



STANDARDS RESEARCH

Splash Zone of Hand Hygiene Sinks in Health Care Facilities

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Authors

Sibina Fisher, BSN, RN, MSC, Alberta Health Services

Anna Bradford, MBT, W21C Research & Innovation Centre

Shane Virani, MSc, PMP, W21C Research & Innovation Centre

Yamile Jasoui, MSc, PMP, W21C Research & Innovation Centre

Jenine Leal, MSc, PhD, Alberta Health Services

John Conly, MD, DSc, University of Calgary and Alberta Health Services

Project Advisory Panel

Jessica Fullerton, The Ottawa Hospital

Kathryn Wyndham, Alberta Health Services

Robin Snell, Parkin

Steven McEwan, Fraser Health

Shiva Akhtarian, CSA Group

Ankita Shah, CSA Group (Project Manager)

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Executive Summary

Outbreaks of antimicrobial-resistant organisms in health care settings have been linked to splash generation from hand hygiene sinks (HHSs), drain contamination, biofilm formation, and faucet design features that may facilitate splash and microbial dispersion. Splash from HHSs may disperse microorganisms onto surrounding surfaces, supplies, and staff clothing. CSA Z8000, *Canadian health care facilities*, and CSA Z3171:21, *Special requirements for plumbing installations in health care facilities*, outline design features such as deeper basins, offset drains, and non-aerated outlets to minimize splash. However, there is limited evidence on whether HHSs that align with these standards still produce splash beyond the required 1 m zone. Therefore, this project aimed to:

1. Synthesize evidence from peer-reviewed and grey literature and conduct an environmental scan of available sinks and faucets that align with CSA Z8000 and Z3171.
2. Experimentally measure splash dispersion during handwashing across multiple sink and faucet combinations.
3. Assess human factors and usability implications of these combinations.
4. Develop evidence-based recommendations for standardization of HHS design requirements regarding floor splash zone dimensions, sink design requirements, faucet design requirements, and backsplash and side splash dimensions.

A structured literature review of peer-reviewed publications and a grey literature search were conducted. An environmental scan compared sink basins and hands-free faucets from manufacturers against CSA Z8000 and CSA Z3171:21 standards. A controlled splash study tested nine combinations of three selected sinks and three faucets. Participants washed their hands using Public Health Ontario handwashing methodology, and fluorescent markers were used to visualize the distance droplets travelled from participants' hands and the drain onto wall surfaces and the floor. Appropriate statistical methods were used to evaluate differences in farthest splash distance across three surfaces: backsplash, side splash, and floor. Human factors were evaluated through validated usability analysis and semi-structured interviews.

Of the 80 included peer-reviewed publications, only six studies measured the droplet travel distance generated by HHSs, with some reporting distances of 1 to 2 m. A review of guidance documents found that nearly half (45%) recommend maintaining clear space around HHSs to reduce splash-related contamination. Where splash zone distance was provided, recommendations ranged from 1 to 2 m. In the splash study conducted for this research, 75% of observed droplets fell within 1 m and 95% within 1.2 m of the faucet outlet on the floor. Of the 75 handwashing events, only four instances of drain splash were identified, supporting the effectiveness of offset drains. No single sink, faucet, or sink and faucet combination significantly reduced the farthest splash on all surfaces. Usability analysis identified the trough sink paired with automatic faucets as the most intuitive and user-friendly combination.

The results suggest that standards should adopt consistent terminology for automatic sensor faucets and standardized specifications for backsplash and side splash dimensions. Measuring the splash zone from the faucet outlet would better accommodate sinks of varying dimensions and shapes. A splash zone of 1.2 m from the faucet outlet is recommended, which would capture 95% of furthest droplets as observed in this study. The backsplash height specified in CSA Z317.1:21 (600 mm above the basin rim) could be maintained, with additional splash barrier dimensions incorporated into standards. Given contamination risks from warm, stagnant water between the thermostatic mixing valve and the faucet outlet, an infection control risk assessment should be required before automatic sensor faucets are used in complex or critical care areas. Additional recommendations include a minimum basin area of 0.1 m², a minimum distance of 260 mm between the faucet outlet and the basin bottom, clarification on laminar flow outlets, inclusion of single-lever faucet controls and review of minimum wrist blade length requirements. Mock-ups of sink and faucet pairings should be prioritized prior to procurement.



“A large international case-control study found that health care workers (HCWs) who did not consistently clean their hands after patient contact during the COVID-19 pandemic were three times more likely to become infected with SARS-CoV-2.”

1 Introduction

1.1 Importance of healthcare worker access to hand hygiene sinks

Frequent hand hygiene reduces the incidence of health care-associated infections [1]–[3]. A large international case-control study found that health care workers (HCWs) who did not consistently clean their hands after patient contact during the COVID-19 pandemic were three times more likely to become infected with SARS-CoV-2 [4]. Although alcohol-based hand rub plays an important role in hand hygiene, HCWs must also have access to hand hygiene sinks (HHSs) at the point of care [5], [6]. A strong safety culture in health care facilities (HCFs) is central to the World Health Organization (WHO) hand hygiene strategy; thoughtful building design and consistent access to clean water, soap, and paper towels are key components of this culture [7]–[9]. These principles are directly relevant to HHS design and placement. The WHO has noted that institutional safety culture remains less studied than other hand hygiene improvement interventions and has prioritized research into how the built environment can support HCW hand hygiene compliance [7], [9].

1.2 HHS infection risks

Although safe and reliable access to HHSs may seem as simple as installing a sink and faucet in a patient care area, not all sinks and faucets are created equal. Some HHSs have been associated

with outbreaks of antimicrobial-resistant organisms in the health care setting, especially in intensive care units (ICUs) [10]–[15]. Genetically identical or highly similar antimicrobial-resistant organisms have been detected in both patients and HHSs, including *Elizabethkingia meningoseptica* [10], multidrug-resistant *Pseudomonas aeruginosa* [12], β -lactam-resistant *Klebsiella oxytoca* [13], [16], carbapenem-resistant *Klebsiella pneumoniae* [11], *Acinetobacter baumannii* [14], and *Citrobacter freundii* [17].

Contamination of HHSs, fixtures, and plumbing components can contribute to transmission of infectious organisms to patient care supplies, HCWs' hands and uniforms [10]–[18]. Beyond sinks and faucets, drain contamination is often implicated in sink-related ICU outbreaks [12], [13], [16], [19], and drain decontamination frequently proves ineffective [12], [13], [15]. Even when drains and waste pipes are replaced, rapid recolonization of drains has been observed after replacement [20]–[23]. Some liquid disinfectants, such as 25% acetic acid [23]–[25], appear to suppress bacterial growth in drains with regular application. Foaming disinfectants combining hydrogen peroxide and peracetic acid, with or without octanoic acid [19], [26], have also shown promise. However, appropriate sink and faucet design that prevents splash back from drains is likely a more effective long-term solution for reducing exposure to pathogenic organisms in drain systems.

The Centers for Disease Control and Prevention (CDC), along with a joint statement issued by the Society for Healthcare Epidemiology of America, the Infectious Diseases Society of America, and the Association for Professionals in Infection Control and Epidemiology, recommend intentional selection and design of HHSs to minimize splash or spray and reduce the risk of exposure to drain-related pathogens [6], [27]. However, evidence quantifying how far droplets travel during handwashing is limited. In a study from 2009, Hota et al. [12] reported that splashes from HHSs travelled at least 1 m from the sink. The study identified shallow basin depth and water flowing directly onto the drain as key contributors to splash and drain-related contamination. More recently, studies have shown that basin shape influences the distance droplets travel during handwashing [28], as does the length of the faucet neck [29].

The type of hands-free faucet controls may also play a role in infection risks associated with HHSs. Automatic sensor faucets require the use of thermostatic mixing valves (TMVs), which automatically mix hot and cold water to deliver consistent and safe water temperature, thereby preventing scalding and supporting ease of use. However, the use of TMVs can unintentionally create conditions that support the growth of *Legionella* and *Pseudomonas aeruginosa* by maintaining water temperatures conducive to bacterial growth and contributing to water stagnation between the TMV and faucet outlets when the faucet is not regularly used [30], [31]. These TMVs are not required for other hands-free controls, such as wrist blade or knee pedal systems.

1.3 Canadian HHS design requirements

CSA Z8000, *Canadian health care facilities* [30], and CSA Z317.1:21, *Special requirements for plumbing installations in health care facilities* [32], provide specific guidance on the design of HHSs. Research published prior to the release of the first edition of CSA Z8000 in 2011 [33] showed that droplets from HHSs could travel more than 1 m from the sink edge, contributing to contamination of the health care environment and health care-associated infections [12].

CSA Z317.1:21 specifies a number of HHS design features (Table 1) [32]. The standard includes many design requirements that aim to reduce the potential for contamination and biofilm formation by reducing the likelihood of soiled hands coming into contact with the sink basin, hands-free faucet controls, and by encouraging the use of surfaces that are easy to clean and disinfect [32]. The design requirements also aim to minimize splash generation from HHSs by incorporating deeper basins, offset faucets and drains, bevelled edges, and requiring the HHS to be a stand-alone fixture. A 1 m splash zone from the edge of the sink basin in all directions must be kept clear of patients, clean work surfaces, equipment, supplies, and care items to prevent these items from being exposed to splash or spray from the sinks, which may result in contamination [30], [32]. For the purposes of this report, the sink splash zone is defined as the floor space extending in all directions around the HHS and is distinct from splash on adjacent vertical surfaces.

Despite advances in sink and faucet technology and the introduction of enhanced design requirements within CSA Z8000 and CSA Z317.1 aimed at reducing splash from HHSs, it remains unclear whether sinks that meet current requirements still necessitate the traditionally recommended 1-metre splash zone. Early evidence supporting the 1-metre requirement was based on sink designs from before the adoption of deeper basins, offset drains, no-overflow construction, and other improvements intended to limit splash dispersion. Consequently, there is insufficient contemporary empirical data to determine whether current sink and faucet configurations produce splash patterns that justify maintaining, reducing, or redefining the required splash radius. Given this uncertainty, research is needed to quantify splash dispersion around sinks and faucets that meet current CSA Z8000 and Z317.1 standards and to provide evidence-informed recommendations for splash zone distances and related installation parameters, such as backsplash and side splash dimensions.

1.4 Objectives

The objectives of this research project were:

1. To conduct a comprehensive literature review, environmental scan, and a review of national and international standards and guidelines to provide

Table 1: Summary of HHSs design features from CSA Z3171:21 [32]

Fixture	Requirements and recommendations
Sink basins	▪ Wall-mounted, not set into a counter ▪ Made of non-porous material that withstands routine disinfection ▪ Interior dimensions of at least 350 mm x 250 mm (14 x 10 in) ▪ Depth of at least 225 mm (9 in) ▪ Narrow outer rim ▪ Outer rim angled toward the interior of the basin ▪ Does not have an overflow ▪ Not able to accommodate a stopper ▪ May have a removable drain cover ▪ Basin shape prevents pooling of water ▪ Compatible with a flow rate of 5.7 L/min (1.5 US gal/min) faucet
Faucets	▪ Non-aerated ▪ Free from modulators, rose sprays, and outlets that increase the risk for biofilm formation ▪ Internal means of achieving a flow rate of at least 5.7 L/min (1.5 US gal/min) ▪ Fixed, does not swivel ▪ Hands-free controls ▪ Does not direct water onto the sink drain

an integrated analysis and to examine the splash zone for sinks installed in HCFs and other relevant settings.

2. To conduct physical testing and data analysis to determine the splash zone of droplets generated by handwashing and potential drain splash back in CSA-compliant HHSs. Splash was measured from both the faucet outlet and sink edge across multiple sink and faucet combinations.
3. To conduct human factors observations to describe user experiences across each sink and faucet combination.
4. To develop evidence-based recommendations for standardization requirements for the splash zone and other relevant sink and faucet installation parameters.

2 Methods

2.1 Literature review

2.1.1 Peer-reviewed publications

A structured literature review was conducted using a systematic approach to identify peer-reviewed literature published from 2000 to the present that investigated the splash zone associated with HHSs in health care settings. Search strategies were developed for Medline, Embase, and Web of Science, incorporating terms related to sinks, faucets, water outlets, plumbing fixtures, health care environments, hospital design, water quality, biofilms, aerosols, and droplets. Searches were limited to English-language publications, with database-specific filters applied to ensure relevance to clinical and environmental infection control contexts.

The review included studies that investigated splash and spray from HHSs in laboratory settings and publications reporting HHS design or splash as a contributor to the transmission of infectious organisms in the health care setting. Articles investigating scrub sinks and non-clinical sinks, such as lavatory sinks, were excluded.

Data from the literature review were extracted using a two-reviewer approach in Covidence, a web-based systematic review management tool, to ensure accuracy and consistency. Studies were categorized by setting: health care facility or controlled environment. Health care facility was defined as a hospital, clinic, or long-term care facility, excluding home care, assisted living, and community care settings. Controlled environment was defined as a simulation space or laboratory where patient care was not conducted.

Further categorization of study methodology included experimental studies and outbreak/transmission investigations. Experimental studies included those that tested sink, basin, faucet, and drain, or other plumbing system characteristics under controlled or partially controlled conditions. These studies examined fixture function, water dynamics, and the effect of design on splash or contamination spread. Outbreak and transmission investigations included studies that examined a defined outbreak, cluster, or transmission event linked to sinks, drains, faucets, or associated water systems.

2.1.2 Grey literature

The grey literature search included national and international standards, guidelines, and other relevant documents that inform sink design requirements across various levels of government (e.g., provincial, national) and non-governmental organizations. Sources included standards development organizations, Canadian provincial health authorities, American national organizations such as the Facilities Guidelines Institute and the CDC, and documentation from other Commonwealth countries, including the United Kingdom and Australia.

2.2 Environmental scan

Manufacturers' websites, including American Standard, Best Sheet Metal Inc, BOSCO, Bradley Corp, Contrac, Elkay, Franke, OMCAN, Sloan, Tarrison, Whitehall, and Willoughby, were examined to identify sink basins potentially suitable for health care settings. Faucet manufacturers' websites, including American Standard, Chicago Faucet, and Zurn, were reviewed.

The images and specification sheets of all the identified sinks and faucets were evaluated by visiting the respective manufacturers' websites. Sinks and faucets that did not meet the inclusion criteria were excluded. Only wall-mounted sink basins were included; faucets without wrist blades, knee controls, foot pedals, or automatic sensors were excluded. Following initial data extraction, each sink and faucet included in the dataset was independently reviewed by another research team member to ensure accuracy and consistency. Items subsequently found not to meet inclusion criteria were removed from the dataset and recorded separately.

2.3 Splash study

2.3.1 Overview

A splash study was conducted to investigate droplet dispersion across nine combinations of three selected sinks and three faucets commonly used in Canadian HCFs. Participants washed their hands at three combinations to simulate real-world handwashing at an HHS in the health care setting using the Public Health Ontario handwashing methodology [34]. Glo Germ™, a non-toxic fluorescent cream, was used on participant hands and sink drains to help visualize splash generated by handwashing. The droplet that was farthest from the faucet outlet was identified on three surfaces: the backsplash where the sink is mounted, side splash wall next to the sink, and the floor. For the backsplash and side splash wall, coordinates were measured relative to the nearest wall and the floor. Floor coordinates were measured from the backsplash and side splash wall. Participants completed a short survey and interview after using each sink and faucet combination to help evaluate human factors associated with handwashing at HHSs.

The splash studies were conducted over the span of three weeks, with faucets rotated between sinks during this period. Splash study design was optimized through consultation with a statistician. A different group of participants was recruited for each week. The minimum number of participants required for statistical significance was five; however, eight

participated in weeks one and two, and nine in week three. As participants could not commit to all three weeks, each was randomized and restricted to a single session. Across the three weeks of data collection, 25 participants completed 75 handwashing trials, with each participant washing their hands once at each of the three sink and faucet combinations (Figure 1).

Figure 1: Splash study overview showing weekly participant counts and sink and faucet combinations.



Each participant was scheduled for a block of time to independently take part in the study. This mitigated the risk that their experience, survey, and interview responses would be influenced by other participants. Participants were randomized to different starting combinations to counterbalance ordering bias.

Specific details of the splash study design are described below. See Appendix A.1 for a simple diagram of the splash study cubicles.

2.3.2 Sink basins

Three sinks that aligned with the requirements of CSA Z8000 and CSA Z3171:21 were selected to represent different basin shapes and designs with offset drains commonly used across Canada.

- Franke clinical wash trough sink (model HWS1414P-00) was selected to represent a **"trough sink"** with a rectangular basin shape.
- Franke Nightingale sink (model AHWSS1720W-00) was selected to represent a **"barrier-free sink"** with a central ridge that was previously identified as a splash reduction design feature.
- American Standard infection control wall-hung EverClean (model 9118.111) was chosen to represent a **"deep rounded sink"**.

2.3.3 Faucets

Although CSA Z8000 and CSA Z3171:21 standards do not require deck-mounted faucets, they were selected for their compatibility with all three sink models. Since the faucets included in the splash study were all gooseneck faucets, the models were selected to compare types of hands-free controls (i.e., wrist blade and automatic sensor faucet) and faucet outlet heights. The gooseneck radius refers to the distance between the vertical portions of the faucet.

- Chicago Faucet wrist blade control faucet (model 50-GN2FC317XKABCP) with a faucet outlet height of 244 mm above the sink edge and radius of 133 mm. Though CSA Z3171:21 requires a minimum wrist blade length of 150 mm (6 in), the Research Advisory Panel approved this model, which has 102 mm (4 in) wrist blades, since it was the only available wrist-bladed

single-hole faucet option available at the time of the study. Of note, this faucet had an unusual wrist blade configuration where wrist blades were rotated vertically instead of horizontally. This faucet is referred to as **"wrist blade"** throughout the report.

- Chicago Faucet automatic sensor faucet (model H-G61K-13ABCPT) with a faucet outlet height of 241 mm above the sink edge and radius of 152 mm. This faucet is referred to as **"tall automatic"** throughout the report.
- Chicago Faucet automatic sensor faucet (model 116.427.AB.T1) with a faucet outlet height of 197 mm above the sink edge and radius of 133 mm. This faucet is referred to as **"short automatic"** throughout the report.

2.3.4 Sink and faucet setup

The Facilities Maintenance and Engineering team built a self-contained cubicle for each sink to provide a controlled handwashing environment (Figure 2). The sink edge was installed at an 865 mm height to align with accessibility and infection prevention and control (IPC) requirements [30], [32]. The centre point of each sink basin was positioned 460 mm from the nearest wall in accordance with barrier-free requirements [35]. The drain was positioned away from the nearest wall to allow drain-related droplets to travel without obstruction. At least 1100 mm of clear space was provided on the drain side of the sink to meet the 1m splash zone requirement [31], [32]. A wall height of 2100 mm was selected to meet minimum backsplash height recommendations from CSA Z8000:24 [30].

