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Assessing user acceptance towards automated and conventional sink use for hand decontamination using the technology acceptance model

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ABSTRACT

Hand hygiene (HH) prevents harmful contaminants spreading in settings including domestic, health care and food handling. Strategies to improve HH range from behavioural techniques through to automated sinks that ensure hand surface cleaning. This study aimed to assess user experience and acceptance towards a new automated sink, compared to a normal sink. An adapted version of the technology acceptance model (TAM) assessed each mode of handwashing. A within-subjects design enabled $N = 46$ participants to evaluate both sinks. Perceived Ease of Use and Satisfaction of Use were significantly lower for the automated sink, compared to the conventional sink ($p < 0.005$). Across the remaining TAM factors, there was no significant difference. Participants suggested design features including jet strength, water temperature and device affordance may improve HH technology. We provide recommendations for future HH technology development to contribute a positive user experience, relevant to technology developers, ergonomists and those involved in HH across all sectors.

Practitioner Summary: The need to facilitate timely, effective hand hygiene to prevent illness has led to a rise in automated handwashing systems across different contexts. User acceptance is a key factor in system uptake. This paper applies the technology acceptance model as a means to explore and optimise the design of such systems.

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Technology acceptance model; public health; hand hygiene; user experience

Introduction

Hand hygiene (HH) covers the practice of washing hands with soap and water (handwashing) and the use of decontaminating agents such as alcohol-based hand rubs (ABHR), including gels, wipes and foams. Such practice is essential to ensure safety within multiple contexts, including domestic, food handling and health care (Curtis and Cairncross, 2003; Strohbehn et al. 2008; WHO 2009). Established as a high priority within health and food settings, the aim of encouraging HH is receiving increasing focus within educational settings, developing countries and public facilities (e.g. Johnson et al. 2003; Curtis, Danquah, and Aunger 2009; Chittleborough et al. 2012). As the evidence base for the role of effective HH in preventing illness continues to grow (e.g. WHO 2009; Todd et al. 2010) so too do guidelines and interventions aimed at increasing levels of this practice (e.g. Mitchell, Fraser, and Bearon 2007; Gould et al. 2010; Huis et al. 2012; FSA 2013).

In 2009, the World Health Organisation published a definitive report establishing that effective HH can be performed using soap and water or ABHR (WHO 2009). Guidance has been shared with the general public, through agencies such as Centers for Disease Control and Prevention (CDC; http://www.cdc.gov/handwashing/). Correct technique is encouraged, ensuring coverage and adequate friction to remove micro-organisms. Gloves may also be needed, though appropriate use is critical (Girou et al. 2004).

Use of soap and water requires a 40–60 s process, whilst ABHR requires a 20–30 s process (WHO 2009). Thus ABHR has represented a major time saving, however it has limitations with regard to some micro-organisms and removing visible contamination (e.g. Oughton et al. 2009; Tuladhar et al. 2015). Across contexts lack of time is often cited as a barrier to performing HH (Green et al. 2007; Pragle, Harding, and Mack 2007; WHO 2009) therefore, technological innovations which can combine the efficacy of soap and water decontamination within a reduced time frame are highly sought after.

Automated sinks for handwashing have been the subject of previous research (Larson et al. 1991; Wurtz, Moye, and Jovanovic 1994; Larson et al. 1997; Dunn, Palombo,

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and Salamone 2002). Two systematic reviews in 2001 concluded that automated sinks were unlikely to pose a useful solution to improving handwashing due to limitations including end-users being discouraged from use due to requiring additional time (Naikoba and Hayward 2001) and end-users using such systems infrequently (Boyce 2001). Newer iterations of automated sinks are available to market, however no data is available regarding end-user perceptions of using them (e.g. Meritech 2014).

Research on sink design has highlighted the benefit of user feedback, and led to novel designs allowing behaviour to be influenced to encourage water conservation and/or increase handwashing (Arroyo, Bonanni, and Selker 2005; Bonanni 2006). Understanding of individuals' perceptions of automated sinks may address limitations such as infrequent use caused by feelings that systems interfere with normal working conditions, doubts on efficacy of cycle time, fear of contamination and confusion regarding functionality (Larson et al. 1991; Wurtz, Moye, and Jovanovic 1994; Larson et al. 1997).

The presented study compared how individuals feel towards the existing procedure of handwashing using soap and water at a conventional sink, with an automated sink, the hand hygiene unit (HHU). The aim was to arrive at recommendations to underpin the development of future automated handwashing technology which will contribute a positive user experience.

Method

The hand hygiene unit

A prototype HHU (Figure 1) was used in this study. The HHU had been validated in the efficacy of decontamination (Campden BRI 2012). Anecdotal data have shown encouraging, positive reactions towards the HHU; however robust exploration of end-user experience is required to understand these more deeply. Notable system specifications of the HHU were:

- 2.8 log reduction in skin micro-organisms during a standardised 15 s wash cycle.
- No automated drying function.
- Requires plumbing into mains water and electricity, (a portable, stand-alone version in development).

