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Major article

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

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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™) 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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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).

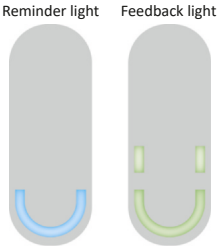

Fig. 1. Sensors with a blue reminder light and a green feedback light. The sensors were placed on the ABHR dispensers. The blue light was activated when an HCW was close to the ABHR dispenser (reminder), and the green light was displayed when the HCW used the dispenser (feedback). ABHR, alcohol-based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

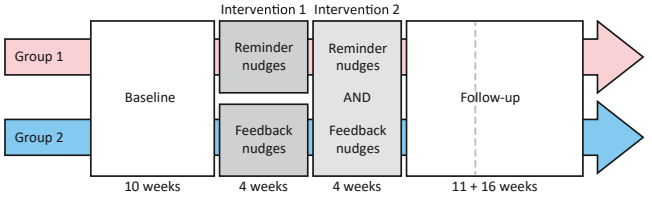

Fig. 2. Study overview. Inpatient wards at the Department of Oncology and the Department of Haematology were randomly assigned to 1 of 2 groups. In the first intervention phase, group 1 received nudges with reminder light, and group 2 received nudges with feedback lights. In the second intervention phase,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

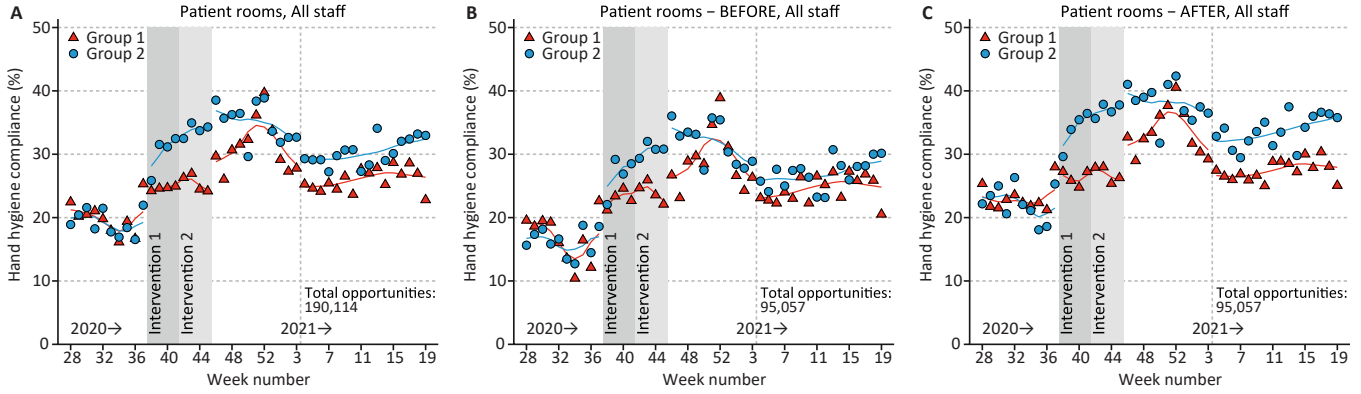

Fig. 3. HHC for physicians, nurses, and cleaning staff in patient rooms. (A) HHC in patient rooms: sum of HHC for both BEFORE entering and AFTER exiting the patient zone. (B) Hand hygiene compliance in patient rooms: BEFORE entering the patient zone (WHO moment 1). (C) Hand hygiene compliance in patient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

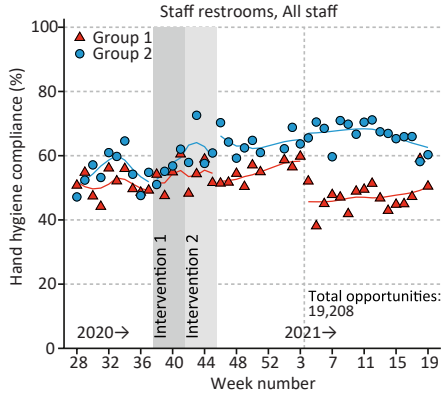

Fig. 4. Overall hand hygiene compliance in staff restrooms for all HCWs. HCWs, health care workers.

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.

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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.