The floor was lined with black craft paper, and the interior walls were lined with black plastic sheeting and Coroplast. The paper was replaced, and the interior walls were cleaned after the week's participants had finished.

2.3.5 Participant recruitment

An ethics proposal was submitted to and approved by the University of Calgary Conjoint Health Research Ethics Board (REB25-1468) prior to participant recruitment. Consenting participants were trained in proper handwashing technique using the Public Health Ontario methodology [34]

Figure 2: Photos of week 1 splash study cubicle setup with trough sink, barrier-free sink, and deep rounded sink from left to right.



which was observed and validated by an infection control professional or a research team member.

To protect the skin integrity of the participants and standardize handwashing across participants, each handwashing event was timed by an assistant to approximately 30 seconds. The assistant cued the participant to begin rinsing after 15 seconds of lathering and to finish handwashing at 30 seconds. The assistant guided hand placement within the basin and provided real-time feedback if the participant deviated from the methodology.

2.3.6 Combined hand and drain splash study

A combined visualization of splash from participant hands and drains was completed using Glo Germ™ [36] to allow visualization of splash under black light. Glo Germ™ oil (bright orange) was applied to the drain strainer, and Glo Germ™ gel (brilliant blue-white) was used on participants' hands (Figure 3). This enabled differentiation between the two splash sources. Prior to participant involvement, the research team completed an exercise to evaluate how much Glo Germ™ needed to be applied to hands by applying varying amounts, completing handwashing, and qualitatively assessing the fluorescence of the resulting splash. The team determined that a quarter-sized amount would be applied to participants' hands.

Figure 3: Orange Glo Germ™ oil on drain strainer and blue-white Glo Germ™ gel on participant hands at the barrier-free sink.



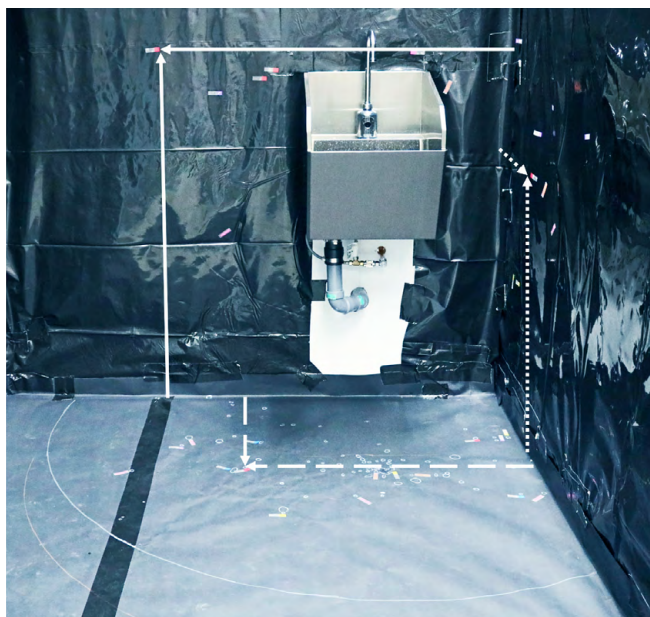
The process for each participant was as follows:

1. 5 mL of Glo Germ™ oil was applied to the drain strainer using a plastic measuring cup.
2. A quarter-sized amount of Glo Germ™ gel was applied to the participant's hands immediately before handwashing.
3. One 30-second handwashing event with soap and water was completed.

4. The participant's gown was photographed under black light to identify any drain-related splashes.
5. All fluorescent droplets on the side splash wall and backsplash were marked with colour-coded stickers to differentiate between participants. The farthest floor droplet was marked with a colour-coded sticker, and all droplets were circled with a marker.
6. Steps 1 through 5 were repeated for each sink and faucet combination.

Measurements of the farthest fluorescent droplet for each participant on each surface were documented (Figure 4). Each droplet had two measurements, which served as coordinates.

Figure 4: Measurements taken to determine farthest droplet on the floor (dashed line), backsplash (solid line), and side splash wall (dotted line).



The horizontal measurements for the backsplash and side splash wall were taken from the corner nearest the HHS; the vertical measurements were taken relative to the floor. Measurements on the floor were taken relative to the backsplash and side splash walls. Where the farthest droplet was not easily identifiable, up to four droplet coordinates were recorded, and the farthest was determined during analysis.

2.3.6.1 Recording equipment and data storage

Handwashing was recorded using a smart phone mounted above the sink to visualize potential drain-related splash. A DSLR camera was used to photograph overall splash patterns at the end of each week. These files were transferred to a secure SharePoint site and did not contain any identifying information.

2.3.7 Human factors

2.3.7.1 Surveys

Each participant completed a demographics survey before beginning the simulations.

After washing their hands at each combination, participants completed a survey via REDCap. This included two validated tools—the System Usability Scale (SUS) and the Single Ease Question (SEQ)—as well as an open-ended question for participants to note any additional thoughts (Appendix A.2 and A.3). The survey took approximately 3 minutes to complete.

2.3.7.2 Semi-structured interviews

Following the survey, a semi-structured interview was conducted to better understand participants' experiences using the sink and faucet combination. This interview explored positive experiences and potential barriers to use and took approximately 5 to 7 minutes to complete. Field notes were collected by the moderator.

2.4 Data analysis

2.4.1 Statistical analysis of splash

Each participant's farthest splash measurements were used as coordinates to map splash patterns. For the backsplash and side splash wall, analysis included the highest droplet relative to the floor and the droplet that travelled farthest horizontally along the wall. For the floor, the farthest droplet from both the backsplash and side splash wall was included. The Pythagorean theorem was used to calculate the straight-line distance from the faucet outlet to the droplet across all three surfaces.

Linear mixed-effects regression was performed in R to analyze the farthest splash measurements for each surface: side splash wall, backsplash, and floor.

This method enabled comparison of splash distances across sinks, faucets, and their combinations. Participant identifiers were included to account for individual variation. When a statistically significant difference was detected ($p < 0.05$), a Tukey post-hoc test was applied to the estimated marginal means to clarify where differences occurred. For example, if a significant difference was detected among sinks, the Tukey test compared each sink pair to determine whether differences were consistent across all sinks or limited to specific pairs.

Splash density plots were created using the ggplot2 graphics package in R to visualize the spatial distribution of droplets. Each point represented a single droplet measurement. A smoothing function was applied to highlight areas of high measurement density, represented by warmer colours ranging from yellow to red.

2.4.2 Human factors analysis

2.4.2.1 Thematic analysis

Semi-structured interviews and qualitative survey responses were analyzed using thematic analysis. An inductive coding approach was used, grouping related concepts into categories and synthesizing these categories into overall themes for each sink, faucet, and combination [37].

2.4.2.2 Quantitative survey responses

SUS responses were scored according to standard procedures, yielding a total score from 0 to 100 for each sink and faucet combination. Higher scores indicate greater perceived usability. SEQ responses were averaged to assess perceived ease of hand hygiene for each sink and faucet combination. SUS and SEQ scores were compared to evaluate consistency between task ease and overall usability.

3 Results

3.1 Literature review

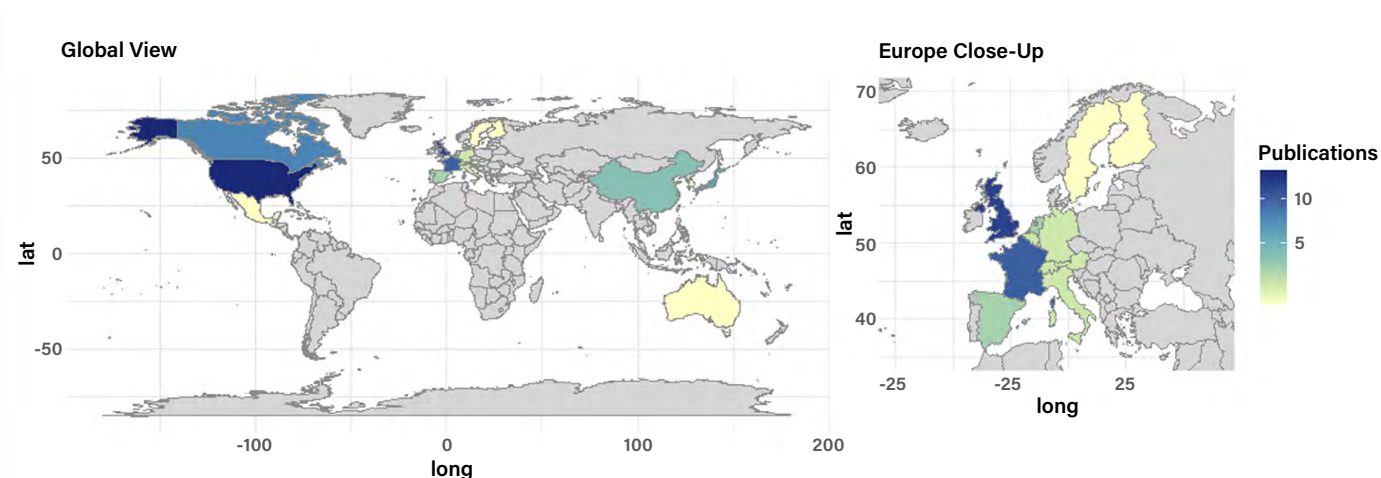
3.1.1 Peer-reviewed literature

A search of three databases returned nearly 4500 studies. Following title and abstract screening, 335 articles were assessed for inclusion. Of these, 80 studies met the inclusion criteria.

The included publications were from 22 different countries and the number of publications per country are visualized in Figure 5. The five countries with the highest number of publications were the United States ($N = 14$), United Kingdom ($N = 12$), France ($N = 10$), Canada ($N = 8$), and Japan ($N = 6$).

Three-quarters of publications took place in HCFs. More than half of the publications reported on

Figure 5: Count of publications included in the HHS splash literature review, by country.



outbreaks or transmission associated with HHSs in patient care areas ($N = 47$). The remaining publications were evenly split between experiments conducted in controlled environments such as laboratories ($N = 17$) and studies examining HHS-related contamination in health care settings ($N = 16$).

3.1.1.1 Splash zone

Almost one-third of studies documented splashing from HHSs: 12 experimental studies conducted in controlled environments and 13 studies focusing on outbreaks or transmission events. However, only six studies reported the distance that droplets travelled (Table 2) [12], [28], [29], [38]–40].

Aranega-Bou et al. [38] compared splash generation from two models of sinks: a HHS with a rear drain and a utility sink in which water fell directly onto the drain. The drains were contaminated with an antimicrobial-resistant organism, and water was run for two 30-second intervals. This was completed under normal drainage conditions and slow drainage

conditions, where water was allowed to pool in the sink basin. Bacteria were detected by air sampling and settle plates only when water fell directly onto the drain under slow drainage conditions. In this case, bacteria were cultured from settle plates placed up to 1 m from the drain [38]. These findings had limited applicability to HHSs since the higher-splash sink was a utility sink rather than a hand hygiene sink; however, the splash findings were nonetheless consistent with other HHS studies that did not report farthest droplet measurements [39], [41], [42].

Another study used fluorescently marked *E. coli* to trace the spread of bacteria along the shared drainage system of five sinks and evaluated how droplets could carry bacteria and fluorescent markers from the strainer and sink basin surface [39]. Although water may have fallen directly onto the strainer, the study used an offset drain, in which the p-trap is positioned away from the drain opening. When *E. coli* was introduced into the drain 100 mm (4 in) below the strainer and the water was run for five minutes, there

Table 2: Summary of peer-reviewed publications that reported splash zone measurements related to HHSs

Study	Country	Setting	Study design	Distance of farthest splash	Reference point for measurements
Aranega-Bou et al. (2019) [38]	United Kingdom	Controlled environment	Experimental	1 m	Drain
Hota et al. (2009) [12]	Canada	Health care facility	Outbreak investigation	At least 1 m	Not specified
Kotay et al. (2017) [39]	United States	Controlled environment	Experimental	762 mm (30 in)	Drain
Yui et al. (2019) [28]	United Kingdom	Controlled environment	Experimental	2020 mm	Centre front of the basin
Pirzadian, et al. (2022) [40]	The Netherlands	Controlled environment	Experimental	Up to 150 mm with a drain cover and up to 160 mm without a cover	Drain
Tian et al. (2024) [29]	China	Health care facility	Experimental	Sink A: 1200 mm horizontally and 600 mm vertically Sink B: 1400 mm horizontally and 800 mm vertically	Faucet outlet

was no evidence of contamination inside the basin or surrounding countertop. However, when water pooled on the strainer, this resulted in contamination of the sink basin [39]. Dispersion of bacteria and fluorescent markers occurred only when the strainer or basin was contaminated, with the farthest detectable *E. coli* reaching 762 mm (30 in) from the strainer.

In a 2019 follow up to their 2017 study [39], Kotay et al. used the same sink configuration, which included mannequin hands to simulate disruption of water flow during handwashing [43]. They found contamination of the sink counter, vertical splatter shield, faucets and handles when the sink drain and drain line were contaminated. The authors supported a 1 m splash zone around HHSs but did not report specific measurements.

In contrast to Kotay et al., Yui et al. [28] evaluated three HHS designs: basins A and B were rectangular, and basin C was oval. Unlike the typical water-repelling sink glaze, basin A featured a water-attracting glaze along with an additional splash reduction design feature. This study added fluorescent dye to the water, and water was either run for 30 seconds or handwashing was completed by a nurse. Droplets from all three basins travelled more than 1 m, from the front edge of each of the three sink basins ranging from 1290 to 2020 mm.

A Dutch study compared four HHSs and a patient lavatory sink with and without a drain cover [40]. Sink 1 was a circular, flat-bottomed stainless-steel HHS, sink 2 was an oval ceramic, curved-bottom HHS, sink 4 was a rectangular, flat-bottomed stainless-steel sink from a soiled utility room, and sink 5 was a circular, flat-bottomed stainless-steel sink from an isolation room's anteroom. Sink 3 was the patient lavatory sink so it did not meet HHS criteria. Fluorescent dye was applied to the p-trap, tailpiece, or drain and water was run for 120 seconds for five repetitions. No fluorescent splash was visualized when the p-trap or tailpiece were dyed. When the drain was dyed, sink 4 generated the most splash, which was attributed to water falling directly onto the sink drain. Drain covers generally reduced both the number and travel distance of droplets: only one repetition of flushing



generated droplets that were 80 and 60 mm from the drain for sinks 1 and 2 respectively, while sink 4 had three instances of splash at 60 mm, 60 mm, and 150 mm from the drain. Without drain covers, splash occurred more frequently and travelled up to 160 mm from the drain; however, sink 5 generated no visible fluorescence outside of the sink basin when used.

The most recent publication of the included literature measuring the distance of the farthest splash was published by Tian et al. in 2024 [29]. The researchers placed paper that changed colour when exposed to water around two HHSs in an active surgical ICU. The paper was left there for 72 h and then the splash patterns were analyzed. The authors describe the two sinks as sink A and B. Sink A had a short-handled faucet with 220 mm between the faucet outlet and sink basin bottom, while sink B had a long-handled faucet with 330 mm between the faucet outlet and sink basin bottom. Sink A had horizontal splashing up to 1700 mm and vertical splashing of up to 900 mm from the faucet outlet. Sink B had similar maximum horizontal splash, while vertical splash reached up to 1500 mm. Sink B had greater concentration of splash at a farther distance than Sink A. They found that the splash patterns were significantly associated with

the distance between the faucet outlet and the sink basin: the basin with 330 mm between the faucet outlet and basin bottom generated more splash travelling farther than the basin with 220 mm. The researchers reported that the area between 400 and 800 mm from the faucet outlet was at highest risk of contamination by splash and that a 1 m splash zone should be maintained around the faucet outlet.

Taken together, these six studies suggest that droplets from HHSs can travel beyond 1 m, though findings vary considerably by sink design, faucet type, and testing methodology.

3.1.1.2 Hands-free faucet operation

Ten studies reported bacterial contamination of internal faucet components, water samples, or both [31], [44]–[52]. Several hands-free faucet design features were associated with increased contamination (Table 3). Although aerators and flow straighteners are faucet components, they are discussed in the following section; this section focuses on differences in water supply between automatic sensor and manually controlled faucets.

In one ICU, sinks were fitted with both manual and automatic sensor faucets at the same basin, sharing

Table 3: Internal component contamination and contaminated water samples from hands-free faucets

Design features	Hands-free control comparison	Evidence
Volume of stagnant water from TMV to faucet outlet	Automatic sensor with temperature control vs automatic sensor without temperature control	Faucets with larger volumes of stagnant water were more likely to support bacterial growth: - Automatic sensor faucets without temperature control were significantly more likely to culture <i>P. aeruginosa</i> than those with temperature control [31], [44]. - One study noted that the amount of stagnant water in faucets with temperature control was 10 mL while those without had 30 mL [31].
Temperature of stagnant water in the faucet	Automatic sensor, manual	Warmer temperatures supported bacterial growth: - When automatic sensor faucets were turned on, the average water temperature was 27.9 °C compared to 24.5 °C for manual faucets [44]. This study also cultured <i>Legionella</i> from all 23 automatic sensor faucets but only 3 of 7 (42%) manual faucets. - Automatic sensor faucets with a 10-second cold-water after-use flush had significantly lower <i>P. aeruginosa</i> contamination when compared to faucets without an after-use flush with a 2-second after-use flush, or with a 30-second pre-use flush [49]. The 10-second after-use flush likely replaced warm water within the faucet with cold water.
Complex components	Automatic sensor faucet	Automatic sensor faucets often had contamination of multiple components: - Two automatic sensor faucets cultured <i>Legionella</i>, bacteria and fungi before and after hyperchlorination [50]. - Another study reported that the magnetic valve, mixing device, and outlet were all contaminated by <i>P. aeruginosa</i> [44]. - Automatic sensor faucets were more likely to have contamination of at least one component by <i>P. aeruginosa</i> than manual faucets [52]. Complex flow straighteners may have contributed to this result. Magnetic/solenoid valve materials conducive to bacterial growth [44], [48]. - When solenoid valves were removed and replaced in automatic sensor faucets that were contaminated with <i>P. aeruginosa</i>, this immediately restored water quality in one experimental model [31].

the same water supply [47]. Although only four sinks had this dual-faucet configuration, three of the four automatic sensor faucets were contaminated with *P. aeruginosa* while none of the manual faucets were. The authors found that the water supply upstream of the TMV was not contaminated, suggesting that the contamination originated between the TMV and the faucet outlet. A simplified diagram of automatic sensor faucet parts is provided (Figure 6).

