Food Control 145 (2023) 109439

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Attitudes towards using artificial intelligence to determine real-time hand hygiene compliance in the food sector

Ellen W. Evans [a,*], Veronika Bulochova [a], Ambikesh Jayal [b], Claire Haven-Tang [c]

[a] ZERO2FIVE Food and Drink Research Unit, Food Industry Centre, Cardiff Metropolitan University, 200 Western Avenue, Llandaff, Cardiff, Wales, CF5 2YB, United Kingdom
[b] School of Information Systems and Technology, University of Canberra, 11 Kirinari St, Bruce, Australian Capital Territory, 2617, Australia
[c] Welsh Centre for Tourism Research, Cardiff School of Management, Cardiff Metropolitan University, 200 Western Avenue, Llandaff, Cardiff, Wales, CF5 2YB, United Kingdom

ARTICLE INFO

Keywords:
hand-Hygiene
Artificial intelligence
Machine learning
Food safety
Technology acceptance

ABSTRACT

Foodhandler hand hygiene is critical to ensure food safety for consumers. Observational studies of foodhandler hand hygiene practices have been conducted in the food sector, although industry values such data the method is time-consuming/expensive. Artificial Intelligence (AI) may provide a solution, it has the potential to distinguish compliant and non-compliant hand hygiene attempts. To inform the development of such technology, this study conducted in-depth interviews (n = 12) with representatives from food manufacturing and food service businesses, to explore their perceptions of using AI technology to obtain real-time hand hygiene compliance data. A thematic analysis approach determined that both sectors discussed the importance of hand hygiene and were supportive of the proposed concept. Discussions indicated perceived benefits to include constant and longitudinal monitoring, utilizing the technology to inform training, and for assessing training effectiveness. It was discussed that real-time compliance data could be utilised to reward, recognise, and promote compliant behaviour, which in turn may enhance the food safety culture of businesses. Development of the proposed technology, informed by these findings, could single-handedly revolutionise hand hygiene compliance – safeguarding food businesses and consumers.

1. Introduction

1.1. Importance of hand hygiene in food manufacturing and food service environments

Although vast differences exist between food service and food manufacturing environments (Morris & Johnston, 1987), hand hygiene practices are essential in both. Hand washing is the single most effective way to prevent the spread of diseases and is essential in food service establishments and food manufacturing businesses to ensure food safety and reduce the risk of foodborne illness to consumers (Todd, Michaels et al. 2010; Griffith, 2013; Health Protection Agency, 2013). Yet, inadequate foodhandler hand hygiene has been frequently cited as a contributory factor in foodborne illness (Todd, Greig et al. 2007; Kadariya, Smith, & Thapaliya, 2014). The provision of adequate and suitably located facilities to enable hand hygiene practices along with the supervision and training of foodhandlers in aspects of hand hygiene in food premises are required by law (European Parliament, 2004). Nevertheless, it must be considered that delivery of training and the provision of suitable facilities alone does not guarantee that foodhandlers will always implement adequate hand hygiene practices. Therefore, there is a need for food businesses to adopt methods to assess hand hygiene practices (Evans & Redmond, 2018).

1.2. Methods of assessing hand hygiene in food manufacturing and food service environments

Research suggests that foodhandlers are aware of the importance of hand hygiene and report the implementation of hand hygiene practices (Zanin, da Cunha et al. 2017). However, hand hygiene knowledge may not convert into appropriate hand hygiene practices (Rossi, Stedefeldt et al. 2017), and self-reported practices may not be indicative of actual behaviour due to social desirability biases – whereby people tend to over-report good practices, and under-report bad practices (Abbot,

* Corresponding author.
E-mail address: elevans@cardiffmet.ac.uk (E.W. Evans).

https://doi.org/10.1016/j.foodcont.2022.109439
Received 4 February 2022; Received in revised form 30 September 2022; Accepted 5 October 2022
Available online 10 October 2022

Byrd-Bredbenner et al. 2009; Grimm, 2010; van de Mortel, 2008). Indeed, substantial inconsistencies have been determined between self-reported practices and actual behaviours (Clayton, Griffith et al. 2002; Clayton, Griffith et al. 2003; Redmond & Griffith, 2003). Consequently, observational data are considered superior to survey data, as observational based data provide precise information regarding foodhandler behaviour (Powell, 2010).

However, such methods are not immune from challenges and potential bias, as researcher presence in overt (direct) observation can cause reactivity bias known as the Hawthorne Effect (Harris & Lahey, 1982), whereby the subject's behaviour may be altered as a result of being aware that they are being observed (Payne & Payne, 2004). Consequently, it is suggested that covert (indirect) observation, using video cameras may reduce subject reactivity (Elder, 1999), and although subjects may initially be camera-conscious when covert observation equipment is originally introduced, it is suggested that as subjects become accustomed with the cameras reactivity bias may reduce (Elder 1995, 1999).

It is common to have closed-circuit television (CCTV) cameras recording activity in food manufacturing businesses, which are predominantly utilised for security purposes and occasionally reviewed in the event of an incident, accident or customer complaint; however, routine structured monitoring of footage for hand hygiene compliance is rare, due to the time-consuming nature of the task (Evans, Samuel et al. 2020). A case study of CCTV camera installations in food manufacturing environments established that fields of view commonly include storage areas, general production workflow perspectives, site security and communal areas (Samuel, Evans et al. in press), such CCTV camera installations provide unlimited covert food safety surveillance opportunities to identify foodhandler behavioural malpractices (Samuel, Evans et al. in press). Therefore, it can be concluded that given the widespread use of CCTV cameras in industry, the technology can be utilised to provide an unhindered comprehensive analysis of behaviour over a sustained period as familiarity with existing workplace CCTV systems over time, may reduce reactivity bias resulting in observed behaviours being representative of actual behaviour.

