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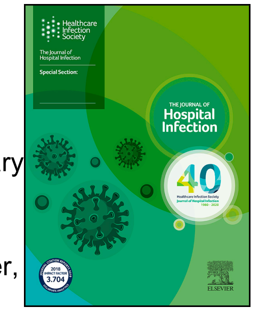

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An interactive feedback system for increasing hand antisepsis adherence in stationary intensive care

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Summary

Introduction: Pathogens causing infections are in many cases transmitted via the hands of personnel. Thus, hand antisepsis has strong epidemiological evidence of infection prevention. Depending on various factors, hand antisepsis adherence ranges between 9.1% and 85.2%. In the present study, we used a new transponder system that reminded medical staff to use an alcohol-based hand rub based on indication by giving real-time feedback, to detect hand antisepsis adherence.

Methods: The monitoring system consisting of three components: a portable transponder detecting alcohol-based hand rub and able to give feedback, a beacon recognizing entries to and exits from the patient's surroundings, and a sensor placed at the hand-rub dispensers to count the number of hand rubs. With these components, the system provided feedback when hand antisepsis was not conducted although it was necessary according to moments 1, 4, and 5 of hand antisepsis. Adherence was measured in two use cases with five phases, starting with the baseline measurement followed by intervention periods and phases without intervention to test the sustainability of the feedback.

Results: Using the monitoring system, hand antisepsis adherence was increased by up to 104.5% in comparison to the baseline measurement. When the intervention ceased, however, hand antisepsis adherence decreased to less than or equal to the baseline measurement.

Conclusion: A short-term intervention alone is not sufficient to lead to a long-term change in hand antisepsis adherence. Rather, permanent feedback and/or the integration in a multimodal intervention strategy are necessary.

Introduction

Data from the German prevalence study of 2016 revealed that in the overall group representing 11.4% (2013) of the hospitals in Germany, 5.1% of patients suffer nosocomial infections (NI). In intensive care units, with 17.1%, the rate was more than four times higher [1]. The consequences of NI depend on the type of infection, e.g., ventilator-associated pneumonia (VAP), central line-associated bloodstream infections (CLABSI), surgical site infections (SSI) or catheter-associated urinary tract infections (CAUTI). Generally, consequences are prolonged hospitalization [2], increased morbidity [3], and higher costs of care [4]. Because pathogens causing infections are in many cases transmitted via the hands of personnel, hands are considered as their main vector [5]. That is why no other infection control measure but hand antisepsis has such strong epidemiological evidence of infection prevention benefits for patients. In a large number of studies, it has been unanimously confirmed that hand antisepsis reduces the number of patients colonized with multi-drug resistant organisms (MDRO) and patients with NI. The effectiveness of hand antisepsis has been proven by the reduction of the NI rate by 40% overall [6]. Hand antisepsis is also a main component of controlling nosocomial outbreaks [5,7–9]. Likewise, in the care bundle approach, hand antisepsis is the most effective measure to decrease NI [10]. The implementation of care bundles improves the adherence for each bundle measure including hand antisepsis. Hand hygiene was also an essential part of bundles for the prevention of VAP [11]. After implementation of an appropriate bundle, Santos et al. [12] revealed a decrease in the incidence of VAP from 29.8%- 36.6% to 17.6%. The introduction of multimodal strategies to improve hand hygiene is significantly decreasing the VAP rates [13–15]. Furthermore, a meta-analysis by Ista et al. [16] showed a decrease in the incidence of CLABSI from 6.4 to 2.5 CLABSI/1000 catheter days using insertion and maintenance bundles. Hand hygiene is also integrated as an effective component in the bundled strategy for the prevention of SSI [17]. Therefore, hand antisepsis by alcohol-based hand rubs is the most cost-effective measure to prevent NI and has the advantage of simple, fast implementation [18]. For virucidal hand antisepsis, there is no alternative to ethanol-based hand rubs [19]. However, it is to be mentioned, that certain pathogens as non-enveloped viruses, spores, and protozoa are not susceptible to all kinds of ABHR and in some situations as when staff are faced by blood or body fluids, hand wash with water and soap is required. However, hand antisepsis before hand washing is recommended when possible.