In the broader study, 92 automatic sensor faucets and 135 manual faucets were evaluated [47]. Automatic sensor faucets were significantly more likely to be contaminated than manual faucets. Other studies similarly reported automatic sensor faucet contamination in the absence of cold- and hot-water supply contamination, including *A. baumannii* in an ICU setting [51] and *P. aeruginosa* in a two-year experimental study [31].

One study reported more frequent contamination of manual faucets than automatic sensor faucets [46]. The authors compared three types of faucets: four automatic sensor faucets with built-in temperature

controls, four automatic sensor faucets without temperature controls, and four manual faucets. Manual faucets were more likely to have biofilm than automatic sensor faucets; however, the small sample size limits the conclusions that can be drawn. Additionally, faucets with the built-in temperature controls had significantly lower contamination than both automatic sensors without temperature controls and manual faucets. Differences in faucet age and location may have contributed to these findings. Faucets with temperature controls had been installed two years prior to the experiment, while the other faucets had been in place for 10 years with original aerators and no cleaning or maintenance. The faucets also differed in location: those with temperature controls were installed in outpatient areas, while the others were located on a surgical inpatient unit.

3.1.1.3 Other hand hygiene sink components

Drain contamination and associated infections have been well established by the literature and were discussed in the introduction. Beyond drain contamination, many studies reported component

Figure 6: Simplified diagrams of automatic sensor faucets with (left) and without temperature controls (right). Not to scale. Electrical wiring is omitted except for connections between solenoid valves on the hot- and cold-water supply lines in the temperature-controlled faucet.

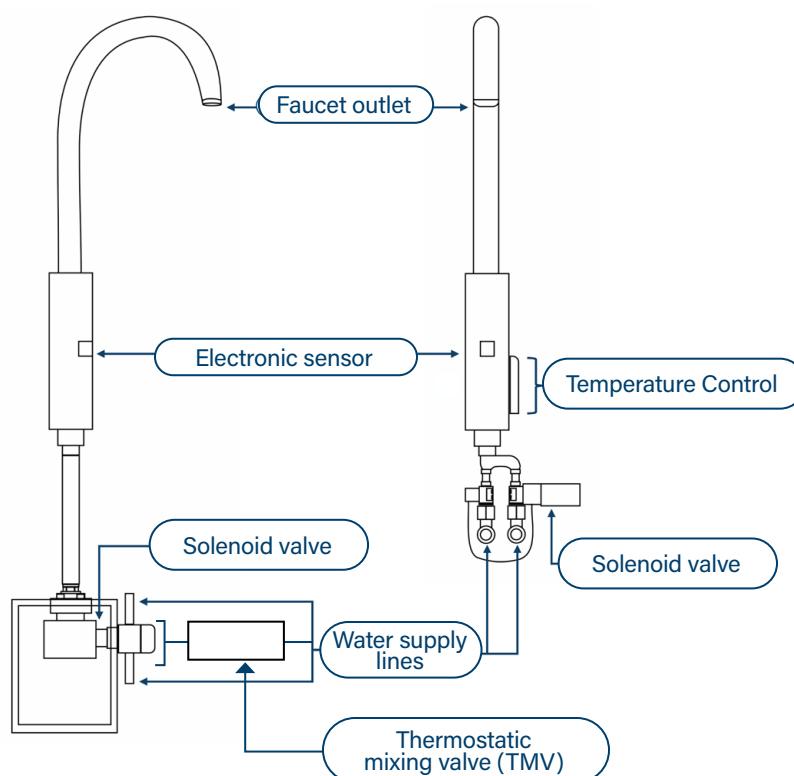


Table 4: Reports of HHSs component contamination and design features associated with increased or reduced contamination and splash

HHS component	Summary of findings from peer-reviewed literature
Aerator	- Aerators were contaminated by <i>S. marcescens</i> [53], [54], <i>P. aeruginosa</i> [53], [55], <i>A. baumannii</i> [14], <i>Mycobacterium mucogenicum</i> [56], and <i>Mycobacterium chimera</i> [57]. - Some studies reported no aerator contamination during outbreak or transmission events [19]. - When drains were contaminated, aerators were not always contaminated [58], [59]. - The presence of an aerator was associated with increased likelihood of culturing <i>P. aeruginosa</i> from tap water [31]. - Approximately one-third of aerators in ICUs were contaminated with <i>P. aeruginosa</i> and other waterborne non-fermenting Gram-negative bacteria [60].
Flow straightener	Flow straightener became contaminated when water systems were contaminated [61]. Complex designs were associated with higher bacterial contamination than simpler designs [52], [61].
Point-of-use filter	Point-of-use filters successfully removed bacterial contamination from faucet water supplies [41], [61]–[63].
Drainage	Slow drainage increased the risk for splash generation [39], [42], [64].
Offset drain	Drains where water fell directly onto drains were associated with increased splash risk [15], [39], [40], [60], [65], [66].
Self-cleaning drain	Self-cleaning drains showed variable effectiveness: - Reduced bacterial aerosols from sinks [21]. - Initial reduction in contamination followed by recolonization over time [54], [67]. - Contamination persisted when patients were colonized with or infected by <i>P. aeruginosa</i> [67]. - No sustained effect in some studies despite disinfection mechanisms [68]. - Disinfection mechanisms became ineffective once colonization occurred [69]. These systems were costly (USD 2,300 to 3,000 per unit) [67], [68].

design features, optimal configurations, and component-related patient infections (Table 4).

Several studies cultured bacterial specimens from aerators and compared them to clinical specimens from patients. In one case, patients were infected by *S. marcescens*, but the patient and drain bacterial specimens were not genetically identical, meaning the infection was not related to the aerator [70]. Many patient cases were genetically similar or identical suggesting aerator-related patient infections [14], [53], [55]–[57]. One publication reported that the patient, aerator, and drain specimens were genetically related [54].

Point-of-use filters reduced the number of infections with Gram-negative water-associated bacterial species such as *P. aeruginosa* [41], [71] and have been effective at removing *Legionella* [71]. They were successfully used as interventions when the water system became contaminated by *P. aeruginosa* or when faucet outlets

became contaminated by *P. aeruginosa*. However, they can be cost-prohibitive and require additional maintenance [62], [72]. One study successfully shifted from using filters to faucet outlets that could be disinfected by a thermal washer disinfectant accompanied by a regular disinfection schedule [72]; however, this would not be a viable risk mitigation strategy if *P. aeruginosa* or *Legionella* were contaminants in the water system itself.

3.1.2 Grey literature

After searching Canada's Drug Agency Grey Matters tool, which returned no results, searches were conducted on the websites of selected professional bodies and health authorities in Australia, Europe, the United Kingdom, Canada, the United States, and other international organizations. Thirty-three of the 65 sources identified were included in the review; a PRISMA flow diagram is provided in Appendix B.

Fifteen publications (45%) recommended maintaining clear space around HHSs to reduce the risk of splash and spray contamination. The language was often general, with several sources recommending only that sufficient distance be maintained without specifying whether measurement should be taken from the basin edge or faucet outlet, and several sources mentioned only that there should be sufficient or adequate distance from the HHSs [73]–[75]. The smallest recommended splash zone was approximately 0.9 m (3 feet) [27] and the largest was 2 m [76]–[80] (Figure 7). Recommendations from Australia [78]–[80], Ireland [76], and the United Kingdom [77] generally required 2 m of clear space around HHSs. Canadian [81]–[83] and American [6], [27], [84] recommendations required approximately 1 m. One Irish online resource recommended a range of approximately 0.9 to 1.8 m (3–6 feet) [85].

Thirteen technical standards and guidance documents from seven organizations were reviewed in depth, including from the CSA Group [30], [32], international publications from the Total Alliance Health Partners International (TAHPI) [86], [87] and the WHO [8], the Australasian Health Infrastructure Alliance (AHIA) [80], the National Health Service (NHS) [88]–[92] from the United Kingdom, the Facility Guidelines Institute (FGI) [93]–[95] and the CDC [96] from the United States.

Only the Canadian standards [30], [32] and AHIA [80] specified a minimum distance measurement for the splash zone (Table 5). The Canadian standards required 1 m from the sink rim in all directions [30], [32] or 750 mm from the faucet outlet if supported by an infection control risk assessment [30]. The AHIA standard required that 1.2 to 2 m around the sink be kept clear of patients and patient equipment [80]. The CDC noted that medication preparation areas should be separated from sinks by approximately 3 feet but did not provide a specific splash zone requirement [96]. The remaining guidance documents focused primarily on water safety and design features to reduce splash risk and prevent microbial contamination [86], [88], [89]. All organizations except the CDC and WHO emphasized faucet and sink compatibility as a means of reducing splash [30], [32], [80], [86], [89], [92]–[95].

Guidance document recommendations for HHSs basins are summarized comparatively (Table 6). The WHO [8] and CDC [96] guidance documents were not included in this table since their design requirements did not include recommendations for sink design. TAHPI [86] and AHIA [80] outlined three different basin types. Type A sinks were clinical scrub sinks for sterile procedures outside of the operating room. Type C sinks were smaller, wall-mounted non-clinical basins used for handwashing in staff amenity and

Figure 7: HHSs splash zone distance recommendations from the grey literature review.

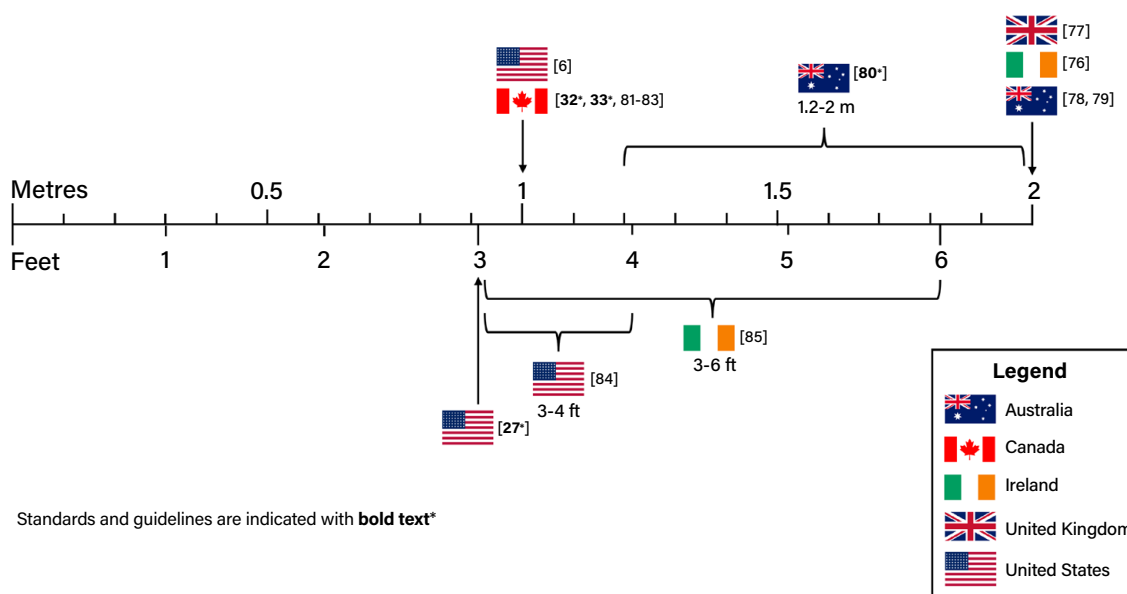


Table 5: Splash zone requirements from international health care facility design guidance documents

Guidance document	Splash zone distance	Notes
CSA Z8000:24 (Canada) [30]	At least 1 m from sink rim in all directions, or a splash barrier should be used	May be reduced to 750 mm from water stream if justified by an infection control risk assessment. Mock-ups and post-occupancy evaluations are recommended.
CSA Z317.1:21 (Canada) [32]	Same as CSA Z8000:24	Reiterates CSA Z8000:24 requirements; sinks must be wall-mounted and not adjacent to counters.
AHIA (Australia) [80]	1.2 to 2 m from patient bedspace and equipment	If not feasible, basin may be placed outside the room. Infection prevention and control (IPC) consultation required.
TAHPI (international) [86], [87]	No numeric distance; sink design must prevent splashing	Basin and tapware must be coordinated to avoid water discharge directly onto the drain or sink rim.
FGI (United States) [95]	No distance specified; HHSs should not be installed within 914 mm (36 in) of a toilet	Sinks must be designed to prevent splashing onto patient care, sterile preparation, or food/medication areas.
NHS (United Kingdom) [89]	No distance specified	Focuses on water safety, biofilm control, and outlet design to prevent microbial contamination and splash.
NHS (United Kingdom) [90]	No distance specified	Emphasizes design features and consultation with IPC teams to avoid splash risks.

domestic food preparation areas. Type A and type C sinks were excluded from the comparison. Clinical basins (Type B) were included as they most closely resembled the HHSs described in other guidance documents, being wall-mounted and intended for handwashing after patient care. The FGI outlined overarching design requirements for all handwashing sinks, including both clinical HHSs and lavatory sinks [93]–[95], and the NHS provided specific design requirements for clinical HHSs [88]–[91].

Overall, the AHIA guidance [80] and CSA Z8000:24 and Z317.1:21 requirements were most closely aligned [30], [32] while other organizations offered more general guidance focused on splash reduction. The FGI [93]–[95] diverged from CSA Z8000:24 and Z317.1:21 [30], [32], AHIA [80], the NHS [91], and TAHPI [86] by allowing HHSs to be mounted in a counter. TAHPI also allowed sinks to be installed in countertops in Section 2.3; however, wall mounting was specified for all HHSs under Section 2.4, making it difficult to interpret when counter-mounted sinks would be acceptable.

The NHS recommended sinks with the largest dimensions, ranging between 0.18 and 0.3 m² [91] while TAHPI [86] and FGI [93]–[95] provided

similar recommendations of a minimum width of approximately 230 mm and a minimum sink basin area of 0.09 and 0.1 m², respectively. Although not explicitly stated, the minimum sink basin dimensions in CSA Z8000:24 and Z317.1:21 are equivalent to approximately 0.09 m² [30], [32].

CSA Z8000:24 and Z317.1:21 recommend a minimum sink basin depth [30], [32]; most other standards provided recommendations based on the distance between the faucet outlet and sink basin bottom [86], [95] or the faucet outlet height relative to the sink edge [91]. Although AHIA did not provide specific measurements, it recommended sufficient basin depth to allow washing up to the elbows in clinical HHSs [80].

The various guidance documents centred on design features that reduced the risk of splashing and provided adequate space for handwashing. All organizations, in addition to various faucet selection criteria, required that water not fall directly onto the drain; faucet selection criteria are summarized (Table 7). The NHS recommended against gooseneck faucets due to concerns about post-use water stagnation [88] while other standards did not address faucet shape.

Table 6: Comparative summary of HHSs basin recommendations in health care facility design guidance documents

Sink features	AHIA [80]	CSA Group [30], [32]	FGI [93]–[95]	NHS [88]–[92]	TAHPI [86], [87]
Installation	Wall-mounted	Wall-mounted	Wall-mounted or in countertop, but not under-mounted	Wall-mounted	Wall-mounted
Sink material	Hard, non-scratch, cleanable	Non-porous, resistant to damage, cleanable	Porcelain, stainless steel, or solid surface	Not specified	Not specified
Minimum interior sink basin dimensions	Allows for appropriate handwashing technique	Designed to prevent recontamination of hands; recommends 350 x 250 mm	At least 228.6 mm and 0.09 m ²	500 x 350–420 mm or 600 x 400–500 mm	At least 230 mm and 0.1 m ²
Distance between faucet outlet and sink basin bottom	Sufficient clearance to allow elbow washing	Recommends basin depth of at least 225 mm	Minimum 254 mm between faucet outlet and basin bottom	150–200 mm between faucet outlet and upper sink edge	Minimum 260 mm between faucet outlet and basin bottom
Basin shape	Prevents pooling of water	Prevents pooling of water	Mentions oval shapes, rounded corners, and curved bottoms	Not specified	Not specified
Sink outer rim specifications	Not specified	Narrow outer rim angled toward interior of basin	Not specified	Not specified	Not specified
Overflow	No overflow	No overflow	Not specified	No overflow	No overflow
Drain covers/plugs	No integrated plugs or caps	Removable drain covers allowed No plugs	Not specified	No plugs	No plugs
Compatibility with faucet flow rate	Not specified	Compatible with 5.7 L/min (1.5 US gal/min) faucet	Not specified	Faucet pressure compatible with the basin to avoid splashing	Not specified

Table 7: Comparative summary of faucet recommendations in health care facility design guidance documents

Faucet features	AHIA [80]	CDC [96]	CSA Group [30], [32]	FGI [93]–[95]	NHS [88]–[92]	TAHPI [86], [87]	WHO [8]
Faucet installation	Usually wall-mounted	Not specified	Fixed (does not swivel)	Not specified	Wall-mounted	Wall- or basin-mounted	Not specified
Faucet outlet	Anti-splash fittings recommended	Aerators may be used but may become contaminated	Non-aerated; no modulators, rose sprays, or anti-splash fittings	Not specified	Advises against aerators, strainers, and flow restrictors	Advises against aerators and flow restrictors	Recommends aerators with wide mesh to reduce bacterial contamination
Faucet controls	Hands-free controls	Not specified	Hands-free controls; minimum wrist blade length 150 mm	Hands-free controls; minimum wrist blade length 102 mm	Hands-free controls preferred	Hands-free controls; automatic sensor faucets recommended	Hands-free controls preferred
Splash reduction	Does not direct water onto drain	Not specified	Does not direct water onto drain	Does not direct water onto drain	Does not direct water onto drain	Does not direct water onto drain	Not specified
Faucet clearance	Not specified	Not specified	Suitable clearance between spout and basin walls	Minimum 152 mm (6 in) spout reach	Not specified	Not specified	Not specified
Water flow	Consider laminar flow	Not specified	Laminar flow via internal means	Not specified	Smooth non-splashing flow	Not specified	Not specified
Flow rate	Not specified	Not specified	Minimum 5.7 L/min (1.5 US gal/min)	Adjust pressure to reduce splash risk	Typical 4.5L/min	Not specified	Not specified

The WHO [8] recommended mesh aerators with sufficiently open mesh to prevent water retention after the tap was turned off, thereby reducing the risk of bacterial contamination. The CDC [96] identified that aerators could become contaminated but advised that they could be used, recommending monthly cleaning and disinfection in high-risk patient care areas or those serving immunocompromised patients. The FGI did not provide direction on aerators [93]–[95].

In addition to aerator design, guidance documents also addressed the broader characteristics of water flow from faucet outlets. Smooth or laminar flow was identified as a key feature by AHIA [80], CSA Z8000:24 and Z317.1:21 [30], [32], and the NHS [88]. CSA Z8000:24 and Z317.1:21 [30], [32], TAHPI [87], and the NHS [88]–[90], [92] recommended against aerators, strainers, and flow-restricting outlets. AHIA recommended consideration of anti-splash fittings.