1.3. Observing hand hygiene behaviours in food manufacturing and food service environments

The method of utilizing CCTV camera footage to assess hand hygiene compliance, has successfully obtained valuable insight into the hand hygiene practices of foodhandlers in food manufacturing businesses (Evans, Samuel et al. in press). Recent research studies utilizing the method in food manufacturing businesses have established that the majority of foodhandlers implement a hand washing attempt before entering food production areas, however the vast majority of attempts are not compliant with hand hygiene protocol (Evans & Redmond, 2018, Evans, Samuel et al. 2020; Evans, Samuel et al. in press). Similarly, research studies utilizing methods to observe foodhandler behaviour have been conducted in foodservice settings (Worsfold & Griffith, 2003, Clayton & Griffith, 2004, Green, Selman et al. 2006, Lubran, Pouillot et al. 2010, Chapman, MacLaurin et al. 2013, Rajagopal & Strohbehn, 2013, Arendt, Strohbehn et al. 2015). Such studies indicate that foodhandler compliance with hand hygiene recommendations are generally low, as many activities for which hand washing is recommended did not observe adequate hand hygiene practices (Worsfold & Griffith, 2003, Clayton & Griffith, 2004, Green, Selman et al. 2006, Lubran, Pouillot et al. 2010, Chapman, MacLaurin et al. 2013, Rajagopal & Strohbehn, 2013, Arendt, Strohbehn et al. 2015).

Whilst such research findings are valuable for industry, this frequent and structured observation is extremely time-consuming and costly for food manufacturing and food service businesses to conduct on a regular basis. Furthermore, there are lost opportunities for targeted interventions and training, as when outcomes are presented to food businesses, data may be outdated and not indicative of current performance (Evans, Samuel et al. in press). Consequently, a research gap exists in relation to exploring the feasibility of technology to provide real-time data regarding handwashing compliance of foodhandlers in food manufacturing and food service environments. Technology, could be the solution to providing food sector businesses with such data.

1.4. The potential application of Artificial Intelligence (AI) technology to assess hand hygiene compliance in food manufacturing and food service environments

Developments in digital technologies, data intelligence and analytics provide the potential for business and societal transformation (Magni, Scuotto et al., 2021). One such development is Artificial Intelligence (AI), which attempts to understand intelligence and develop systems that behave in intelligent ways, such as machines that replicate human behaviour. Trocin, Hovland et al. (2021) assert that AI can counteract the limitations of information processing by humans by mimicking complex tasks and analysing large datasets. AI technology has increased in popularity as more organisations seek to create competitive advantage and business value by improving quality and efficiency through automated processes and work activities (Ransbotham, Kiron et al., 2017; Nam, Dutt et al., 2020; Fruehwirt & Duckworth, 2021) and AI is transforming information processing methods in a range of fields, such as staff recruitment and selection, marketing and medical diagnosis (Trocin, Hovland et al., 2021). A subset of AI, Machine Learning (ML) is a set of algorithms, which enable computers to learn patterns from specific data. ML has enhanced revenue management, operational analytics, customer experiences and destination image selection (Fruehwirt & Duckworth, 2021). Vitezić and Perić (2021) note that the tourism and hospitality industries are often quick to adopt AI and earlier studies of AI within the hospitality industry Nam, Dutt et al. (2020), suggest that it can be split into three broad categories: robotics, human resource issues and theoretical perspectives of the impact of technology adoption and implementation.

Previous research (Vitezić & Perić, 2021) also suggests that positive features of AI, such as the accuracy and consistency of machines that replicate human behaviour, promote AI adoption in hospitality. Nevertheless, uncertainty exists about the implications of AI and ML (Rahwan, Cebrian et al., 2019), especially the replacement of people, and there is little research on the use of AI and ML to improve processes that could protect consumers, such as foodhandler compliance with recommended handwashing protocols. Best practice guidelines for hand hygiene indicate several prescriptive steps including wetting hands before dispensing liquid soap, rubbing all parts of the hands, rinsing, drying, and applying hand sanitizer (Taylor & Holah, 2000, Taylor, Kaur et al., 2000). In relation to this particular study on hand hygiene compliance, the research team proposed that AI technology could develop a system that captures and recognises human movement in hand hygiene and analyses the subsequent data to determine whether attempts are compliant or non-compliant with the best practice guidelines. The ability of AI to collect and process extensive quantities of information provides an opportunity to gather and analyse real-time data on hand hygiene compliance. In turn, this offers a novel way of creating business value through timely and targeted interventions for foodhandlers; ultimately avoiding detrimental economic consequences for food businesses and protecting consumers from foodborne diseases due to improper food handling practices.

Given the prescriptive nature of hand hygiene protocols, the potential accuracy and consistency offered by AI and ML appeared to be an appropriate technology to determine if hand hygiene attempts are compliant or non-compliant with the procedure, as this proposed technology would remove the human element in existing observational techniques to enable quicker, real-time delivery of data. This was the proposition upon which the research team initiated the project. However, there was also recognition that to support the development of the proposed technology, there was a need to include the intended user of

the technology in the development of the technology through co-creation. Co-creation needs to consider the current practices, preferences, and experiences of the intended audience/user (Ohern & Rindfleisch, 2010). The four core principles of co-creation are; planning, conducting, evaluating and reporting (Leask, Sandlund et al. 2019). This research will generate data to enable the planning of co-created technologies. The collation of user-generated ideas for future technology is important to ensure a successful outcome (Kristensson, Matthing et al. 2008).

The purpose of this study was to explore the perceptions of the food sector regarding the unproven concept of developing AI and ML technology to provide real-time data on the hand hygiene compliance of foodhandlers, based on the proven benefits of covert observational data for food businesses (Powell, 2010, Evans, Samuel et al. in press; Samuel, Evans et al. in press), and the potential for AI technology to provide such data in real-time. Exploring the perceived benefits, acceptability, practicalities, and concerns regarding the application of such technology in food environments is essential prior to its development (Dugstad, Eide et al. 2019).

The Technology Acceptance Model, developed by Davis, Bagozzi et al. (1989) suggests that the acceptance of a new technology is determined by two factors; the perceived usefulness of the technology, and the perceived ease of use (Davis, Bagozzi et al., 1989). The purpose of this study is to address the first factor of the Technology Acceptance Model, namely the perceived usefulness of the proposed technology to provide real-time data on the hand hygiene compliance of foodhandlers.

2. Materials and methods

The aim of this study was to explore the perceptions of the food sector regarding the application of AI technology in food environments to obtain real-time hand hygiene compliance data. As discussed, obtaining such information from the intended user is essential prior to the creation of such technology.