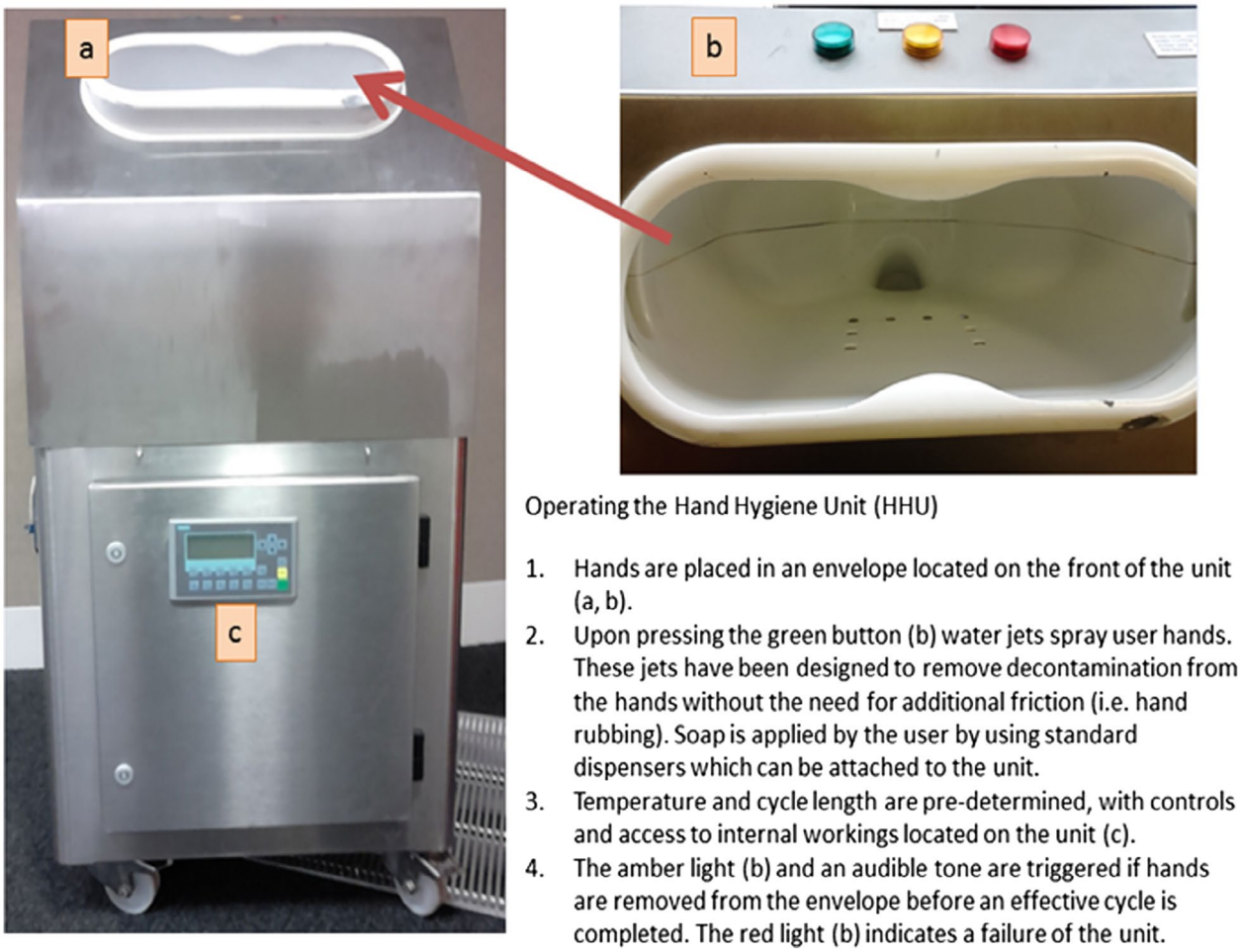

Figure 1. Example of automated sink (HHU) used to compare end-user perceptions.

- The aesthetic appearance of the HHU is under development.
- Required only one button to be pressed to trigger the hand washing cycle.

Sampling and recruitment

A powered sample of $N = 46$ was calculated using G*Power software with a medium effect size (0.5) 95%CI resulting in a test power of 0.95. As HH is an important, familiar mechanism for protecting individuals in everyday life, sampling targeted members of the public with a diverse range of ages, experiences and specialities. Recruitment took place across a large university campus, using flyers, emails and verbal invitations. Individuals with experience of hand decontamination innovations or agents, those with occupational dermatitis, skin irritation or known allergies to hand soap were not eligible to participate.

Technology acceptance model

The technology acceptance model (TAM) (Davis 1989), which predicts acceptance of new technologies by eventual end-users, provides a robust tool to understand user perceptions, allowing improved technology development.

TAM is based upon understanding the end-users' perceptions on Perceived Usefulness (PU) and Perceived Ease of Use (PE) towards a new technology. PU asks: 'Will using X increase my performance at Y?' PE asks: 'Will using X equal little physical/mental effort?' PU and PE influence Attitude (A) and Behavioural Intention (BI). More recently, Attitude has been measured through two sub-categories, Satisfaction of use (SU) and Confidence of use (CU) (Shi et al. 2015). TAM was modified by ensuring statements represented the handwashing process to ensure context was represented accurately (Appendix 1).

Study design

A mixed-methods repeated measures study was conducted (Figure 2). Participants completed the TAM questionnaire following each hand decontamination procedure. Qualitative data were collected using free-text notes. To counter order affects, the participant sample ($N = 46$) was counterbalanced and tested over two distinct phases. In Phase 1, half the group (Group 1) used the HHU whilst the other (Group 2) used a normal sink. In Phase 2, the participants were exposed to the alternative decontamination procedure. When interacting with the HHU participants were informed it was a prototype design, and a facilitator remained present but did not guide participants on the use process.

