Consumers' use of smart devices while preparing food in the domestic kitchen on the island of Ireland

safefood

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Foreword

In February 2021, ***safe*****food** commissioned a research project to understand the use of smart devices in the kitchen and associated microbiological food safety risks on the island of Ireland. The aim of this research was to collect data to gain insights into how smart devices are being used in the domestic environment, to assess consumer behaviour and understand how this affects food safety on the island. This report presents research findings and recommends ways to support the safe utilisation of smart devices during meal preparation.

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Executive summary

Aim

This research project utilised a combination of both quantitative and qualitative methods (delivered in four tasks) to understand consumer behaviour around the use of smart devices[1] while preparing food in the domestic kitchen, and to assess the prevalence of bacteria on smart devices. In addition, the potential for bacterial contamination as a food safety hazard in the kitchen was assessed.

Objectives

1) To **summarise and identify** knowledge gaps (via a critical literature review) in relation to (a) consumer behaviour around the use of smart devices while preparing food in the domestic kitchen, and (b) the prevalence of bacteria, possibility of bacterial contamination, in addition to the survival of microbial contaminants on the surfaces of electronic/smart devices.
2) To **assess** (via an in-kitchen observational study) consumer behaviour using smart devices when preparing food in the domestic kitchen across the island of Ireland.
3) To **investigate** the prevalence of the levels of bacteria on the surface of smart devices (via in-kitchen experiment swabs). In addition to investigating the survival of foodborne pathogens and the effect of cleaning on the surfaces of smart devices (via the validation studies).
4) To **explore and quantify** (via focus groups and an online survey) consumers' perceptions attitudes, food safety awareness and use of smart devices while preparing food in the domestic kitchen, as well as consumer knowledge, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen on the island of Ireland.

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[1] *In this project the term 'smart devices' is used to describe smartphones and tablets.*

Methods

To achieve these objectives, a combination of both qualitative and quantitative methods (delivered in four tasks plus a literature review) were used to collect data with the aim of understanding consumer use of smart devices in the domestic kitchen and the potential associated food safety hazards.

- **Literature review:** A literature review explored consumer behaviour around the use of smart devices while preparing food in the domestic kitchen, and investigated the prevalence of bacteria, the possibility of bacterial contamination and the survival of microbial contaminants on the surfaces of smart devices.
- **Qualitative data:** An in-kitchen observational study (n=51 participants) was conducted to observe actual behaviours when using smart devices during the preparation of a high-risk meal.
- **Quantitative data:** An in-kitchen observational study (n=51 participants). In addition to observing and coding actual behaviours, swab data from participants' hands, tablet devices and personal mobile phones and were analysed for general bacteria in addition to *Enterobacteriaceae*, as an indicator of food hygiene and safety.
  Additional validation studies were conducted to determine the survival and effect of cleaning smart devices had in relation to potentially pathogenic bacteria (*Salmonella* and *E.coli*) on the surfaces of smart devices.
- **Qualitative Data:** Focus groups were conducted, with the same participants (n=51) who were observed in the "in-kitchen observational study", to explore consumers' perceptions, attitudes and use of smart devices while preparing food in the domestic kitchen, as well as consumer knowledge, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen.
- **Quantitative data:** An online survey was conducted with a nationally representative sample (age, gender and Ireland/Northern Ireland (NI) split) of

520 island of Ireland (IOI) adults aged 18-80 years. In addition to gathering socio-demographic information, the survey explored consumers' perceptions, attitudes and use of smart devices while preparing food, as well as knowledge, food safety awareness, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen. Other variables such as risk perceptions, deemed relevant from the literature review, were also included.

Results

The **literature review** highlighted limited research around consumers' behaviours relating to smart devices in the domestic kitchen. However, research has found that mobile devices used in clinical settings can be a source/vehicle for the cross-contamination of pathogenic bacteria. The level of contamination varied depending on various self-reported behaviours and socio-demographic behaviours, such as gender.

Observations showed that participants' food safety behaviours fluctuated, and that poor hygiene practices were frequently observed during meal preparation. The frequency with which participants touched the tablet during meal preparation ranged from 1-10 occasions during a 30-minute cooking activity, with a mean frequency of 5.84. A third (34%) of participants did not wash their hands after touching chicken before touching the tablet. Comparatively, the majority of participants (74%) did not wash their hands after touching eggs and before touching tablets. Only a fifth of participants cleaned their tablets during the cooking activity, with 60% cleaning them because they were visibly dirty or contaminated.

The **microbial analysis** from the **validation study** found that *Salmonella* and *E.coli* were able to survive on tablet screens for more than 24 hours at room temperature, indicating that smart devices could contribute to cross contamination. The **cleaning validation** study found that decontamination of smart devices with antimicrobial wipes (containing alcohol) was demonstrated to be an effective approach to eliminate the presence of general bacteria and pathogenic bacteria (*Salmonella* and *E.coli*). In the observational study, a high contamination rate for phones and tablets for general bacteria was reported (log_{10} mean CFU/swab: 2.1 ± 0.75 and log_{10} mean CFU/swab: 1.81± 0.74 respectively). *Enterobacteriaceae* bacteria were detected on 7% of smart device screens (n=4 mobiles and n=3 tablets). The observation study found *Enterobacteriaceae* contamination on the surface of 3 pre-cleaned tablets (n=3/51) showing cross contamination of these devices occurred during the cooking activity.

Gender and education level were associated with good behaviours in relation to use of smart devices in the kitchen, leading to reduced microbial load and contamination rates.

The **focus group study** developed four themes around food safety and smart device use in food preparation: 1) 'No food poisoning in my home'; 2) 'Behaviours – identification, perceptions, and catalysts'; 3) 'Devices – type and usage'; and 4) 'Bacterial survival and transference'. These themes related to general food safety and how participants believed the home was a low-risk environment for foodborne disease (FBD), and how devices were actively and passively used during meal preparation. Participants were generally able to identify good and poor safety practices; however, they highlighted that external factors, such as such as a lack of time and the presence of children could influence their food safety behaviours. Additionally, participants were aware that there is a risk of bacteria on objects, and through the group discussions they realised the potential for a higher risk of bacterial transference from devices as they are mobile, potentially multi-user devices.

The **online survey** found that younger participants and females were more likely to use a device while cooking or preparing a meal. Participants were aware that devices could be a source of cross-contamination but ranked using devices in the kitchen low in a list of potential sources of cross-contamination. Generally, females and those who are older reported better kitchen and device hygiene practices. The significant variables influencing participants' safety hazard identification score were gender, awareness of smart devices as a source of cross-contamination, food poisoning severity and susceptibility perceptions, and food safety knowledge score.

Conclusions

- The use of smart devices during meal preparation is common, with smart phones being the most popular device.
- *Salmonella* and *E.coli* can survive on the surfaces of smart devices for more than 24 hours.
- The observation study found *Enterobacteriaceae* contamination on the surfaces of 3 pre-cleaned tablets (n=3/51) showing cross contamination of these devices occurred the during the cooking activity.
- Disinfecting with antibacterial wipes (containing alcohol) is an effective approach to significantly reduce the microbial load on the surface of smart devices.
- There were notable rates of unsatisfactory compliance to recommended hand hygiene and cross-contamination prevention behaviours across studies. Therefore, greater consumer compliance to good food hygiene practices is essential to ensure food safety during meal preparation.
- Socio-demographic variables such as gender, age and education were associated with self-reported and actual behaviours in relation to general food hygiene, the use of smart devices in the kitchen and their cleaning. This indicates that some groups are more attentive than others.
- There was evidence of good awareness of cross-contamination and food hygiene practices. However, food safety knowledge and actual food behaviour scores did not correlate with tablet hygiene scores.
- There is a low perceived risk regarding cross-contamination from devices and contracting food poisoning in the home.

Key project recommendations

- Targeted education campaigns, particularly for those preparing food for people in vulnerable groups such as the over 65's, pregnant or immunocompromised to increase awareness of the potential food-safety implications associated with smart device usage in the kitchen.
- Engage consumers to increase compliance with good food hygiene practices, e.g., handwashing between touching raw ingredients and smart devices.
- Promotion of regular and proper disinfection of smart devices.
- Reserve and store a single device for the kitchen. Consumers could perhaps reserve an older device that they may have for kitchen-only use.

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1 Introduction

Foodborne diseases (FBD), also commonly referred to as foodborne illness or food poisoning, can be defined as illness arising from contamination of a food product with a variety of bacteria, parasites, chemicals and viruses. The exposure and transfer of these chemical or biological hazards in food products to humans can result in illness and fatality to any individual; however, vulnerable groups include children, the elderly, pregnant women and those already experiencing compromised health conditions (Mehlhorn, 2016; World Health Organisation, 2017). Contamination of food products can originate at any stage of the food chain, from primary production through to the domestic environment (Mehlhorn, 2016; World Health Organisation, 2017).

Foodborne disease remains a significant public health threat and cause for concern. In 2010, the World Health Organisation (WHO) estimated that more than 23 million people fell ill from eating contaminated food, resulting in an estimated 4,654 deaths in European regions (World Health Organisation, 2017). More recent estimates in the UK indicated that 2.4 million cases of FBD occurred in 2018, with 222,000 GP presentations and 16,400 hospital admissions (Holland & Mahmoudzadeh, 2020). Additionally, the Food Safety Authority of Ireland (FSAI) reported a noticeable rise of FBD cases associated with *Campylobacter* (FSAI, 2016; Holland & Mahmoudzadeh, 2020). While substantial efforts have been made to record and ascertain the prevalence of FBD from national and international reports such as the Food Standards Agency (UK), European Food Standards Agency (EFSA) and WHO, the true number of FBD is unknown and figures are likely to underestimate the gravity of this issue (European Food Safety Authority, 2011; Holland & Mahmoudzadeh, 2020; World Health Organisation, 2017). For instance, the finding that unknown cases of FBD account for 60% of cases (Holland & Mahmoudzadeh, 2020) is strengthened by the results of the “Food and You” survey completed in the UK, which reported that 43% of participants who experienced food poisoning took no action (FSA, 2014). In addition to the public health threat FBD poses, FBD contributes to huge economic burden in the UK, costing approximately £9bn, with the majority of this cost associated with unknown cases (Holland & Mahmoudzadeh, 2020).

Contamination can occur at any stage of the food chain. However, tremendous work has been done to strengthen and regulate food safety systems through focused food risk assessments, contamination prevention and management to alleviate the burden of FBD (European Food Safety Authority, 2011; World Health Organisation, 2017). Historically, in Ireland, salmonellosis was the most prevalent source of FBD, but *Campylobacter* infections have surpassed salmonellosis incidence associated with FBD. Experts credit the reduced salmonellosis incidence to the implementation of food safety management practices focused on salmonellosis in the poultry industry (FSAI, 2016). Therefore, the introduction of strategies and policies to control and mitigate pathogenic contamination of food produce is essential, as highlighted in the FSAI report.

While extensive work has been done to regulate the food safety risks within the production sector of the food industry, it is important not to overlook the final link in the food supply chain, i.e., food preparation in the home environment. The domestic kitchen is considered a high-risk area in which consumers are likely exposed to a broad diversity of microbes (Flores et al., 2013). The European Food Safety Authority reported that 36.4% of FBD occurred in the home environment (European Food Safety Authority, 2011), while a systematic review completed by the FSA reports that up to 64% of foodborne illness in the EU originates in the home environment (Curnin et al., 2018). Numerous reviews have demonstrated the difficulty in ascertaining food safety practices in a domestic setting, and have identified the variability and diversity of food safety practices within the home environment (Byrd-Bredbenner et al., 2013; Curnin et al., 2018). Despite studies emphasising the correlation between FBD and the home environment, the majority of consumers displayed optimistic bias and considered the home as an unlikely source of FBD (Byrd-Bredbenner et al., 2013; Fein et al., 1995; FSA, 2014; Holland & Mahmoudzadeh, 2020; Lee et al., 2017). Furthermore, inconsistencies between perceived behaviours, food safety knowledge and actual practices are evident. For instance, in the USA only 50% of participants adhered to general recommended food safety practices (Abbot et al., 2009; Byrd-Bredbenner et al., 2007). Numerous studies have identified that consumers' intention and their knowledge of appropriate food safety practices within the kitchen does not result in the implementation of recommended behaviours (Abbot et al., 2009; Redmond & Griffith, 2003). When coupled with optimistic bias, a low perceived risk of food poisoning in the home creates a behavioural challenge whereby safety practices in meal preparation are not a priority (Taché & Carpentier, 2014).

There is considerable evidence that cross-contamination within the kitchen is a major vehicle for the spread of pathogenic bacteria, where common offenders include hands, surfaces, sponges, dishcloths and utensils, handles and oven knobs (Azevedo et al., 2014; Gorman et al., 2002; Taché & Carpentier, 2014). Studies highlight that pathogens can remain viable on surfaces for considerable periods of time and thus present as a significant contamination hazard and food safety risk (Kusumaningrum et al., 2003; Mattick et al., 2003). Indeed there have been calls for a need to increase awareness and knowledge on hygiene procedures in the domestic environment to minimise cross contamination and FBD (Azevedo et al., 2014; Gorman et al., 2002).

Increasing consumer reliance on technology is undeniable, with the recent COVID-19 pandemic catalysing a surge in the utilisation of digital technologies and cooking (De et al., 2020; Murphy et al., 2021). Technology has infiltrated our daily activities, including meal preparation, with nearly half the consumers in a US study using electronic devices while cooking (Lando et al., 2018). Surgenor et al. (2017) also found that embracing electronic/smart devices while cooking could enhance learning experiences. However, smart devices have been found to be carriers of general bacteria and multidrug-resistant bacteria (Rozario et al., 2020). In health care settings, several studies have identified that mobile devices are a potential vehicle for the cross-contamination of pathogenic bacteria (Basol et al., 2014; Foong et al., 2015). Therefore, it stands to reason that the increased utilisation of technologies in the kitchen increases the potential of contamination, cross-contamination and exposure to food safety hazards, further contributing to the incidence of FBD in the home. Moreover, the use of these devices throughout other regions of the home could further spread the bacterial contamination.

As a result, it is important to consider the potential food safety risks introduced by smart electronic devices in the domestic kitchen. Little is known of the frequency, level and types of bacterial contamination on these smart devices, and the extent these devices pose as a food safety hazard. This project aimed to understand consumer use of smart devices in the domestic kitchen and the potential food safety hazards associated with this use.

Aims and objectives

This research project utilised a combination of both quantitative and qualitative methods (delivered in four tasks) which aimed to understand consumer behaviour around the use of smart devices while preparing food in the domestic kitchen, and to assess the prevalence of bacteria on smart devices in addition to assessing the potential for bacterial contamination as a food safety hazard in the kitchen.

Objective 1

To **summarise** and **identify** knowledge gaps (via a critical literature review) in relation to:

(a) consumer behaviour around the use of smart devices while preparing food in the domestic kitchen;

(b) the prevalence of bacteria and the possibility of bacterial contamination, in addition to the survival of microbial contaminants on the surfaces of electronic/smart devices.

Objective 2

To **assess** (via in-kitchen observational study) consumer behaviour using smart devices when preparing food in the domestic kitchen across the island of Ireland.

Objective 3

To investigate the prevalence of the levels of bacteria on the surface of participants hands, smart devices and personal mobile phones (via in-kitchen experimental swabs). In addition to investigating the survival of foodborne pathogens and the effect of cleaning on the surfaces of smart devices (via the validation studies).

Objective 4

To **explore** and **quantify** (via focus groups and online survey) consumers' perceptions, attitudes, food safety awareness and use of smart devices while preparing food in the domestic kitchen, as well as consumer knowledge, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen on the island of Ireland.

Methods

Background

Technology is undeniably becoming more important to consumers, with the recent COVID-19 pandemic catalysing a surge in the use of digital technologies for daily tasks including cooking. It is clear that smart devices could contribute to cross-contamination during meal preparation. To date, there has been little research in relation to consumer behaviours associated with smart devices in the kitchen and the potential food safety hazards. The current project provided an exciting opportunity to combine behavioural science approaches: qualitative and quantitative methodologies together with microbial techniques and analysis to obtain a comprehensive and holistic understanding of the use of these devices in the domestic setting, in addition to ascertaining the potential food-safety risk.

The work plan for this project is outlined in Figure 1; it is characterised by an interdisciplinary approach designed to understand consumer use of smart devices in the domestic kitchen and the potential associated food safety hazards.

Task 1: Literature Review

Initially, an in-depth desk study identified current practices and food safety hazards in relation to smart devices in the domestic kitchen. Findings from this study informed the next four tasks. Three of these tasks were in-kitchen studies. Due to potential issues around entering participants' homes because of COVID-19, the observations took place in kitchen laboratories. The kitchen laboratories (at the Ulster University and St Angela's College, Sligo) replicated the home environment and had existing protocols implemented to ensure the safety of participants around COVID-19. Furthermore, a controlled lab environment enabled a timelier collection of data and facilitated the collection of multiple swabs of the used devices over a greater period, which would not have been possible in a participant's home.

Task 2: In-Kitchen Research

Task 2.1: Observations

The ‘in-kitchen observation study’ was designed to assess consumers’ actual behaviours (as opposed to perceived or reported) in relation to using smart devices while preparing a high-risk meal, coupled with assessing other food safety behaviours, including hand washing/cleaning during the meal preparation. Head-mounted video recorders (to record consumer behaviour) were used in the observational study as direct observation of participants by researchers can cause participants to modify their behaviours, as well as cause anxiety (as observed in a previous cooking study).

Task 2.2: Microbial Analysis

The microbial component of this research was divided into two strands including the validation studies and the in-kitchen cooking activity. Initially Validation studies were completed to.

1. To determine whether potentially pathogenic microorganisms (*Salmonella* and *E.coli*) could be successfully inoculated onto and recovered from the surfaces of smart devices, as well as investigating their survival rates.
2. To determine whether the disinfection procedure – using antibacterial wipes (containing alcohol) was effective.

For the “In-Kitchen study”, microbial data was also collected after the completion of the cooking activity. Immediately after the participants completed the in-kitchen culinary study, swabs were taken from each participants.

- Hands
- Tablet they used for the cooking activity
- Personal mobile phone

Swabbing was completed in accordance with ISO 18593:2018. All samples were plated on Plate Count Agar (PCA), a general-purpose medium supporting the growth of most bacteria, yeasts and moulds, and Violet Red Bile Glucose Agar (VRBG) agar - a selective media for *Enterobacteriaceae*, on which potential pathogenic bacteria such as *E. coli* and *salmonella* can grow. This is commonly used to assess food safety, quality and spoilage potential in the food industry. The use of two agars provided an overview of the microbial diversity of these devices, thus ascertaining the potential threat of smart devices as a food safety hazard.

Task 2.3: Focus Groups

There was a need to understand consumers' use of devices in the kitchen and their perceptions and attitudes around potential safety hazards associated with their use. Understanding their perceptions, attitudes and behaviours around device use and safety, in relation to other potential safety hazards, helped elicit the priority of this risk to the consumer – for example, if the risk is deemed high enough to consider changing behaviour such as handwashing and wiping devices. The use of focus groups enabled diverse viewpoints and discussion to be heard around these points, as well as the collection of rich qualitative data. Conducting the focus group after the experiment provided a recent experience which increased the relevance of the topic under discussion, as well as allowing the researchers to access the participants' lived experience. Additionally, the use of vignettes (relating to safe and unsafe behaviours) during the focus groups not only helped to keep participants engaged but allowed the researchers to explore participants' ability to identify potential kitchen safety hazards.

Task 3: Consumer Survey

Finally, the findings from the in-kitchen research and focus groups informed the development of a nationally representative online survey. The survey explored consumers' perceptions, attitudes and use of smart devices while preparing food, as well as their knowledge, food safety awareness, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen. Other relevant variables elicited from the literature review, such as risk perceptions, were included.

The synergy of microbial analysis coupled with qualitative and quantitative behavioural methodologies components are illustrated in Figure 1. Combining analytical and social sciences methodologies, the project captured a comprehensive picture of food safety practices in relation to the use of smart devices in the kitchen and determined the risks associated with current food safety practices. The integration of the project partners' expertise provided a holistic and comprehensive approach, strengthening our understanding of food safety practices and risks, and to generate recommendations for the future.

Workflow of research project

Figure 1:The work plan for the smart device project

Task 1 included a desk-based literature review to understand smart device usage in the kitchen and the prevalence of potential bacteria and cross-contamination on smart devices.

⇩

Task 2 involved in-kitchen research with three studies: quantitative (pre- and post-survey), qualitative (glasses video) and microbial analysis. This allowed for observation of behaviours when using devices during meal preparation.

⇩

Task 3 was focus groups (with the same participants from the in-kitchen research) to explore perceptions, attitudes and the use of smart devices while preparing food in the domestic kitchen.

⇩

Task 4 was an online survey with a representative sample to explore consumer perceptions, attitudes and the use of smart devices while preparing food in the domestic kitchen, as well as consumer knowledge, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen.

Literature review methodology

Search strategy and screening

The critical review was completed in a structured way in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009). The critical review is separated into two sections: Part A, "Consumer use and behaviour surrounding the use of smart devices while preparing food in the domestic kitchen," and Part B, "The prevalence of and possibility of bacterial contamination on smart devices, in addition to the survival of microbial contaminants on the surfaces of electronic/smart devices." For Part A to satisfy the research question, the following search terms were generated. Search terms included consumers, public, and psychological parameters including use, behaviours, practices, understanding, opinions, knowledge, feelings and thoughts. Literature searches for personal devices include mobile, iPad, Kindle, tablet, electronic devices, devices, smart, phone, smart phone. Additional searches were conducted for environment, which included the terms kitchen, home, domestic, and household. For Part B of the review, the search terms relevant to personal devices and the environment remained from Part A. Literature searches for personal devices include mobile, iPad, Kindle, tablet, electronic devices, devices, smart, phone, smart phone, and the environment search terms included kitchen, home, domestic, household. However, there were limited studies in domestic setting; therefore, the search expanded terms to clinical settings and hospitals to identify microbes including bacteria, microbe, microbiological, microorganism, pathogen. Food safety risk terms were also generated, including cross-contamination, hygiene, safety, survival, growth, proliferation and spread. To ensure that the author had exhausted the relevant terminology, the second author (FL) reviewed the search terms, identifying three additional terms. In October 2021, a systematic search of the keywords catalogue was conducted across four electronic databases: MEDLINE, PsycINFO, Scopus, and Web of Science.

One author (CMK) independently screened article titles and abstracts. Duplicated articles were crosschecked and removed. Eligibility criteria (provided below) were then used to further select relevant articles for full-text review. Further articles were identified by manually searching reference lists for articles of interest. See Figures 2 and 3 for details on each stage of searching and screening.

Eligibility criteria

Part A

- Language: Published in English
- Date: From 2010
- Location: No restriction
- Outcomes: Assess the use of smart devices in a domestic setting

Part B

- Language: Published in English
- Date: From 2010
- Location: No restriction
- Outcomes: Assess the microbial profile of personal devices (not on medical equipment) within the clinical setting.

Data extraction and synthesis

All articles were evaluated and the following data was extracted: country of study, study design, sample size, sample description, aim, experimental design and results. Extracted data was thematically coded inductively in accordance with the Braun and Clarke protocol (Braun & Clarke, 2006). Findings from the eligible articles were coded for information of relevance to satisfy research aims. Subsequently, all articles in relation to the use of smart devices and potential food-safety risks within the domestic environment were coded. To ensure the reliability of the sample, 50% of papers that were independently reviewed were crosschecked and verified by a second author (FL).

Figure 2: Flow diagram illustrating the assessment and selection of articles for Part A of the review, “Consumer use and behaviour surrounding the use of smart devices while preparing food in the domestic kitchen”.

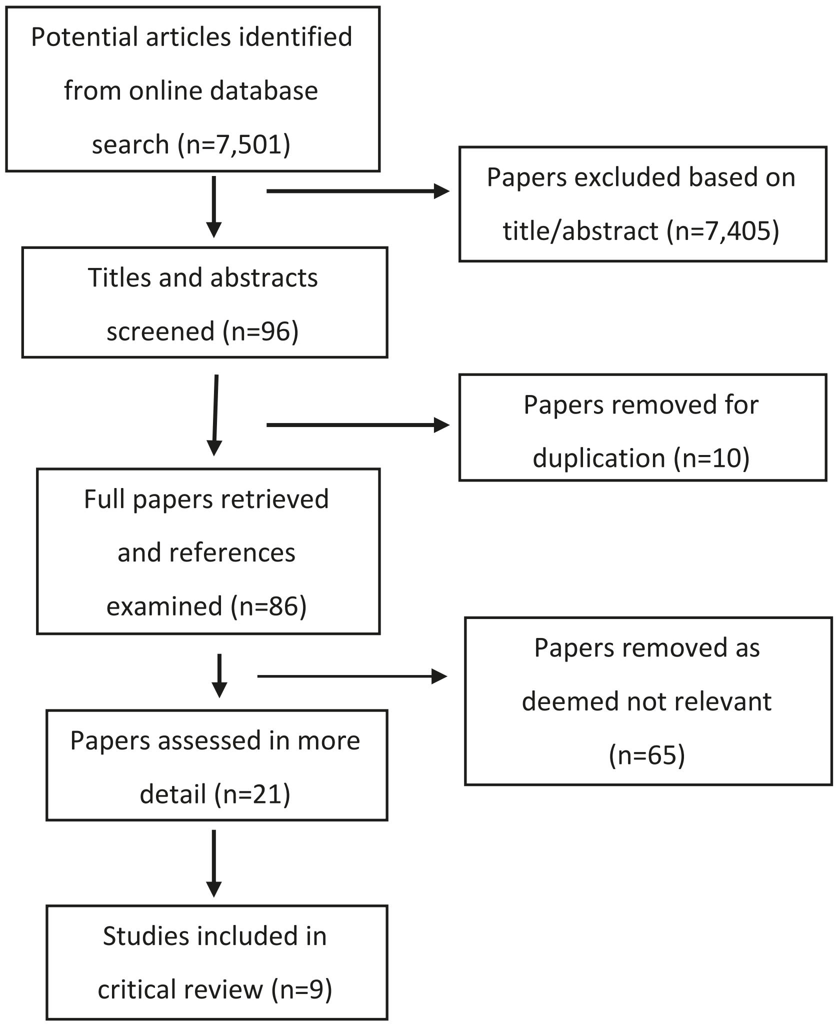


Figure description: Initial search for Part A of review identified 7,501 articles: 7,405 papers were excluded based on title/abstract, leading to screening of 96 titles and abstracts. Ten duplicate papers were removed. Overall, 86 full papers were retrieved and references examined. Twenty-one of these papers were assessed in more detail, with a total of nine of these included in the critical review.

Figure 3: Flow diagram illustrating the assessment and selection of articles Part B of the review, “The prevalence of and possibility of bacterial contamination on smart devices, in addition to the survival of microbial contaminants on the surfaces of electronic/smart devices”.

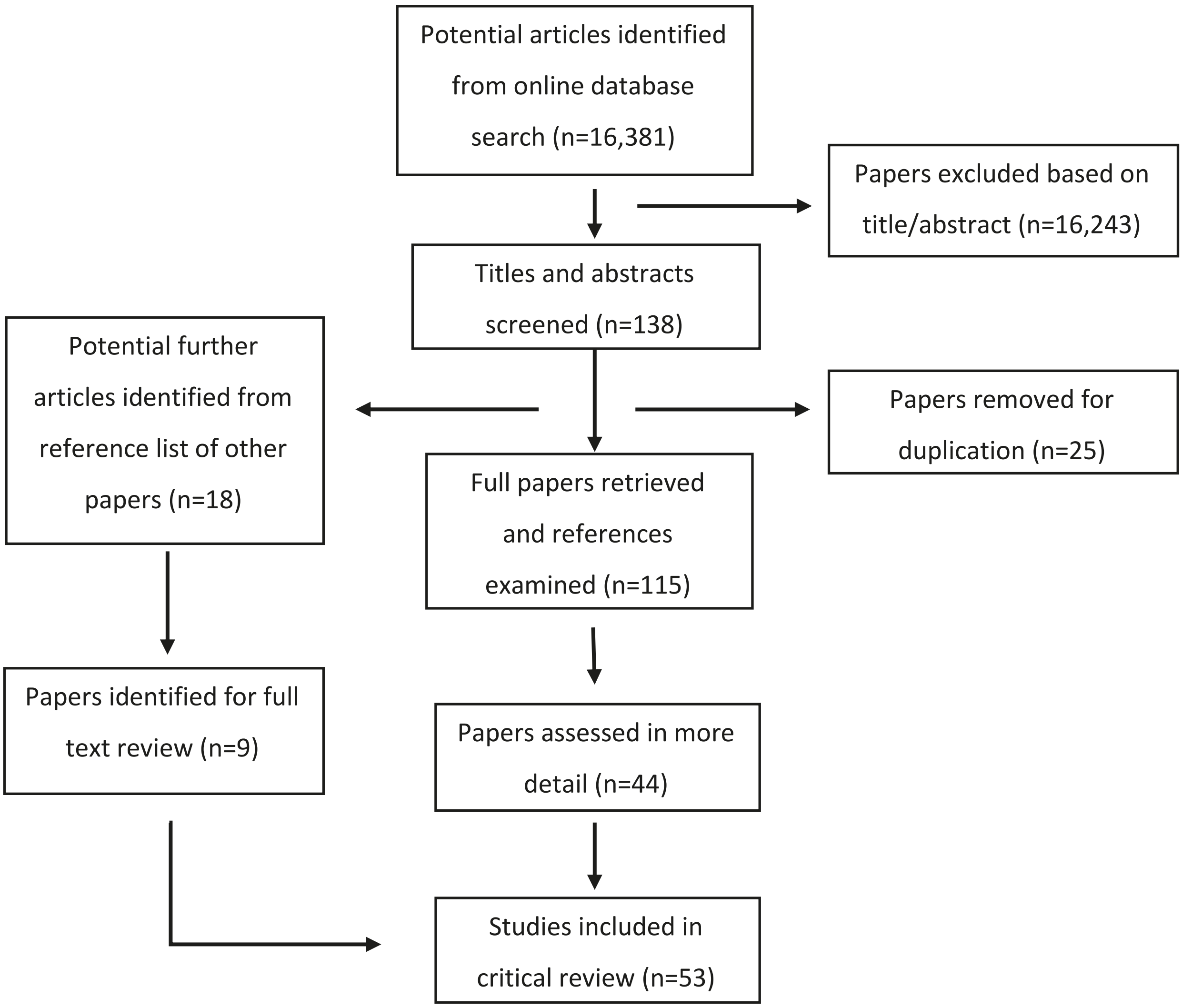


Figure description: Initial search for Part B of review identified 16,381 articles, of which 16,243 were excluded based on title/abstract, resulting in 138 abstracts being screened. Twenty-five duplicate papers were removed. Overall, 115 full papers were retrieved and references examined. Forty-four of these papers were assessed in more detail, alongside nine papers identified from reference lists of other papers. In total, 53 papers were included in the critical review.

In-Kitchen research

Because the in-kitchen research consisted of multiple research studies, an overview on the in-kitchen study methods is provided. Following this, specific methods relating to observation, microbial and focus group studies are provided. The cooking activities took place in kitchen laboratories in Ulster University (Coleraine; UU) and St Angela's College (Sligo; STACS). In total, five cooking sessions were held: two sessions in NI (UU), and three sessions in Ireland (STACS) in June 2022. The sample bridges two jurisdictions; however, it is treated as one island of Ireland sample. This is consistent with previous research for food behaviours on the island, where no differences have been found between the jurisdictions (***safe*****food**, 2001); combined samples have been used in both cooking research (Lavelle et al., 2016, 2017) and in food safety behaviour research (Lavelle, McKernan, et al., 2023).

Participant selection and recruitment

Participants were recruited using a combination of purposive convenience and snowball sampling, as well as through social media by the research team. A wide range of participants was sought; selection criteria for the jurisdictions was 60% Ireland and 40% NI. Participants were eligible if they were between the ages of 18 and 80 years old. Exclusion criteria included vegans and vegetarians (unless willing to handle raw meat), and individuals working in food safety, food processing/manufacturing or home economics were also excluded. Once recruited, participants were given information about the study and given time to consider their participation as well as ask questions relating to the research. Willing participants completed and returned the screener survey and consent form to the research team. Participants received a £50/€60 honorarium to compensate for their time and travel. This study was conducted according to the guidance laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Medicine, Health and Life Sciences Faculty Research Ethics Committee at Queen's University Belfast (MHLS 22_31).

Cooking activity

The cooking activity was developed in collaboration with psychologists, behavioural scientists, microbiologists, and home economists at the three collaborating institutes (Queen's University Belfast (NI), Ulster University (NI), and St Angela's College Sligo (ROI)). Subsequently, participants were asked to prepare a high-risk meal (chicken goujons and side salad) while following a recipe on a tablet device provided by the research team (see Appendix 1). The recipe was available on the tablet device in two formats to enhance ecological validity: a video (similar format to cooking channel videos) or as a written recipe (provided alongside most video recipes) to enable participants to choose their preferred method. This ensured participants' real-life practices were simulated and captured during the activity. At the beginning of each session, participants were provided with a sanitised tablet (cleaned with an antibacterial wipe) to establish if cross-contamination occurred during the cooking activity. Participants were informed to use the tablet provided to them to complete the cooking activity and were not specifically instructed to take part in any food hygiene practices such as hand washing, changing utensils/chopping boards to emulate normal practices.

Procedure and measures

The cooking experiment and observations were facilitated by the same two experienced researchers (FL, CMK) in both locations for consistency. The participants' cooking stations were kept uniform across both sites, with the placing of all necessary equipment on the unit benches. The setup of the individual kitchen units was inspected, and the tablets were cleaned between each session by the two researchers (FL, CMK), who were present at all sessions across both locations. There was a minimum of one spare kitchen unit for each session of the cooking task, in case of fault in the equipment, to ensure each participant would be able to complete the task. Upon arrival, participants completed a pre-task survey and were then provided with head-suspended video recording devices and allowed time to orientate themselves with the devices. They were told to behave as they would during cooking or meal preparation in their own home, and this included taking pictures or using social media on their own device if they normally did so. Participants were then guided to their own individual cooking station, which was fitted with all the equipment necessary to complete the cooking task by following instructions provided on a tablet. Participants could use a written text recipe or follow a video recipe, both provided on the device; this was to increase ecological validity, by allowing participants to use the method they would in their home environment.

The recipe chosen for the meal preparation was chicken goujons and a side salad. This meal was used as the raw chicken is considered a high-risk dish and there were multiple potential opportunities for cross contamination. Additionally, as the focus of the research was not concerned with the participants' skill level, this dish was chosen as it is considered a basic recipe in terms of level of difficulty.

Questionnaire

A survey questionnaire was administered to all participants to capture socio-demographic data, including age, gender, location(rural/urban), educational status and relationship status. In addition, survey questions were included to gain a better understanding of the participant's use of smart devices in the kitchen, including frequency of use, cleaning habits, and behaviours after touching a smart device (phone or tablet) while preparing food. Food safety knowledge was assessed using a scale adapted from Cairnduff and colleagues (2016). Items were scored as correct or incorrect. Each correct response was given a score of 1. The possible total scoring range was 0 – 12, with a higher score indicating greater food safety knowledge.

Survey analysis

Participant socio-demographic characteristics and survey items such as food safety knowledge were calculated and summarized using IBM SPSS Statistics version 26 (SPSS, Chicago, IL).

Pilot

In May 2022, the cooking activity and focus group discussion were piloted with one group of five individuals. This was conducted to assess practicality (i.e., the structure, content and instructions provided), clarity and understanding of all procedures and measures used, including the topic guide for the focus group. The pilot was conducted at STACS.

Observations

Point-of-view (POV) video observations were conducted with consumers to investigate actual food safety behaviours, both generally and in relation to using smart devices during the meal preparation process. Video observation was used as opposed to direct observation (participant being observed by researcher) as, during a previous cooking task, participants found direct observations by researchers stressful (Surgenor et al., 2017), which might influence behaviours. Additionally, POV video observations allow detailed recording of participants' actual behaviours, which may be missed during direct observation.

Data analysis

A retrospective performance analysis was conducted on the video recording data to identify food safety behaviours. As it was not a real-time analysis, NVivo software (QSR International Pty Ltd, Doncaster, Victoria, Australia) was used to enable the coding of the video data. A systematic approach to the data analysis was conducted to ensure scientific integrity. Using a deductive approach and a pre-determined codebook, 10% of the videos were initially coded and any additional codes arising within these videos, not previously identified, were added to the codebook. Multiple researchers independently coded 10% of the video footage and compared for discrepancies. All videos were then coded with the updated codebook (Appendix 2). The codebook was developed using an iterative process by the research team, with expertise in behavioural analysis, qualitative analysis, coding, and culinary and food safety behaviours. To evaluate food safety behaviours and performance, the codebook consisted of three sections. 'General cross-contamination behaviours' were derived from the recipe and included behaviours such as washing hands, chopping chicken, swapping chopping boards, etc. Scoring categories for both these sections included 'Unsatisfactory behaviour/poor hygiene practice,' scored as zero, 'Somewhat satisfactory behaviour,' scored as 0.5, and

‘Satisfactory behaviour/good hygiene practice,’ scored as 1. These scores were then added to create a general cross-contamination behaviour score (minimum 0 to a maximum of 12). The third codebook section specifically related to ‘tablet behaviours relating to cross-contamination’ and consisted of a tally of handwashing behaviours before and after touching the tablet device/phone, and also any cleaning of the device. A tablet device hygiene score was computed, where the sum of the participants’ scores for behaviors before and after touching the device was divided by the frequency of times the device was touched.

Overall, 51 videos with a total duration of approximately 23.3 hours were recorded and coded.

Microbial analysis

The aim of the microbial element of this study was to assess the prevalence of bacteria on smart devices in addition to assessing the potential for bacterial contamination on smart devices as a food safety hazard in the kitchen. In addition to experimental swabs collected after the cooking activity, two experimental validations were conducted to investigate the effectiveness of cleaning and the survival of pathogenic bacteria on the surfaces of smart devices. Microbial analysis was completed in an ISO-accredited laboratory (Beechwood Laboratories, NI) in accordance with recommended procedures. This section of the report discusses the methodology used for the microbial analysis.

Microbiological analysis

Microbiological analysis comprised of three elements. The first two activities were experimental validation studies, referred to as evaluation of the efficacy of cleaning smart devices and confirmation of target microorganism detected. The third element of the study was designed to investigate the level of microbial contamination on smart devices after use in the kitchen via in-kitchen swabbing of devices. These validations and the testing of collected swabs from the cooking activity were conducted and processed in Beechwood Laboratories. In addition, participants were not made aware of swabbing ahead of the activity, as this could have influenced behaviours.

Experimental validation studies

Evaluation of the efficacy of disinfection of smart devices

To ensure the proposed disinfection procedure was effective, a total of 10 tablet devices (Amazon Fire HD 8, measuring 13cm x21cm) were analysed. Ten tablets were swabbed with NRS Il Transwab stick swabs without prior cleaning (uncleaned) and plated on Plate Count Agar (PCA, NCM0010A, Neogen, UK). The same ten devices were then disinfected with alcohol-based wipes. A new wipe was used for each tablet device (Bactericidal Disinfectant wipes REF:7200, Premier Laboratory Services Ltd, UK). Devices were swabbed again after disinfection and plated on PCA plates.

Ten disinfected devices were contaminated with wild strains of *Salmonella (Nottingham)* and *Escherichia coli* previously isolated from food products (to emulate strains from a realistic environment). The bacteria were streaked on Plate Count Agar (PCA), and after overnight incubation one colony of *Salmonella* and *E. coli* was separately, directly smeared onto the whole surface of the tablets using a sterile spreader (Sterile disposable blue spreaders, Technical Service Consultants Ltd, UK). Each inoculated tablet was stored in a sterile sealed plastic bag at room temperature (20-21^{o}C) for 30 minutes. Following this, the whole surface of the tablet was swabbed and plated on agar plates specific to *E coli* and *Salmonella* (Harlequin Tryptone Bile Glucuronide Agar and Xylose Lysine Deoxycholate, respectively), to empirically determine the starting inoculum by counts from swabs. The whole surface of the tablets was then disinfected with an alcohol-based wipe impregnated with 70% Ethanol solution and 1% Chlorhexidine (Bactericidal Disinfectant wipes REF. 7200, Premier Laboratory Services Ltd., UK), using a new wipe for each tablet. The disinfected devices (n=10) were immediately re-swabbed and plated on PCA agar a general-purpose medium supporting the growth of most bacteria, yeasts and moulds in addition to specific agars for *E. coli* and *Salmonella*.

Confirmation of target organisms

To determine whether pathogenic microorganisms could be successfully inoculated onto and recovered from the surfaces of smart devices, as well as investigating their survival rates, 45 tablet devices were disinfected with alcohol wipes (70% Ethanol solution and 1% Chlorhexidine), and then inoculated directly with a colony of wild strains of *E.coli* and *Salmonella* using a sterile spreader, as described above, and stored in a sterile sealed plastic bag at room temperature. Tablets were swabbed at three separate time points: Time zero (n=15); 30 minutes after inoculation of target microorganisms to empirically determine starting inoculum counts; followed by "Time 24hr" (n=15) and "Time 48hr" (n=15). All swabs were collected using NRS II Transwab stick swabs (NRSII™, Medical Wire and Equipment, UK) containing a buffer (10 ml) treated as neat dilution and plated directly on agar plates specific to *E. coli* and *Salmonella*.

Cooking activity – Sample collection and transportation

As previously discussed, participants were instructed to use the tablet provided throughout the cooking activity. Moreover, at the end of the cooking activity a swab of the participants mobile phone (uncleaned if that is their normal behaviour), to obtain a true representation of the microbial load and profile of a personal device, as the tablets are sterilised in between cooking activities. At the end of the cooking session, NRS II Transwab stick swabs (NRSII™, Medical Wire and Equipment, UK) containing a buffer (10 ml) to preserve swabs for 24 hours were utilised to collect samples from participants. From each participant (n=51), a moistened swab of their hands and from the mobile phone or tablet device they used during the cooking activity was collected. The whole surface area of mobile phone and tablet were swabbed in accordance with ISO protocols (ISO 18593:2018; PHA, 2017). A designated fridge was used to store swab samples until transported via courier to the testing laboratory (Beechwood Laboratories). The samples were kept cool during transit with ice packs in an insulated box and were processed within 24 hours of their arrival at the laboratory. All swabs were treated as neat and were directly plated on PCA to quantify total viable count (TVC) of fastidious bacteria, fungi, and yeasts. In addition, all swabs were plated on Violet Red Bile Glucose (VRBG) agar as this approach is commonly used for food and environmental samples to detect *Enterobacteriaceae*, which includes some pathogenic bacteria.

Microbial analysis

Sterile swabs containing a buffer (10ml) to preserve swabs for 24 hours were utilised for all samples using NRS II Transwab stick swabs.

Plate Count Agar (Total viable count (TVC)): plating was based on ISO 4833-1: 2013 Horizontal method for the enumeration of microorganisms (Part 1). Where colony count at 30°C by the pour plate technique, 1 ml of the swab supernatent *(treated as -1)* was plated out into an empty agar plate and poured using molten Plate Count Agar (PCA) (NCM0010A, Neogen, UK) and incubated for 24 hours at 37°C.

Violet Red Bile Glucose Agar (VRBG): was processed using the based-on BS EN ISO 21528-2:2017 Horizontal method for the detection and enumeration of *Enterobacteriaceae*. Briefly, 1 ml of the swab supernatent (*treated as -1 dilution*) was plated out into an empty agar plate and poured and overlayed with molten Violet Red Bile Glucose Agar (VRBGA) (NCM0022A, Neogen, UK). VRBG plates were incubated at 37°C for 24 hours.

***Salmonella* specific plate**: BS EN ISO 6579-1:2017+A1:2020 ISO 6579-1:2017/Amd 1:2020 Microbiology of the food chain — Horizontal method for the detection, enumeration and serotyping of *Salmonella* — Part 1: Detection of *Salmonella* spp. Briefly, 0.5 ml of the swab sample (*treated as -1 dilution*) was plated onto Xylose Lysine Deoxycholate (XLD) pre-poured plates (SGL 8091), spread using sterile spreaders (Technical Service =Consultants Ltd.) and incubated at 37°C for 24 hours.

***E. coli* specific plate**: plating was based on ISO 16649-2:2001 Microbiology of food and animal feeding stuffs — Horizontal method for the enumeration of beta-glucuronidase-positive *Escherichia coli* — Part 2: Colony-count technique at 44°C using 5-bromo-4-chloro-3-indolyl beta-D-glucuronide. Briefly, 1 ml swab sample (*treated as -1 dilution*) was plated out into an empty Petri dish and poured with Harlequin Tryptone Bile Glucuronide Agar (TBX, NCM1001A, Neogen, UK) and incubated at 44°C for 24 hours.

After the 24-hour incubation period, the number of colonies on the surface of the various culture media were counted and CFU/swab calculated. On plates that recorded *Enterobacteriaceae* growth (VRBG analysis), further analysis was conducted on selected colonies using the well-established Analytical Profile Index (API) 20E test (BioMerieux) to biochemically identify and differentiate members of the *Enterobacteriaceae* family.

Data analysis

All data were analysed using IBM SPSS Statistics version 26.0 (IBM Corporation, Armonk, NY, USA), with a p-value $p < 0.05$ considered to be significant. Descriptive statistics such as frequencies and percentages were performed on socio-demographic characteristics, self-reported behaviours and contamination rates. A Pearson's Chi-Square Test or Fisher's Exact Test were used to analyse the bacterial contamination rate of different socio-demographic data such as age, gender, location and educational status, as well as perceived behaviours associated with using smart devices in the kitchen (frequency of use and cleaning habits). In addition, CFU/swab data was log-transformed to eliminate the influence of skewed data within the data set, then t-tests and one-way ANOVAS were performed on socio-demographics and behaviours associated with the use of smart devices as previously described. Using Pearson's correlations ($\log_{10}$ CFU/swab), the relationships of the level of microbial contamination in relation to general (TVC bacteria) phones, tablet and hands was also investigated.

In-Kitchen research: focus groups

Participant selection

The participants who completed the in-kitchen research also took part in focus group discussions after the task.

Procedure

Focus groups were conducted in line with the principles outlined in Krueger (2014). The discussions were facilitated by an experienced moderator (FL). The focus group discussions followed a guided, open-ended topic guide developed from the literature review and refined by the research team (see Appendix 3).

The facilitator emphasized that all opinions and points were equally valid and for all participants to contribute as best as they could. All participants were assured of their confidentiality and all discussions were recorded. Each discussion lasted between 22 and 42 minutes. The study was conducted in accordance with the Declaration of Helsinki. All participants provided written and verbal consent and were aware that they could withdraw from the research study at any point.

Data collection and analysis

The discussions were professionally transcribed verbatim and checked for accuracy by the coders (CMK, FL). NVivo 12 software (QSR International Pty Ltd, Doncaster, Victoria, Australia) was used to facilitate the analysis. An inductive thematic analysis in accordance with Braun and Clarke (2006) was undertaken. All transcripts were read and re-read in order to achieve data immersion and familiarisation. FL (a behavioural scientist) coded all transcripts. CMK (a food scientist) independently coded two transcripts selected at random. The coders had an initial high agreement of coding of the transcripts, with discrepancies discussed and agreement reached on all codes. The next phases involved the generation of themes from the codes (FL), inspecting themes for overlap and where necessary refining themes (FL, CMK, TB), and ensuring that there were *“clear and identifiable distinctions”* between the themes (Braun & Clarke, 2006). Illustrative quotes extracted from the data are used to demonstrate typical views in the themes. Data saturation was reached as determined by two members of the research team (FL, CMK).

Online survey

Researchers conducted an online survey of 520 nationally representative respondents: 366 participants living in Ireland and 154 living in NI. Perceptions, use of smart devices while preparing food, as well as knowledge, food safety awareness, understanding and attitudes towards food safety hazards associated with using smart devices in the kitchen, were investigated.

Two videos showing food preparation were shown to participants to assess their ability to recognise food safety hazards. In video A, the actor used a smart device (tablet) while preparing the meal. In video B, the actor used a paper recipe while preparing the meal.

Participant selection

An external research agency (Dynata) recruited the sample of 520 consumers (366 living in Ireland and 154 living in NI) from their online panel to complete a 20-minute online survey. The sample was made up of people aged between 18 and 80 years, 51% female, 48% male, and 1% other. All participants had to be responsible for main meal preparation for themselves or their household at least once or twice a year. In addition, at least 60% of participants were required to use smart devices in the kitchen (in some way) at least once a month.

People working in food safety, food processing or manufacturing, or living in a household with someone working in those industries, were excluded from taking part in the survey. People under 18 years of age and people over 80 were also excluded.

Online survey development

The online survey was developed based on the results of the literature review. The proposed survey was critically reviewed by Principal Investigator Professor Moira Dean, the research team and ***safe*****food*****,*** and was refined. The survey was piloted with three participants, with no issues arising.

The survey (Appendix 4) measured several factors including:

Food safety hazard identification

To measure their ability to identify food safety hazards, participants were shown two video clips (A & B) and asked questions related to these. The video clips were developed by the researchers and showed an actor preparing a meal. In clip A, a tablet device was used during meal preparation. In clip B, a paper recipe was used during meal preparation. Each clip was approximately one minute long, and participants had the opportunity to play the clips a maximum of twice. The order of the clips was randomised, such that half of the participants saw clip A first and half of the participants saw clip B first.

Following the clip, participants were presented with a list of 26 food safety problems and asked to select the problems they saw in that clip. This list was developed by researchers at QUB and reviewed by researchers at STACS. It included correct as well as incorrect answers. If a participant selected a food safety problem that was in the clip, they were given a score of 1. If they did not select a food safety problem from the list in the clip, they received a score of -1. Similarly, if they selected a food safety issue that was not in the clip, they received a score of -1, and received a score of 1 if a food safety issue that was not in the clip was not selected. These individual scores were added to give each participant a score for clip A and a score for clip B, with possible scores ranging from -26 to 26 for each clip. A higher score indicated a greater ability to identify food safety hazards.

Food safety knowledge

Food safety knowledge was assessed using a scale adapted from Cairnduff and colleagues (2016). Questions were asked about a variety of food safety aspects such as refrigeration and defrosting. Items were scored as correct or incorrect, with some items having multiple correct responses. Each correct response was given a score of 1, with the exception of those questions with multiple correct answers, where each correct answer was given a score of 0.5. The possible total scoring range was 0 – 10, with a higher score indicating greater food safety knowledge.

Food safety behaviours and device use

Participants were asked about their frequency of handwashing and use of devices while handling food, as well as how and how often they clean their devices.

Awareness of devices as sources of bacteria

Awareness of devices as sources of bacteria was assessed using three items with ‘yes/no’ answers; electronic devices can harbour bacteria, phones/tablets can be a source of cross-contamination in the kitchen, and general cleaning of smart devices can reduce bacteria. ‘Yes’ answers were given a score of 1, with a total possible scoring range of 0 – 3, with a higher score indicating greater awareness of devices as sources of bacteria.

In addition, participants were provided with a definition of cross-contamination and a list of nine causes of cross-contamination in the kitchen, for example, not washing hands before preparing foods, using electronic devices in the kitchen, and door handles. They were asked to rank these from 1 (most likely cause of cross-contamination) to 9 (least likely cause of cross-contamination). These rankings were then reverse scored so that a score of 1 became 9 and a score of 9 became 1, and so on. Therefore, each cause of contamination had a score from each participant, with a higher score indicating participants viewed it as a more likely source of contamination.

Cooking skills confidence

A 14-item scale was used to measure cooking skills confidence (Lavelle et al., 2017). Skills such as chopping, peeling, weighing ingredients and using an oven were measured on a 7-point Likert scale. The score for each skill is then added to create a total cooking competence score, with possible scores ranging from 0 to 98.

Food shopping and cooking behaviours

To understand participants’ food shopping and cooking behaviours, they were asked several questions, such as what type of cook they are (using only fresh and raw ingredients through to buying ready-made), how many people they typically cook for, and how often they are responsible for the food shopping and main meal preparation in their household.

Socio-demographic variables

Each participant was asked about their gender, marital status, living situation, education, occupation status, location and income.

Psychosocial variables

- *Health consciousness* was measured with the General Health Interest scale (Roininen et al., 1999), consisting of eight items with a Likert scale from 1 (strongly disagree) to 7 (strongly agree). Participants could therefore have a minimum score of 8 and a maximum score of 56, with a higher score indicating greater health consciousness.
- *Self-perceived health* was measured with one item on a scale of 1 to 5 (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor). Scores were reverse coded for analysis.
- *Food poisoning susceptibility* was measured using a six-item measure with a 5-point Likert scale (Cairnduff et al., 2016). In response to findings from the focus groups that meals from outside of the home were perceived as more risky than meals prepared at home, an item was added to reflect this. Participants could score a minimum of 6 and a maximum of 30, with a higher score indicating greater perceived susceptibility to food poisoning.
- *Food poisoning severity* assessed participants' perceptions around the severity of food poisoning and was measured using a six-item (5-point Likert scale) measure (Cairnduff et al., 2016). Participants could score a minimum of 6 and a maximum of 30, with a higher score indicating greater perceived severity food poisoning.

Analysis

Data were cleaned, coded and analysed using IBM SPSS Statistics v26 (IBM Corporation, Armonk, NY, USA). As a 'forced response' option was used for each question, there were no missing data. Descriptive statistics (Mean, SD, percentages) were used to explore and summarise the data. Chi-Square Tests of Independence were used to explore relationships between two categorical variables. Analysis of Variance

(ANOVAs) were used to examine differences between groups on continuous variables such as scores and scales. Where assumptions of these parametric tests were not met, equivalent non-parametric tests were used: the Mann-Whitney U Test and the Kruskal-Wallis Test. A hierarchical multiple regression was also used to understand how much of the variance in the dependent variable, total food safety hazard identification score (calculated by combining participants' hazard identification scores for video clips A and B), was predicted by the independent variables (socio-demographic variables, food shopping and cooking behaviours, food safety behaviours and device use, awareness of devices as sources of bacteria, etc.). All analyses were checked to ensure that data met assumptions, for example, linearity, multicollinearity, normality, homoscedasticity. A significance level of 0.05 was used for all analyses.

Ethical approval

Ethical approval for the online survey was granted in August 2022 by the Faculty of Medicine, Health & Life Sciences Ethics Committee at Queen's University Belfast (Reference number: MHLS 22_115).

Results

Literature review

The full literature review can be found in appendix 5.

In-Kitchen research: Participant overview

Overall, the cooking activity lasted between 18 – 40 minutes with a mean duration of 28 minutes (SD 5.98). Participants had an average food safety knowledge score of 7.76 (SD 1.93) and a mean actual food behaviour score of 7.37 (SD 2.18), range between (0-12).

A total of 51 individuals participated in the study: 18 (35%) males and 33 (65%) females ranging from 19-72 years old, with a mean age of 44 (SD 16.1 years). This was a sample across the island of Ireland (NI 17 (33%) and Ireland 34 (67%)), with even representation across rural 27 (53%) and urban 22 (43%) regions. The majority of respondents were highly educated, having obtained a university degree (59%), and were either married or living with a partner (61%). A complete overview of socio-demographic characteristics of the sample can be found in Table 1. The size of the session groups ranged from 7 -11 participants.

Table 1: Socio-demographic characteristics of sample for in-kitchen research

Parameter	**Total n (%)**
Region	
NI	17 (33)
Ireland	34 (67)
Gender	
Male	18 (35)
Female	33 (65)

Parameter	Total n (%)
Age	
18-34	16 (31)
35-54	14 (28)
55+	16 (31)
Location	
Rural	27 (53)
Urban	22 (43)
Education	
Less than university	19 (37)
University	30 (59)
Occupation Status	
Full-time paid work (30+hrs per week)	34 (67)
Part-time paid work (<30 hours per week)	4 (8)
Retired	4 (8)
Full-time higher education	3 (6)
Unemployed	2 (4)
Full-time home-maker	2 (4)
Marital status	
Married / living with partner.	31 (61)
Single (widowed, divorced, separated)	19 (37)
Total	51

The majority (n=41, 80%) of participants indicated that they used a mobile phone whilst preparing a meal. Moreover, over a third (n=17, 33%) of participants indicated that they continued to prepare food after touching a smart device. Just under a third (n=15, 29%)

of participants only cleaned their phone if it was visibly dirty or if something spilled on it, and only five (10%) participants reported that they wipe clean their phone frequently (almost every day). The most popular method of cleaning a device was a disinfectant/antibacterial wipe (n=21, 41% of participants). A complete overview of behaviours associated with smart device use in the kitchen can be found in Table 2.

Table 2: Responses to in-kitchen survey questions on smart device usage and cleaning behaviours

Parameter		**Total** **n (%)**
Total		51
Use a mobile phone while preparing food	Yes No	41 (80) 10 (20)
Behaviour after touching device while preparing food	Continue preparing food Rinse hands with water Wash hands with soap Wipe hands (e.g., cloth or towel) Other	17 (33) 13 (26) 14 (27) 6 (12) 1 (2)
Use smart devices (e.g., tablets, mobile phone, laptop) when cooking	Always Very often Sometimes Rarely Never	2 (4) 8 (16) 19 (37) 15 (29) 7(14)

Cleaning of mobile phone	Only if it is visibly dirty/something spills on it	15 (29)
	2-4 times a week	9 (18)
	Once a week	8 (16)
	Two to three times a month	7 (14)
	Almost every day (5-7 days a week)	5 (10)
	Never	4 (8)
	Every 2-3 months	1 (2)
	Once a month	1 (2)

Observations

For the observation, participants prepared chicken goujons and a side salad using a recipe provided on a tablet. Table 3 provides an overview of the types of behaviours observed during the cooking activity and the percentage of participants who demonstrated the correct behaviour or unsatisfactory behaviour.

Handwashing

In general, the majority of participants (59%) washed their hands with soap before taking part in the cooking activity. However, it is worth noting that a substantial proportion (approx. 40%) did not engage with the recommended handwashing practices before meal preparation, with approximately a fifth not handwashing at all (22%) or only washing hands with water (absence of soap). Participant hand hygiene behaviours were also recorded after touching ingredients such as raw chicken and eggs. Approximately half of participants washed their hands with soap and water after preparing chicken, with a third of participants (34%) not washing hands at all. In addition, the majority of participants (74%) did not wash their hands after touching raw egg.

Cross-contamination

The majority of participants (86%) only used one hand to move chicken from plate to chopping board and to chop the chicken. However, when participants progressed to coat the chicken strips with flour and eggs to prepare the chicken goujons, the majority of participants (80%) used two hands. This behaviour substantially increased the risk of contaminations, as participants' hands were exposed to raw chicken and raw egg. Furthermore, a high proportion of participants were engaging in risky food safety behaviour. For example, only 63% washed their hands after preparing chicken goujons - where participants' hands had high exposure to risky ingredients such as raw eggs and chicken. Over a third of participants only washed hands with water and one participant did not wash their hands at all.

The majority of participants engaged in satisfactory behaviour and either changed or washed their chopping board (73%) and knife (66%). Approximately one fifth of participants only washed their chopping board with water and three participants did not wash their chopping board at all between ingredients. Similarly, one third of participants only washed their knife with water and one participant did not wash their knife at all.

Participants' food safety knowledge score did not correlate with their actual food behaviours score. In addition, socio-demographic data was used to compare participants' food safety knowledge with their actual food behaviours. No significant differences were found for socio-demographic data (age, location, education level and gender).

Smart Device usage

The frequency with which participants touched the tablet during meal preparation ranged from 1-10 occasions during a 30-minute cooking activity, with a mean frequency of 5.84 (SD 1.80). Approximately half of the participants washed their hands with soap and water after touching chicken before touching the tablet, while a quarter did not wash their hands. Furthermore, only a fifth of participants washed their hands after touching eggs and before touching tablets, with the majority (57%) not washing hands at all. During the cooking activity, only a fifth of participants cleaned the tablet, with the majority (60%) of these individuals cleaning it because it was visibly dirty or was contaminated with ingredients such as flour. On all occasions of cleaning, an unclean teacloth, dishcloth or sleeve was used as a method of cleaning. The tablet hygiene score did not correlate with food safety knowledge and actual behaviour scores. In addition, no statistically significant difference was observed between tablet hygiene score and categorised socio-demographic variables of age, gender, education status and location. Only nine participants touched their mobile phone during the cooking activity, with the frequency of touching ranging from 1- 4.

Table 3: Overview of the behaviour of participants while preparing a high-risk meal (chicken goujons and side salad) in relation to cross-contamination.

Action	No. participants' behaviours observed	Unsatisfactory behaviour (poor hygiene practice)	Somewhat satisfactory	Satisfactory behaviour (good hygiene practice)
	N	N (%)	N (%)	N (%)
Wash hands before starting	51	11 (22)	10 (19)	30 (59)
Dry hands	50*	11 (22)	15 (30)	24 (48)
Moving chicken from plate to chopping board	50*	7 (14)	-	43 (86)
Chopping chicken goujons	50*	7 (14)	-	43 (86)
Washing hands after preparing chicken	50*	17 (34)	10 (20)	23 (46)
Coat chicken strips with flour, eggs and oats	51	41 (80)	-	10 (20)
Washing hands after cracking eggs	51	38 (74)	7 (14)	6 (12)
Washing hands after preparing chicken goujons	51	1 (2)	18 (35)	32 (63)

Washing hands before touching tablet, if touched egg	51	29 (57)	12 (23)	10 (20)
Washing hands before touching tablet, if touched chicken	51	13 (25)	10 (20)	28 (55)
Changing chopping board or washing before veg	51	3 (6)	11 (21)	37 (73)
Changing chopping knife or washing before veg	51	1 (2)	16 (32)	33 (66)

** All participants' behaviours could not be recorded for these actions due to an issue with the video recording equipment*

In-Kitchen research: Microbial Analysis

Validations

The first validation conducted was to determine whether potentially pathogenic bacteria could be inoculated onto and recovered from the surfaces of smart devices. After some preliminary trials with different inoculation strategies (such as an inoculum with control *E. coli* (NCTC 10418) and *Salmonella* (*S. Nottingham* NCTC 07832) prepared in the grown up to stationary phase at ~10^8 CFU/ml in nutrient broth, where 0.1ml of the mixed culture on the surface of the tablets to achieve~10^4 CFU/$10cm^2$), it was found that the spreading of a single colony of each bacterium across the entire surface of the tablet device using a sterile spreader yielded the most consistent and reproducible contamination levels per device and between devices. By the colony technique, *E. coli* and *Salmonella* inoculum levels of ~10^5 CFU/swab were achieved (Table 4).