However, hand hygiene adherence refers to a complex concept targeting the dynamics of behavioural change on both the individual and the institutional level. These complex dynamics acknowledge psychosocial parameters changing hand-hygiene behaviour, including intention, attitude towards the behaviour (change), perceived social norms and perceived social control, perceived risk of infection, habits of hand-hygiene practice, along with perceived knowledge, and motivation [18]. Taking the complexity of behavioural change into account, the WHO introduced the "*5 moments of hand hygiene*" as a basis to monitor adherence with the following indications:

1. Before touching a patient
2. Before clean/aseptic procedures
3. After body-fluid exposure/risk
4. After touching a patient
5. After touching patient surroundings.

Depending on the ward type, geographic region, and type of health-care workers, hand antisepsis adherence differs between 9.1% and 85.2% [20,21]. To improve adherence and maintain it at a high level, a multimodal strategy is needed in order to exhaust all intervention options [22]. Multimodal intervention programs have been proven to be the most effective in improving adherence [23]. They include regular staff training, consumption measurement with feedback, improving the availability of alcohol-based hand rubs, use of reminder and promotional materials, and support from administrative levels. A requirement for targeted intervention is the recording of hygiene performance data, as mainly performed by direct observation [22]. Although this method is traditionally accepted as the gold-standard hand-hygiene auditing method [24], some disadvantages, such as a high need for considerable expertise, observations lasting only short periods of time, and rapid decision making, are associated with it. Furthermore, direct observation has limited comparability between different observers (observer bias) [25,26] and the Hawthorne effect might influence the outcome. The Hawthorne effect is based on an influence of the observation itself on the observed data, resulting in data that do not reflect everyday reality, because people behave differently when they are aware of being observed [27]. An indicated method to acquire hygiene performance data is to measure the consumption of alcohol-based hand rubs as a surrogate parameter. However, this method does not allow any conclusions about general adherence [28], because it presupposes that the number of indications according to the moments of hand hygiene has been accurately recorded through direct observation. To exactly measure the consumption of alcohol-based hand rubs and combine it with a feedback function, initial tools for adherence observation using transponder systems became popular [29].

The latest legislation to come into effect in Germany is the *Law on the Digital Modernization of Healthcare and Nursing Care* (DVPMG). This promotes and regulates digitalization of health care; thus, new technologies must be developed to improve the quality and availability of health care.

In the present study, we tested a new transponder system developed as an interactive feedback system to remind medical staff to perform hand antisepsis and monitor adherence using real-time feedback. The system reminds the staff member to perform hand antisepsis in case the person did not perform it within a certain time interval before or after an indication. Additionally, the system monitors the consumption of alcohol-based hand rub and the number of times it was used.

Methods

Transponder system: The hand-hygiene monitoring system used in this study consisted of three components. A portable transponder, which can be carried on the working clothes monitored the number and duration of hand antisepsis with alcohol-based hand rubs by means of a gas detector. Backtracking to the person who wore the transponder was not possible, because every transponder could have been used randomly by each staff member per shift or day at work. The transponder had the optional function of giving feedback via vibration, blinking LED, or sound (for haptic, acoustic, and visual sensory perception), if the healthcare worker did not perform a hygienic hand rub within a certain time interval before or after an indication.

The transponder communicates with a beacon, which was installed above the patient's bed. The beacon recognized the entries into and exits from the patient's surroundings by health-care workers who carried a transponder.

The third component was a sensor placed at the hand-rub dispenser, counting the number of hand rubs and allowing a spatial allocation to assign each hand rub to its specific patient surroundings.

The described hand-hygiene monitoring system thus combined hand antisepsis with three of the five moments (1, 4, 5) according to the WHO. Moment 1 is approximated by analysing use of ABHR when entering the patient's zone since touching the patient cannot be monitored. Moments 4 and 5 are comprised and approximated by analysing hand antisepsis when leaving the patient's surroundings.

Study design: The study was composed of two use cases. In use-case 1, a crossover design study was implemented in an intensive care unit [ICU] (table 1). Use-case 2 was implemented in a medium care unit without crossover design (table 2). Before starting phase 1, hand hygiene adherence was determined using direct observation in the absence of an electronic hand-hygiene monitoring system. Furthermore, the time frame for hand antisepsis before/after entering the patient's zone and before/after leaving it was determined.

All participants were briefed about the aim of the study, the use of the device, and the anonymity of the data. The study was approved by the ethics committee of the University of Greifswald (registration nr. BB 156/17).

In the intensive care unit in use-case 1, 18 beds were available. The medium intensive care unit in use-case 2 holds 12 rooms with 2 beds each. When possible, rooms were used as single rooms.

In both cases, direct observation and monitoring adherence by the transponder system, just ABHR use was analysed. Hand washing with water and soap were not considered.