In order to capture useful and valuable information to inform the future development of the proposed technology, a qualitative research approach using in-depth interviews was selected as qualitative research is a social inquiry that adopts a flexible, data-driven approach using unstructured data, the research focuses on a smaller number of cases in greater detail with in-depth examination, rather than large sample sizes and statistical forms of analysis as seen in quantitative research (Hammersley, 2013). The qualitative research approaches can be utilised to explore experiences, behaviours, perceptions and clarify situations without numerical data (Basias & Pollalis, 2018). Furthermore, involving intended users in the design process is intended to develop technologies that are useful, useable and desirable from the service users' perspective (Dugstad et al., 2019).

2.1. Design and development of a data collection tool

Before conducting any interviews, there is a need to consider the questions that will be asked (Knox & Burkard, 2009). To enable this a review of relevant literature and discussions with project co-investigator with expertise in AI/ML software development were conducted. A standardized semi-structured interview schedule consisting of open-ended questions was devised to organise the discussion and give a forthcoming conversation. Information regarding the proposed AI technology to determine real-time hand hygiene compliance data was propositioned to each participant, points of discussion related to initial thoughts regarding the proposed technology including perceived impact, acceptability, benefits, concerns, and application in the food sector.

The Technology Acceptance Model, developed by Davis, Bagozzi et al. (1989) is a theoretical framework for the acceptance of information systems or technology (Lee, Kozar et al. 2003), which is based upon the Theory of Reasoned Action (Ajzen & Fishbein, 1980), and suggests that the acceptance of technology is determined by two factors; the perceived usefulness of the technology, and the perceived ease of use (Davis, Bagozzi et al., 1989). The data collection tool was intended to explore only one factor of the Technology Acceptance Model, namely the perceived usefulness, as the perceived ease of use of the technology can only be established once the technology has been created. Recruitment of food service and food manufacturing representatives.

Project invitations with participant information sheets detailing the purpose of the study were sent to United Kingdom-based representatives of food manufacturing businesses, food service businesses and industry experts known by the researchers at the [information removed to anonymise the manuscript]. In larger businesses, technical managers and food safety leads were specifically contacted as potential participants for this study given their senior position within the company, being accountable for all technical and food safety aspects of the businesses, and ensuring all processes meet food safety requirements; whereas, in smaller businesses owners or manager would be responsible for food safety and technical considerations and were contacted as potential participants. Contacted individuals that were interested in participating in the study responded to the project invitation call-to-action and subsequent interviews were scheduled at a time convenient to the participant. All participants had the opportunity to ask questions about the study prior to participation. No monetary incentives were given for participating.

2.2. Data collection

The strength of the interviewer-participant relationship is perhaps the single most important aspect of a qualitative research project as it can impact upon the participants' self-disclosure, and the depth of information they may share (Knox & Burkard, 2009). Therefore, food manufacturing businesses known by the [information removed to anonymise the manuscript] were conducted by the researcher with experience of the manufacturing industry and food service businesses known by the [information removed to anonymise the manuscript] where conducted by the researcher with experience of the food service sector. It may be suggested that in-person interviews can be more effective in obtaining rich and complete data than telephone interviews (Knox & Burkard, 2009), the researchers intended conducting in-person interviews, however, due to restrictions during the period of data collection (May 2020–April 2021) to constrain the transmission of COVID-19, in-person interviews were not conducted. Recent research suggests that remote interviews, using the telephone or videoconference technologies, should be seen as equivalent to or even superior to in-person interviews, they likely do come at a cost to the richness of information produced by the interviews (Johnson, Scheitle et al., 2019).

Ethical approval for the semi-structured interviews was granted by the [information removed to anonymise the manuscript] School of Sport and Health Sciences research and ethics committee (Ethics reference number: Sta-2549, February 2020). Participant consent was obtained from interview by means of reading a participant information sheet regarding the study and giving audio recorded verbal consent prior to participating in the study.

Remote interviews were conducted by members of the research team via Microsoft® Teams (Microsoft Corporation, Redmond WA) video call or telephone (to the preference of the participants). Each interview was conducted in English, digitally audio recorded using Dictaphones (Olympus VN-733PC Digital Voice Recorder, Tokyo, Japan) or the record function in Microsoft® Teams. Verbal consent was given by participant and completion took up to 40 min. Interview audio files were transcribed into a word processor document (Microsoft Word, 2010; Microsoft Corporation, Redmond WA).

2.3. Data analysis

Transcripts were reviewed by the researchers who conducted the

interviews to discuss and identify themes. Interview transcripts were analysed using a thematic analysis approach (Braun, Clarke et al. 2018) using a line-by-line approach in NVivo Release 1.3 (QSR International, Cambridge, MA) to capture key themes, codes were created according to the context of the transcript, additional sub-codes were created after the initial coding for further analysis. Two researchers were responsible for reviewing and coding each of the transcripts. Codes for responses to the key discussion points were reviewed and agreed by the two researchers to ensure agreement. Identified 'themes' across the qualitative datasets, enabled the three researchers to establish the perceptions of representatives from food manufacturing environments and food service sectors regarding the proposed real-time hand hygiene compliance technology. The key themes that arose from the research related to the importance of hand hygiene in the food sector; the acceptability of the proposed technology; the perceived benefits of the proposed technology; concerns about the proposed technology; and the possible application of the proposed technology. These are the themes utilised to organise the results and discussion of the research.

Following completion of the twelve interviews, the researchers recognized that many responses and themes were similar and identified that a theoretical saturation point may have been reached. As suggested by Guest, Bunce et al. (2006), saturation of data often occurs within the first 12 interviews. Therefore, it was determined that no additional participants would be recruited and interviewed as they would not provide any additional insights and ensured that no new categories or relevant themes emerged (Corbin & Strauss, 2014). As established in previous research (Evans & Redmond, 2017), the researchers agreed that after completing 12 interviews, that a total sample of 12 participants would be sufficient for the aims of the study as a theoretical saturation point may have been reached.

3. Results and discussion

A total of twelve food sector representatives participated in the semi-structured interviews (see Table 1). These included; representatives of the manufacturing sector (which comprised of technical managers and food safety leaders from small and medium-sized, and large food and drink manufacturing and processing businesses) ($n = 6$); representatives of the food service sector (which consisted of independent owners of micro and small-sized outlets, and a senior technical manager for a large, international franchise café chain) ($n = 3$); and food safety specialists from organisations that support food sector businesses ($n = 3$). All businesses were based in the south Wales region of the UK.

3.1. Importance of hand hygiene in the food sector

Participants discussed the importance of hand hygiene in ensuring safe food production, *"there is a lot of emphasis on hand hygiene in the sector because a lot of our foods are handmade"* (Participant 10), *"hand hygiene is the single biggest factor in determining the microbiological safety of the food that we're producing"* (Participant 05), despite this, some indicated that practices of foodhandlers may not be adequate all of the time, stating; *"there's no way you can guarantee that everybody is following it strictly … I would never put my life on it that everybody does it 100% all the time"* (Participant 01), *"Perhaps not all the time, they definitely will if you're watching them, but I wouldn't put my hand on my heart and say, yes, they do it properly 100% of the time"* (Participant 03), ensuring the "*consistency*" of hand hygiene practices was a challenge "*I think it's just consistency, making sure that every individual is doing it in the same fashion time after time after time"* (Participant 04). Structured and frequent observations were generally not conducted, nevertheless it was discussed that there is a need to determine hand hygiene compliance to *"facilitate improvement"* and that cameras could be used as a *"system of verification"* providing *"an opportunity to evidence compliance":*

Table 1
Narrative of participant role in food sector and business type ($n = 12$).

ID	Description of role in food sector business[a]	Sector
01	Technical Manager, at a small-sized, SALSA[b] certified, manufacturer of bakery goods for retail	Food manufacturing
02	Technical Manager, at a small-sized, BRCGS[c] certified, manufacturer of ready-to-heat meals for retail and food service	Food manufacturing
03	Senior Technical Manager, for a large, international quick-serve franchise café chain.	Food service
04	Head of Technical, at a medium-sized, BRCGS certified, manufacturer of ready-to-eat retort pouches for retail and food service	Food manufacturing
05	Global food safety Manager, for an international multi-site manufacturer of ready-to-eat meals for passenger transport food service	Food manufacturing
06	Head of Technical, at a medium-sized, BRCGS certified, manufacturer of bakery and pastry goods	Food manufacturing
07	Baker and Owner, of a small-sized, independent bakery and tearoom/café chain	Food service
08	Chef and Co-owner, of a micro-sized, independent coffee shop café with experience in large resort hotel kitchens	Food service
09	Technical Manager at a small-sized bottling and distilling company without a 3rd party food safety certification	Food manufacturing
10	Director, at a food sector supporting association	Supporting organisation
11	Principle Scientist, at a food sector supporting business	Supporting organisation
12	Technical Director at a food manufacturing sector supporting institution and board member of food sector supporting association	Supporting organisation

[a] Business size definition: Micro business: <10 employees, ≤€2m turnover; Small business: <50 employees, ≤€10m turnover; Medium business <250 employees, ≤€50m turnover; Large business >250 employees, >€50m turnover (EUR-Lex, 2003).

[b] Safe and Local Supplier Approval (SALSA), a UK based food safety assurance certification specifically created for small and micro businesses (SALSA, 2011).

[c] Brand Reputation through Compliance Global Standard (BRCGS) Food Safety Issue 8. A complex food safety assurance schemes adopted by the majority of large international manufacturers and restaurant chains and accepted by the majority of global retailers (BRCGS, 2018).

> "To improve hand washing, I think one of the challenges is around the method of hand washing for a period of time. You know it's using the right methods and making sure the hands are washed and they're dried. Observing practices in order to achieve compliance, it is important that there is a system of verification that people need to be aware of that there is an audit that could happen at any time. So whether that is through physical observation or through digital observation through cameras. I think there there's an opportunity to evidence compliance using digital cameras." (Participant 12).

Consequently, this study corroborated the importance of hand hygiene in the food sector to safeguard consumers and the business, as inadequate foodhandler hand hygiene practices can have significant implications for any food sector business as it can be a contributory factor in foodborne illness (Todd, Greig et al. 2007; Kadariya, Smith, & Thapaliya, 2014). Previous research has established that there may be a sense of complacency in relation to hand hygiene practices in the food sector as foodhandlers are typically instructed what to do, and are trusted to do so (Evans, Samuel et al. in press). However, participants of this study indicated that there is room to improve methods and ensure hand hygiene practices are consistent. Furthermore, the study has identified the need for a mechanism to establish hand hygiene compliance rates to ensure consistency, to facilitate improvement and evidence compliance. Indeed, there currently are no clear mechanisms for industry to determine if hand hygiene practices are constantly compliant, it is suggested that there is need for a rigorous mechanism that is reliable to enable management to verify compliance and enable improvements

(Evans, Samuel et al. in press). As previously determined by Evans, Samuel et al. (in press), it is commonplace for food sector businesses to have CCTV systems in hand hygiene areas, however these are predominantly used for security purposes and structured monitoring of footage is not customary.

3.2. Acceptability of the proposed technology

Respondents from both food manufacturing and food service sectors were supportive of the proposed technology to provide real-time hand hygiene compliance data, stating *"it sounds really good"* (participant 02) and *"that sounds right up my street"* (Participant 01), and that the technology would be *"really very interesting and useful"* (Participant 07). It was discussed that businesses are becoming more familiar and reliant on *"real-time data"* for business competences, whereas in terms of food safety, there currently aren't any real-time data metrics; "I think it's really interesting. I do think there's some potential there because businesses are getting more and more used to data delivering in real time for efficiencies and productivity. They no longer work it out at the end of the week. They've got it by the minute as they're operating. With food safety your measures are 'did we give anyone food poisoning' and 'what's the scores on the internal audits' and 'how are we doing on our third-party audit's, and that's not real time. I can see that there definitely could be something in this. (Participant 05).

Indeed, the novel and innovative nature of the proposed technology to provide real-time hand hygiene compliance data was perceived to have the potential to revolutionise hand hygiene standards in the food sector; "For all of my time in the industry and before that, the management of handwashing has been the same. So we've had the same failings or successes for the last 50 years. So we need to make a fundamental step change and this offers the ability to make a fundamental step change. So I would be very supportive of it." (Participant 11).

Interestingly, respondents in this study considered that, given the increased reliance and desire for real-time data, the proposed data would be acceptable to the sector. Earlier research has suggested that AI technology systems have the potential to detect food safety and quality attributes (Linko, 1998, Goyache, Bahamonde et al. 2001) and implied that novel AI tools, could have food-related applications, such as the control of processing variables (Eerikäinen, Linko et al. 1993). Indeed, significant technological advancements have been made in recent years, and AI technologies have been welcomed to support process control. The food sector has embraced and invested in several emerging technologies to improve the sector; for example, blockchain technology has enabled vast improvements in food traceability, operational efficiencies and streamlined food trading processes (Rejeb, Keogh et al. 2020). Therefore, whilst the proposed technology for handwashing compliance is different to anything that currently exists, it was deemed necessary to facilitate change for the benefit of the future industry.

4. Perceived benefits of the proposed technology

Many potential benefits were perceived in relation to the proposed technology. It was believed that the proposed technology had the potential to *"help the operatives to understand the implications of what they're trying to achieve"* (Participant 11) and would be beneficial to *"identify where training needs to be reinforced or reiterated is always important."* (Participant 10). Having a tool for management to track hand hygiene compliance rates and identify the need for training was perceived to be positive:

> "I think information that management can use to help them understand that their staff are complying with basic food safety requirements is a positive step forward. If a system can be implemented which automates that observation and if there's some clear metrics around it as to what is acceptable isn't acceptable. That could then automatic trigger retraining for staff and review of standards." (Participant 12).

It was suggested that the proposed technology would *"save time"* in terms of watching and analysing footage, and having real time data would provide meaningful data regarding foodhandler behaviour. Indeed, participants indicated that such data was superior to other methods, for example AI technology could *"remove the subjectivity"* that may exist when observing behaviour, additionally *"constant monitoring"* would provide a more comprehensive understanding of behaviour and provide the *"bigger picture"* in comparison to monthly swabs to determine microbiological contamination of hands (Table 2).

Table 3 illustrates that the proposed technology was perceived to be *"more beneficial"* to the food manufacturing sector due to a high number of foodhandlers, than the food service sector where fewer foodhandlers may work. Furthermore, it was considered that manufacturing businesses producing ready-to-eat foods in high-care and high-risk environments would benefit the most from the proposed technology, given how critical food safety is to ensure the safety of ready-to-eat products that do not undergo heat treatment or processing before consumption. Nevertheless, it was believed that the proposed technology would be a *"useful tool"* to enable businesses to *"implementing change"*.

Many of the participants perceived potential benefits of the proposed AI technology, with some identifying potential benefits for their own businesses, whereas others believed the proposed technology would be of greater benefit to other businesses. It was perceived that the proposed technology would be a more efficient use of time and would give a comprehensive understanding of hand hygiene behaviour, such information could be utilised to inform the delivery of highly targeted

Table 2
Perceived benefits of the proposed technology.

Summary of findings	Selected comments from interview participants
Benefits of the proposed technology included saving time, removing subjectivity of in-person observation, and obtaining a wider understanding of behaviour.	"You can't be on top of everything, all the time, you know that's just fact. So having a system that actually delivers that information to you, yes without a doubt." (Participant 01). "Obviously, not having people having to sit and watch and analyse, also for the business, having that data updated in real time just gives a real indication of peoples' understanding of the hygiene and whether we are actually focusing on the wrong thing, i.e. like performance rather than our safety and our quality practises." (Participant 09). However, when you get people involved, we've all got different levels of knowledge, different levels of experience. So inevitably, there will be some variation. So of course, if you created something which was able to observe behaviours or observe a certain requirement and it's either compliant or non-compliant, it's more like an attribute is there or it's not there, then that perhaps would remove the subjectivity of people observing. (Participant 12). "Constant monitoring rather than just once a month hand swabbing, maybe this day you did wash your hands pretty well and other days you don't. It's a bigger picture than just what the swabs can give." (Participant 09). "And it's not short-term, the benefit is a longer term as an improved practice and improved food safety. It's not a tick-box to say, 'We've got a different monitoring tool'." (Participant 11).

Table 3
Perceived benefits of the proposed technology in high-risk and high-care manufacturing sites.

Summary of findings	Selected comments from interview participants
Real-time hand hygiene compliance data was perceived to be of greatest benefit to food manufacturing businesses, particularly those producing ready-to-eat, high-risk products.	"I can see why it would be really useful in a big food manufacturer, because they have large throughput of staff in very short periods of time. Whether we would use something like that, I doubt it very much." (Participant 03). "I'd have to have it on a wish list, it would be amazing to have it, but … the bakery are low risk products, it wouldn't be a priority to have that software. Maybe high-risk baby foods, ready-to-eat foods, etc., that could be a step changer." (Participant 06). "Certainly that would have a place I would say, even more so in a ready-to-eat, high-risk, high-care facility where it is absolutely crucial that you have individuals doing the right thing, to have that, live on the spot data, as a technical manager there to have an alert you have one, two, three individuals who have just entered the factory that have not complied with the hand washing protocol, you can do, you can react on that very quickly rather than be retrospectively having to worry about contaminated product. So I think that as a technology would be very useful. For a business like ours, low care facility, maybe not as much because it would certainly have a place but would it have a place as an ongoing concern or would it be better off as a data collection exercise for implementing changes, that what I would feel. (Participant 04). "And there's an argument then as to where to use this technology. So if I was in a chilled food plant, would I have CCTV monitoring low-risk activities and high-risk activities? High-risk activities would be critical in terms of the food safety and the ready-to-eat product. Low risk, if I'm handling raw meat and vegetables, washing your hands you could argue is almost of limited relevance." (Participant 11).

training, and the proposed technology could also enable immediate action. Findings from this study suggest that, in general, the proposed AI technology may be more applicable to high-care and high-risk production where there is a highly defined and critical PPE and hand hygiene procedure than low-care or food service production areas. Thus, AI has the potential to be the most significant technological development for businesses as AI-powered software can be utilised to identify potential operational efficiencies and process productivity improvements (Chai, 2020). It is the duty of AI researchers to ensure that the future impact on new AI technology is beneficial (Russell, Dewey et al. 2015). Therefore, it is important to establish how the proposed technology could be used to benefit businesses.

4.1. Concerns about the proposed technology

Despite perceiving benefits for industry, some participants couldn't see the relevance of the proposed technology for their business:

> "Investment would be better off elsewhere in the business because hand washing isn't currently problematic." (Participant 02)

Some participants indicated that they would not be in a position to invest in the proposed technology, as they did not believe they currently had an *"issue"* with hand hygiene compliance, another indicated awareness of hand hygiene *"issues that needs to be fixed"* and that the proposed technology would confirm that, but not help to resolve it (Table 4). It was discussed that non-compliant hand hygiene *"is only part of the problem"*; "So I think I'd love to have something that ensures that people do wash their hands when they start work, like the technology that you're talking about because at least you're starting off well, but it's not something that I would really want to invest a massive amount of money in because it is only a part of the problem." (Participant 01).

Regardless of the majority expressing positive attitudes towards the proposed technology and perceiving potential benefits from the technology, some concerns regarding the technology were also discussed. A Technical Manager at a manufacturing business providing ready-to-heat food to retail and food service, did not believe the proposed technology would benefit the company stating their concerns regarding the technology:

> "A computer can't think outside of the box, need your presence on the factory floor with experience to get the 'feeling' of what's going on, to understand the whole picture." (Participant 02).

As indicated in Table 5, it was suggested that *"the cost"* of purchasing the proposed technology could be *"prohibitive"* particularly for *"smaller companies"* from accessing the proposed technology, in relation to cost, businesses would need *"proof that investment is working"*. Cost-benefit analysis was important, particularly for smaller businesses. Other concerns regarding the proposed technology were related to *"data protection"* and *"privacy"*. Another discussed that the proposed technology had the potential to create *"more work"* because of *"identifying non-compliance"* and having to conduct *"root cause analysis"* and implementing actions to prevent reoccurrence. The practicality of introducing cameras into food production areas was also discussed in terms of introducing a new hazard into the area which would need to be documented and monitored as part of a control policy for glass and hard plastic.

Given the variable nature of food service settings, the proposed technology may not be as feasible or applicable in some food service settings compared to others. The businesses that perceived the proposed technology would not benefit them, made valid points that would need to be considered in the development of the proposed technology, it should not solely identify the issue or problem that exist within a business but help with resolving or addressing it. Some concerns expressed regarding the proposed AI technology related to protection of privacy. It is reported that as a result of increasingly sophisticated AI systems and the aggregation of information – often without people's consent or knowledge – privacy concerns have increased (Mazurek & Małagocka,

Table 4
Perceptions regarding not needing the technology.

Summary of findings	Selected comments from interview participants
Despite perceiving a benefit for the industry, some participants did not perceive the technology would benefit their company.	"Well, I don't know if it would have a huge amount of benefit for us because we haven't seen any issue … investment would be better off elsewhere in the business because hand washing isn't currently problematic." (Participant 02) "We don't think that it's an issue and there are other things that we would focus on before we focused on that." (Participant 03). "I think from my company at this moment in time probably not. I know I've got an issue that needs to be fixed so I don't necessarily need the data to confirm that if you understand what I mean." (Participant 04).

Table 5
Concerns expressed regarding the proposed technology.

Summary of findings	Selected comments from interview participants
Concerns regarding the proposed technology related to General Data Protection Regulation (GDPR), potential cost and proof of investment. Generating additional work was also discussed in terms of root cause analysis and glass control policy.	"I think CCTV is a common technology, so having cameras in the food processing environment is common, a lot of companies are using CCTV it's quite an accepted technology, but in order for companies to have CCTV in there they have to go through the GDPR protocols with staff." (Participant 12) "It's like anything it's all about the GDPR isn't it, initially." (Participant 04). "I think the cost of it could be prohibitive to some smaller companies, so there's a barrier the cost of it. (Participant 12). "I think with anything like that just all comes down to cost to be honest with you." (Participant 01) "That payback thing isn't it, if we've invested in technology, it's proof that you're getting value for money, you change something is it working." (Participant 04). "So, I think it's a powerful tool and it will give me information that I can use to improve my practices. The downside of it is, I will then have to demonstrate that I've actioned everything that has been seen as poor. So effectively it will be seen as a non-compliance, so if things are poor and if the results show that people have only been washing their hands for 10 s and we've stated 20, there's a non-compliance. Therefore, it goes into my quality system as a non-compliance, I must then show root cause analysis, I need to show how I manage it and how I'm going to try and improve it. So ultimately, you're asking the company to do more work, but the benefit of that is you should be enhancing food safety and doing the hand hygiene appropriately." (Participant 11). "So, if that technology then came through and it tells me I've just had a 100 people come through and one person hasn't washed their hands, what do I do? Do I stop my factory and do I get everyone to go and wash their hands again, I think that would soon get tiresome I'd soon get in a spot of bother with the operations guys if everyone started doing that. So it's that sort of thing, what do you do with that information that would be my worry." (Participant 04). "Obviously the camera is a hazard in a food factory you have to monitor that as well. So, there's a number of different elements that you would need to consider if you're going to implement this technology for the first time, but I think it's kind of doable." (Participant 12).

2019). However, despite the heterogeneity of the food service sector, with the dominance of microbusinesses (Jones & Haven-Tang, 2005; Haven-Tang & Jones, 2008, Haven-Tang & Jones, 2013), the potential economic devastation of any foodborne illness was acknowledged when considering concerns in relation to the proposed AI technology.

4.2. Possible application of the proposed technology in the food sector

Given the interest in the proposed technology, as part of the discussions, the desirable functionality of the proposed technology was considered by many respondents. As part of this, significant discussions regarding the benefit of capturing individual data compared to general trend data were had (Table 6). For example, Participant 12, considered that they would want the proposed technology to pick out individuals that are not compliant, they believed that this would enable them to *"identify individual barriers to compliance"* and *"facilitate bespoke training"* with those individuals to improve practices; "I would want this technology to identify individuals that are not always compliant, because I would want to then individually help them to improve." (Participant 12)

Whereas others believed that obtaining general trend data, as opposed to individual data, would be informative for *"retraining"* and that there was a need to ensure *"feedback"* from the proposed technology in relation to key parameters to inform training and *"action an outcome"*.

Although some participants perceived that using the proposed technology in *"reprimanding"* individuals would not beneficial for their business, others, such as participant 11, wanted the proposed technology to identify those that are *"deliberately"* or *"consistently non-compliant"* to *"eliminate"* them from food handling responsibilities as failure to wash hands is a *"disciplinary action"*; "I think you have to identify the individuals who are deliberately not washing their hands. And if you do, you're doing two things – you are subsequently disciplining them and eliminating them as foodhandlers. But secondly, you are suggesting to everybody else that not undertaking that hand hygiene process will not be acceptable … You're identifying people who haven't washed their hands, which is a disciplinary action." (Participant 11).