Aside from CSA Z317.1:21 [32], NHS Scotland was the only other organization to specify a flow rate [92]; it noted 4.5 L/min as typical in the context of water sample collection for testing. The NHS [89] and FGI [93]–[95] recommended adjusting water pressure to prevent splash rather than specifying flow rates.

In addition to flow characteristics, all organizations required hands-free controls [8], [30], [32], [80], [86], [88], [91], [93]–[95] except the CDC [96]. Single-lever faucet controls were not recognized as an accepted hands-free option in CSA Z317.1:21 or Z8000:24 [30], [32] but were included by AHIA [80], NHS [90], [91], and FGI [93]–[95]. Although automatic sensor faucets were widely accepted as hands-free controls, TAHPI was the only standard to specifically recommend them as the preferred faucet type for HHSs [86].

Despite their widespread acceptance, automatic sensor faucets were associated with contamination risks in several guidance documents. CSA Z317.1:21 [32], the NHS [88]–[90], and FGI [93]–[95] all noted the potential increased contamination of automatic sensor faucets or their association with patient infections. The NHS and FGI further recommended that an

infection control risk assessment be conducted before selecting and installing automatic sensor faucets in patient care areas. This risk assessment was also supported by the American Society for Healthcare Engineering and Association for Professionals in Infection Control and Epidemiology [97].

The NHS cautioned against installation of these faucets in augmented care areas serving severely immunocompromised patients, patients requiring organ support such as critical care, and areas such as burn units where patient care involves use of water on significantly breached skin [88], [90]. The NHS noted that the complex internal mechanisms of automatic sensor faucets and the pre-mixed water retained between the TMV and faucet outlet create conditions that may support *P. aeruginosa* colonization. The NHS and TAHPI recommended that these TMVs be fitted directly to the faucet or be integrated into the automatic sensor faucet design [87], [88], [90]–[92].

Beyond faucet selection, guidance documents also differed in their requirements for backsplash and side splash surfaces adjacent to HHSs. These requirements differed between CSA Z317.1:21 [32] and CSA Z8000:24 [30] due to separate updates and publication cycles, despite overlapping content. CSA Z317.1:21 required backsplashes and side splashes to extend 600 mm (24 in) above the sink rim and down to the cove base [32]. Backsplashes were also required to extend 300 mm (12 in) on either side of the sink, and side splashes were required on vertical surfaces within 300 mm (12 in) of the sink. CSA Z8000:24 differed by requiring backsplashes and side splashes to extend 2100 mm above the finished floor from the coved base [30]. Although the outward extension of backsplashes was unchanged, CSA Z8000:24 required side splashes on vertical surfaces within 1000 mm of the sink.

TAHPI required backsplashes to extend at least 310 mm above the sink edge [86], and all standards except the FGI mentioned that backsplashes should be constructed of water-resistant material [30], [32], [80], [88], [93], [94].

The placement of HHSs within the broader clinical environment was also addressed by some guidance documents. TAHPI [98] and AHIA [99] supported the placement of HHSs within a bay or alcove. Both organizations specified a depth of 600 mm and width of 1000 mm. TAHPI required vinyl wall protection up to 1500 mm above the floor, approximately 635 mm above the sink edge [98]. AHIA required wall protection to 1,200 mm on the backsplash and side walls, approximately 335 mm above the sink edge [99].

3.2 Environmental scan

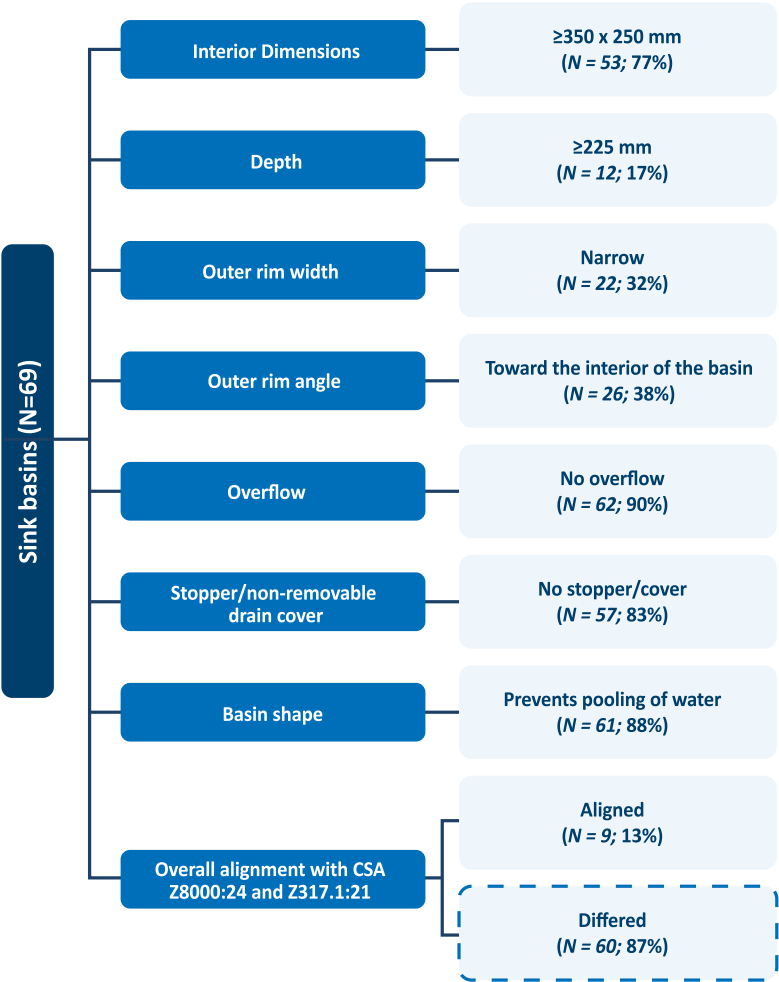
3.2.1 Sink basins

A total of 69 sinks from 12 brands were reviewed. The 69 sinks represented distinct models across four

materials: fine fireclay (*N* = 3), solid surface (*N* = 12), stainless steel (*N* = 39), and vitreous china (*N* = 15). Of these, 28 (41%) sinks had an offset drain, 38 did not (55%), and drain replacement was unknown for three (4%). Basins were compatible with deck (*N* = 41; 59%) or wall-mounted faucets (*N* = 15; 22%), with some compatible with both (*N* = 13; 19%).

Nine sinks (13%) aligned with CSA Z8000:24 and Z3171:21 criteria for sink selection (Figure 8). These sinks were from the following brands: American Standard (*N* = 1), BOSCO (*N* = 1), Bradley Corporation (*N* = 1), Contrac (*N* = 1), Franke (*N* = 3), and Whitehall (*N* = 2). Eight featured an offset drain, while one required pairing with a compatible faucet to ensure water did not fall directly onto the drain.

Figure 8: Summary of sink basin design features highlighting elements that aligned or diverged from CSA Z8000:24 and Z3171:21 recommendations.



3.2.2 Faucets

A total of 147 hands-free faucets from three brands were reviewed: American Standard ($N = 37$), Chicago Faucet ($N = 43$), and Zurn ($N = 67$). Of these, 145 were deck-mounted and two were wall-mounted. Most featured wrist blade controls ($N = 83$), with the remainder having automatic sensors ($N = 64$). Eight wrist-blade faucets (11%) had 6-inch blades, while 75 (90%) had 4-inch blades. Sixty-six (45%) were gooseneck models and 81 (55%) were non-gooseneck. The height of the faucet outlet relative to the sink edge ranged from 34 mm to 261 mm. Gooseneck faucet radii ranged from 89 to 305 mm.

Of the 147 faucets, only 12 (8%) met all CSA Z8000:24 and Z317.1:21 [30], [32] design requirements (Figure 9). All of these faucets were goosenecks, of which eight (67%) were automatic sensors and four (33%) had 6-inch wrist blades. Zurn was the only included manufacturer that offered 6-inch wrist blade handles. Faucets with 4-inch wrist blades

were available from American Standard ($N = 3$), Chicago Faucet ($N = 1$), and Zurn ($N = 13$).

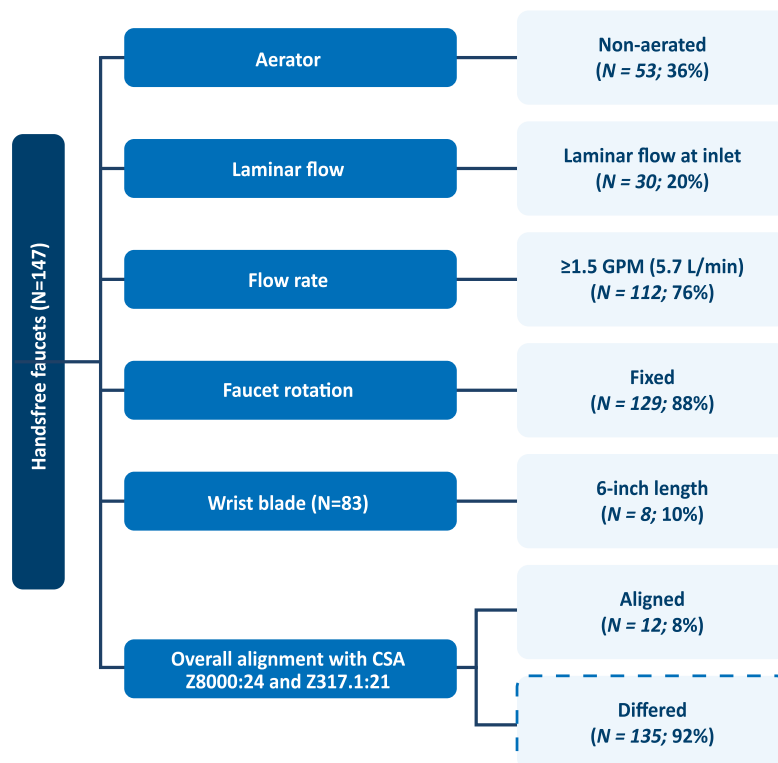
All three manufacturers had models with above-deck mixing, where the TMV was built into or installed directly below the faucet ($N = 15$): Zurn had one model, Chicago Faucet had five, and American Standard had nine. Only two Chicago Faucet models with above-deck mixing aligned with CSA Z8000:24 and Z317.1:21 recommendations [30], [32].

3.3 Splash study

3.3.1 Reporting of farthest droplet

Reference points for the farthest droplet distance measurements were specific to the surface (Figure 10). Since sink dimensions varied and faucet outlet height and spout reach differed slightly, these reference points helped to standardize farthest droplet measurements to support comparisons across combinations. The reference points for horizontal

Figure 9: Summary of hands-free faucets design features highlighting elements that aligned or diverged from CSA Z8000:24 and Z317.1:21 recommendations.



distance, vertical distance, and splash zone radius are explained in the following subsections.

3.3.1.1 Farthest droplet distance on the floor

As described in Section 2, original measurements were used to calculate the farthest droplet from the faucet outlet. Since sinks varied in shape and size, the faucet outlet served as a reference point for comparing floor droplet measurements across all combinations.

3.3.1.2 Vertical farthest droplet distance

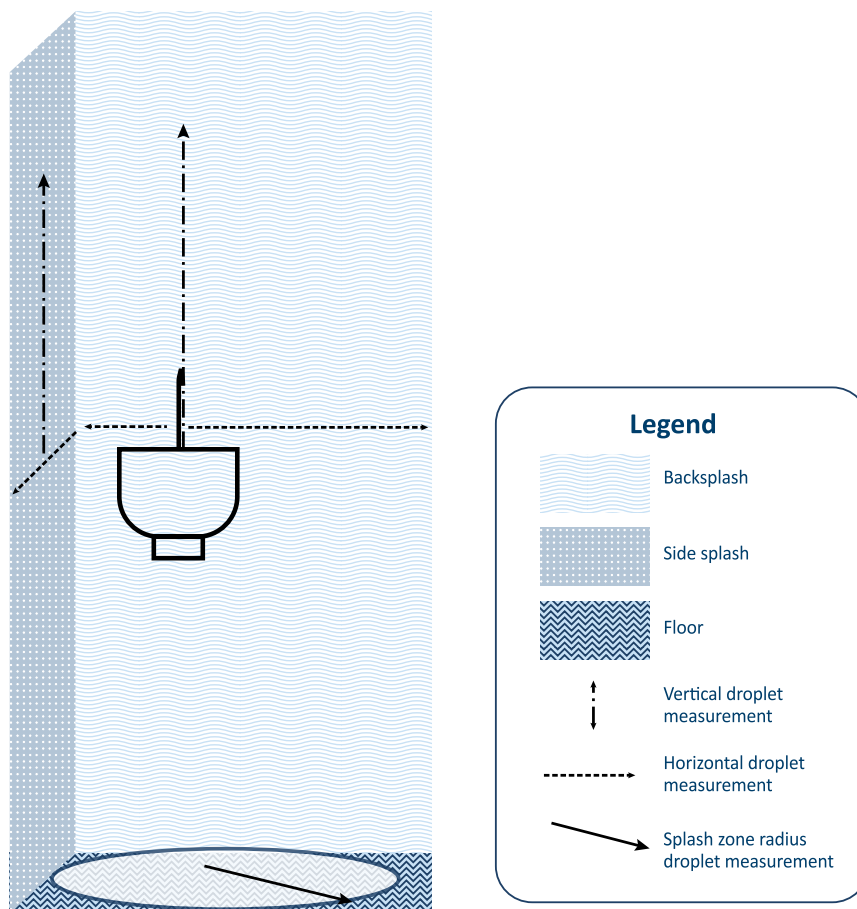
The vertical measurements for the side splash wall and backsplash were taken relative to the sink edge, which was consistent across all installations, to inform side splash wall, splash barrier, and backsplash height requirements.

3.3.1.3 Horizontal farthest droplet distance

The farthest horizontal droplet distance on the backsplash was measured relative to the centre of the sink. Although the three sink models varied in width, all were installed at a standard distance from the side splash wall to the sink centre. This measurement informs how far the backsplash should extend on either side of the HHS.

The farthest horizontal droplet distance on the side splash wall was measured from the corner where the side splash wall meets the backsplash. Since all sinks were installed at the same height and distance from the side splash wall, this measurement can inform the required depth of side splash wall protection and splash barriers.

Figure 10: Visual representation of farthest droplet distance measurement reference points for the backsplash, side splash wall, and floor.



3.3.2 Summary of farthest droplet distance

Handwashing was conducted 75 times across all sink and faucet combinations. The majority of fluorescently marked splash was from the Glo Germ™ on the participants' hands. Descriptive statistics are summarized (Figure 11, Table 8).

Few droplets were observed above the sink edge on the side splash wall and backsplash. Most splashes

on the side splash wall occurred below the sink edge, and three-quarters of droplets observed on the backsplash were less than 250 mm above the sink edge. Photographs of the side splash and backsplash walls for each sink and faucet combination are provided (Figure 12). Droplets on these surfaces are marked with stickers that were colour-coded by participant. On average, floor droplets fell 745 mm from the faucet outlet, with three-quarters of droplets falling within 1 m.

Figure 11: Overall distribution of farthest splash on the side splash wall, backsplash, and floor

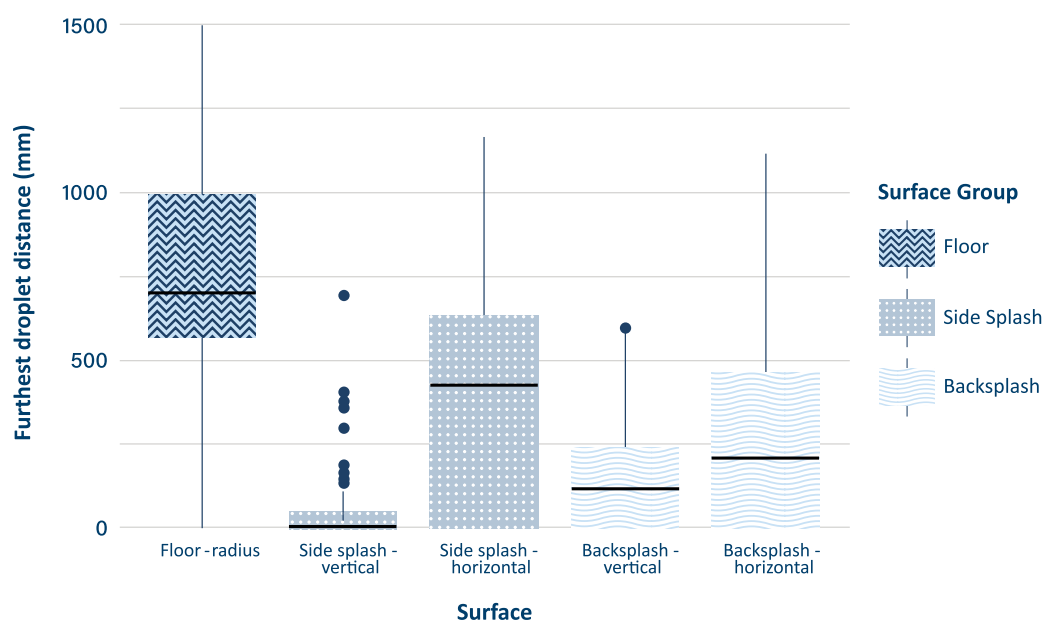
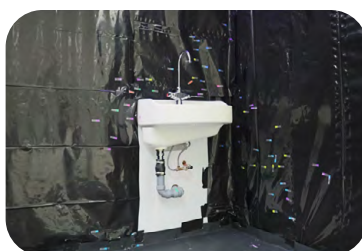
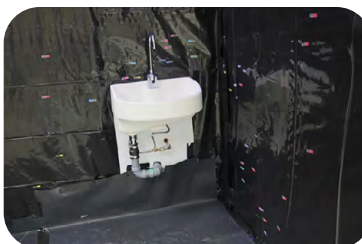


Table 8: Statistical summary of farthest droplet measurements on the floor, backsplash, and side splash

Splash distance (mm)	Floor radius (N = 75)	Side splash vertical (N = 75)	Side splash horizontal (N = 75)	Backsplash vertical (N = 75)	Backsplash horizontal (N = 75)
Mean (SD)	745 (333)	50.4 (117)	399 (313)	141 (150)	267 (257)
Median	709	0	424	114	222
Min	0	0	0	0	0
Max	1500	693	1170	596	1110
75 th percentile	988	44	631	236	459
95 th percentile	1124	315	819	397	676

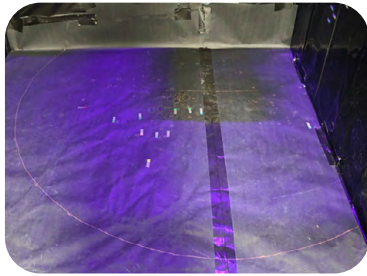
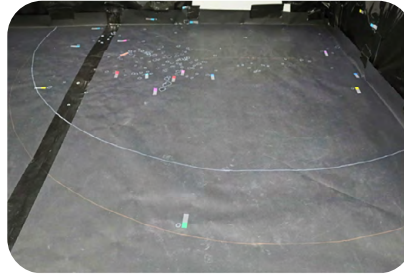
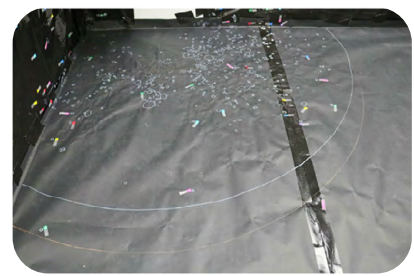
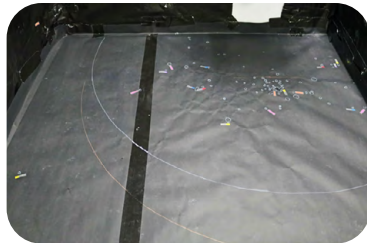
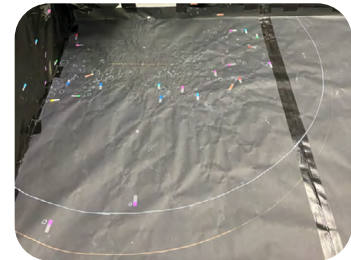
Figure 12: Photographs of farthest droplet markers on the backsplash and side splash for all nine sink and faucet combinations.Trough sink and
wrist blade faucetBarrier-free sink and
wrist blade faucetDeep rounded sink and
wrist blade faucetTrough sink and
tall automatic sensor faucetBarrier-free sink and
tall automatic sensor faucetDeep rounded sink and
tall automatic sensor faucetTrough sink and
short automatic sensor faucetBarrier-free sink and
short automatic sensor faucetDeep rounded sink and
short automatic sensor faucet

Photographs of the floors for various sink and faucet combinations are presented in Figure 13. Droplets were circled using marker and the farthest splash for each participant was flagged using a colour-coded sticker. The smaller circle represents a 1 m radius from the faucet outlet, and the larger circle represents a 1 m radius from the largest dimension of each sink basin.