In use-case 1, 44 volunteers – health-care professionals including nurses and physicians – were randomly assigned to the control and the intervention group (22 volunteers each) The investigation period of 197 days was split into five phases of 24 to 50 days (table 1). The staff members wore portable transponders during their shift in all five phases but without the use of the sensors at the hand rub dispensers. In phases 1 and 4, no intervention was conducted. During phase 1, the number of hand rubs in everyday work was measured as baseline. In phases 2, 3, and 5, intervention (vibration, blinking LED) was practised in one (phases 2, 3) or both groups (phase 5), when no alcohol-based hand rubs were used in the given time frame when entering or leaving the patient's surroundings as recognized by a beacon. The staff members were informed about the measurement in all phases.

In use-case 2, in addition to transponders and beacons, the sensors at the dispensers were applied in order to monitor the number of hand rubs. Up to 15 volunteers per day used the transponders. Use-case 2 was investigated for a period of 137 days in five phases (table 2). In contrast to use-case 1, in phase 1, baseline measurement was executed without the knowledge of the staff members, then followed by phase 2, in which information on baseline measurement was given beforehand to identify a possible Hawthorne effect. In phases 3 and 5, intervention (vibration, blinking LED) was used as in use-case 1. Phase 4 served as proof of a learning effect; application of alcohol-based hand rubs was measured without intervention, similar to phase 2.

Table 1 Crossover design of use-case 1 with two groups (A, B) in a crossover design and five different phases.

Group	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	24 days	46 days	43 days	50 days	34 days
A	Baseline measurement**	Intervention***	No intervention**	No intervention**	Intervention***
B	Baseline measurement**	No intervention**	Intervention***	No intervention**	Intervention***

* Staff **were not** informed about running baseline measurement

** Staff **were** informed about running baseline measurement

****Intervention by a portable transponder, vibrating when hand antisepsis was not carried out

Table 2 Design of the study for use-case 2 with only one group and five phases.

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
14 days	14 days	35 days	49 days	25 days

Baseline measurement*	Baseline measurement**	Intervention***	No intervention**	Intervention***, analogue to phase 3

* Staff **were not** informed about running baseline measurement
** Staff **were** informed about running baseline measurement
***Intervention by a portable transponder, vibrating when hand antisepsis was not carried out

Participants: All volunteers were staff members (nurses, physicians, physiotherapists). Staff of other occupational groups and from other hospital wards were excluded. Participation was voluntary and anonymous. Detailed descriptive statistics on participants which would have disclosed their profession were not assessed due to the delicacy of the topic and anonymous data collection. A small subset of the participants presented in this study are described in more detail by Meng et al. [30].

Statistical analysis: To detect an increase in hand antisepsis adherence with a confidence level of 95% (p=0.05), a minimum of 310 indications recorded per shift were calculated. The analysis was performed with a linear mixed model. The outcome variable hand antisepsis/zone event (zone event = entry/exit of patient surroundings) is the part of hand antisepsis and zone event per transponder and shift per day. The intervention is the independent effect. Random effects are transponder ID, shift, and day.
The null hypothesis was defined as: the average count of hand antisepsis/zone event will not increase from phase 1 and 2 to phase 3.

Direct observation: Before introduction of the transponder system, adherence was analysed by direct observation. According to the recommendations of the WHO, the observer introduced him/herself to the health-care workers and the patients and informed them about his/her task. Every session lasted not more than 20 min (± 10 min). A maximum three health-care workers were observed simultaneously. In contrast to the analysis with the transponder system, in direct observation not the entry/exit of the patient's surroundings was considered but as defined by the WHO 5 Moments, touching of the patient or their surroundings was recognized.

Determination of time frame of hand antisepsis: As prerequisite for an adequate intervention if hand antisepsis is not performed, the average time typically needed before and after an indication for hand antisepsis was measured in clinical routine. Time was measured before and after entering and exiting the near-patient surroundings. Ten test persons were observed and time was measured with a timer. The results were used to set the time for the intervention if hand antisepsis was not carried out.

Results

Time frame for hand antisepsis and adherence by direct observation: The time frame for the intervention was set to 60 seconds before entering the patient's zone and 30 seconds after entry. Upon leaving the patient's zone, hand antisepsis must be conducted within 20 seconds before or 30 seconds after exiting. By direct observation, 2,098 indications were recorded. The adherence was highest at moments 1, 4, and 5 (table 3).

Table 3 Adherence of hand antisepsis measured by direct observation.