Several discussions suggested how the proposed technology could be utilised to support development of the *"food safety culture"* in a food production environment.

> "People like to be recognized for doing good stuff so the technology would have a positive impact on the culture of the business." (Participant 12).

As illustrated in Table 7, Participant 01 discussed how the proposed technology would have a positive impact if it was to determine handwashing compliance rates for different shift teams (e.g. morning shift, afternoon shift, evening shift), they believed that having healthy competition between different teams would enable *"reward"* and *"recognition"*, similarly Participant 12 discussed that the proposed technology would *"reinforce good behaviours through recognition"*. Indeed, utilizing the proposed technology for *"enforcing good behaviour"* to *"drive food safety and quality culture"* and *"linking compliance assessments to bonuses"* were discussed by Participant 04 and Participant 05, furthermore, Participant 11 also suggested using the proposed technology to give staff a *"hygiene compliance bonus"* to help *"recognise the benefit of food safety"*.

It was perceived that the proposed technology had the potential to increase ownership and responsibility for food safety which would have a positive impact upon food safety culture; "… get accountability at the heart of food safety and make people actually responsible that there's a ramification for it … and those employees can see that those faults are being pulled up all the time and that there is an actual end result in poor practise." (Participant 08).

It was discussed that the proposed technology could be offered to food businesses in two formats; firstly, on a short-term basis to assess current performance and facilitate behaviour change to improve compliance, or secondly, on a long-term/permanent basis to maintain high-levels of compliance and identify if standards drop.

Some discussions in this study indicated the desire to identify malpractice and non-compliant individuals in relation to taking disciplinary action as a punishment, whereas others desired the proposed technology to identify compliant individuals or provide trend data for different shifts/teams which could result in reward and recognition of best practice. Reinforcement and punishments are two elements of the Operant Conditioning Theory that are said to influence learning

Table 6
Perceptions regarding the application of the proposed technology to identify non-compliant individuals.

Summary of findings	Selected comments from interview participants
Broad discussions comparing what businesses can do with general trend data regarding non-compliance or data that identifies non-compliant individuals deliberated how such data could be utilised by food businesses to inform training or remove people from food handling roles.	"But if you have trends, if you get everyone together and say, you know X% of your as a team aren't doing this correctly or that correctly and you know you put it in numbers like that it tends to add a bit more impact than just saying one of you did something wrong today." (Participant 01). "I prefer the trend data. I think that is better culturally. However, I would say that there are many of our facilities who would say we want individual data because we need to target those poor performing individuals because they need to be given the opportunity to improve … I would say our approach is not to go down to the personal level and to try to treat everybody more generically, but I would say that there would be some facilities that would probably want to see data down to the individual." (Participant 05). "I think what I've seen in all of my time is that if you can't pinpoint it to an individual it's, 'it wasn't me' … how would you then make them accountable? So, in theory the whole process sounds great but if you're only seeing hands and sink you still have the issue of 'well it wasn't me'." (Participant 08). "I'm guessing it can't show like how is, like, it's not person by person, it's just a general consensus of this amount of people did wash their hands correctly and these didn't. So, I think if maybe a third of the workforce were not compliant in that procedure then just using that to retrain and bring greater awareness to not just the operatives but senior management, like, everyone in the business so that we're all like a level playing field." (Participant 09). "There needs to be some sort of feedback. There needs to be some action that arises from it in the case of non-compliance. So, that's the thing about we notice that you haven't been doing it properly, you didn't do this or whatever. So, there needs to be some sort of outcome. There is no point having it for show … I mean if you're going to use the data and just know what the non-compliance is, that isn't enough because you have to act on non-compliances. It comes down to individuals." (Participant 10). "I think you would try and pick four or five parameters that you believed were critical to an effective hand wash. And that might be the correct amount of soap, it might be do people pre-wet their hands first or put soap on first, whether that's important, I'm not sure. It would be total coverage of the hands. If I just do one action for 20 s, that's just as bad as not doing everything for 5 s. So, it is a combination of surface coverage, it's a combination of time. I think you might have to tease out the four or five things that you thought were critical for a good hand wash and report back on each of those factors. Because then the follow-up would be, "You're not wetting your hands first guys, you're just putting the soap on. What we want you to do is …", or whatever the failure was that was found." (Participant 11). "I think if you were able to assimilate the footage into a list of in individuals operator ABC went to the station 10 times, complied twice, so that's 80% non-compliance then that kind of information could be used for GMP, so as part of compliance to a third-party standard in terms of compliance to food hygiene rating scheme. Because I think at the end of the day, we want a workforce that is compliant. So otherwise, if we weren't able to identify the top the 20% of people who are failing to comply, I'd want to understand why that was, why they were failing to comply. What were the reasons behind it because that could then suggest there were failures in training. There were failures in the management of people entering and exiting the facility. It could be that there are other mitigating or barriers which we were aware of and the only way you can find out what is preventing somebody from doing it is to perhaps chat to them, talk to them and do a bit of an investigation around it so you get to the root cause. And if you don't get to the root cause of the problem then it'll keep recurring." (Participant 12).

(Skinner, 2019), this type of conditioning means a person will learn by associating a certain behaviour with a certain consequence, either a positive reward, negative reward, positive punishment, or negative punishment (Sincero, 2011). Multidisciplinary and multifaceted interventions which included educational promotions/communications, audits and a reward and recognition programme for best performance, were found to deliver sustained improvement in hand hygiene compliance in a clinical setting (Jamal, Grady et al. 2012). However, it is suggested that a "one size fits all" approach to rewards and recognition will not be sufficient to motivate everyone due to personality or cultural characteristics (Ali & Ahmed, 2009), especially given the difference between food manufacturing and food service environments (Morris & Johnston, 1987).

In relation to this, it was believed that the proposed technology could enhance food safety culture within a food sector business. Food safety culture is defined as *"a long-term construct existing at the organisational level relating to the deeply rooted beliefs, behaviours and assumptions that are learned and shared by all employees which impact the food safety performance of the organisation"* (Sharman, Wallace et al. 2020). Food safety culture has become increasingly important to the food sector in recent years. For example, the senior management of food manufacturing business certified against the BRCGS Global Food Safety Standard, are required to define, and maintain a clear plan for the development and continuing improvement of food safety and quality culture (BRCGS, 2018). There are five 'dimensions' of food safety culture, within the 'people dimension'; major elements include educating employees, reinforcing good behaviour, creating proper governance, and metrics. A critical component of the dimension is 'incentives, reward and recognition', which can help management to guide desired food safety behaviours in a business (Global Food Safety Initiative, 2018). It is suggested that organizational culture factors have a great part to play in hand hygiene compliance (Evans, Samuel et al. in press). In relation to

Table 7
Perceptions regarding application of the proposed technology to enhance food safety culture.

