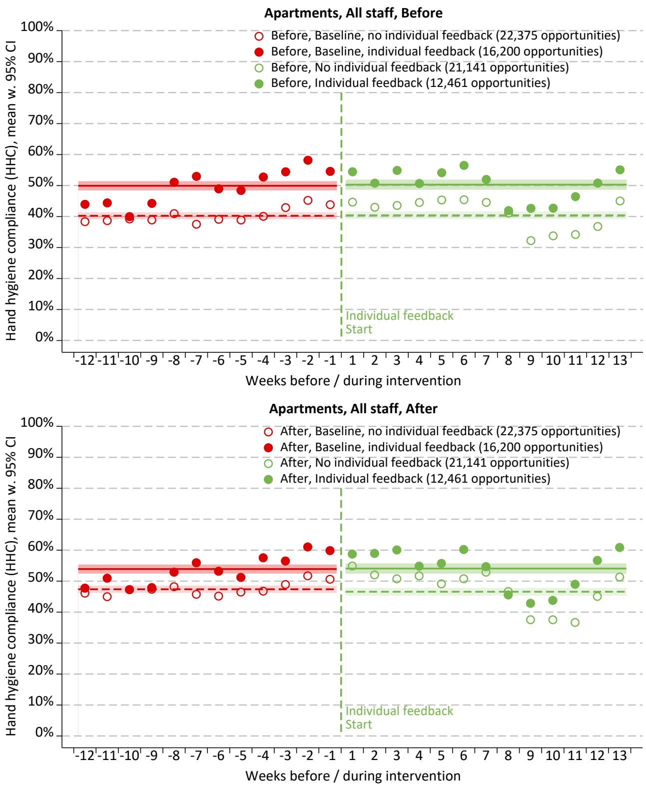

Figure 4. HCWs' HHC in residential apartments BEFORE entering and AFTER exiting the apartment with 95% CI stratified into study phases and study clusters.

Compliance with the intervention

Nurses and nurse assistants (n=67) signed up to receive the email during the period. Table 2 shows the number of HCWs who opened the weekly email during the 13-week intervention period.

Table 2. Number of HCWs who signed up to receive the weekly email with individual feedback data and number of HCWs who opened the weekly email in percentages.

Week number	HCWs signed up for the email (absolute numbers)	Number of opened reports (in percentage)
1	60	25%
2	-	-
3	63	37%
4	66	41%
5	66	20%
6	65	31%
7	-	-
8	67	30%
9	67	10%
10	67	31%
11	63	43%
12	60	48%
13	-	-

- Missed value

Discussion

This study investigated the effect of individual feedback on HCWs HHC in nursing home wards. The study found no effects of the intervention.

To the best of our knowledge this study is the first to investigate the effect of weekly individual feedback on HHC data monitored with a AHHMS in nursing homes. However, studies from hospitals, using the same individual feedback approach and AHHMS, has reported effects of providing HCWs with an email with individual feedback [6-8]. However, two studies reported no effects of providing HCWs with individual feedback [9, 10]. More data are needed to evaluate the effect of providing HCWs with individual feedback on HHC data, especially to evaluate the possible long-term effect of this type of intervention.

We found that the HCWs who volunteered to sign up for individual feedback had a higher HHC already in the baseline period than HCWs receiving no individual feedback, with a mean difference of +8 percentage points (95% CI: 6, 10. p<0.0001) (Table 1). This indicates that the cluster receiving individual feedback already possessed a heightened awareness of the importance of HH before being exposed to the intervention with individual feedback. This finding is in line with the finding from a similar study from a hospital (published by this author group) reporting a higher baseline HHC for the group that later on receive individual feedback on HHC data [9]. This highlights the importance of stratifying HCWs into intervention groups already from the baseline period as it may facilitate investigations of potential differences between the groups before they are exposed to the intervention with individual feedback.

Furthermore, we found that HCWs had a higher baseline HHC after exiting the apartments (WHO moments 4 and 5) than before entering the apartments (WHO moment 1), with a mean difference of +4 percentage points in the cluster "individual feedback" and +7 percentage points in the cluster "No individual feedback" (Figure 4). This is aligned with other studies reporting a higher HHC after than before contact with residents and the near surroundings [11-13].

The study found a higher baseline HHC for HCWs working day shift than HCWs working evening shift (mean diff. +18; 95% CI: 15, 23) (Table 1) in the cluster "Individual feedback". This finding is in line with the findings from two other studies from hospitals, using an AHHMS, reporting a higher baseline HHC during the mornings and subsequently decreasing throughout the day [2, 14]. However, in the present study, the cluster "No individual feedback" found a higher HHC among HCWs working night shift than HCWs day shift, with a mean difference of +18 (95% CI: 15, 21) (Table 1), which is a conflicting result. More data are needed on the difference between work shifts.

This study had several strengths: 1) it was a large-scale study comprising more than 144,000 HH opportunities from nine nursing home wards, 2) it was the first to report the effect of weekly individual feedback on HHC data in nursing home wards, 3) and it reported HHC rates stratified into work shifts.

However, the study also has some notable limitations.

First, HCWs who volunteered to receive individual feedback were unequally exposed to the intervention as only 10-48% of the emails were opened each week (Table 2), which is a major limitation. Furthermore, we were not able to register if the HCWs who opened the email actually read and related to the data. As a result, not all 67 HCWs received the weekly intervention with feedback, posing a challenge in evaluating its effectiveness. This is a plausible explanation for the missing effect and a major limitation of the study.