Though the overall number of droplets on the floor was not counted, the trough sink appeared to generate fewer droplets than the barrier-free

and deep rounded sinks. However, splash patterns appeared to vary depending on faucet pairing. Most floor splash was concentrated near the sink edge.

In two instances, droplets from participant hands travelled the full length of the cubicle and landed on the wall opposite the side splash wall. One occurred with the trough sink and tall automatic faucet, and the other with the barrier-free sink and short automatic faucet. As only two droplets were observed across 75 handwashing events, they were considered outliers.

Figure 13: Photographs of farthest droplet markers on the floor for all nine sink and faucet combinations.Trough sink and
wrist blade faucetBarrier-free sink and
wrist blade faucetDeep rounded sink and
wrist blade faucetTrough sink and
tall automatic sensor faucetBarrier-free sink and
tall automatic sensor faucetDeep rounded sink and
tall automatic sensor faucetTrough sink and
short automatic sensor faucetBarrier-free sink and
short automatic sensor faucetDeep rounded sink and
short automatic sensor faucet

3.3.3 Density of farthest droplets

Farthest droplet measurements for each sink, aggregated across all participants and faucet types ($N = 25$ per sink), were mapped for the floor, backsplash, and side splash wall (Figure 14). Although statistical significance is addressed in subsequent sections, this mapping allows for visual identification of trends by sink.

3.3.3.1 Floor

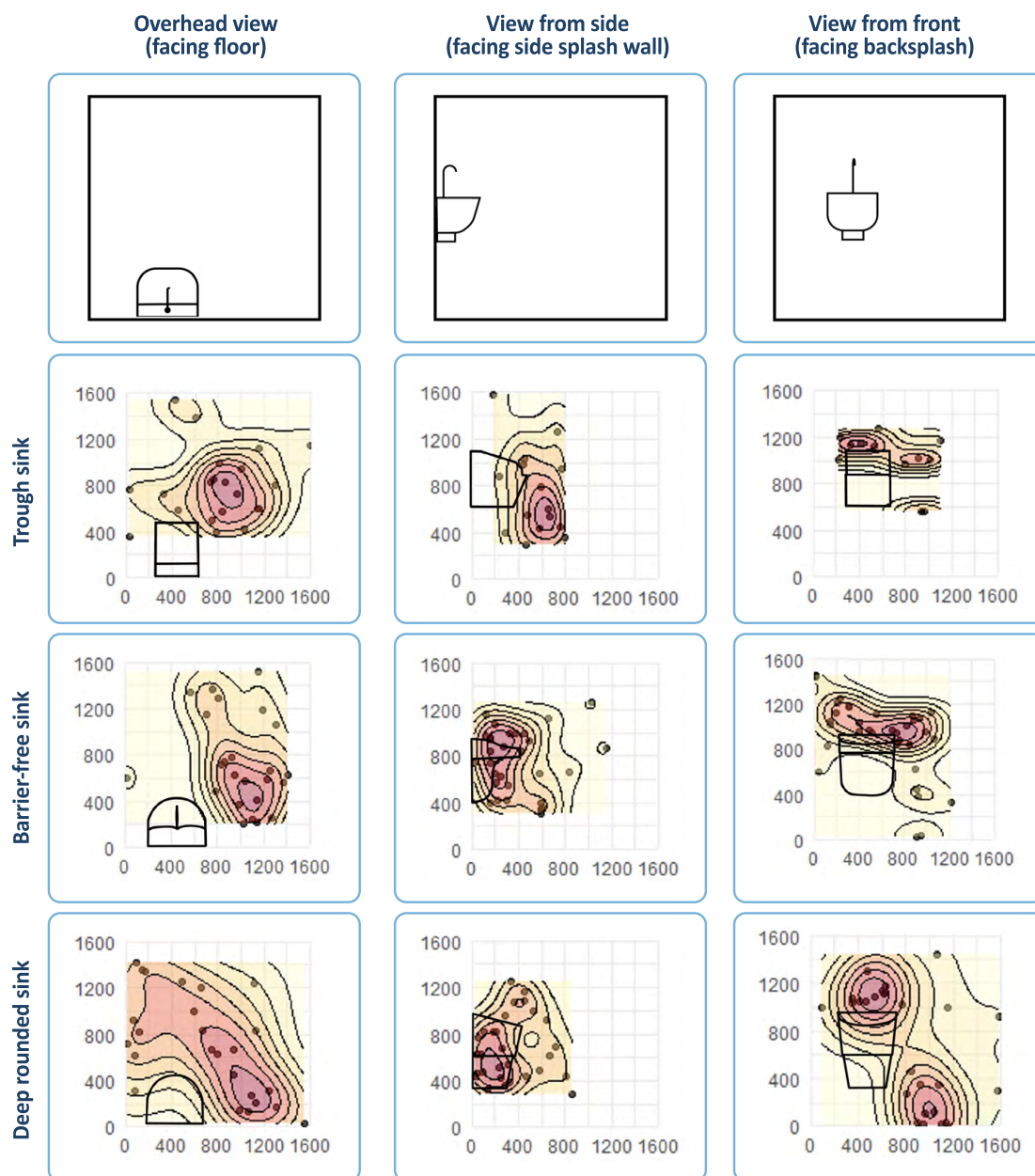
The deep rounded sink had the most variable farthest droplet distribution. Although the highest concentration of farthest droplets was on the drain side, as with the other two sinks (i.e., the side opposite to the side splash

wall), the distribution across the floor was broader for the deep rounded sink regardless of faucet pairing.

3.3.3.2 Side splash wall

For both barrier-free and deep rounded sinks, the highest concentration of farthest droplets on the side splash wall fell between the backsplash wall and the front sink edge, spanning 430 mm and 432 mm, respectively. The trough sink had the highest concentration of farthest droplets below the sink edge and between 400 and 800 mm from the backsplash. The built-in splash barrier walls on the trough sink likely redirected splash forward, away from the backsplash and toward participants.

Figure 14: Consolidated heat map of farthest droplet measurements by sink type across three surfaces (backsplash, side splash wall, and floor). Colour intensity represents droplet density, with lighter yellow indicating lower density and orange to red indicating higher density. Axis measurements are in millimetres. Sink basin outlines are overlaid for spatial context and approximate scale. Each point represents the farthest splash for a participant.



3.3.3.3 Backsplash

The trough sink generated less droplet dispersion on the backsplash than the barrier-free and deep rounded sinks. For the trough and barrier-free sinks, farthest backsplash droplets were concentrated near or above the sink edge, while the deep rounded sink showed a larger concentration of farthest droplets below and to the right of the sink edge.

3.3.4 Source of splash

Only three instances of orange drain-related splash were identified: on the lower backsplash of the trough sink and short automatic faucet, on the side splash wall of the barrier-free sink and short automatic faucet combination, and on the floor from the trough sink and tall automatic faucet combination (Figure 15). The droplet on the backsplash was 201 mm from the left edge of the trough sink and 619 mm above the floor (Figure 15a); the droplet on the side splash wall was 24 mm above the floor and 741 mm from the backsplash (Figure 15b); and the droplet on the floor fell within the 1 m splash zone at 785 mm from the faucet outlet (Figure 15c). Review of video recordings for these three events did not capture the moment of splash back.

Only one participant had visible splash on their gown from the drain of the trough sink and wrist-blade faucet, which is circled in orange (Figure 16). The drain-related splash on the participant gown occurred during use of the wrist-blade faucet, while the orange Glo Germ™ droplets identified on surrounding surfaces (Figure 15) were generated with automatic sensor faucets. Upon video review of all four instances of drain-related splash, no notable differences were observed in handwashing techniques among participants.

3.3.5 Floor

Given variation in sink dimensions and shape, floor splash analysis was conducted relative to the faucet outlet. No significant differences in farthest droplet distance were found between sink models or sink and faucet combinations; however, a statistically significant difference was detected between faucet types (Figure 17, Table 9). The short automatic faucet produced a significantly larger splash radius than the tall automatic faucet ($p = 0.025$). No significant difference was found between the wrist-blade faucet and either of the automatic faucets.

Figure 15: Instances of drain-related droplets (orange Glo Germ™) on the backsplash (a), side splash (b), and floor (c).

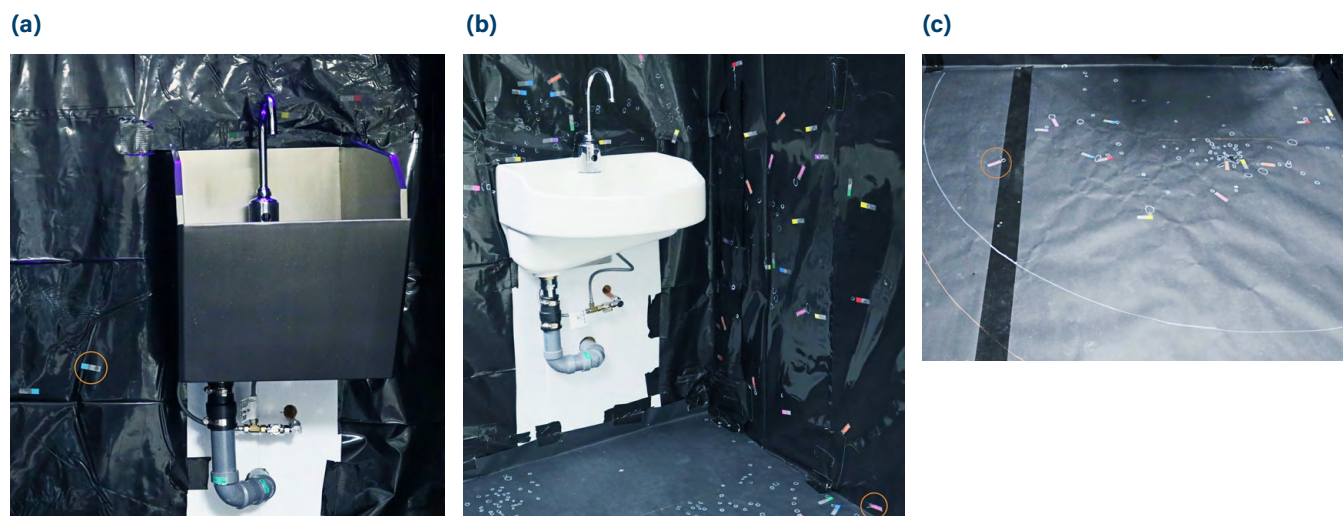


Figure 16: Photograph of drain-related droplet (orange Glo Germ™) on a participant's gown circled in orange.

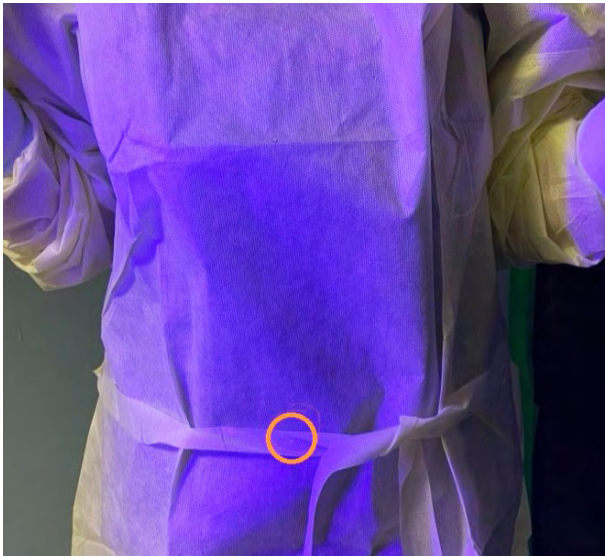


Figure 17: Farthest splash on the floor relative to the faucet outlet for each sink design grouped by faucet type. The centre line represents the median; the box shows the interquartile range (Q1–Q3); whiskers indicate the minimum and maximum values; points indicate outliers.

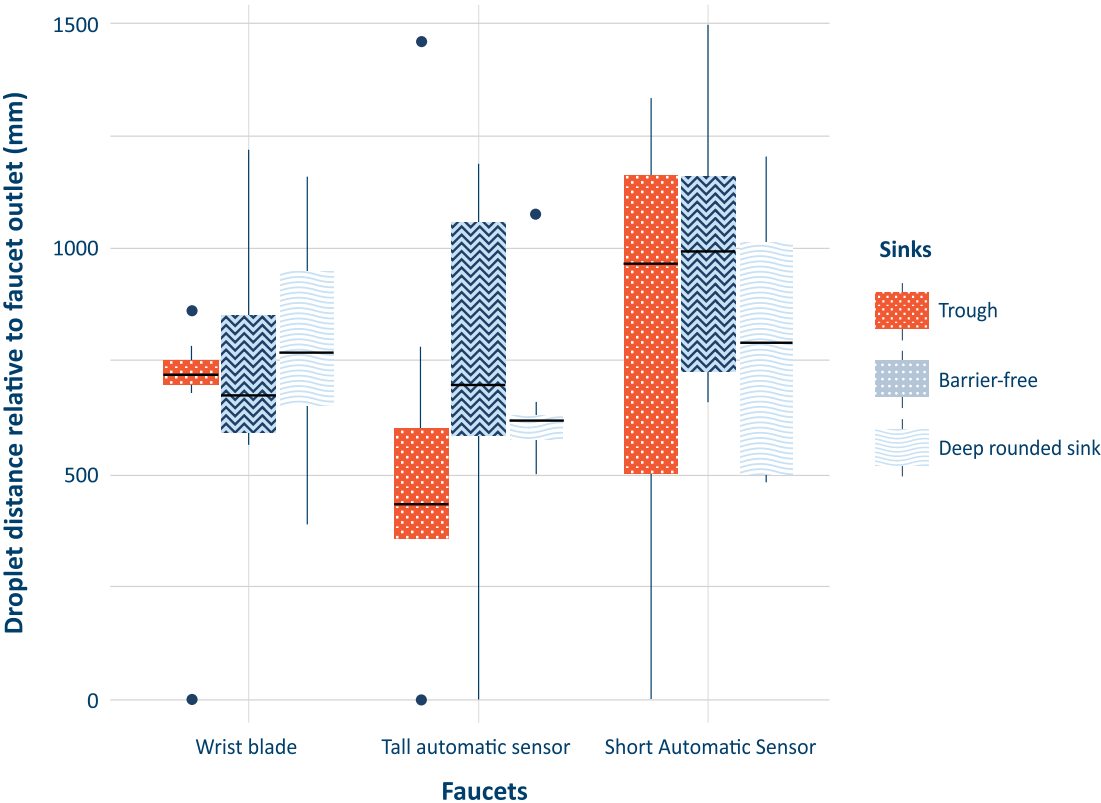


Table 9: Comparison of farthest splash on the floor by faucet pairs across all sinks

	Tall automatic sensor faucet	Short automatic sensor faucet
Tall automatic sensor faucet	Not applicable	Short automatic sensor faucet generated droplets that travelled significantly farther than the tall automatic sensor faucet
Wrist-blade faucet	No significant difference	No significant difference

3.3.6 Backsplash

Sink type had a significant effect on backsplash droplet height (Figure 18). Faucet type and its interaction with sink type were not significant, indicating that the sink effect was independent of faucet type. Averaged across faucet types, the barrier-free sink produced significantly higher splash than the trough sink regardless of faucet pairing (Tukey-adjusted $p = 0.0138$; Table 10). No significant differences were found between the trough and deep rounded sinks or between the barrier-free and deep rounded sinks.

A significant interaction between faucet type and sink was found for farthest horizontal backsplash splash (Figure 19). The wrist-blade faucet produced significantly greater horizontal splashes at the deep rounded sink than at the trough ($p = 0.0001$) and barrier-free sinks ($p = 0.0177$).

At the deep rounded sink, the wrist-blade faucet generated droplets travelling significantly greater horizontal distances than either the tall automatic faucet ($p = 0.0020$) or the short automatic faucet ($p = 0.0003$; Table 11). This difference was not observed with the other two sinks, and the tall and short automatic sensor faucets did not differ meaningfully from each other across sinks (Table 12). These findings suggest that the increased horizontal splash at the deep rounded sink was specific to the wrist-blade faucet. Significant variability in average horizontal splash was also observed between participants, even after accounting for faucet type and sink.

3.3.7 Side splash wall

The absence of droplets above the sink edge on the side splash wall limited statistical analysis, as sparse data of this kind undermines the reliability of standard mixed-effects models. Overall, 71% of handwashing events ($N = 53$) produced no visible splash above the sink edge on the side splash wall (Figure 20). No splashes above the sink edge were recorded for the deep rounded sink paired with the wrist-blade faucet.

A supplementary analysis was conducted using only cases where splash above the sink edge was recorded (i.e., values greater than zero). The data were log-transformed to stabilize variance and improve comparability across results. These analyses confirmed that the primary challenge was the high proportion of “zero” measurements rather than meaningful differences between faucet or sink types.