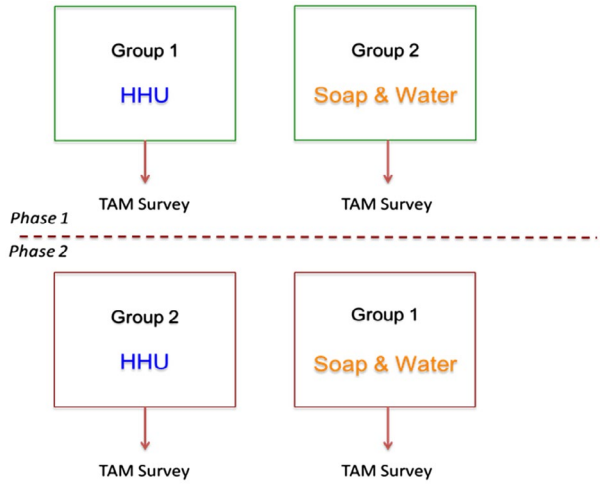

Figure 2. Study design.

Participants were provided with a blank sheet of paper with written instruction to write and/or draw any improvements, changes or additional comments they may have regarding the hand decontamination procedure experienced (Appendix 1). Verbal comments made by participants during interactions were also noted by the facilitator.

Data collection occurred over 4 consecutive days between November and December 2015, with approximately 11 participants taking part on each day. To enable participants to interact with both decontamination methods, individual participation in Phase 1 and Phase 2 occurred on the same day. Both decontamination methods were located within a large staff common room area in an office building. Completing both Phase 1 and Phase 2 took approximately 20 minutes for each participant.

Participants

Forty-six participants took part in this study, ranging in age from 20 to 58 years (mean age = 30), consisting of 14 females and 32 males (differences in gender were not the focus of the study). Participants included lecturers, painters, administrators, cleaners and students. As the study was evaluating technology, and HH has a particularly high profile within health care domains, individuals were asked whether they were involved in activities covering engineering and manufacturing ($N = 27$) and/or health care ($N = 1$), or held a professional health care qualification ($N = 2$) (Table 1).

Data analysis

Normality of the data was checked and Cronbach alpha was used to determine internal consistency of the question items. Once normality and internal consistency had been

Table 1. Participant demographics.

	Gender (F/M)	Involved in healthcare research	Professional healthcare qualification	Involved in engineering or manufacturing research
Group 1: Hand hygiene unit followed by normal sink				
No. participants	23 (6F, 17M)	1	0	16
Group 2: Normal sink followed by hand hygiene unit				
No. participants	23 (8F, 15M)	1	1	11
Totals	46 (14F, 32M)	2	1	27

established, a Wilcoxon Signed Ranks Test determined the difference in scoring between the two decontamination methods across each TAM factor (PU, PE, SU, CU and BI).

Thematic analysis was used to extract meaning from the free-text data, incorporating a mixture of deductive and inductive analysis. The approach of Boyatzis (1998) was followed, whereby specific themes were manually looked for within the qualitative data related to the TAM factors in a deductive manner (PU, PE, SU, CU and BI).

Ethical approval

Ethical approval was granted for this study by the University of Warwick Biomedical and Scientific Research Ethics Committee (REGO-2015-1622 AM01).

Results and discussion

Statistical analysis

Internal consistency of responses to the statements for each TAM factor was tested using a Cronbach alpha with the assumption that the Cronbach alpha should be >0.6 to indicate consistency (Hair et al. 1992, 449) (Table 2). When rating the sink across BI, a low internal consistency was recorded, suggesting inconsistent responses to questions on this factor by participants. Results from this factor were therefore not included subsequent analysis.

Normality testing revealed a skewed distribution, and supported a non-parametric statistical testing. The Wilcoxon Signed-Ranks Test revealed a significant difference between the acceptance of the HHU and sink (Table 2).

The Wilcoxon Signed-ranks test indicated that the sink was rated more easy to use (Mdn = 7) than the HHU (Mdn = 6), ($Z = -2.861$, $p = 0.004$, $r = 0.42$). There were also significant findings for CU, where medians of CU Sink and CU HHU were 6 and 6, respectively ($Z = -3.567$, $p = 0.000$, $r = 0.526$).

There was no statistically significant difference for Perceived Usefulness or Satisfaction of Use ($p \geq 0.005$). These results indicate that:

- Users perceive the sink as easier to use than the HHU
- Users are more confident using the sink than the HHU
- Users perceive the HHU to be as useful as the sink
- Users are as satisfied using the HHU as they are using the sink

Table 2. Analysis of technology acceptance model (TAM) factors.

	Hand hygiene unit (HHU)	Normal sink
Perceived ease of use		
Cronbach alpha	0.6362	0.6912
Mean	5.625	6.0054
Std Dev	1.7385	1.5906
Z value	−2.861	
p value	0.004	
Effect size (*r*)	0.42	
Confidence of use		
Cronbach alpha	0.7130	0.8182
Mean	4.9783	5.6304
Std Dev	1.8286	1.4540
Z value	−3.567	
p value	0.000	
Effect size (*r*)	0.526	
Perceived usefulness		
Cronbach alpha	0.7283	0.5019
Mean	5.3370	5.2228
Std Dev	1.7479	1.6724
Z value	−0.952	
p value	0.341	
Satisfaction of use		
Cronbach alpha	0.7266	0.6670
Mean	4.5707	4.5978
Std Dev	1.8600	1.7372
Z value	−0.253	
p value	0.801	
Behavioural intention		
Cronbach alpha	0.8019	0.2544
Mean	4.6359	5.4511
Std Dev	1.9398	2.1798
Z value	−3.398	
p value	0.001	

Qualitative data

Participant comments provided insights particular to each TAM factor. The comments revealed both positive and negative views regarding PE, PU, CU and SU. No comments were related to BI (Table 3).