Summary of findings	Selected comments from interview participants
It was perceived that the technology had the potential to have a positive impact upon the food safety culture of a food production environment.	"Beer and chocolate competition between two teams and with nice really colourful flashy posters saying 'this team are better than that team' up on the wall and get a bit of competition … Then things become habit, you know, it doesn't take long for something just to become." (Participant 01) "I think it's about enforcing those good behaviours. So, I think if you get good behaviours at the front of the factory it drives good food safety and quality culture throughout the business. So, it's about making sure from start all the way through regardless of whether I'm high care or low care. It's just the right thing to do … For me, disciplinary action, always the last resort for everything, because again that can drive the wrong culture, that can drive that fear culture of fear of retribution, and I don't want to say anything I don't want to raise anything." (Participant 04) "I would say it's more cultural, to be honest. If there will be feedback through compliance in their own internal compliance assessments getting linked into bonus payments and things like that." (Participant 05). "Has anybody ever talked about bonuses or any other monetary award that 5% of your pay is made up of showing that you can demonstrate that your personal hygiene, the way that you dress, wash your hands, everything related to that is following company policies? I've never seen it, but I don't know whether – going back to food safety culture, whether monetary reward has got any merit? A hygiene compliance bonus? I don't think it's unethical. Why should you have to do it, why shouldn't people recognise the benefit of food safety for everybody? So why should you have to put a monetary value to it is more of a question for me?" (Participant 11). "And the other thing as well as it is with food safety culture is recognizing when good is happening. That could be really positive way of reinforcing good behaviour through recognition system. You know on this shift we've had X amount of things and we had brilliant behaviours and that could be recognizing good behaviours or positive behaviours and perhaps negative behaviours as well. It's easy to focus on negatives. Because obviously we're into problem prevention, in industry we don't want any problems, but as well, I think what is so important for culture and the development of the of the right culture is to recognise when good happens and when you see something being done really well, let's use that as a role model and you could then convert that footage and it could then become part of your training program. So you could use and you could invest and take out what good looks like and use that to underpin your training." (Participant 12).

the 'people dimension', businesses need to recognise the importance of 'human factors' in food safety management and commit time and resource to identify and address 'human error' in food handling facilities and to safeguard food businesses (Walsh & Leva, 2019), the proposed technology could help address such time and resource requirements.

4.3. Future research

The Technology Acceptance Model is a commonly utilised theory to describe an individual's acceptance of information systems or technology (Lee, Kozar et al. 2003). The model developed by Davis, Bagozzi et al. (1989) is based on the Theory of Reasoned Action (Ajzen & Fishbein, 1980), it considers that an individual's acceptance of technology is determined by two major variables, namely the perceived usefulness of the technology and the perceived ease of use (Davis, Bagozzi et al., 1989). Although this study has explored and established the perceived usefulness and benefits of the proposed technology, and discussions indicate that the concept of using AI technology to provide real-time hand hygiene compliance data would be acceptable to the food sector; based on the constructs of the model (Davis, Bagozzi et al., 1989), the actual acceptability of the proposed technology to the sector can only be established once developed and piloted in the sector to establish the ease of use of the technology and the usefulness of the data it provides. Future work needs to focus on developing and piloting the proposed AI technology to distinguish between compliant and non-compliant hand hygiene practices. After which there is a need to trial the technology in a food sector environment. There is also a need to consider which factors best predict acceptance of technology in the food sector.

Although this study has explored the perceptions of managers, if further developments are to be made to create the proposed technology, there is a need to explore the perceptions and acceptability of foodhandlers in relation to the technology.

Furthermore, there is also a need to consider if this proposed technology is applicable to other sectors where hand hygiene practices are of critical importance, such as in healthcare settings to help prevent healthcare-associated infections (Ellingson, Haas et al. 2014; Wigglesworth, 2019), on large cruise ships to reduce the transmission risk of gastrointestinal illnesses such as noroviruses (Chimonas, Vaughan et al. 2008; Wikswo, Cortes et al., 2011) or at temporary event catering sites (Ghezzi & Ayoun, 2013; Worsfold, 2003). During the interviews, respondents provided additional suggestions regarding uses for AI technology that would benefit the food sector, such as technology to determine 'mispack' – when products are packaged in incorrect packaging with inadequate allergen labelling.

5. Conclusion

With covert observational methods providing a valuable insight to foodhandler hand hygiene compliance for food businesses and AI technology having the potential to provide such information as real-time data; this study has explored the perceptions of the food sector regarding the use of AI technology to obtain real-time hand hygiene compliance data. This is the first study of its kind which has important findings for technology developers. Application of the innovative technology proposed in this paper, in which AI technology, teamed with specifically located CCTV cameras at hand hygiene facilities in food production and food service environments, to differentiate 'compliant' handwashing attempts from 'non-compliant' handwashing attempts and give real-time hand hygiene compliance data, was perceived to be acceptable, useful, and beneficial to representatives from both food manufacturing and food service sectors. The proposed technology would enable food sector businesses to swiftly implement targeted interventions to address instances of non-compliance, ensure the development of bespoke training, facilitate the reward and recognition of compliant behaviour, enhance food safety culture, and support disciplinary actions relating to non-compliant behaviour. The proposed

technology was perceived to be of particular benefit, as the development of this proposed technology could revolutionise hand hygiene compliance in food sector businesses, thus reducing the potential risk of foodborne illness to consumers, avoiding detrimental economic consequences for food businesses and safeguarding food safety management systems.

CRediT authorship contribution statement

Ellen W. Evans: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. **Veronika Bulochova:** Formal analysis, Writing – original draft. **Ambikesh Jayal:** Conceptualization, Funding acquisition. **Claire Haven-Tang:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

Acknowledgements

Funding: This work was supported by the "Global Academies Research and Innovation Development Fund" awarded to the research team by the Research & Innovation Services that enabled completion of the research. The authors confirm that the funding sources had no involvement in the study design, in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

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