Another limitation of this study is that data were collected during the COVID-19 pandemic. It is unknown if the pandemic affected the HHC levels in this study, however no effect of the COVID-19 pandemic was seen in the cluster who did not receive an intervention (cluster "No individual feedback"). Other studies from hospitals have reported temporary improvements during societal lock-downs, followed by a return to baseline after a relatively short period [15-17], while others found no improvements of HHC during the pandemic [18-20].

This study is the last part of a multimodal project (Figure 1). In the first part of the multimodal project Nursing home 1 investigated the effect of increased accessibility to ABHR and found a long-term effect of the intervention of +13 percentage points (95% CI: 11, 14. $p<0.0001$) (pending study). Nursing home 2 investigated the effect of feedback with light on ABHR dispensers as the first intervention and found an immediate effect of +5 percentage points (95% CI: 2, 8. $p<0.001$) followed by a return to baseline when the light was swift off (pending study). Consequently, all nine wards investigated the effect of individual feedback after being exposed to other interventions. It is unknow whether we could have seen other results of this present study if HCWs had been exposed to the individual feedback as the first intervention, especially in Nursing home 1 as they had a long-term effect of the first intervention.

Another limitation to this study is that we were unable to assess whether all 198 HCWs participated in the entire study period. To ensure anonymity, we did not register the individual ID numbers. Consequently, we could not determine if some HCWs stopped, and new ones were included, during the study period. It is unknown if this could have impacted the overall HHC rates in either direction.

This study adds some important insights for enhancing HHC in nursing homes. Our data suggest that providing HCWs with individual feedback as a single intervention does not impact the HHC rates. We speculate that obtaining improvements in HHC demands a more intensive approach to the intervention (e.g. allocating time to open and read the weekly email).

CONCLUSION

The AHHMS enabled the assessment of the intervention in nursing homes. There was no effect of providing HCWs with individual feedback on HHC data. A too low-intensive approach to individual feedback may explain this.

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Author contribution

Iversen, AM: Conceptualisation, Methodology, Investigation, Writing - Original Draft, Visualisation, Project administration, Funding acquisition.
Hansen, MB: Conceptualisation, Methodology, Writing - Review & Editing, Supervision.
Münster, M: Conceptualisation, Methodology, Writing - Review & Editing, Supervision.
Kristensen, B: Conceptualisation, Methodology, Writing - Review & Editing, Supervision.
Ellermann-Eriksen, S: Conceptualisation, Methodology, Writing - Review & Editing, Supervision, Funding acquisition.

Conflicts of interest

MBH was employed with Konduto ApS; the developer of Sani Nudge™ during the data collection period. The other authors have no competing interests to declare.

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Appendix I

Observation sheet.

Registration of patient beds in hospital departments.

Stuenummer	Korrekt placering	Ikke-korrekt placering
Kræftafdelingen Sengeafsnit 1		
865		
868		
866		
864		
862		
863,1		
863,2		
861,1		
861,2		
847		
848		
846		
845		
844		
842		
843		
841		
840		
Kræftafdelingen Sengeafsnit 2		
856		
855		
854		
853		
851		
852		
849		
850		
831		
832		
833		
834		
835		
836		

Stuenummer	Korrekt placering	Ikke-korrekt placering
Blodsygdomme Sengeafsnit 1		
556		
555		
554		
553		
551		
552		
549		
550		
531		
532		
533		
534		
535		
536		
537		
539		
538		
Blodsygdomme Sengeafsnit 2		
540		
541		
542		
543		
544		
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546		
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547		
560		
561		
562		
563		
564		
566		
568		
565		

Appendix II

Observation sheet.

Direct observations of healthcare workers' hand hygiene compliance in hospital departments.

Registreringsark:

Dato: ____________________ Rumnummer som observeres: ____________________

Observatør initialer: ____________________ Klokkeslæt for start af observation: ____________________

Klokkeslæt for slut af observation: ____________________

Rumnummer/type: ____________________

Faggruppe: ____________________

Test ID nummer: ____________________

Sidder test ID korrekt: Ja/Nej: ________________

Er patientsengen placeret under sensor: Ja/Nej: ________________

Alt hvad personen gør med sine hænder registreres under et defineret besøg:

Klokkeslæt	Procedure/adfærd	Dispenser (anvendt korrekt)	Kommentarer

Appendix III

Observation sheet.

Group feedback.

Registrering af gruppe-feedback:

Afdeling: ________________________________

	Dato: ___________	Dato: ___________	Dato: ___________	Dato: ___________	Dato: ___________	Dato: ___________
Navn på person der giver feedback:						
Antal personale der deltog i informationen: (Cirka-antal)						
Hvor lang tid tog det at give feedback:						
Er data udskrevet og ophængt i personalestuen:	(Ja/Nej)	(Ja/Nej)	(Ja/Nej)	(Ja/Nej)	(Ja/Nej)	(Ja/Nej)
Overvejelser/ kommentarer						

Appendix IV

Observation sheet.

Weekly registration of total number of emails with individual feedback.

Uge	Dagvagt	Aftenvagt	Nattevagt	Korttidsansat
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:
Uge: _____ Søndag d.: __________	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport:	Antal tilmeldte: Åbnet rapport: