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Validation of a hand hygiene visual feedback system to improve compliance with drying time of alcohol-based hand rub in a neonatal intensive care unit: the Incubator Traffic Light system

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SUMMARY

Background: Compliance with the recommended 30 s drying time of alcohol-based hand rub (ABHR) is often suboptimal. To increase hand hygiene compliance at a neonatal intensive care unit (NICU), we installed an Incubator Traffic Light (ITL) system which shows 'green light' to open incubator doors after the recommended drying time.

Aim: To measure the impact of this visual feedback system on NICU healthcare professionals' compliance with the recommended ABHR drying time.

Methods: Ten traffic light systems were installed on incubators at a NICU, five of which provided visual feedback, and five, serving as a control group, did not provide visual feedback. During a two-month period, the systems measured drying time between the moment of dispensing ABHR and opening the incubator's doors. The drying times of the incubators were compared with and without feedback.

Findings: Of the 6422 recorded hand hygiene events, 658 were valid for data analysis. Compliance with correct drying time reached 75% ($N = 397/526$) for incubators equipped with visual feedback versus 36% ($N = 48/132$; $P < 0.0001$) for incubators lacking this feature.

Conclusion: The ITL improves compliance with the recommended 30 s ABHR drying time in a NICU setting.

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Introduction

Prematurely born infants are at risk of healthcare-associated bloodstream infection in invasive procedures due to their immature host defence [1—3]. These infections occur quite frequently (11—53%) and result in worse outcomes, longer hospital stays, and subsequently higher additional costs [2,4—8].

The World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) recommend correct hand hygiene (HH) following 'My Five Moments' as the best method to reduce horizontal transmission of pathogens from one patient to another by healthcare professionals [1,9,10]. In line with European guidelines, correct hand disinfection is achieved by rubbing the hands with an alcohol-based hand rub (ABHR) for 30 s [11].

However, maintaining sustained adequate hand hygiene compliance (HHC) is challenging. Studies have highlighted issues such as inappropriate drying times or insufficient rubbing techniques [12,13]. Whereas interventions such as education programmes or reminders can improve HHC, compliance tends to diminish over time once the intervention ends [14,15]. Several studies have assessed whether electronic HH monitoring systems could achieve a more lasting effect on HHC [16—21]. These systems often encourage users' HH behaviour through sensory feedback, such as light signals. Nevertheless, none of these technical interventions are particularly well-suited for an incubator bedspace at a NICU.

Therefore, the 'Incubator Traffic Light' (ITL) was specifically designed to improve HHC at an incubator bedspace. The ITL provides real-time visual feedback by light signals and video playback, with a focus on ensuring the correct ABHR drying time. This observational study aims to assess the ITL's effect on compliance with ABHR drying time at NICUs.

Methods

Design and setting

From August 15th to October 15th, 2022, an observational study was performed at the NICU of the Erasmus MC Sophia Children's Hospital. Ten ITL systems were installed (Figure 1), five of which provided visual feedback (referred to as 'Feedback systems'), and five, serving as a control group, did not provide visual feedback ('Blind systems') [22]. During a two-month intervention period the ABHR Drying Times of the incubators were recorded with and without feedback.

To familiarize the healthcare professionals with the presence of this new device at the incubators, the intervention period was preceded by a three-and-a-half month functional testing period, safety certification, and adaptation pilot period. Technical stress-testing of the systems in the real NICU-setting took place in the pilot period. Preceding the pilot period, awareness of the upcoming study was created through clinical lectures to the NICU personnel, and announcements via screensavers and a NICU newsletter.

Study population

The ITL systems recorded all HH events of healthcare workers at the NICUs. Systems were randomly allocated to incubators by the nursing staff. The NICU of the Erasmus MC Sophia Children's Hospital is organized into four open-bay subunits with eight beds each. Approximately 700 neonates are admitted annually. During the study period, the clinical staff included 17 neonatologists, nine residents, 91 nurses, 16 nurse trainees, 22 nursing assistants, and nine nurse practitioners.

Ethical committee assessment

The Medical Research Ethical Committee of the Erasmus University Medical Centre Rotterdam assessed the study design as not subject to the Dutch Medical Research involving Human Subjects Act (WMO) (Reference number MEC-2016-102).

The incubator traffic light

The ITL was co-designed with NICU nurses; its development and technical details are described in an earlier article [22]. Since 2018, we final-engineered our ITL proof-of-concept and manufactured ten systems for clinical evaluation. The ITL system used in this study was designed for the Dräger Caleo incubator (Dräger, Lübeck, Germany).