Horizontal splash distances on the side splash wall showed a significant interaction between sink type and faucet type (Figure 21). For the wrist blade and tall automatic faucets, farthest droplet distances were similar across sinks, with no statistically significant differences. In contrast, the short automatic faucet showed a significant interaction with sink type: droplets from the barrier-free and deep rounded sinks travelled significantly farther horizontally than those from the trough sink ($p = 0.006$ and $p = 0.048$, respectively; Table 13). No significant difference was observed between the barrier-free sink and deep rounded sink for this faucet. These findings suggest that the short automatic faucet, particularly when paired with the barrier-free sink, produced conditions associated with markedly greater horizontal splash distances on the side splash wall.

Figure 18: Highest splash on the backsplash above the sink edge for each faucet type, grouped by sink type. The centre line represents the median; the box shows the interquartile range (Q1–Q3); whiskers indicate the minimum and maximum values; points indicate outliers.

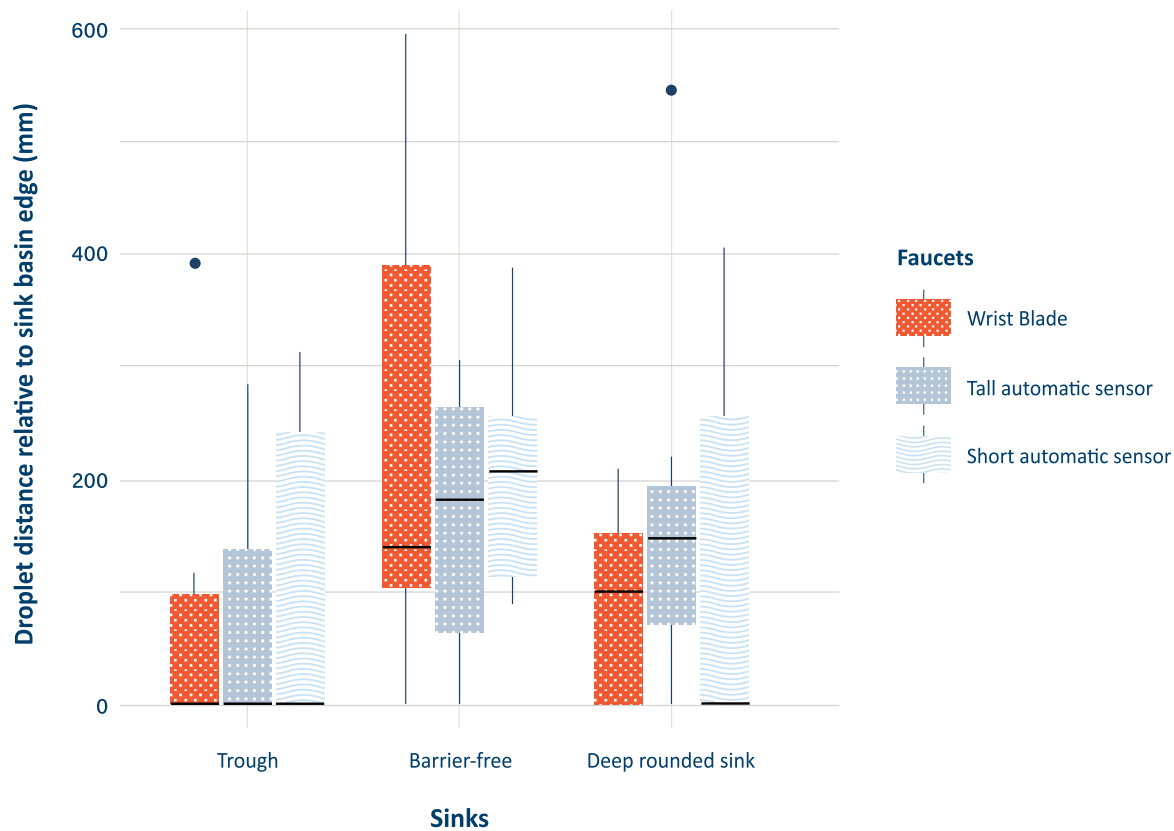


Table 10: Comparison of highest splash on the backsplash by sink pairs

	Trough sink	Barrier-free sink
Trough sink	Not applicable	Significantly higher splash in barrier-free sink compared with trough sink
Deep rounded sink	No significant difference	No significant difference

Figure 19: Farthest horizontal splash on the backsplash for each faucet type, grouped by sink type. The centre line represents the median; the box shows the interquartile range (Q1–Q3); whiskers indicate the minimum and maximum values; points indicate outliers.

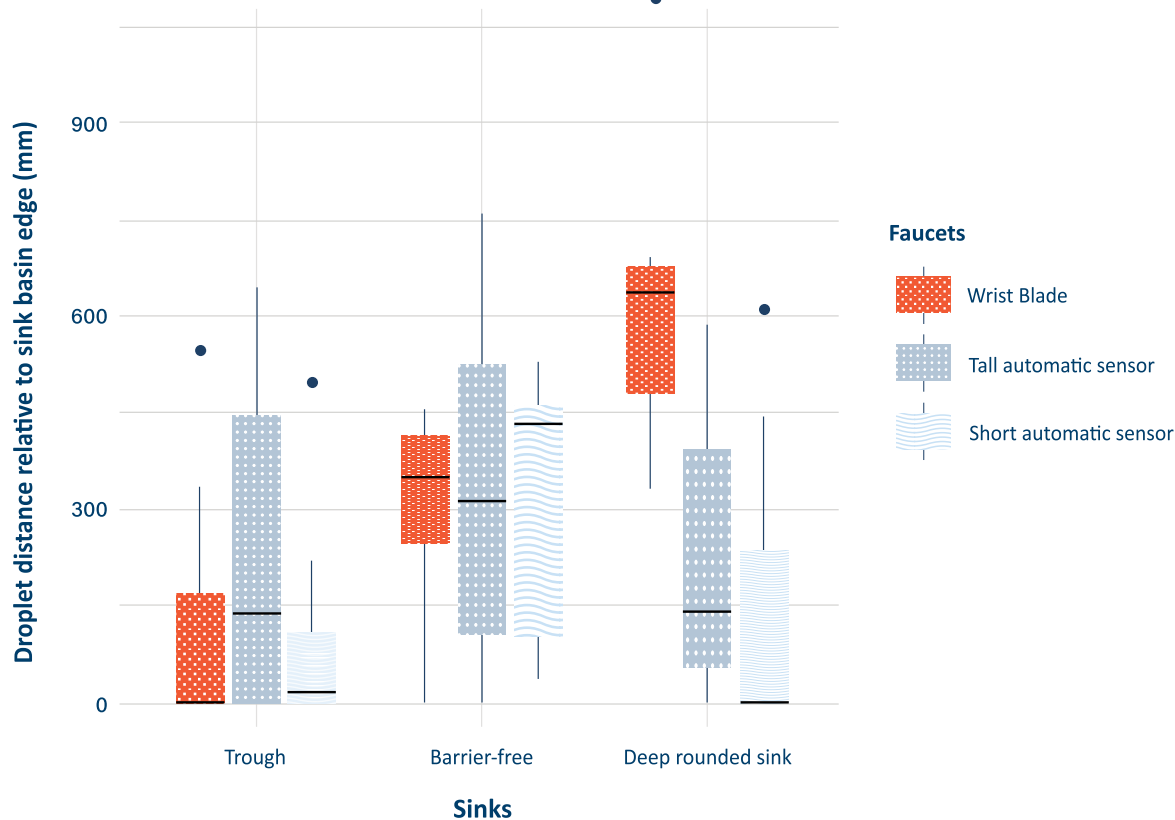


Table 11: Comparison of farthest horizontal splash on the backsplash by wrist-blade faucet paired with each sink

	Barrier-free sink	Deep rounded sink
Trough sink	The barrier-free sink/wrist-blade faucet combination generated significantly farther horizontal splash than the trough sink/wrist-blade faucet combination	The deep rounded sink/wrist-blade faucet combination generated significantly farther horizontal splash than the trough sink/wrist-blade faucet combination
Deep rounded sink	No significant difference	Not applicable

Table 12: Comparison of farthest horizontal splash on the backsplash by deep rounded sink with each faucet

	Barrier-free sink	Deep rounded sink
Wrist blade	The wrist-blade faucet generated significantly farther horizontal splash than the tall automatic sensor faucet	The wrist-blade faucet generated significantly farther horizontal splash than the tall automatic sensor faucet
Short automatic sensor faucet	No significant difference	Not applicable

Figure 20: Highest splash on the side splash wall above the sink edge for each faucet type, grouped by sink type. The centre line represents the median; the box shows the interquartile range (Q1–Q3); whiskers indicate the minimum and maximum values; points indicate outliers.

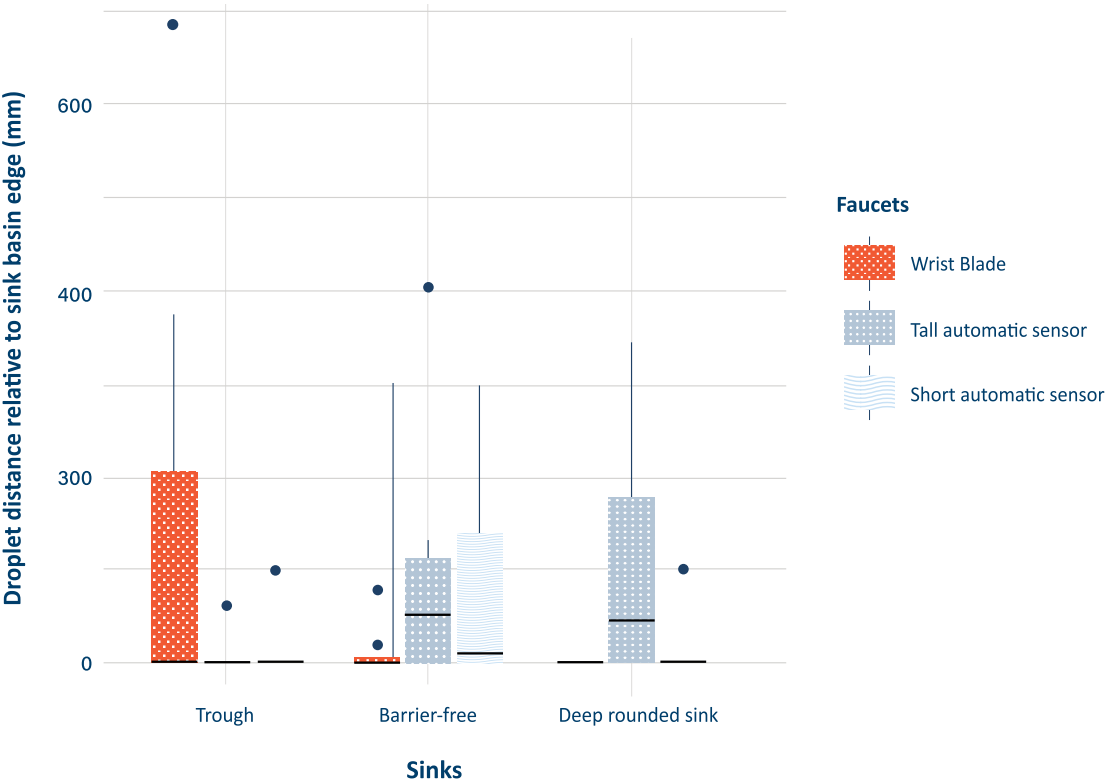


Figure 21: Farthest horizontal splash on the side splash wall for each faucet type, grouped by sink type. The centre line represents the median; the box shows the interquartile range (Q1–Q3); whiskers indicate the minimum and maximum values; points indicate outliers.

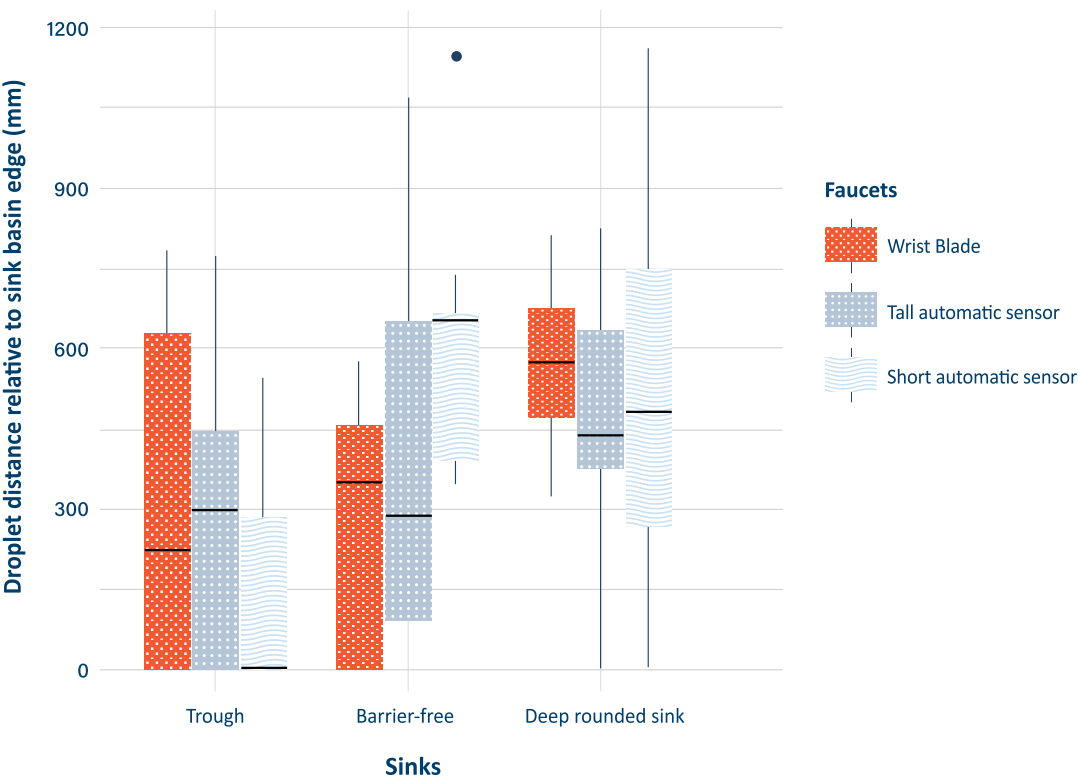


Table 13: Comparison of farthest horizontal splash on the side splash wall generated by the short automatic faucet across all sinks

	Barrier-free sink	Deep rounded sink
Trough sink	The barrier-free sink/short automatic sensor faucet combination generated significantly farther horizontal splash than the trough sink/short automatic sensor faucet combination	The deep rounded sink/short automatic sensor faucet combination generated significantly farther horizontal splash than the trough sink/short automatic sensor faucet combination
Deep rounded sink	No significant difference	Not applicable

3.3.8 Human factors

3.3.8.1 Usability and ease of use scores

SUS scores provided a measure of overall usability, with 68 representing the threshold of acceptable usability [100]. Higher scores indicated greater usability and a more user-friendly experience. SEQ scores measured perceived task ease, with 5.5 representing the estimated lower threshold for acceptable ease of use [101]. Higher scores indicated greater perceived ease of use.

SUS and SEQ scores for all sink and faucet combinations are presented (Figure 22), with benchmarks of 68 and 5.5 used as axis intercepts for SUS and SEQ, respectively. Combinations with high SUS and SEQ scores appear in the upper right quadrant, low scores in the lower left quadrant, and high SUS and low SEQ scores are in the upper left. No combinations had low SUS and high SEQ scores.

The trough and deep rounded sinks paired with the wrist-blade faucet, as well as the deep rounded sink paired with the tall automatic faucet, had SEQ scores below 5.5. Although the deep rounded sink with the tall automatic sensor faucet or wrist blade scored above the benchmark SUS at 70 and 69, respectively, the trough sink scored below it at 62. This showed that participants found these to be the least usable sink and faucet combinations.

Although all faucets paired with the barrier-free sink, as well as the deep rounded sink and short automatic faucet combination, had above-benchmark SUS scores, they fell in the mid-range of overall usability scores. The barrier-free sink with the tall

automatic sensor faucet had a below-average SEQ score of 5.25. The highest SUS scores of 93 and 94 were achieved by the trough sink with tall and short automatic sensor faucet combinations, respectively. These combinations also had comparatively higher SEQ scores, indicating that participants found them to be the most usable and user-friendly overall.

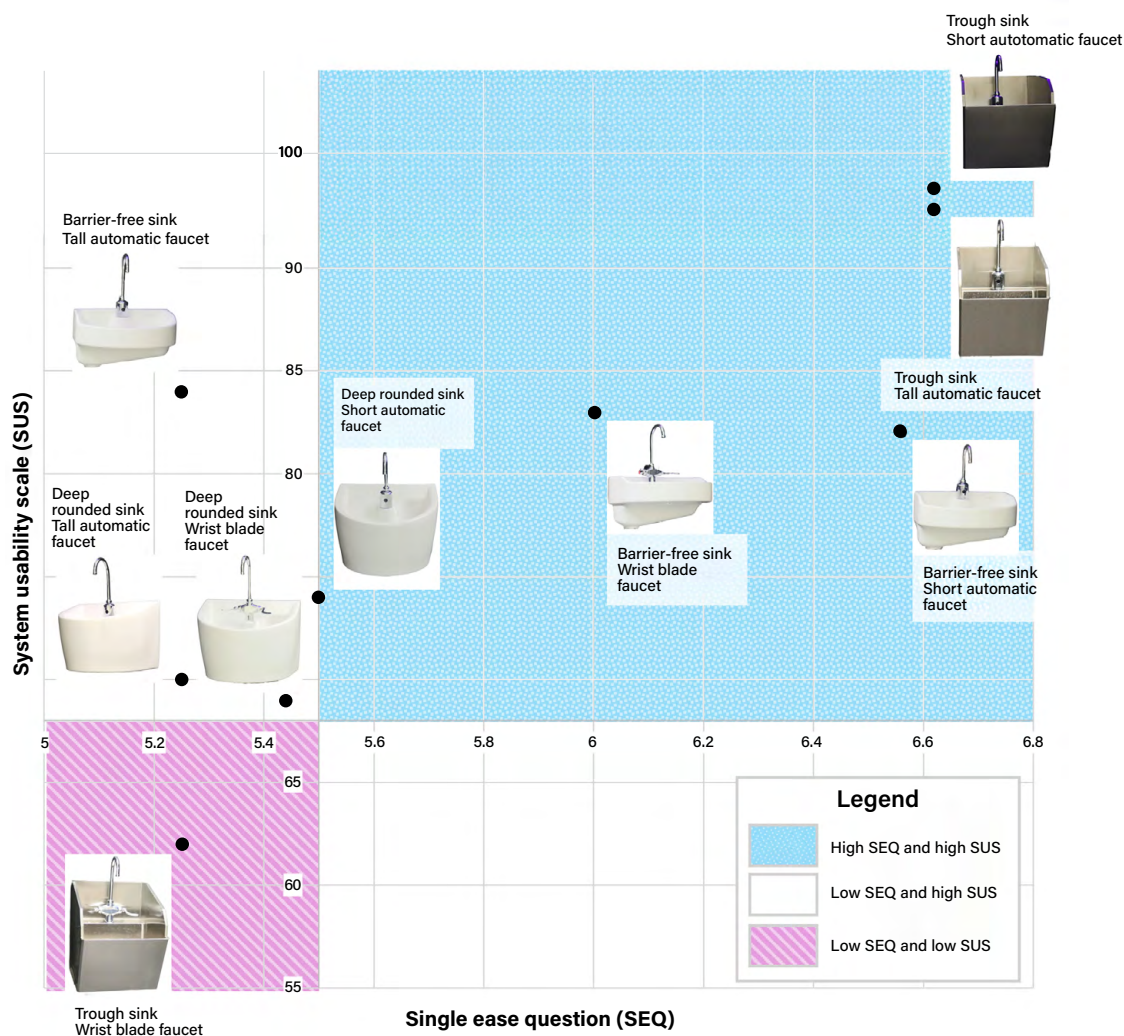
3.3.8.2 Thematic analysis

Participant responses from interviews and the qualitative survey question were analyzed thematically. The identified themes provided insight into differences in usability, workflow implications, and user experience across sink and faucet combinations.