References

1. Saleem Z, Godman B, Hassali MA, Hashmi FK, Azhar F, Rehman IU. Point prevalence surveys of health-care-associated infections: a systematic review. *Pathog Global Health.* 2019;113:191–205.
2. World Health Organization Team - Guidelines Review Committee, Infection Prevention and Control, and Medical Devices and Diagnostics. WHO Guidelines on Hand Hygiene in Health Care: First Global Patient Safety Challenge: Clean Care is Safer Care. 2009:1–262.
3. Erasmus V, Daha TJ, Brug J, et al. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. *Infect Control Hosp Epidemiol.* 2010;31:283–294.
4. Sant'Anna A, Vilhelmsson A, Wolf A. Nudging healthcare professionals in clinical settings: a scoping review of the literature. *BMC Health Serv Res.* 2021;21:543.
5. Thaler RH, Sunstein CR. *Nudge Improving Decisions About Health, Wealth, and Happiness*. Yale University Press; 2008.
6. Wolf A, Sant'Anna A, Vilhelmsson A. Using nudges to promote clinical decision making of healthcare professionals: a scoping review. *Prev Med.* 2022;164:107320.
7. Starcke K, Brand M. Decision making under stress: a selective review. *Neurosc Biobehav Rev.* 2012;36:1228–1248.
8. Vilhelmsson A, Sant'Anna A, Wolf A. Nudging healthcare professionals to improve treatment of COVID-19: a narrative review. *BMJ Open Quality.* 2021;10:e001522.
9. Ogdie A, Asch DA. Changing health behaviours in rheumatology: an introduction to behavioural economics. *Nat Rev Rheumatol.* 2020;16:53–60.
10. Caris MG, Labuschagne HA, Dekker M. Nudging to improve hand hygiene. *J Hosp Infect.* 2018;98:352–358.
11. Lamprell K, Tran Y, Arnolda G, Braithwaite J. Nudging clinicians: a systematic scoping review of the literature. *J Eval Clin Pract.* 2021;27:175–192.
12. Sunstein CR. Nudging: a very short guide. *J Consum Policy.* 2014;37:583–588.
13. Yoong SL, Hall A, Stacey F, et al. Nudge strategies to improve healthcare providers' implementation of evidence-based guidelines, policies and practices: a systematic review of trials included within Cochrane systematic reviews. *Implement Sci.* 2020;15:1–50.
14. Mols F, Haslam SA, Jetten J, Steffens NK. Why a nudge is not enough: a social identity critique of governance by stealth: why a nudge is not enough. *Eur J Political Res.* 2015;54:81–98.
15. van Roekel H, Reinhard J, Grimmelikhuijsen S. Improving hand hygiene in hospitals: comparing the effect of a nudge and a boost on protocol compliance. *Behav Public Policy.* 2022;6:52–74.
16. National Center of Infection Control, Statens Serum Institut, Copenhagen, Denmark. Timeline for COVID-19, Denmark. Updated April 2022. Available from: https://www.ssi.dk/-/media/arkiv/subsites/covid19/presse/tidslinje-over-covid-19/covid-19-tidslinje-for-2020-2022-lang-version—version-1—april-2022.pdf.
17. Sani Nudge, Denmark. Available from: https://saninudge.com.
18. Iversen A-M, Hansen MB, Kristensen B, Ellermann-Eriksen S. Clinical evaluation of an electronic hand hygiene monitoring system. *Am J Infect Control.* 2023;51:376–379.
19. Iversen A-M, Kavalaris CP, Hansen R, et al. Clinical experiences with a new system for automated hand hygiene monitoring: a prospective observational study. *Am J Infect Control.* 2020;48:527–533.
20. Hansen MB, Wismath N, Fritz E, Heininger A. Assessing the clinical accuracy of a hand hygiene system: learnings from a validation study. *Am J Infect Control.* 2021;49:963–965.
21. Boyce JM. Hand hygiene, an update. *Infect Dist Clint Nt Amt.* 2021;35:553–573.
22. Frey E, Rogers T. Persistence: how treatment effects persist after interventions stop. *Policy Insights Behav Brain Sci.* 2014;1:172–179.
23. Hertwig R, Grüne-Yanoff T. Nudging and boosting: steering or empowering good decisions. *Perspect Psychol Sci.* 2017;12:973–986.
24. Casaroto E, Generoso JR, Tofaneto BM, et al. Hand hygiene performance in an intensive care unit before and during the COVID-19 pandemic. *Am J Infect Control.* 2022;50:585–587.
25. Sandbøl SG, Glassou EN, Ellermann-Eriksen S, Haagerub A. Hand hygiene compliance among healthcare workers before and during the COVID-19 pandemic. *Am J Infect Control.* 2022;50:719–723.
26. Stangerup M, Hansen MB, Hansen R, et al. Hand hygiene compliance of healthcare workers before and during the COVID-19 pandemic: a long-term follow-up study. *Am J Infect Control.* 2021;49:1118–1122.
27. Moore LD, Robbins G, Quinn J, Arbogast JW. The impact of COVID-19 pandemic on hand hygiene performance in hospitals. *Am J Infect Control.* 2021;49:30–33.
28. Williams V, Kovacs-Litman A, Muller MP, et al. Impact of COVID-19 on hospital hand hygiene performance: a multicentre observational study using group electronic monitoring. *CMAJ Open.* 2021;9:E1175–E1180.
29. Makhni S, Umscheid CA, Soo J, et al. Hand hygiene compliance rate during the COVID-19 pandemic. *JAMA Intern Med.* 2021;181:1006–1008.
30. Mouajou V, Adams K, DeLisle G, et al. Hand hygiene compliance in the prevention of hospital-acquired infections: a systematic review. *J Hosp Infect.* 2022;119:33–48.
31. World Health Organization team - Infection Prevention and Control. A Guide to the Implementation of the WHO Multimodal Hand Hygiene Improvement Strategy. 2009. Available from: https://www.who.int/publications/i/item/a-guide-to-the-implementation-of-the-who-multimodal-hand-hygiene-improvement-strategy.