Whilst we found no significant difference between participants' perceptions of perceived usefulness and satisfaction of use, our findings suggest that perceived ease of use and confidence of use may be critical factors to overcome if implementation of automated methods for handwashing

Table 3. Overview of qualitative feedback from participants.

Factor	Positive/negative comment	Number of comments from participants			
		Hand hygiene unit (HHU)		Normal sink	
		Positive	Negative	Positive	Negative
PE		1	2	1	2
	Overview of comments	No touching required (*N* = 1)	Need for instructions (*N* = 2)	Easy to use (*N* = 1)	Problems with tap functions (*N* = 2)
CU		4	4	2	3
	Overview of comments	Hands considered cleaned (*N* = 4)	Hands not considered cleaned (*N* = 4)	Hands considered cleaned (*N* = 2)	Hands not considered cleaned (*N* = 3)
PU		1	5	0	1
	Overview of comments	Commercial appeal (N = 1)	Need/expectation that unit would perform drying (N = 5)		No soap available (*N* = 1)
SU		5	25	0	5
	Overview of comments	Pleasant water temperature (*N* = 3), pleasant water jet strength (*N* = 2)	Unpleasant water temperature (*N* = 2), unpleasant water jet strength (*N* = 5), too noisy (*N* = 6), use led to splashing/wetting user (*N* = 12)		Unpleasant water temperature (*N* = 4), not as good as automated method (*N* = 1)
BI	Overview of comments	0	0	0	0

is desired. Enhancement of these is therefore needed. The following sections discuss each of the TAM factors in turn.

Perceived ease of use (PE)

The prevalence and frequency of interaction with sinks to wash our hands mean it is unsurprising that the perceived ease of use (PE) for the sink was higher than for the automatic sink. The mental models and schemas we hold in our cognition provide a means to interact with sinks with minimal effort (Plant and Stanton 2012). Indeed, participants themselves highlighted the need for more information to guide future users of the HHU (*Please include user-friendly instructions to allow use without assistant being present; Information about the system/method might help get more trust from the users!*) Design novelty has previously been noted as a temporary influence, with effects waning over time (Sonderegger et al. 2012). Larson et al. (1997) indicated that additional research would be needed to address the challenge of establishing prolonged use of automated sinks, as opposed to the novelty of a new technology temporarily influencing behaviour. Ensuring that an automated sink is perceived as easy to use may be crucial to this challenge. Perceived ease of use is similar to the characteristics of transparency and affordance outlined by Barnard et al. (2013). A transparent system enables users to understand what the system can do, and effects of their actions as a user. It therefore elicits low levels of perceived difficulty. Affordance, whereby a system should be intuitive to use, ensures continued usage. Focusing technology design on transparency and affordance may increase usability, which in turn may address the challenge of engagement, demonstrated through sustained usage after habituation to the novelty.

Confidence of use

Existing research demonstrates the importance of confidence in the formation of attitudes towards using automated HH technology. Larson et al. (1991) looked at the effect of an automated sink on attitudes and practices of health care professionals within two settings; a post-anaesthesia recovery room and a neonatal intensive care unit (NITU). Whilst findings were positive towards increased quality of decontamination, frequency of handwashing fell. Post-anesthesia staff preferred the automated sink as a method for improving handwashing by ensuring correct practice and length of wash, however indicated that when busy, they would opt for the manual sink. NITU attitudes were less favourable, with only 20% of staff expressing confidence that the automated sink improved handwashing, and approximately 30% feeling it helped them achieve correct practice and handwash length. At the end of the trial within the NITU, 100% of staff preferred the manual sink with 90% reporting that the automated sink caused them to avoid handwashing.

Concurring, participants here showed confidence in the ability of the HHU to decontaminate hands (e.g. *Hands feel VERY CLEAN; Improved hygiene due to minimal contact*). However, overall the survey suggests that participants felt more confident that the sink achieved the goal of clean hands, with comments revealing doubts about the efficacy of the HHU (*I didn't feel my hands were clean because I just got the impression that the device only rinses the hand, and the important bit that is rubbing with soap was overlooked; It cleaned my palm perfectly, but not for my fingers*). This may be due to existing knowledge held by participants that manual effort is required for 'effective' handwashing. Provision of information has previously been identified

as essential to build confidence in users of technology (Barnard et al. 2013). Using this concept, it is suggested that informing users of the efficacy of the HHU and similar technology compared to manual handwashing may be an important step in increasing user confidence in its ability. Such information provision may take varied forms, from in-built information screens or audio prompts, to more traditional paper manuals.

Perceived usefulness

Participants rated the HHU and sink almost identically in terms of perceived usefulness, however data from the qualitative feedback suggests individuals were more inclined to offer views on how the HHU could be improved. This is unsurprising, as the prototype design was likely to have encouraged participants to offer suggestions for future developments.

Dispenser design has previously been shown to affect individuals' attitudes towards handwashing. In the public setting, Kuznetsov and Paulos (2010) found that 'playful design', using a series of coloured lights to represent water usage, increased utilisation of a water saving device by inspiring curiosity. Within health care, Wurtz, Moye, and Jovanovic (1994) detailed investigations following an outbreak on a surgical intensive care unit equipped with handwashing machines (HWM). Observations conducted found that HWM improved levels of handwashing on the unit, however staff expressed mixed opinions about its design and efficacy, with extensive re-design required based on concern about potential contamination risk through normal usage. Whilst no users in the current study raised concerns about contamination, feedback about design was still forthcoming.