3.3.8.2.1 Sinks

Participants found the trough sink spacious and appreciated its depth. Participants reported sufficient room to lather without contacting the basin sides. Despite having the smallest width (381 mm compared to 509 mm and 512 mm for the other sinks), the trough sink was perceived as the most spacious and comfortable to use. Several participants noted sufficient space to wash up to their elbows. The straight front edge was described as ergonomically intuitive, aligning naturally with the body during handwashing. Participants felt well protected by the high side walls, which were noted to function as splash barriers, and the stainless-steel material was viewed as suitable for clinical settings.

In contrast, participants found the barrier-free sink more confusing and restrictive. The built-in ledge was a source of confusion, with its purpose unclear to all participants; some expressed surprise that it would be

Figure 22: Scatter plot of SUS and SEQ scores for all sink and faucet combinations.

considered appropriate for a health care setting. The sink was described as too shallow and narrow, leaving participants concerned about contacting the basin sides during handwashing. Overall, the size and layout were described as “cramped” and unintuitive to use.

Participants appreciated the offset drain, which was viewed as a positive design feature. Similar to the barrier-free sink, participants reported challenges with the deep rounded sink, largely due to its narrow shape and deep basin. Many participants reported reaching

awkwardly into the sink, resulting in uncomfortable body positioning. As with the barrier-free sink, participants expressed concerns about contacting the sides of the IC basin. Participants found the basin shape restrictive and noted insufficient space to wash up to their elbows. One participant noted that the central faucet placement reduced usable basin space, leaving only two small areas on either side for lathering. This participant preferred a layout where one side could be used for lathering and the other for rinsing.

3.3.8.2.2 Faucets

Participants identified both benefits and challenges with the wrist-blade faucet. Some appreciated the control it offered over water pressure and temperature, and several noted that the continuous flow facilitated rinsing of hands, wrists, and forearms compared to automatic sensor faucets. However, many participants found the motion required to turn the faucet on and off awkward and difficult. Participants noted that this could present particular challenges for individuals with limited mobility or disabilities. As the sinks selected for the study had only a single mounting hole, the wrist-blade faucet used had an atypical configuration in which water was activated by moving the blades upward rather than side to side or front to back (Figure 23). This configuration likely contributed to participant confusion.

Several participants also mentioned that, without clear instructions, they likely would have used their hands instead of their wrists to operate the faucet. Other concerns included uncertainty about which handle controlled hot or cold water, the need to touch the faucet—perceived as increasing the potential contamination risk—and concerns about water waste associated with manual operation.

Some participants indicated a preference for manual faucets over automatic sensor options, noting that automatic sensor faucets could be finicky. However,

the unintuitive positioning of the wrist blades made this manual faucet less desirable. Several participants noted that their preference ranking would place a well-functioning automatic sensor faucet first, followed by a manual faucet, and a finicky automatic sensor faucet last.

Experiences with the tall automatic faucet varied by sink. Participants generally liked the automatic, hands-free design, but sensitivity was a key factor in performance. When used with the trough sink, the faucet performed well, turning on when expected and staying off during lathering. When combined with the barrier-free sink, the faucet received mixed reviews, with some participants activating the sensor reliably and others struggling to find the correct hand position. When combined with the deep rounded sink, the faucet performed poorly, with participants reporting unintended activation during lathering and difficulty consistently triggering the sensor.

Feedback on the short automatic sensor faucet also centred on sensor sensitivity. When used with the trough sink, the faucet was viewed positively and functioned as expected. When used with the barrier-free sink, it was considered unreliable, with unintended activation while lathering. The combination with the deep rounded sink caused frustration, as participants found it difficult to identify the correct position to trigger the sensor. Despite these issues, participants appreciated that the faucet was automatic and required no physical contact.

Figure 23: Wrist blade orientation of the splash study faucet (left), where the faucet is turned on by rotating the wrist blades upward, and a faucet with standard wrist blade orientation (right), which is turned on by rotating the wrist blades left or right.





“Drain splash back has been identified as a risk factor in drain-related patient infections and was frequently included in the publications.”

3.3.8.3 Summary of human factors analysis

The trough sink paired with automatic sensor faucets represented the strongest combinations from a user perspective. These combinations offered reliable sensor performance alongside sufficient basin size and depth to support uninterrupted hand hygiene. In contrast, the wrist-blade faucet paired with the trough and deep rounded sinks, as well as the deep rounded sink paired with the tall automatic sensor faucet, were identified as the weakest combinations. These weaknesses were attributed to the non-standard wrist blade orientation, unreliable sensor triggering, and basin designs that constrained handwashing and increased user frustration.

4 Discussion

Drain splash back has been identified as a risk factor in drain-related patient infections and was frequently included in the publications [15], [39], [40], [60], [65], [66]. Although this risk is widely acknowledged, only six included studies measured the distance droplets travelled from HHSs [12], [28], [29], [38]–[40]. Only two of these studies involved participant handwashing [28], [29], the remainder simulated splash by running water for varying durations [12], [38]–[40]. CSA [30], [32] and AHIA [99] were the only standards to provide specific splash zone requirements of 1 m and 1.2 to 2 m, respectively.

4.1 Splash study findings

In the splash study, drain-related droplets were infrequently identified. Single droplets were observed on a participant's waistband, the floor, and the backsplash when using the trough sink with various faucets, and one droplet was identified on the side splash wall from the barrier-free sink paired with the short automatic faucet. One participant generated drain-related droplets (orange Glo Germ™) in two handwashing events: on the floor with the trough sink and tall automatic sensor faucet, and on the side splash wall with the barrier-free sink and short automatic sensor faucet. Given the small number of handwashing repetitions at each combination ($N = 8$ or 9), it was not possible to determine whether this reflected a participant-specific factor or an anomaly. Three of the four drain-related droplets originated from the trough sink. The trough sink was the only sink without a drain strainer and was spacious enough to accommodate appropriate hand placement within the basin. These features may have influenced droplet generation; however, this could not be confirmed by the current study.

No single best sink, faucet, or sink and faucet combination was identified for minimizing splash. Floor splash distance was influenced by faucet model (Table 9), while vertical backsplash droplet height varied by sink model (Table 10). For the wrist-blade

faucet, horizontal splash on the backsplash differed by sink pairing (Table 11); horizontal splash at the deep rounded sink also differed by faucet type (Table 12). Horizontal splash on the side splash wall differed for the short automatic faucet by sink pairing (Table 13). These findings support the value of conducting a mock-up prior to selecting sink and faucet pairings.

The barrier-free and deep rounded sinks were perceived as smaller, and were not optimally shaped for handwashing. Participants experienced considerable confusion using the wrist-blade faucet, likely compounded by the unusual configuration in which the blades were mounted on the faucet neck rather than in the standard deck position (Figure 23). Both automatic sensor faucets showed variable sensitivity at the barrier-free and deep rounded sinks, triggering either too readily or inconsistently. By contrast, participants expressed strong preferences for the trough sink when paired with automatic sensor faucets. Participants described this combination as offering more reliable sensor sensitivity, a deep and spacious basin, and stainless-steel construction appropriate for clinical settings. Participants also noted that the straight front edge of the trough sink allowed easier access to the faucet during handwashing. While this design may not suit home-like aesthetics in long-term care settings, the lack of a consistently superior combination for splash reduction suggests that user preference and usability are relevant factors in sink and faucet selection.

4.2 Integrated analysis of study findings and design implications

4.2.1 Mitigating exposure to drain-related splash

Several publications report that slow drainage compounds the risk of drain-related splash by allowing water to pool in the sink basin [38], [39], [41], [42], [64]. The general absence of drain-related droplets in this study supports the hypothesis that offset drains mitigate splash back risk. This reinforces the role of engineering controls, such as sink design, in reducing exposure to drain-related pathogens.

In the splash study, orange Glo Germ™ droplets observed on adjacent surfaces fell within expected splash zones: on the floor, near the floor on the side

splash, and 210 mm above the sink edge on the backsplash. These splashes would not be expected to contaminate clean supplies, equipment, or patient care items when spaces are designed to meet CSA Z8000:24 and Z3171:21 requirements [30], [32].

Another strategy identified in the literature for reducing exposure to drain-related pathogens is the use of self-cleaning drains. These systems use heat and vibration to prevent biofilm formation; however, studies report that they are costly [67], [68], do not universally prevent biofilm growth [67]–[69], and are ineffective once contamination is established [68]. Although the current study did not directly evaluate these devices, the reported limitations suggest that self-cleaning drains are unlikely to provide a straightforward solution for preventing HHS drain contamination.

4.2.2 Hands-free controls

Hands-free faucet controls are required by most standards and guidelines [30], [32], 80, [88]–[91], [95]. CSA Z8000:24 specifies a minimum wrist blade length of 150 mm [30], although this requirement is not included in CSA Z3171:21 [32]. The FGI specifies a minimum wrist blade length of 102 mm [93]–[95]. The availability of 150 mm minimum wrist-blade faucets that meet CSA Z8000 and CSA Z3171:21 requirements is limited. Although the unusual wrist blade configuration used in the splash study likely contributed to participant confusion (Figure 23), some participants noted that, without instruction, they would have used their hands rather than their wrists to operate the faucet.

Single-lever faucet controls may represent a more intuitive hands-free option. They are considered acceptable by several organizations included in the grey literature search [80], [88], [91], [93]–[95] but are not mentioned in CSA Z3171:21 or Z8000:24 [30], [32].

The risk of contamination, biofilm growth, and potential patient infection associated with automatic sensor faucets is documented in CSA Z3171:21 [32], the NHS [89], [90] and FGI [93]–[95]. The complexity of internal components, elevated temperatures of stagnant water, and increased water volume between the TMV and faucet outlet likely contribute to this risk (Table 3). The NHS and FGI recommend conducting risk assessments to determine whether automatic sensor faucets are

appropriate for specific settings, with the NHS advising against their use in critical care areas [88], [90], [95].

For settings where sensor faucets are used, the NHS recommends selecting faucets with automated flushing [89]. Routine maintenance of TMVs, including decontamination and descaling [90], and installation of TMVs directly at or integrated into the faucet inlet to minimize stagnant water volume upstream of the outlet are also recommended [89], [90]. TAHPI recommends monthly inspection of solenoid valves [87].

The recommendation for regular flushing is supported by evidence showing a significant reduction in *P. aeruginosa* in tap water when a 10-second cold-water flush follows each handwashing event [49]. Regular maintenance, including replacement of contaminated solenoid valves, is also supported by evidence demonstrating restoration of water quality following valve replacement [48]. Finally, automatic sensor faucets with integrated temperature control, where a solenoid valve is installed directly upstream of the faucet inlet, are less likely to become contaminated [31], [44]. The environmental scan identified two Chicago Faucet automatic sensor models that meet CSA Z8000 and CSA Z317.1:21 requirements and include integrated temperature control (models 116.597.AB.1T and 116.993.AB.1T).

4.2.3 Faucet outlets and water flow

CSA Z8000 and CSA Z317.1:21 standards provided the most detailed design requirements for HHSs among the organizations reviewed. Regarding aerators, CSA Z8000:24 and Z317.1:21 [30], [32] require that aerators not be used, a position supported by the NHS [88]–[90] and TAHPI [87]. Although the WHO supports the use of aerators, it cautions that these outlets could become contaminated [8]. The peer-reviewed literature demonstrates that aerators are often contaminated by bacteria, which have been associated with patient infections [31], [55], [60], [70], and documents several aerator-related patient infections [14], [53]–[57]. These findings support the CSA Z8000 and CSA Z317.1:21 requirement to omit aerators from faucet outlets.

CSA Z317.1:21 requires non-aerated laminar flow and a minimum flow rate of 5.7 L/min (1.5 US gal/min),

achieved through internal means at the faucet inlet [32]. Flow straighteners, which include laminar flow outlets, are addressed in several guidance documents: AHIA recommends consideration of anti-splash fittings and laminar flow [80], while the NHS advises against strainers and flow-restricting outlets, supporting a smooth, non-splashing flow [88]–[91]. No specific flow rate requirements were identified in the grey literature.

CSA Z317.1:21 notes that water supply outlet devices may increase the risk of biofilm growth [32]. This is supported by the literature, which reports that flow straighteners become contaminated when the water supply is contaminated [61] and that more complex designs are associated with heavier contamination than simpler ones [52], [61]. The environmental scan identified only one non-gooseneck faucet with 5.7 L/min (1.5 US gal/min) flow control at the inlet from Chicago Faucet (model 116.708.AB.1T). As it featured a laminar flow outlet, it was excluded from the splash study. At the time of writing, clearer requirements are needed to determine whether HHS faucets should include water supply outlet devices, as existing guidance is limited to clause 8.1.4.1 which is specific to lavatory faucets [32].

4.2.4 Point-of-use filters

CSA Z317.1:21 notes that point-of-use filters can effectively remove microbial contaminants from water [32]. The literature supported their efficacy against organisms such as *Legionella* or *P. aeruginosa* [41], [61]–[63]. However, cost and maintenance are identified as the primary challenges associated with this intervention [62], [72].

4.3 Strengths, limitations, and future research

Limiting the grey literature search to jurisdictions with well-established health care design standards (Canada, Australia, Europe, the United Kingdom, and the United States) enhanced comparability across sources. This enabled clearer synthesis of regulatory approaches and design expectations across comparable health system models. The systematic approach and scale of the peer-reviewed literature search supported a comprehensive and structured analysis of included publications.

The peer-reviewed literature consisted mostly of outbreak reports, which often involved bundled interventions, making it difficult to attribute successful outcomes to any single measure. However, this reflects the real-world complexity of infection prevention practice in health care settings. Although many studies referenced splash, few included quantitative measurements, and those that did generally excluded participant handwashing due to the use of infectious organisms such as *E. coli* in their methods. This constraint reflects important methodological and safety considerations rather than a lack of inquiry in the field.

Studies varied in the sink and faucet models tested and generally included a low number of repetitions. For example, studies from the United Kingdom involved large sink basins with rear drains not commonly used in Canada, which may limit the applicability of some findings to the Canadian context [28], [38]. Furthermore, many studies did not specify the sink type, and those for which evaluators could not confirm that the sink was an HHS were excluded. This lack of clarity may have resulted in exclusion of relevant articles but was necessary to maintain the quality of the review.

Prior research has often been limited by the exclusion of realistic handwashing, small sample sizes, and a narrow range of sink and faucet configurations tested. The splash study addressed several of these gaps by incorporating simulated handwashing and evaluating sink and faucet designs more representative of Canadian health care environments. This improved the applicability of findings for design and infection prevention; however, the findings should still be interpreted in light of several limitations. The tested fixtures represent selected design configurations, and results may vary with alternative sink and faucet profiles; however, the general patterns of splash observed are expected to be broadly consistent.

Although dispersion of a product similar to Glo Germ™ gel has been reported as 100% accurate for detecting Gram-negative bacteria in the area surrounding the sink [42], the oil product used on the drain may have been less accurate given its non-water-soluble formulation. Application of Glo Germ™ to the drain was more challenging with the trough sink, which lacked a strainer; the oil was instead applied around the drain collar.



Variation in research team members across study weeks may have affected the application of Glo Germ™ to the trough sink drain; nevertheless, three instances of drain-related droplets were still observed from this sink. As the black polyethylene sheeting on the walls had wrinkles and folds that could not be fully removed, measurement accuracy was likely affected, introducing variability of a few millimetres. Measurements were taken by a single trained team member using a standardized approach, with a second observer independently verifying each measurement. This process improved measurement reliability and reduced the potential for recording error. Future studies could incorporate colour-changing paper or fluorescently dyed water for greater measurement accuracy; however, these approaches involve additional costs and safety considerations, respectively.

Participants followed a standardized handwashing protocol delivered and reinforced by infection control professionals and trained research staff. This approach enabled identification of sink and faucet effects on splash patterns while minimizing variability in handwashing technique. Although some variability in splash measurements still occurred, the controlled approach may not fully capture the diversity of hand hygiene practices observed in clinical settings.

Participants were not asked about their occupation, though many self-identified as students. Variability in real-world clinical hand hygiene practices may also influence the amount of splash generated. Though eight to nine repetitions were completed per week, future studies would benefit from a larger number of repetitions per combination to better account for this variability.

CSA Z8000:24 and Z317.1:21 recommend minimum HHS dimensions of 350 by 250 mm with a depth of 225 mm [30], [32]. Given the limited evidence on splash generation from shallower basins and the absence of minimum depth requirements in other international guidance documents, future studies should evaluate sinks with shallower depths such as 127 mm or 152 mm. Such studies should maintain a minimum distance between the faucet outlet and sink basin bottom (Table 6). If splash generation from shallower basins does not differ meaningfully from current recommendations, such designs could support broader barrier-free accessibility, expand available HHS model options, and present cost-saving opportunities.

4.4 Recommendations

Please note that this report was completed prior to the anticipated publication of the 2026 edition of CSA Z317.1. Some of these recommendations may no longer be applicable in light of updated requirements.

4.4.1 Splash zone

4.4.1.1 Shift the splash zone measurement reference point from the sink basin edge to the faucet outlet

The environmental scan demonstrated that sink shapes and dimensions vary considerably. Furthermore, it is difficult to apply a radius measurement to the edge of a square or rectangular basin. The splash study found that most splash from HHSs originated from hand contamination. Due to these factors, consider changing the splash zone measurement from the sink edge to the faucet outlet. This would provide a consistent basis for measurement across sink basins of varying sizes and shapes.