The ITL as used is shown in Figure 1, and Table I describes the type of visual feedback per modus. In brief, the ITL integrates a touchless ABHR dispenser, video playback, coloured lights, and a door-opening sensor mounted on the incubator. Similar to a globally recognized traffic light, the ITL displays a 'green light' to signal that it is safe to open the incubator's doors after 30 s of hand rubbing time. Attempting to open the doors before 30 s or without dispensing ABHR will evoke orange blinking warning lights.

Conditions: feedback systems and blind systems

At one NICU unit, five incubators were equipped with fully functional ITL systems, referred to as 'Feedback systems', dispensing ABHR (Sterillium med, BODE Chemie GmbH, Hamburg, Germany) and providing visual feedback to users during an HH event. In another unit, acting as control, five ITL systems were installed on incubators, identical but configured as 'Blind systems' with all visual feedback features disabled (Figure 1).

The systems were stand alone, meaning that no manual supervision or monitoring was needed. However, at the end of each working day, a researcher (O.H. or R.G.) walked through the two participating NICU units, to check all systems.

Data collection

Data of the HH events of both Feedback and Blind systems was sent wirelessly to a web-based database (ThingsBoard data collection platform, New York, NY, USA; see Supplementary Appendix). An HH event was started by dispensing alcohol or opening an incubator door. Variables recorded in the database are described in Table II. The main variable was the time difference in whole seconds between dispensing alcohol and opening doors, hereafter referred to as Drying Time.

Data analysis

Valid data events, defined as events when alcohol was dispensed and an incubator door was opened within 60 s for both the Feedback and Blind systems, were selected from the

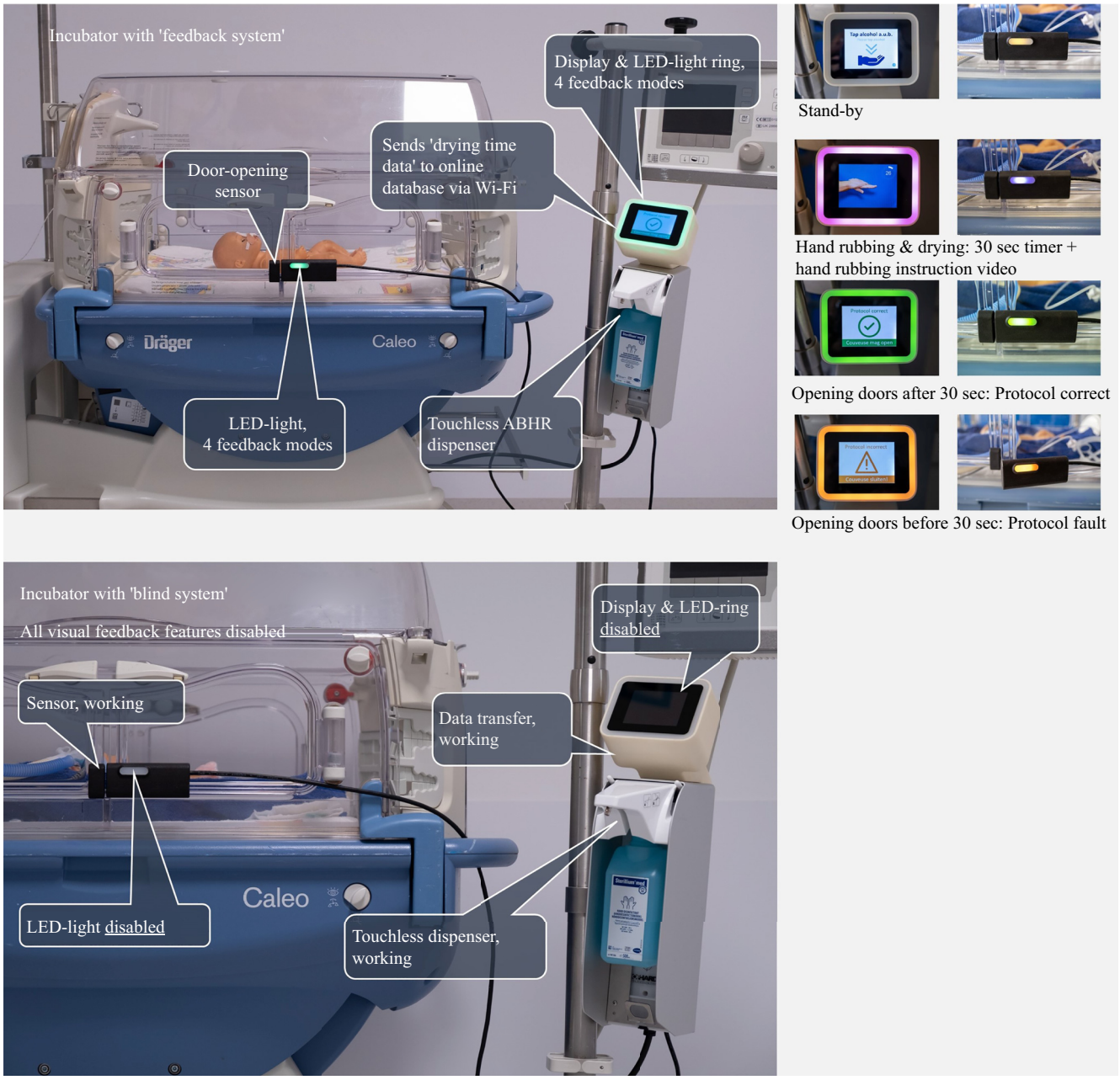

Figure 1. Overview of the Incubator Traffic Light (ITL) system, mounted on the Dräger Caleo incubator. The ITL provides visual feedback by a display surrounded by a light-emitting diode (LED)-ring situated above a touchless alcohol-based hand-rub (ABHR) dispenser (Ophardt, Issum, Germany), and an LED-light in the door-opening sensor situated on the incubator's small doors, at the 'working side' of the incubator. Via Wi-Fi, compliance data is sent to a web-based database. Feedback is triggered by placing a hand under the touchless ABHR dispenser and/or opening the incubator's doors: (1) Stand-by; (2) Hand rubbing/drying; (3) Protocol Correct; and (4) Protocol Fault. The 'Blind systems' were identical, but with all visual feedback features disabled. See demo video in Supplementary Appendix or YouTube: https://youtu.be/h7Px-QczVos.

imported data. Events were classified as invalid for data analysis if:

(a) the Drying Time was <0 or >61 s, due to technical issues;
(b) the ITL system was bypassed, doors were directly opened (Drying Time $= 0$ s);
(c) alcohol was dispensed without opening doors within 60 s;
(d) Parental Override button was activated.

Resulting valid events are Protocol Correct (Drying Time ≥ 30 s) and Protocol Fault events (Drying Time <30 s), for both Feedback and Blind systems. Compliance with the correct

Table I
Feedback modes of the Incubator Traffic Light

Feedback modus	Visual feedback to user	Remarks
Stand-by	Display: 'Please dispense alcohol'. Display surrounding LED light: none. Door sensor LED light: amber.	The 'Stand-by' mode invites to dispense ABHR
Hand rubbing/drying	Display: video with hand-rubbing instructions showing a good execution of hand rubbing with ABHR (video approved by Infection Prevention Dept of Erasmus MC), and a graphic and numeric 30 s countdown. Display surrounding LED light and Door sensor LED light: purple light, indicating hand rubbing is going on.	'Hand rubbing/drying' modus starts by placing a hand under the dispenser's tap point to activate the touchless dispenser
Protocol correct	Display: 'Protocol Correct'; 'You may open incubator'. Display surrounding LED light and Door sensor LED light: green.	'Green light' after dispensing ABHR and opening doors after 30 s (rubbing/drying time $\geq$30 s), or when activating 'parental override button'. If no doors are opened within 60 s, system will go back to 'Stand-by'.
Protocol fault	Display: 'Protocol Incorrect'; 'Please close incubator!' Display surrounding LED light and Door sensor LED light: blinking orange	Blinking orange lights and a display message urge users to close the doors if they have opened them too early (rubbing/drying time $<$30 s) or without dispensing ABHR
Parental override	Same as 'Protocol Correct': green lights, 'You may open doors'	'Parental Override button' touchscreen button in right-hand display corner, allowing opening incubator doors without using ABHR, for example parents, who are allowed to use soap instead of ABHR, or in the case of rescue procedures

LED, light-emitting diode; ABHR, alcohol-based hand rub.

Drying Time is considered as the proportion (in %) of Protocol Correct events per system category.

Statistical analysis

The Drying Times of the Feedback and Blind systems were compared by calculating the median, interquartile range (IQR), and frequencies. Normality of Drying Time distribution was tested with a Shapiro–Wilk test and data plotting. The significance of difference was tested by Mann–Whitney *U*-test. Two-proportion *Z*-test tested for equality in proportions of correct protocols of Feedback versus Blind. R Statistical Software Version 4.2.1 was used for statistical analysis (R Foundation of Statistical Computing, Vienna, Austria). Two-sided $P < 0.05$ was considered statistically significant.

Results

During the intervention period, 6422 events were recorded. Eventually, 658 events fulfilled the inclusion criteria for valid events and were selected for data analysis. The data flow chart in Figure 2 shows the selection process of valid events.

Drying time of feedback versus blind systems

The median Drying Time associated with the Feedback systems ($N = 526$ events) was 32.0 s (IQR: 30–39), and that associated with the Blind systems ($N = 132$ events) 24.5 s (IQR: 14–38) ($P < 0.0001$). Neither for Feedback systems nor Blind systems was Drying Time normally distributed, according to the Shapiro–Wilk test and bee swarm point plot (Figure 3). The median Drying Time associated with the Feedback systems was 7.5 s longer than that associated with the Blind systems.

Compliance with correct drying time

Correct Drying Time compliance for incubators with visual feedback was 75% ($N = 397$ Correct, $N = 129$ Fault events) and for incubators without feedback 36% ($N = 48$ Correct, $N = 84$ Fault events), and the difference is significant ($P < 0.0001$) (Figure 3).

Discussion

This study evaluated the effect of the ITL visual feedback system for neonatal incubators on compliance with the prescribed 30 s ABHR hand-drying time prior to patient contact. The incubators equipped with the ITL's visual feedback exhibited significantly higher compliance with the correct drying time compared to incubators without such feedback. Enhanced compliance with the prescribed drying time can potentially contribute to a reduction of nosocomial infections in a NICU [3,23]. Moreover, fewer infections may lead to less antibiotic treatments needed, which may help address another growing concern in the medical field, namely rising antibiotic resistance [9].

Our findings align with comparable studies involving feedback systems aimed at improving HHC. A variety of non-technical and technical (electronic) systems have been developed to monitor HHC [16–21,24–27], including one study conducted within a NICU setting [24]. However, comparing HHC in other studies with our results may be challenging. In general,

Table II
Description of database variables

Variable	Values/units/formats	Description
Entity name	Incubator 001 … 010	This identifies an incubator with ITL system
Category	'Feedback' or 'Blind' system	Depends on Entity Name, with Incubators 001 … 005 being 'Feedback systems' and Incubators 006 … 010 being 'Blind systems'
Timestamp	Date, time of day (CET)	Records the date and time of registration of the data event
Opened	Date, time of day (CET)	Records the date and time of opening doors
Started	Date, time of day (CET)	Records the date and time of dispensing alcohol, or opening doors if opened directly
Drying time	Whole seconds	Elapsed time in whole seconds, between dispensing alcohol and opening doors. In case no doors are opened within 60 s, Drying Time of 59, 60 or 61 s is documented
State	Protocol Correct (Drying Time ≥30 s) Protocol Fault (Drying Time <30 s) No Action (Drying Time ≥59 s) Parental Override (button activated on touchscreen)	Documented state of the event, with categorical values. Dependent on Drying Time value or activation of Parental Override button on the touchscreen display. If no doors are opened within 60 s, the system returns to Stand-by, and records a No Action event.

ITL, Incubator Traffic Light; CET, Central European Time.

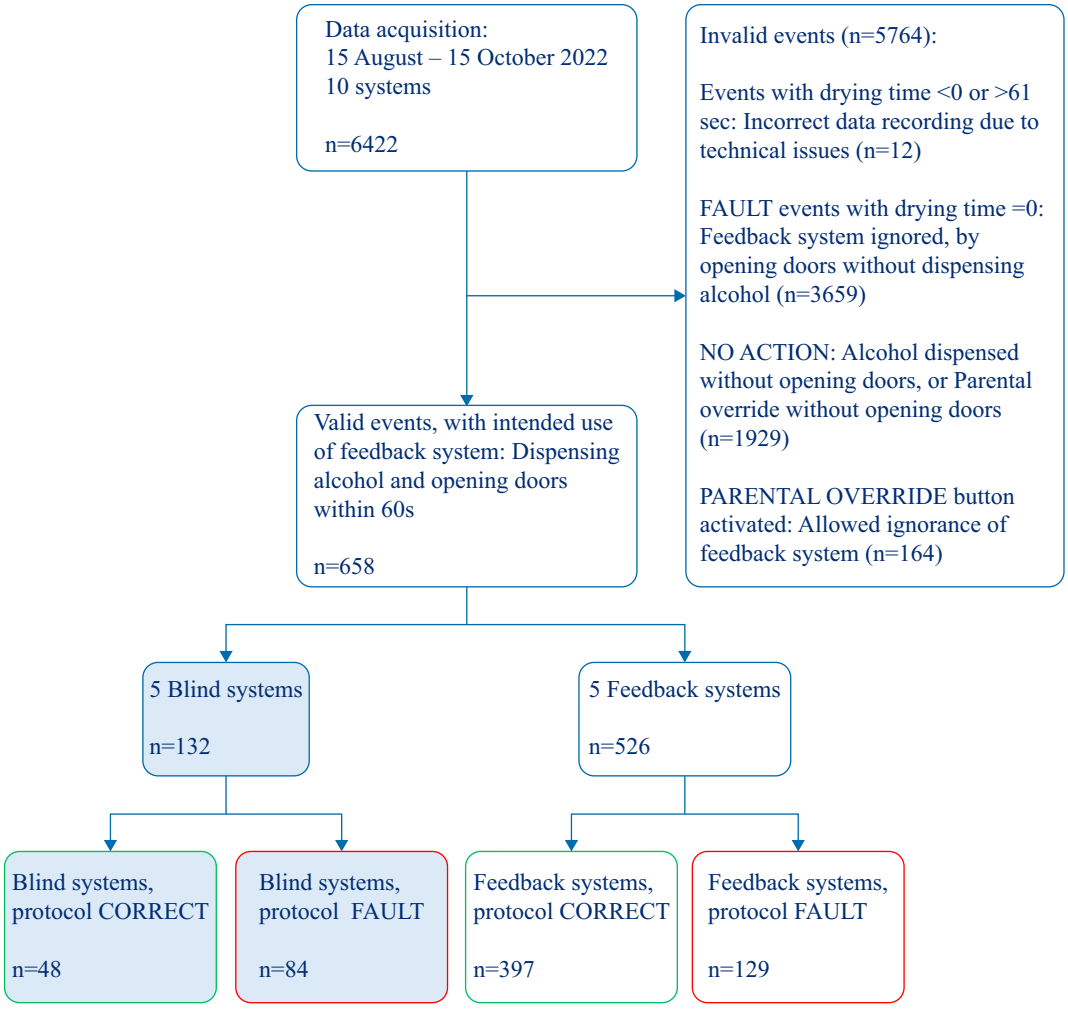

Figure 2. Data acquisition flow chart.

studies define HHC as the occurrence of the WHO My Five Moments, mostly by counting hand sanitation moments using some form of electronic sensing. In this definition, a higher number of moments indicates greater compliance, and drying time is not factored in. One earlier study, performed at the same NICU as our study, examined the impact of an educational programme on HHC and did measure drying time compliance in a NICU setting [12]. Although the educational programme significantly improved drying time compliance, the median drying time after the intervention (12 s; IQR: 8–15) still fell well short of the recommended 30 s. In contrast, our median Drying Time for Feedback systems was 32.0 s, and remarkably, even the Blind systems averaged 24.5 s, both much higher.

For this study, we adhered to the ABHR manufacturer's prescribed 30 s drying time, consistent with our NICU's HH protocols. However, the definition of correct drying time as set for this study is arbitrary, as the 30 s drying time is open to debate. The WHO recommends an application time of 20–30 s, while the CDC recommends rubbing hands until dry, which typically takes around 20 s [28]. A study conducted in a NICU setting even suggests that a 15 s drying time yields similar microbiological efficacy as 30 s [29]. Remarkably, in that study, reducing the recommended time led to an increased rate of hand hygiene events at a NICU.

We deliberately planned an adaptation period to mitigate the potential Hawthorne effect, which refers to the alteration of behaviour in subjects of a study due to their awareness of being observed [30,31]. We expected the Hawthorne effect to manifest if we were to start the intervention period directly after installing the ITL systems at the NICU, as the mere presence of the new systems could influence behaviour. However, since not all incubators were equipped with the ITL system, the presence of the system was obvious; so, despite the adaptation period, the Hawthorne effect cannot be ruled out.