Participant comments concerned the HHU having a drying function. As transmission of bacteria is more likely from wet skin than dry (Huang, Ma, and Stack 2012), hand drying should be considered an integral part of HH. Participant expected automated drying by the HHU possibly due to prevalence of automated dryers. Evidence suggests that paper towels are superior to electronic methods of hand drying, especially in environments where hygiene is vital (Huang, Ma, and Stack 2012). Automated sinks should integrate paper towels dispensers and places for disposal. This again supports the need for better usability through integrated design features that prompt behaviour and inform the user.

Satisfaction of use

Although no significant differences were found for SU between the two handwashing approaches, participant comments yielded five times as many negative comments as positive for the HHU. Negative comments were collected regarding water strength, temperature, noise and splashing (n = 25 comments in total). When assessing these, a lack of control was seen to be problematic (e.g. *No control on temperature; Cannot change the temperature of the water*). As some individuals commented positively on the temperature (*The temperature was perfect; The water temperature was just perfect*) and some discussed issues getting a 'perfect' temperature using the sink (*Water is often too hot or is cold; Having a hard time adjusting the perfect water temperature*), this infers that no one 'set' temperature may be suitable for all users performing handwashing – control appears key. Usability is important for the acceptance of technologies and with the inability to control temperatures users may not feel as confident using the HHU, with worry of unexpected consequences (e.g. cold water) – thus supporting the CU findings described above.

Splashing was considered negative, meaning that users felt the technology yielded a more unpleasant experience compared to using a sink (*The water was not directed properly, the water sprayed all the way till my elbows; I had problem regarding the water spray, which somehow sprayed onto my glasses. This contributed to a less pleasant experience*). A lack of knowledge and control over the operation may partially explain such comments. Additional information was needed when interacting with the HHU rather than a sink (*Clear signs needed to roll your sleeves up – to avoid getting wet clothes*).

Non-visual aesthetics have previously been shown to influence positive user-experience (Wellings, Pitts, and Williams 2012). Here, noise generated by the HHU was also reported as a negative. Sound can positively reinforce user interaction with products, however when noise is produced, dissatisfaction may occur. Product attributes of aesthetic, sound, tactility, smell, contribute to a multisensory interaction and require consideration for positive user interaction. Indeed, multisensory interactions have been shown to promote more effective HH (King et al. 2016), and unattractive facilities have been identified as key barriers to regular HH (Chittleborough et al. 2012).

Behavioural intention

The results from behavioural intention showed that participants had no intention to use the HHU if a sink provides an alternative option. Indeed, the results from both CU and SU reinforce this attitude. Nevertheless, these factors offer a means to consider technology improvement through introducing and redesigning features to encourage SU and CU thereby leading to a stronger BI by the user.

Future picture and recommendations for prototype development

Published research into automated sinks has been lacking since the late 1990s, despite developments in this field recently increasing. Independent laboratory studies published by Meritech (Meritech 2014) indicate that the latest automated sink is effective in removing harmful contamination from hand surfaces, including E-Coli, Feline Calicivirus (substitute for Norovirus) and Serratia Marcescens. This is similar to the efficacy claimed by private trials conducted by the manufacturer of the HHU prototype used for the present study (Campden BRI 2012). Such information is promising for the future of hand decontamination; however the current study has indicated that the adoption of such technologies may be negatively affected by user experience.

At present, a normal sink offers a known avenue to perform handwashing along with additional sensory interaction through scented soaps and the tactility of gels and liquids. Automated sinks however, may not necessarily communicate their efficacy and value clearly. Technology development may address this through providing information for the user and providing affordance to the process of interaction and the resultant benefits in terms of reduced microbial contamination.

In light of the study findings, based on a prototype HHU, five key recommendations for development emerged, explicitly linked to the TAM factors. Such recommendations may be of additional value to other developers of automated handwashing technologies.

(1) To positively affect Confidence of Use and Perceived Usefulness, the efficacy of automated sinks to clean hands should be communicated clearly to users. Achieving this may include exploring the use of a visual display unit (VDU), or printed material to accompany the unit.
(2) Highlighting the simplicity of automatic sinks through improved usage instructions should positively affect Perceived Ease of Use. Using a VDU, or symbols/writing incorporated onto the system itself should aim to negate the need for an informed facilitator to be present.
(3) All TAM factors could be addressed by considering recommendations 1 and 2 along with the need to improve the industrial appearance of automated sinks, which may also reduce the excessive noise. An automated sink should appear easy to use, which may involve consideration of existing schemas surrounding user expectations when performing hand decontamination.
(4) Offering control of temperature allowing users to meet their own preferences within settings ensuring a hygienic hand clean, but preventing scalding to occur, should positively affect Satisfaction of Use.
(5) Satisfaction of Use could further be positively affected by designing water jet direction and envelope design to ensure no splashing.

Limitations and future work

Limitations in the presented findings are acknowledged. Although the study was designed for each participant to interact with both handwashing methods on the same day to aid convenience, this may have led to participant fatigue. Future studies may wish to conduct Phase 1 and Phase 2 on consecutive days to avoid fatigue.