Indication according to WHO	Adherence (%)
Moment 1	83
Moment 2	54
Moment 3	84
Moment 4	97
Moment 5	99

Hand-antisepsis adherence

In both use-cases, an increase in hand-antisepsis adherence was observed when feedback was given by the transponder system in comparison to the baseline measurement.

To test the sustainability of the intervention, after the intervention phase, a phase without feedback was integrated. In this phase in both use-cases, adherence markedly decreased (up to -64%, tables 4 and 5).

Use-case 1

For 197 days, hand antisepsis was performed a total of 27,606 times as counted by the transponder system. In all phases, adherence upon entering the patient's zone was higher than when leaving the patient's surroundings (table 4).

Group A, Phase 1 versus Phase 2: The intervention with real-time feedback from the transponder increased hand antisepsis in moments 1 and 5 (entry/exit of patient surroundings) about 0.018 when comparing intervention and control phases ($t=1.29$; $p=0.2$). Thus, no significant increase in hand antisepsis was observed.

Group A, Phase 2 versus 3: The intervention with real-time feedback increased hand antisepsis-adherence (hand antisepsis/zone event) significantly by 0.049 in the intervention phase compared to the second control phase ($t=3.53$; $p<0.001$).

Group B, Phase 1 and 2 versus phase 3: The intervention significantly increased the hand antisepsis/zone event value by 0.099 when comparing the prolonged control phase (baseline + phase 2) to phase 3 ($t=7.12$; $p<0.0005$).

Group A, phase 2 with group B phase 2: The intervention increased the hand antisepsis/zone event value significantly by 0.099 when comparing the prolonged control phase of group B to the intervention phase of group A ($t=7.12$; $p<0.0005$).

Overall observation: When comparing all phases with and without intervention, hand-antisepsis adherence (hand antisepsis/zone event) significantly increased by 1.037 ($t=10.15$; $p<0.0005$). Regarding the first intervention phase with the phases without intervention (phases 1, 2 and 3), a significant increase by 0.764 was observed in hand antisepsis/zone event ($t=6.55$; $p<0.0005$).

Use-case 2

For 137 days, hand antisepsis was performed a total of 11,931 times. In all phases, adherence was lower when entering a patient's zone than when leaving the patient's surroundings (table 5).

The real-time feedback increased the hand antisepsis/zone event value significantly ($z=4.34$; $p<0.0005$) when comparing intervention phase 3 to combined values of phases 1 and 2 (table 5).

Comparing phase 1 and 2 of group B makes it possible to calculate whether a Hawthorne effect existed. The descriptive statistical analysis reveals a slight decrease of hand antisepsis/zone event from phase 1 to phase 2, indicating a lack of Hawthorne effect.

The statistical analysis revealed a clear decrease of hand antisepsis/zone event in phase 4 without intervention in comparison to phase 3 with feedback. A relapse to the former hand-antisepsis routine was already visible within a few days (fig. 1). When the intervention started in phase 5 again, the hand antisepsis/zone event value increased.

Table 4 Performed hand rubs (%) of necessary hand rubs according to moments 1, 4 and 5, recorded by the feedback device during use-case I. HA/ZE= hand antisepsis per zone event

		Phase 1		**Phase 2**		**Phase 3**			**Phase 4**			**Phase 5**	
		24 days		46 days		43 days			50 days			34 days	
		Baseline		Intervention in Group A		Intervention in Group B			No intervention			Intervention A+B	
		HA/ZE	Comparison to baseline	HD/ZE	Comparison to baseline	HD/ZE	Comparison to baseline	Comparison to intervention	HD/ZE	Comparison to baseline	Comparison to intervention	HD/ZE	Comparison to baseline
Group A	Zone entry	16.81%	0%	21.02%	+25%	16.21%	-6%	-25%	10.77%	-39%		23.37%	+35%
	Zone exit	16.17%		20.24%		14.88%			9.35%			21.19%	
Group B	Zone entry	15.34%	0%	15.38%	+1%	25.40%	+67%		15.45%	0%	-40%	27.38%	+79%
	Zone exit	13.62%		13.97%		22.98%			13.59%			24.60%	

Table 5 Hand antisepsis adherence during use case II. HA/ZE= hand antisepsis per zone event. Baseline measurement II with prior information of staff.

	Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**
	14 days	14 days	35 days	49 days	25 days
	Baseline measurement I	Baseline measurement II	Intervention	No intervention	Intervention, analogous to phase 3
Zone entries	1967	1677	3636	1229	1473
hand antisepsis total	1588	1204	6059	446	2634
hand antisepsis combined with zone event	584	385	1975	117	487
HA/zone entry	0.098	0.085	0.264	0.040	0.144
HA/zone exit	0.198	0145	0.279	0.55	0.187
HA/ZE	0.148	0.115	0.272	0.048	0.165
Comparison to baseline Sum I+II			+104.5%	-64.0%	+ 24.1%

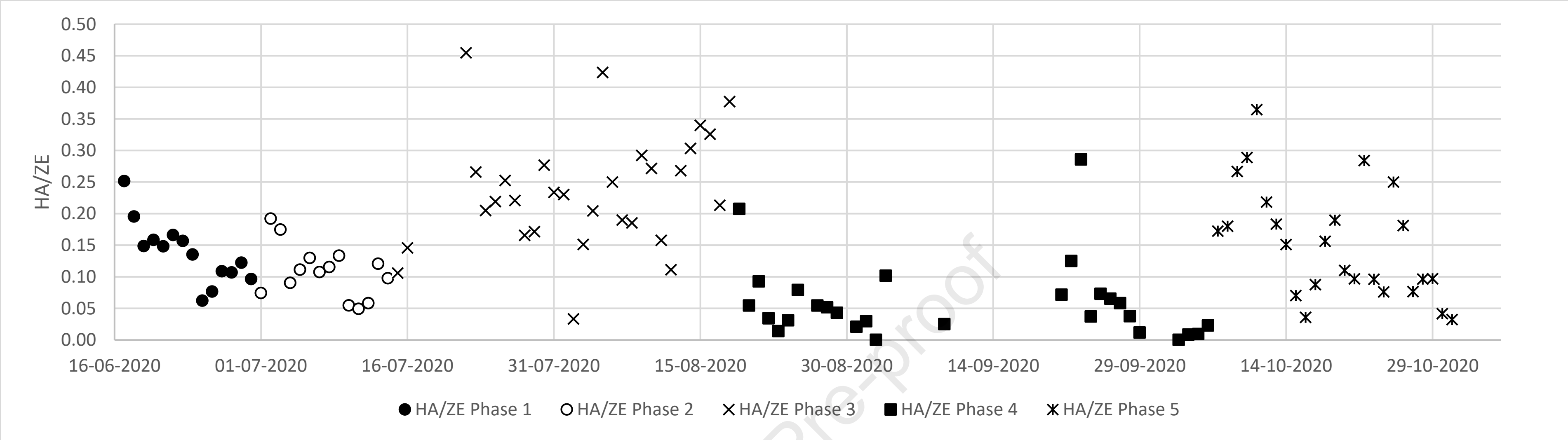

Figure 1 Hand antisepsis per zone event (HA/ZE) in chronological order, split into five phases of use-case 2. In phases 3 and 5, feedback via vibration was activated, leading to increased adherence.

Discussion

Using a new system which provides feedback via vibration when medical staff do not use alcohol-based hand rubs when necessary (approximating to the moments 1, 4, and 5 of hand antisepsis), hand-antisepsis adherence was significantly increased. Thus, transponders with a feedback function can be seen as a simple, cost-effective and non-judgmental device to improve hand-hygiene adherence behaviour. Staff members participating in this study intentionally improved their hand-hygiene related behaviour. However, this behavioural change was not sustained.

In the present study, hand-antisepsis adherence obtained by the gold standard (direct observation) was better than hand-antisepsis adherence obtained with the new feedback system. Direct observation detected an adherence of 54-99% depending on the hand-antisepsis moment, whereas the baseline adherence detected with the transponder system was about 13-17%.

When using direct observation, adherence to hand antisepsis was very high in comparison to other studies [20,21] what might result from the observation done at an intensive care unit, since data of two other wards of the same hospital revealed a lower adherence [31], and the fact, that the direct observation was conducted in an academic teaching hospital.

Furthermore, direct observation did not measure hand antisepsis when entering/leaving the patient's zone without touching the patient or the surroundings. That is why adherence might be higher than for the feedback system that additionally records these cases that don't require hand antisepsis according to the WHO 5 moments. Unfortunately, until now no data exist clarifying in detail in how many cases the patient's surroundings are entered without touching the patient or the surroundings. Further research to optimize the adherence observation may be necessary.

When entering the patient's surroundings, adherence was slightly higher than when leaving the patient's zone. This result might be associated with a positive external perception by the patient while using the transponder system represents a professional responsibility [32].