To the best of the authors' knowledge at the time of writing, the ITL is the first-of-its-kind HH feedback system specifically designed for neonatal incubators, developed in co-design with NICU nurses. In the co-design sessions, we also discussed the effect of 'social nudging': in an open-bay NICU with multiple incubators, staff, and parents, the clearly visible green light 'when doing well', or the blinking orange light 'when doing wrong', could serve as an extra incentive for correct HH behaviour. Furthermore, the real-time or retrospective compliance data is linked to each specific incubator/department location, enabling location-specific 'compliance per department' data. Such data, visualized in a dashboard, could also nudge HH behaviour. Finally, despite its intended design for incubators, the ITL system can easily be adapted for other HH monitoring purposes.

Several limitations in this study need to be discussed. First, the majority of recorded events were deemed invalid for data analysis. These events involved instances where the ITL was not used as intended, resulting in 658 valid events out of a total of 6422 events. In most of the invalid events (Drying Time = 0 s), users opened a door without utilizing the ITL dispenser. Many other invalid events were No Action events: the user utilized the ITL dispenser, but did not open the incubator doors (within 60 s). Both of these events seemed to be associated with the open bay department layout: after patient contact, individuals may have disinfected their hands at one incubator and then proceeded to another without adhering to the protocol of re-disinfecting at the next incubator. In addition, it was suspected that, due to years of habituation, many NICU nurses simply ignored the 'new' ITL dispenser and continued to use the 'old' existing manually operated ABHR dispensers,

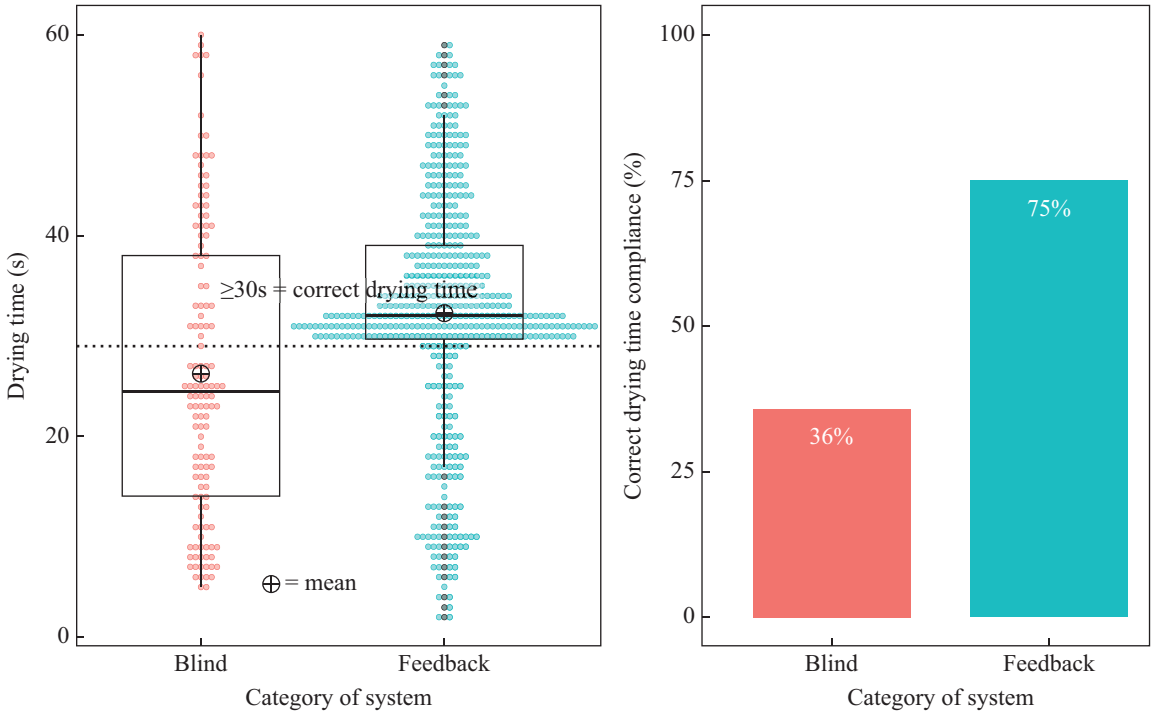

Figure 3. Drying Time (s) distribution (box plot superimposed on bee swarm point plot), and Correct Drying Time Compliance (%), for incubators without Feedback (Blind) versus with Feedback. Compliance = percentage of correct protocols. Difference in Compliance is 39% ($P < 0.0001$).

which were positioned approximately 1.5 m away from the incubators. Attempts to remove the existing dispensers failed, as nurses were inclined to maintain the bedspaces as they were. Furthermore, due to the open-bay layout, the ITL dispensers might also have been used for 'not-patient-related' HH events, for NICU staff disinfect their hands on several occasions, for example after using their phone. Some of the No Action and 'Drying Time = 0 s' events might be explained by the (arbitrary set) limit of 60 s, after which the system went back to Stand-by. When users, for some reason, opened doors after 61 s, two invalid events (No Action + Drying Time = 0 s) were recorded, while drying time was indeed correct. This 60 s limit was set assuming that users, with the intent of (bare hand) patient care, would open doors after ABHR within 60 s.

Second, a limitation regarding the data is the large difference in number of recorded events between Feedback systems ($N = 526$) and Blind systems ($N = 132$). The reasons causing this discrepancy might have introduced bias in our results. It is possible that users perceived the Blind systems as 'not working' due to the black (disabled) video screen and disinfected hands elsewhere, resulting in an invalid event (Drying Time = 0 s). Another reason for ignoring Blind systems more often than Feedback systems could be that Feedback systems simply were more obviously present, with the active stand-by LED doorlight and display message.

Third, data recording was limited to the Drying Time between dispensing and activation of the door sensor, with no insight into what activities were performed during Drying Time. Drying Time in NICU HHC was our particular interest in this study. However, it should be noted that Drying Time compliance is only one aspect of HHC, considering all My Five Moments.

Fourth, although we configured five systems as Blind systems to serve as controls, a limitation in our study design is the absence of pre-intervention baseline measurements of Drying Time before the ITL systems were installed, which could have been obtained through observations of Drying Time by an independent observer.

Fifth, an unexpected initial technical limitation related to the touchless dispenser was that it unintendedly dispensed ABHR on the back and sides of nurses' uniforms, which was a source of annoyance and complaints from the nurses. Although the issue was resolved before the intervention period started, a negative attitude towards the system might have persisted, resulting in a tendency to continue using the old dispensers instead of the ITL system.

Finally, the current design of the ITL has limitations. In the current configuration, only one door-opening sensor is mounted, at the 'working side' of the incubator. This means that the doors at the opposite side can be accessed without the ITL sensing. Furthermore, the ITL is not suitable for use with open beds, which are also used at a NICU. On open beds, the door sensor has no use. Nevertheless, the video with a countdown timer and 'green light' nudge could still be beneficial for HHC, and the number and timing of ABHR dispensing events could still be monitored.

We encourage future studies utilizing the ITL system or similar systems with a longer intervention period to investigate the long-term effects of a HH visual feedback system. In such studies, measurement methods will be more reliable if all incubators are equipped with the ITL systems, and with all 'old' dispensers removed. Baseline HHC measurements should be incorporated as well. In addition, outcomes should go beyond drying time only, and could also include the quality of handrubbing execution, possibly by using automatic posture recognition techniques available today.

In conclusion, the ITL is an innovative visual feedback system specifically designed for promoting HHC at neonatal incubators. The visual feedback provided by the ITL has been shown to significantly improve compliance with the recommended 30 s ABHR drying time in a clinical NICU setting. Compliance rates reached 75% for incubators equipped with visual feedback versus only 36% for incubators lacking this visual feedback feature.

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Author contributions

O. Helder was involved in the design of the study, acquisition of funding, and reviewing the manuscript. R. van Gils and O. Helder were involved in the planning and execution of the study. R. van Gils analysed and visualized data and wrote the first draft of the manuscript. R. Kornelisse and J. Dankelman were involved in reviewing the manuscript. All authors read and approved the final manuscript.

Conflict of interest statement

The ITL used in this study was co-developed with industry partner Protoworkz Sliedrecht, The Netherlands (the ITL was commercialized under the company Tap2Clean, which ceased activities in 2022). This study was not funded by Protoworkz/Tap2Clean and the company had no influence in the design, results, and conclusion of this study. The authors declare they have no commercial or financial interest with Protoworkz at the time of writing of this manuscript or later. No generative AI and AI-assisted technologies were used in the writing process of this manuscript.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2024.01.007.

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