Whilst the current study only applied the modified TAM approach to one design of automated sink, the HHU, the method could be applied to evaluate many automated sink models. The low internal consistency for behavioural intention and feedback from two participants who found some survey questions confusing indicate that refinement would be needed to improve internal consistency. Nevertheless, the resultant recommendations for the HHU may be useful for those developing automated sinks, with further specific evaluation using the outlined method now possible, generating further recommendations for the chosen innovation.

Conclusions

The study successfully compared user experience and acceptance of a new type of automated sink to using a normal sink for hand decontamination. Whilst Perceived Ease of Use and Satisfaction of Use were significantly lower for the automated sink, compared to the conventional sink ($p < 0.005$), there was no significant difference for Confidence of Use and Perceived Usefulness. Qualitative feedback from participants allowed these findings to be explored in more detail, leading to recommendations focussed around improving design to engage users more effectively in the use of handwashing technology. Design alterations and innovations addressing these recommendations might be benchmarked against concepts of TAM to improve users' confidence and ease of use that may ultimately improve user satisfaction, with positive implications for the adoption of handwashing technology. It is specifically this point that the study highlights; whilst currently automated sinks are developed that demonstrate effective decontamination, with a time-saving component, further attention to end-user acceptance is

required. Understanding and optimising factors related to technology acceptance is as much a requirement as is the efficacy of decontamination.

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Disclosure statement

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References

Arroyo, E., L. Bonanni, and T. Selker. 2005. "Waterbot: Exploring Feedback and Persuasive Techniques at the Sink." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*: 631–639. doi:10.1145/1054972.1055059.

Barnard, Y., M. D. Bradley, F. Hodgson, and A. D. Lloyd. 2013. "Learning to Use New Technologies by Older Adults: Perceived Difficulties, Experimentation Behaviour and Usability." *Computers in Human Behavior* 29 (4): 1715–1724. doi:10.1016/j.chb.2013.02.006.

Bonanni, L. 2006. "Ambient Intelligence in Everyday Life." Chap. 6 in *Living with Hyper-reality*. Heidelberg: Springer Berlin.

Boyatzis, R. E. 1998. *Transforming Qualitative Information: Thematic Analysis and Code Development*. London: Sage.

Boyce, J. M. 2001. "Antiseptic Technology: Access, Affordability, and Acceptance." *Emerging Infectious Diseases* 7 (2): 231. doi:10.3201/eid0702.700231.

Campden BRI. 2012. *Validation of a Novel Design Automated Hand Wash Unit – Phase II: Project Reference SBRI – 1008-049. Report No: FMT/122800/1*. Available upon request.

Chittleborough, C. R., A. L. Nicholson, E. Basker, S. Bell, and R. Campbell. 2012. "Factors Influencing Hand Washing Behaviour in Primary Schools: Process Evaluation within a Randomized Controlled Trial." *Health Education Research.* 27 (6): 1055–1068. doi:10.1093/her/cys061.

Curtis, V., and S. Cairncross. 2003. "Effect of Washing Hands with Soap on Diarrhoea Risk in the Community: A Systematic Review." *The Lancet Infectious Diseases* 3 (5): 275–281.

Curtis, V. A., L. O. Danquah, and R. V. Aunger. 2009. "Planned, Motivated and Habitual Hygiene Behaviour: An Eleven Country Review." *Health Education Research* 24 (4): 655–673. doi:10.1093/her/cyp002.

Davis, F. D. 1989. "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology." *MIS Quarterly* 13 (3): 319–340. doi:10.2307/249008.

Dunn, L. A., E. A. Palombo, and S. Salamone. 2002. "The Effectiveness of Different Wash Basins in Reducing the Microbial Load on the Hands of Food Handlers." *Environmental Health* 2 (4): 13.

FSA (Food Standard Agency). 2013. *Food Hygiene: A Guide for Businesses*. London: Food standard agency. FSA/1690/0613. https://www.food.gov.uk/sites/default/files/multimedia/pdfs/publication/hygieneguidebooklet.pdf.

Girou, E., S. H. Chai, F. Oppein, P. Legrand, D. Ducellier, F. Cizeau, and C. Brun-Buisson. 2004. "Misuse of Gloves: The Foundation for Poor Compliance with Hand Hygiene and Potential for Microbial Transmission?" *Journal of Hospital Infection* 57 (2): 162–169. doi:10.1016/j.jhin.2004.03.010.

Gould, D. J., D. Moralejo, N. Drey, and J. H. Chudleigh. 2010. "Interventions to Improve Hand Hygiene Compliance in Patient Care." *The Cochrane Database of Systematic Reviews* (9): CD005186. doi:10.1002/14651858.CD005186.pub3.

Green, L. R., V. Radke, R. Mason, L. Bushnell, D. W. Reimann, J. C. Mack, M. D. Motsinger, T. Stigger, and C. A. Selman. 2007. "Factors Related to Food Worker Hand Hygiene Practices." *Journal of Food Protection* 70 (3): 661–666.

Huang, C., W. Ma, and S. Stack. 2012. "The Hygienic Efficacy of Different Hand-drying Methods: A Review of the Evidence." *Mayo Clinic Proceedings* 87 (8): 791–798. doi:10.1016/j.mayocp.2012.02.019.

Huis, A., T. van Achterberg, M. de Bruin, R. Grol, L. Schoonhoven, and M. Hulscher. 2012. "A Systematic Review of Hand Hygiene Improvement Strategies: A Behavioural Approach." *Implementation Science* 7: 92. doi:10.1186/1748-5908-7-92.

Hair Jr, J. F., R. Anderson, R. Tatham, and W. C. Black. 1992. *Multivariate Data Analysis*. 3rd ed. New York: Macmillan.

Johnson, H. D., D. Sholcosky, K. Gabello, R. Ragni, and N. Ogonosky. 2003. "Sex Differences in Public Restroom Handwashing Behavior Associated with Visual Behavior Prompts." *Perceptual and Motor Skills* 97 (3): 805–810.

King, D., I. Vlaev, R. Everett-Thomas, M. Fitzpatrick, A. Darzi, and D. J. Birnbach. 2016. "'Priming' Hand Hygiene Compliance in Clinical Environments." *Health Psychology* 35 (1): 96–101. doi:10.1037/hea0000239.

Kuznetsov, S., and E. Paulos. 2010. "UpStream: Motivating Water Conservation with Low-cost Water Flow Sensing and Persuasive Displays." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*: 1851–1860. doi:10.1145/1753326.1753604.

Larson, E. L., J. L. Bryan, L. M. Adler, and C. Blane. 1997. "A Multifaceted Approach to Changing Handwashing Behavior." *American Journal of Infection Control* 25 (1): 3–10. doi:10.1016/S0196-6553(97)90046-8.

Larson, E., A. McGeer, Z. A. Quraishi, D. Krenzischek, B. J. Parsons, J. Holdford, and W. J. Hierholzer. 1991. "Effect of an Automated Sink on Handwashing Practices and Attitudes in High-Risk Units." *Infection Control & Hospital Epidemiology* 12 (7): 422–428. doi:10.1086/646372.

Meritech. 2014. "Clinical Bulletin: Independent Laboratory Studies Summary January 2014." Accessed June 20, 2016. http://meritech.com/wp-content/uploads/2014/04/Summary-of-Studies-01-24-14.pdf

Mitchell, R. E., A. M. Fraser, and L. B. Bearon. 2007. "Preventing Food-borne Illness in Food Service Establishments: Broadening the Framework for Intervention and Research on Safe Food Handling Behaviors." *International*

Journal of Environmental Health Research. 17 (1): 9–24. doi:10.1080/09603120601124371.

Naikoba, S., and A. Hayward. 2001. "The Effectiveness of Interventions Aimed at Increasing Handwashing in Healthcare Workers - A Systematic Review." *Journal of Hospital Infection* 47 (3): 173–180. doi:10.1053/jhin.2000.0882.

Oughton, M. T., V. G. Loo, N. Dendukuri, S. Fenn, and M. D. Libman. 2009. "Hand Hygiene with Soap and Water is Superior to Alcohol Rub and Antiseptic Wipes for Removal of Clostridium Difficile." *Infection Control & Hospital Epidemiology* 30 (10): 939–944.

Plant, K. L., and N. A. Stanton. 2012. "Why Did the Pilots Shut down the Wrong Engine? Explaining Errors in Context Using Schema Theory and the Perceptual Cycle Model." *Safety Science* 50 (2): 300–315. doi:10.1016/j.ssci.2011.09.005.

Pragle, A. S., A. K. Harding, and J. C. Mack. 2007. "Food Workers' Perspectives on Handwashing Behaviors and Barriers in the Restaurant Environment." *Journal of Environmental Health* 69 (10): 27.

Shi, L., C. Dawson, J. B. MacKrill, E. Dimitrokali, and R. Cain. 2015. "Digital Co-design: A Future Method?" *Proceedings of the 2015 British HCI Conference*: 295–296. doi:10.1145/2783446.2783618.

Sonderegger, A., G. Zbinden, A. Uebelbacher, and J. Sauer. 2012. "The Influence of Product Aesthetics and Usability over the Course of Time: A Longitudinal Field Experiment." *Ergonomics* 55 (7): 713–730. doi:10.1080/00140139.2012.672658.

Strohbehn, C., J. Sneed, P. Paez, and J. Meyer. 2008. "Hand Washing Frequencies and Procedures Used in Retail Food Services." *Journal of Food Protection* 71 (8): 1641–1650.

Todd, E. C., J. D. Greig, B. S. Michaels, C. A. Bartleson, D. Smith, and J. Holah. 2010. "Outbreaks Where Food Workers Have Been Implicated in the Spread of Foodborne Disease. Part 11. Use of Antiseptics and Sanitizers in Community Settings and Issues of Hand Hygiene Compliance in Health Care and Food Industries." *Journal of Food Protection* 73 (12): 2306–2320.

Tuladhar, E., W. C. Hazeleger, M. Koopmans, M. H. Zwietering, E. Duizer, and R. R. Beumer. 2015. "Reducing Viral Contamination from Finger Pads: Handwashing is More Effective than Alcohol-based Hand Disinfectants." *Journal of Hospital Infection* 90 (3): 226–234. doi:10.1016/j.jhin.2015.02.019.

Wellings, T., M. J. Pitts, and M. A. Williams. 2012. "Characterising the Experience of Interaction: An Evaluation of Automotive Rotary Dials." *Ergonomics* 55 (11): 1298–1315. doi:10.1080/00140139.2012.708057.

WHO (World Health Organization). 2009. *WHO Guidelines on Hand Hygiene in Health Care: First Global Patient Safety Challenge. Clean Care is Safer Care*. Geneva: World Health Organization.

Wurtz, R., G. Moye, and B. Jovanovic. 1994. "Handwashing Machines, Handwashing Compliance, and Potential for Cross-contamination." *American Journal of Infection Control* 22 (4): 228–230. doi:10.1016/0196-6553(94)99001-8.

Appendix 1

Post-experience survey. What do you think?

(to be completed by researcher)

Study Session: **PHASE 1** *or* **PHASE 2**

Participant Number: _____

Procedure: **Hand Hygiene Unit (HHU)**

(to be completed by Participant)

Thank you for taking part in our research study exploring end-user views on different procedures available for hand hygiene.

Please take a moment to think about the procedure you have just used to clean your hands, and then read the statements below. For each statement, think about how much you agree or disagree with what is written. When you are ready, please circle a number on the scale to indicate your view, with **1** meaning you **strongly disagree**, and **7** meaning you **strongly agree**.

In this survey, **procedure** refers to: **Hand Hygiene Unit (HHU)**

Thoughts on my experience	Please circle ONE number on the scale, with 1 = strongly disagree, and 7 = strongly agree						
The procedure helped me to perform hand hygiene	7	6	5	4	3	2	1
The procedure was user-friendly	7	6	5	4	3	2	1
The procedure was an unpleasant way to perform hand hygiene	7	6	5	4	3	2	1
I would not use the procedure again for hand hygiene	7	6	5	4	3	2	1
I would tell people about the procedure	7	6	5	4	3	2	1
I did not feel confident that the procedure cleaned my hands	7	6	5	4	3	2	1
I felt confident to use the procedure for hand hygiene	7	6	5	4	3	2	1
The procedure did not help me to perform hand hygiene	7	6	5	4	3	2	1
Learning to use the procedure was easy	7	6	5	4	3	2	1
I would not frequently use the procedure for hand hygiene	7	6	5	4	3	2	1
I felt confident the procedure was safe way for me to perform hand hygiene	7	6	5	4	3	2	1
The procedure was pleasant to use	7	6	5	4	3	2	1
I would not remember how to use the procedure again for hand hygiene	7	6	5	4	3	2	1
It was not easy to perform hand hygiene using the procedure	7	6	5	4	3	2	1
I would use the procedure again for hand hygiene	7	6	5	4	3	2	1
The procedure was not fun to use	7	6	5	4	3	2	1
The procedure was attractive to use	7	6	5	4	3	2	1
The procedure didn't make me want to perform hand hygiene	7	6	5	4	3	2	1
I did not feel confident using the procedure for hand hygiene	7	6	5	4	3	2	1
The procedure was an engaging way to perform hand hygiene	7	6	5	4	3	2	1

Post-experience survey. What do you think?

(to be completed by researcher)

Study Session: **PHASE 1** *or* **PHASE 2**

Participant Number: _____

Procedure: **Soap and Water at Sink**

(to be completed by Participant)

Thank you for taking part in our research study exploring end-user views on different procedures available for hand hygiene.

Please take a moment to think about the procedure you have just used to clean your hands, and then read the statements below. For each statement, think about how much you agree or disagree with what is written. When you are ready, please circle a number on the scale to indicate your view, with **1** meaning you **strongly disagree**, and **7** meaning you **strongly agree**.

In this survey, **procedure** refers to: **Soap and Water at Sink**

Thoughts on my experience	Please circle ONE number on the scale, with 1 = strongly disagree, and 7 = strongly agree						
The procedure helped me to perform hand hygiene	7	6	5	4	3	2	1
The procedure was user-friendly	7	6	5	4	3	2	1
The procedure was an unpleasant way to perform hand hygiene	7	6	5	4	3	2	1
I would not use the procedure again for hand hygiene	7	6	5	4	3	2	1
I would tell people about the procedure	7	6	5	4	3	2	1
I did not feel confident that the procedure cleaned my hands	7	6	5	4	3	2	1
I felt confident to use the procedure for hand hygiene	7	6	5	4	3	2	1
The procedure did not help me to perform hand hygiene	7	6	5	4	3	2	1
Learning to use the procedure was easy	7	6	5	4	3	2	1
I would not frequently use the procedure for hand hygiene	7	6	5	4	3	2	1
I felt confident the procedure was safe way for me to perform hand hygiene	7	6	5	4	3	2	1
The procedure was pleasant to use	7	6	5	4	3	2	1
I would not remember how to use the procedure again for hand hygiene	7	6	5	4	3	2	1
It was not easy to perform hand hygiene using the procedure	7	6	5	4	3	2	1
I would use the procedure again for hand hygiene	7	6	5	4	3	2	1
The procedure was not fun to use	7	6	5	4	3	2	1
The procedure was attractive to use	7	6	5	4	3	2	1
The procedure didn't make me want to perform hand hygiene	7	6	5	4	3	2	1
I did not feel confident using the procedure for hand hygiene	7	6	5	4	3	2	1
The procedure was an engaging way to perform hand hygiene	7	6	5	4	3	2	1

Post-experience Reflection. What do you think?

(to be completed by researcher)
Study Session: **PHASE 1** *or* **PHASE 2**
Participant Number: _____
Procedure: **Hand Hygiene Unit (HHU)**

Please use the space below to record any thoughts you may have about your recent experience of performing hand hygiene.

Please feel free to use words, or draw diagrams or pictures, to best illustrate how your thoughts.

Post-experience Reflection. What do you think?

(to be completed by researcher)
Study Session: **PHASE 1** *or* **PHASE 2**
Participant Number: _____
Procedure: **Soap and Water at Sink**

Please use the space below to record any thoughts you may have about your recent experience of performing hand hygiene.

Please feel free to use words, or draw diagrams or pictures, to best illustrate how your thoughts.