The relatively low adherence when measured by the feedback system might result from additional protective equipment that is especially worn in intensive care units which may cover the alcohol sensor, thus resulting in apparently low adherence. This disadvantage might be overcome by using the feedback system as one part of a multimodal intervention. As part of this multimodal intervention, training courses and observations can help improve adherence. Additionally, the role model effect of the supervisor should be considered. Another point explaining the lower adherence measured by the transponder system might be a possible Hawthorne effect during direct observation, as the staff members are more aware of being observed and are thus more compliant [32]. In reverse, a Hawthorne effect when using the transponder system was excluded by proofing adherence in a further phase of use case 2. Thus, the feedback system provides reliable data overcoming a possible effect due to the observation itself.

However, short-term interventions do not lead to long-term changes in behaviour. Using a feedback system for longer periods of time, a learning process might lead to the acquiring new behavioural patterns. Short-term effects were also shown by Ibrahim et al. [33], for instance. They tested the effect of a voice reminder, requesting participants to bear hand antisepsis in mind at certain times to increase the adherence in two hospitals. They recorded a baseline adherence of 31.4% and 48.0% and a post-intervention adherence of 78.0% and 65.2%; increases of 148% and 36%, respectively. However, the increased adherence was not statistically significant. Zhong et al. [34] observed an immediate increase of >12% in hand antisepsis after implementation of a feedback system in the first month. Afterwards, adherence increased at a rate of about 1.242% per month in comparison to adherence without use of the feedback function. An increase in hand-hygiene adherence from 16-39% to 42-78% by use of an automated monitoring system was also observed by Iversen et al. [35]. After a baseline measurement of two months, two intervention phases of 12 months (group intervention, team data) and 4 months (individual intervention) followed. Unfortunately, the intervention period in our study was relatively short, thus not reinforcing the enhanced adherence to maintain behavioural change. When the intervention was not continued, positive effects disappeared; a relapse to the former hand-antisepsis routine was already noticeable within a few days (fig. 1). Thus, sustainability could not be proven. When the intervention was started in phase 5 again, the hand antisepsis/zone event value increased again.

Long-lasting high adherence is only possible when medical staff are motivated to change their behaviour. Potential intentional non-adherence is not considered. Problems such as the resistance to change have been documented in previous studies, e.g., by Al Salman et al. [36], although an average increased adherence from 38-42% to 60% was observed due to the use of sensors at soap and hand-antisepsis dispensers for 28 days. Scepticism about the device possibly monitoring the health-care workers was overcome by further explanations and emphasizing the advantages, such as the system being a measure to prevent infectious diseases, which would thus also protect the staff. However, concerns could never completely be allayed [36]. As in other studies, the acceptance of the transponder system used in our study was likewise moderate as shown before correlating to the experience with technologies in general [30]. Practical support and an increase in experience may lead to higher acceptance.

Resistance to change is defined as a counterproductive behaviour towards a change initiative, which results in a negative impact on the change effort [37,38]. The reasons for this resistance to change might be diverse. Landaete et al. [38] summarized common reasons during the implementation of a new system. Among others, disagreement of a group about the nature of the problem and its consequences, embedded routines, or a lack of capabilities were mentioned. Furthermore, the relationship between the value of the change initiative and its importance for the individual and the organization are important. Further problems may arise when the validity of the automated readings is questioned [39].

This might result from distrust of the device or the data security. Instead of feeling monitored by the device, it should be seen as a positive-feedback system supporting the patient's and staff's maintenance of health.

Granqvist et al. [40] found a change in opinion about a pilot implementation comprising direct observations, interviews, and a monitoring system from sceptical to more accepting over time. A prerequisite, however, is optimal functioning of the device to support daily work. During our study, the use of the feedback devices fluctuated. On some days, no device was used. To overcome the resistance to change, more information about the utility of the device and its anonymity are necessary.

In conclusion, new technologies for changing the hand-hygiene behaviour only work when feedback is constantly switched on. Just as traffic lights need to be in operation, the interactive feedback system is needed during the work shift. However, it cannot be ruled out that positive effects may be diminished by a habituation effect. Thus, testing a longer intervention period might yield deeper insight. Additionally, differences in adherence – both with and without feedback – by profession, age and gender may be worth future study.

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Conflict of Interests

The author Tobias Gebhardt is managing director of GWA Hygiene GmbH.

He was the negotiator of the technology acquisition of HyHelp AG (former project coordinator) in 2019. As a consequence, GWA Hygiene has become the new coordinator of the related funding project PräBea. Afterwards they received the remaining funding amount.

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