Based on the splash study results, consider increasing the splash zone measurement from 1 m to 1.2 m to contain 95% of furthest droplets on the floor. This aligns with the minimum splash zone specified by AHIA, although their guidance document [80] does not define a reference point for this measurement. Given the limitations of the splash study (i.e., limited repetitions, a standardized handwashing protocol, and participants who were primarily students rather than clinical staff), further reduction of the splash zone is not recommended.

Note: A distance of 1.2 m from the faucet outlet would be comparable to the existing 1 m from the sink edge for sinks 400 mm wide.

4.4.1.2 Amend backsplash dimensions

The CSA Z8000:24 requirement for a backsplash height of 2100 mm above the finished floor [30] was not supported by the splash study findings and differs considerably from TAHPI (1500 mm above the finished floor, or 635 mm above the sink edge) [98] and AHIA (335 mm above the sink edge) [99]. If the primary purpose of the backsplash is wall protection from splash, it is recommended that the 600 mm (24 in) above the sink edge specified in CSA Z317.1:21 [32] be maintained, or that requirements align with TAHPI's specification of 1500 mm above the finished floor, given that the maximum backsplash splash height observed in the splash study was 596 mm.

Consider increasing the backsplash wall protection width and changing the recommended measurements relative to the centre point of sink instead of the sink edge. A centre point reference provides consistent wall protection regardless of the sink dimensions and may simplify design and installation.

CSA Z8000:24 requires a backsplash width of 300 mm from the edge of the sink, which is equivalent to the TAHPI and AHIA requirements of 1 m when used with a sink that is 400 mm wide [30], [98], [99]. Based on splash study measurements, 95% of farthest splash fell within 676 mm of the sink centre point and 75% of splash fell within 459 mm.

CSA Z8000:24 requires a side splash for any vertical surface within the splash zone of the sink, currently 1 m. The technical committee should consider which of the following options best balances cost and risk:

- Backsplash extends the full width of the splash zone
 - 1 m from the basin edge (CSA Z8000:24 [30]), or
 - 1.2 m from the centre point of the sink (as recommended in this report)
- Align with TAHPI and AHIA for a total wall protection width of 1 m [98], [99]
- Extend 700 mm from the sink centre point to capture 95% of farthest droplets observed in the splash study

4.4.1.3 Provide splash barrier dimension recommendations

Although CSA Z8000:24 and Z3171:21 require a splash barrier when the 1 m splash zone cannot be achieved [30], [32], neither standard provides recommendations for splash barrier dimensions.

Consider providing specific directions that splash barriers be installed at least 460 mm from the sink centre point to meet barrier-free requirements [35]. Maintaining the same height as the backsplash and side splash is recommended for simplicity. The maximum splash height above the sink edge on the side splash wall in the splash study was 693 mm, with the 95th percentile at 315 mm.

In the splash study, the distance between the backsplash wall and faucet outlet ranged from 200 to 270 mm. For a splash barrier wall to intersect with the recommended 1.2 m splash radius from the faucet outlet, it would need to measure between 1308 and 1378 mm from front to back. This depth is unlikely to be achievable or practical in most health care settings.

The depth requirement for HHS alcoves in TAHPI [98] and AHIA [99] is 600 mm. Based on the splash study results, a depth of 631 mm would contain 75% of farthest droplets observed; however, the dimensions of splash barriers that do not extend to the floor are limited by what can safely be cantilevered from a wall. Further investigation is required to understand how splash barrier depth affects surface contamination within the splash zone space.



4.4.2 Fixture selection

4.4.2.1 Require an infection control risk assessment when considering automatic sensor faucets for HHS

Automatic sensor faucets present increased infection risks due to larger volumes of stagnant water between the TMV and the faucet outlet. Their complex internal components have been associated with increased contamination by organisms such as *P. aeruginosa* and *Legionella* [44], [48], [50], [52].

Consider adding a requirement for an infection control risk assessment before automatic sensor faucets are selected for complex and critical care areas serving immunocompromised patients.

Additional mitigation strategies include selecting faucets with temperature control (e.g., above-deck mixing, built-in TMVs), integrated cold-water after-use flush, and regular disassembly and maintenance. However, maintenance through disassembly, descaling, and disinfection may be resource intensive.

4.4.2.2 Emphasize the importance of completing a mock-up of the proposed sink and faucet combination to assess splash and usability

Although no single sink, faucet, or sink and faucet combination significantly reduced the farthest splash on all surfaces in the splash study, some sinks appeared to have less diffuse splash density patterns (Figure 14). Furthermore, user feedback indicated strong preferences for specific configurations.

The following should be considered when completing a mock-up:

- Include front-line staff, leadership, or both, in handwashing exercises in which participants wash their hands using a plumbed version of the proposed sink and faucet combination.
- If automatic sensor faucets are being considered, assess sensor sensitivity.
 - Does the sensor respond when the participant intends to start the flow of water?
 - Does triggering the sensor require awkward hand placement or ergonomics?
 - Is the flow of water interrupted during use, making it difficult to complete handwashing?
 - Does the sensor trigger water flow unintentionally in ways that interfere with lathering?
- Assess the sink and faucet combination.
 - Does the water fall directly onto the drain?
 - Do participants have enough room to lather and wash their hands?
 - Is there noticeable splash onto the participant or surrounding surfaces?

Consult with facilities maintenance and engineering regarding installation and maintenance. For example, sinks made from heavier materials may be difficult to install and require additional wall support.

4.4.2.3 Consider adding minimum requirements to sink basin size and distance between the faucet outlet and sink basin bottom

The CSA Z8000:24 and Z3171:21 minimum sink basin dimensions are currently recommendations rather than requirements [30], [32]. TAHPI [86] and FGI [93]–[95] specify a minimum sink basin area of 0.1 m² and 0.09

m², respectively, as well as a minimum distance of 260 mm between the faucet discharge point and the basin bottom; these values could be considered in developing minimum requirements intended to establish a baseline.

4.4.2.4 Clarify whether laminar flow outlets can be used with HHSs

CSA Z3171:21 clause 8.4.2.4, "Construction requirements", references clause 8.4.1.1, "Sinks in clinical areas and patient washrooms," which in turn references clause 8.1.4, "Lavatory faucets." This suggests that laminar flow outlets may be acceptable, provided the required flow rate is met and regulated by internal means [32]. However, these outlets have been associated with bacterial contamination [52],[61].

Consider including laminar flow and outlet requirements under clause 8.4.2.4, with clarification of whether such outlets are acceptable given the associated risk of bacterial contamination. Only one non-gooseneck faucet identified in the environmental scan aligned with CSA Z8000 and CSA Z3171:21 requirements; however, it featured a laminar flow outlet.

Manufacturers should consider including laminar flow outlet material descriptions (e.g., plastic, metal) and schematics in their specification sheets to facilitate assessment of outlet design during faucet selection.

4.4.2.5 Consider adding single-lever faucets to the list of hands-free controls

Participants in the splash study were confused by wrist blade controls, with some perceiving them as handles to be operated by hand. Given that AHIA [80], TAHPI [86], NHS [91], and FGI [93]–[95] permit single-lever faucets, these could be considered for inclusion in CSA Z8000 and CSA Z3171:21 standards as an accepted hands-free control.

4.4.2.6 Consider amending minimum wrist blade length

The minimum wrist blade length significantly reduced the number of faucets aligned with CSA Z8000 and CSA Z3171:21 requirements. Most standards did not specify minimum wrist blade lengths, the FGI permits a minimum of 102 mm (4 in) [93]–[95].

4.4.3 Standardization across publications

Several inconsistencies between CSA Z8000:24 and Z3171:21 were identified during the review [30], [32]. For example, CSA Z3171:21 uses the term “automatic sensor operation” while CSA Z8000:24 uses the term “electric eye.” Standardization of terminology across publications is recommended to support consistent interpretation for users referencing multiple standards.

Overlapping requirements for backsplash and side splash dimensions specifying different minimums were identified in CSA Z8000:24 and Z3171:21 [30], [32]. Ideally, overlapping requirements across standards should be avoided; however, where overlap is unavoidable, a process for coordinated updates across standards is recommended.

Clauses that reference other clauses for further detail reduce duplication within a standard. While a single cross-reference is manageable, requiring readers to navigate multiple clauses to locate relevant information may obscure its applicability. For example, locating the laminar flow requirements currently listed under the lavatory faucets section required navigating from one clause to a second, which referenced a third clause containing the relevant information [32]. This increases the risk of users overlooking relevant requirements.

5 Conclusion

This report integrates evidence from the literature, guidance documents, an environmental scan of available HHS fixtures, and a splash study to inform HHS design and splash zone requirements. The splash study found that most droplets generated during handwashing originated from participants’ hands (blue-white Glo Germ™), while drain-related droplets (orange Glo Germ™) were rarely observed. This supports the role of offset drains in reducing splash back risk.

No sink, faucet, or sink-faucet combination consistently minimized how far droplets travelled across all surfaces. User feedback highlighted ergonomic challenges with wrist blade controls and variable sensor faucet responsiveness, suggesting that single-lever faucet controls warrant consideration as an alternative. Many reviewed guidance documents emphasized



the importance of sink and faucet compatibility. These findings underscore the need for mock-ups that assess both usability and droplet generation before final fixture selection.

The splash study results support shifting the splash zone reference point from the sink edge to the faucet outlet and adopting a 1.2 m radius to capture the majority of observed splash, along with amendments to backsplash and side splash dimensions to reflect observed patterns. The review also identified infection risks associated with automatic sensor faucets. These risks may be mitigated through infection control risk assessments to determine appropriateness for high-risk patient populations, design features such as above-deck mixing, and routine maintenance or replacement of solenoid valves.

Although the splash study addressed limitations of prior research by incorporating participant handwashing and HHS fixtures representative of the Canadian market, findings should be interpreted in light of the controlled protocol, modest number of repetitions, and measurement constraints. Future research should evaluate shallower basin depths, diverse hand hygiene practices, and additional sink and faucet combinations.

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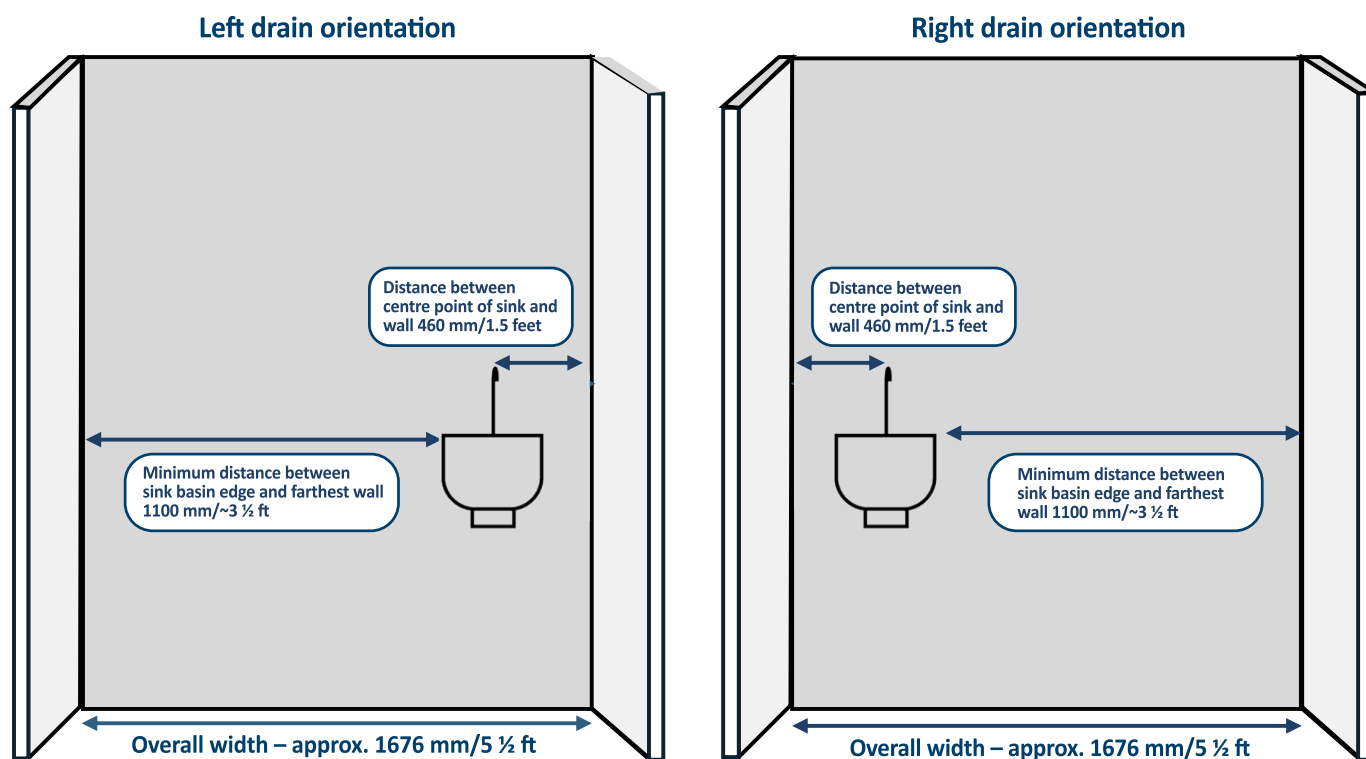
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Appendix A – Splash study

A.1 Simple drawing of mock-up

Figure A.1: Simplified layout drawing showing sink placement within a test cubicle and defined splash zone boundaries.



A.2 Sink and faucet usability survey

1. Enter the code of the sink/faucet combination that you just completed a hand hygiene moment with: _____
2. Participants were asked to rank the ease of the task from 1 to 7, 1 being very difficult and 5 being very easy.
3. Participants were asked to rank from 1 to 5, 1 being strong disagreement and 5 being strong agreement for the following statements:
 - a. I think that I would like to use this system frequently.
 - b. I found the system unnecessarily complex.

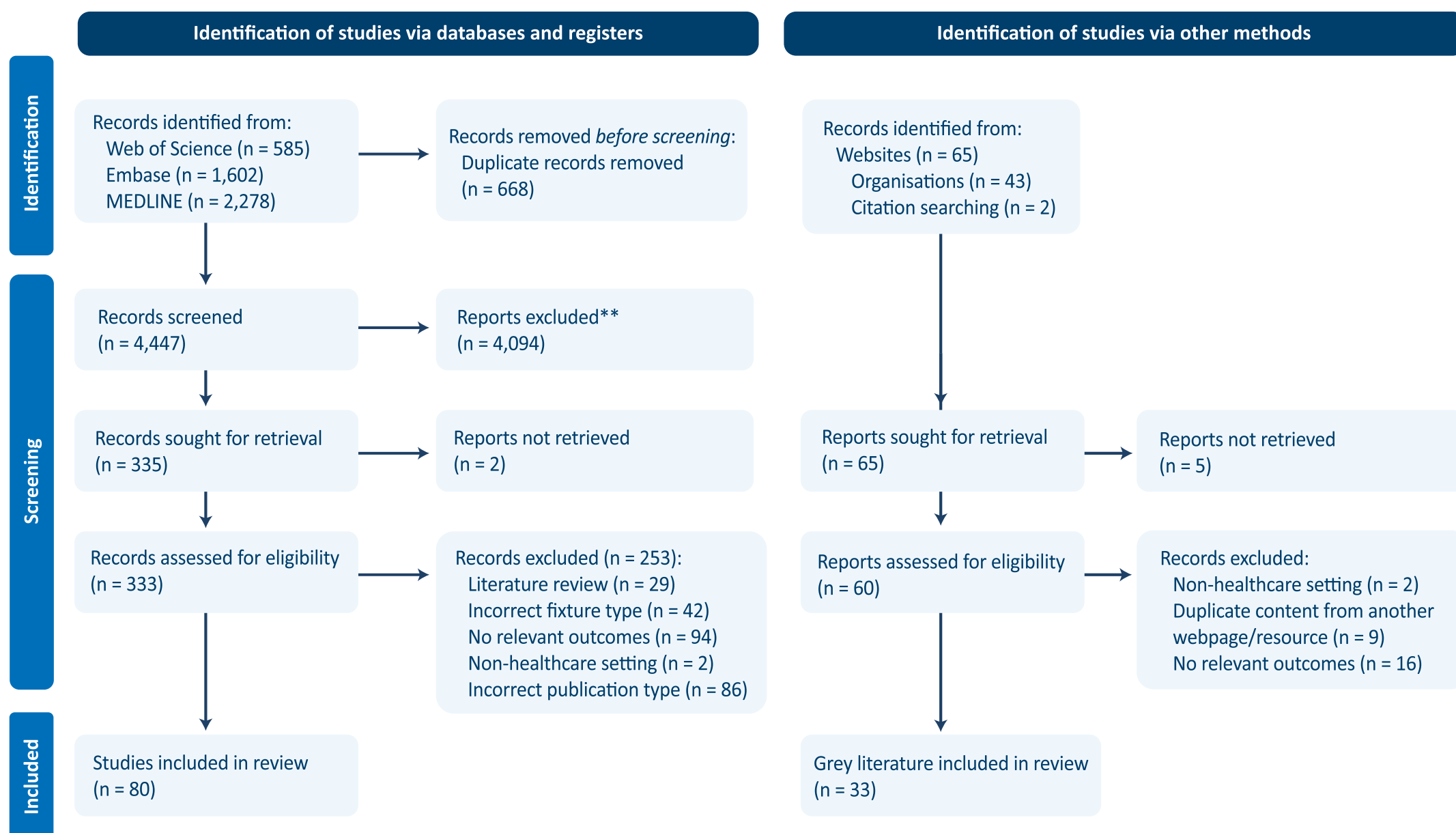
- c. I thought the system was easy to use.
 - d. I think that I would need the support of a technical person to be able to use this system.
 - e. I found the various functions in this system were well integrated.
 - f. I thought there was too much inconsistency in this system.
 - g. I would imagine that most people would learn to use this system very quickly.
 - h. I found the system very cumbersome to use.
 - i. I felt very confident using the system.
 - j. I needed to learn a lot of things before I could get going with this system.
- 4. Were there particular design elements or interactions with this setup that impacted your experience or influenced your above ratings?**

A.3 Interview questions

- 1. Can you describe your experience using this sink and faucet combination just now?**
- 2. Was there anything that stood out to you or surprised you during the process?**
 - Were there any features that made handwashing more intuitive or efficient?
 - Did any features create challenges or slow down the hand hygiene process?
- 3. Did anything about the setup affect how you performed hand hygiene?**
- 4. Is there anything else you'd like to share about your experience with this particular setup?**

Appendix B – PRISMA flow diagram

Figure B.1: PRISMA flow diagram showing the study selection process



CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.