Survival of inoculated *E. coli* and *Salmonella* on the tablet devices was assessed by swabbing contaminated devices at 0h, 24h and 48h, post-inoculation. The results of this study have shown that the two potentially pathogenic bacteria can survive on the surface of smart devices without any substantial die-off for 24h. Thereafter, the numbers of viable *Salmonella* and *E. coli* decreased up to 48h (the last sampling point included). Decimal reduction values (D value) were calculated as the reciprocal of the slope of the linear trend line for the full data set (0-48h). Results from this calculation indicate that it took 28.25h for a 1 $\log_{10}$ reduction in viable *E. coli* (Figure 4a and 4b) and 26.59h for a 1 log10 reduction in viable *Salmonella* (Figure 4c and 4d) on tablet screens at ambient temperature (20-21° C). However, it appears there may be a ‘shoulder’ in both survival curves, and significant die off (p=<0.000) of the pathogens only began to occur after the 24h time point, which would mean that the calculated D values would be overestimates.

Figure 4: Levels (CFU/swab) of *E. coli* (a) and *Salmonella* (c) recovered from the surface of tablet devices (mean of how many replicates ± standard deviation) and D values calculated for *E. coli* (b) and *Salmonella* (d) at room temperature.

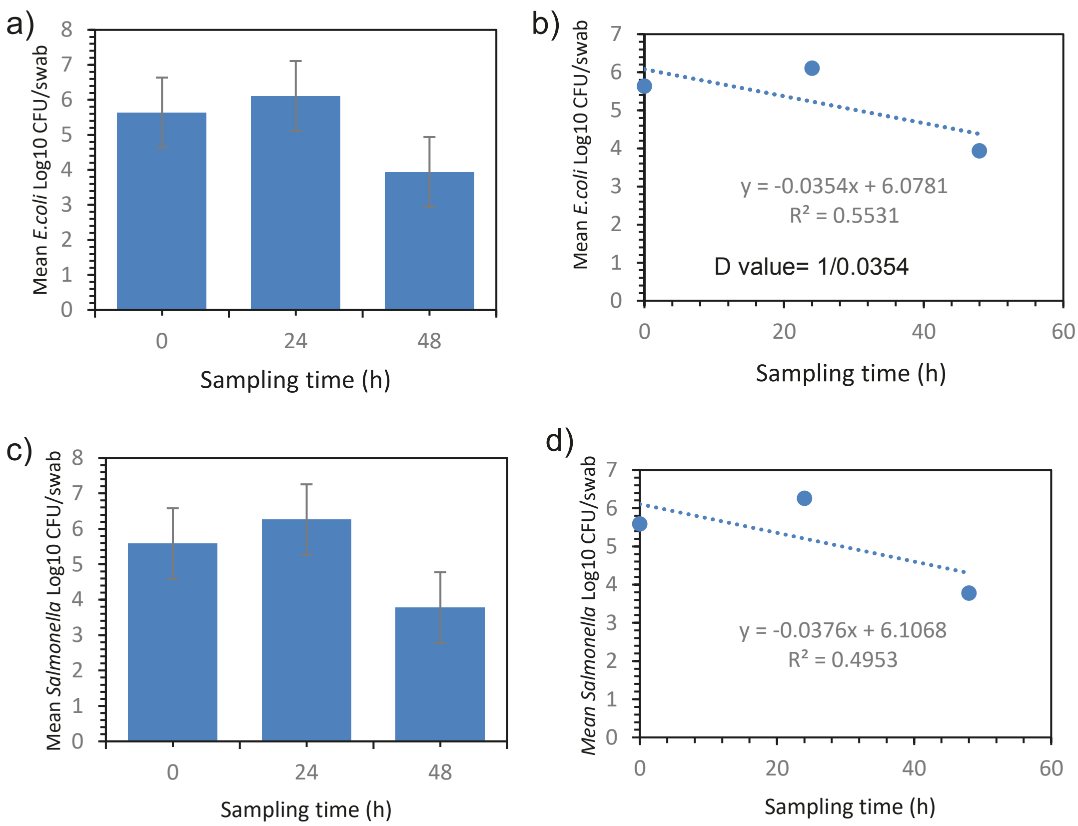


Figure description: E. coli (4a & 4b) and *Salmonella* (4c & 4d) showed similar survival on the surface of smart devices at 24 hours. Rates then decreased up to 48 hours. It took 28.25h for a 1 log10 reduction in viable *E. coli* (4b) and 26.59h for a 1 $\log_{10}$ reduction in viable *Salmonella* (4d) on tablet screens at ambient temperature.

Results of the cleaning/disinfection efficacy study (Table 4) demonstrated that disinfecting tablet device screens with antibacterial wipes containing alcohol and chlorhexidine substantially reduced the load of microorganisms generally (TVC), and more importantly consistently reduced numbers of pathogenic strains of *E. coli* and *Salmonella* to below the limit of detection (<1.0 $\log_{10}$/ <10 CFU/swab).

Table 4: Comparison of the mean $\log_{10}$ CFU/swab before and after disinfection for total viable *E. coli* and *Salmonella* counts.

Microbiological analysis	**Log_{10} mean CFU/swab (SD)**
Total Viable Count	
Before cleaning (n=10)	2.64 (0.08)
After cleaning (n=10)	<1.0
E. coli	
Inoculation level (n=10)	5.31 (0.72)
After cleaning (n=10)	<1.0
Salmonella	
Inoculation level (n=10)	5.02 (0.81)
After cleaning (n=10)	<1.0

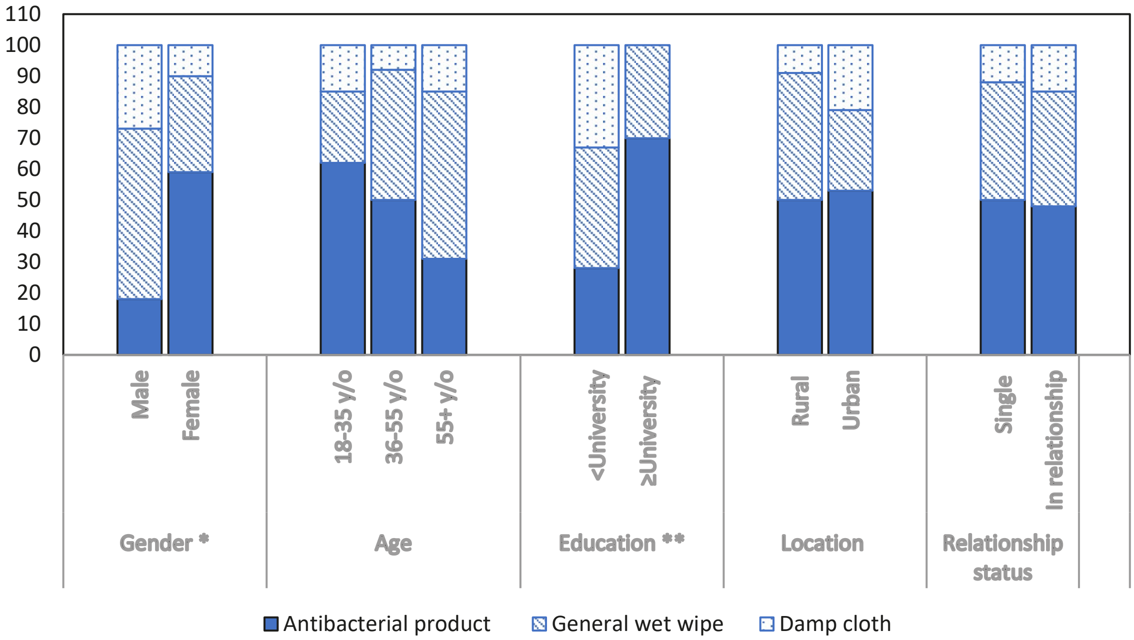
Cooking activity

Demographics and behaviours

Three participants' phones were absent during the cooking activity; therefore, the following total numbers of swab samples were collected during the cooking activity: participants' hands (n=51), participants' tablet devices (n=51) and participants' phones (n=48).

In order to determine if participants' socio-demographic characteristics (gender, age, location and education level) were associated with self-reported smart device behaviours (including what participants do after touching a device, and more generally cleaning frequency and differing methods), Chi-Square or Fisher's Exact Test was conducted. In relation to cleaning frequency and method, statistically significant differences of behaviours were observed between genders. A Fisher's Exact statistical analysis found that the majority of women (n=20, 60%) reported cleaning their phones more frequently (weekly), this in contrast with men, where the majority (n=11, 61%) did not clean their devices at all or only when they became visibly dirty (p=0.003). Moreover, Fishers' Exact analysis found that females reported using antibacterial products when cleaning devices (p=0.03). It also showed that education level influenced the preferred cleaning method and that the majority of participants with a university education preferred antibacterial products (p=0.002) (Figure 5). In relation to self-reported behaviour after touching a device during meal preparation, no significant socio-demographic differences were detected.

Figure 5: Stacked cluster bar chart to illustrate the products used to clean smart devices in relation to socio-demographic groups (%)



Fisher's Exact Test; *$p<0.05$, significant; ** $p< 0.001$, highly significant

Figure description: Females (approximately 60%) were more likely to use antibacterial products to clean their smart devices than males (approximately 20%). Those educated to at least a university level were also more likely to use an antibacterial product (approximately 70% versus approximately 30% of those not educated to university level). Products used to clean devices did not significantly differ by location, relationship status or age, with approximately half of individuals in urban and rural locations, those single and in a relationship, and those 18-55 years old, using antibacterial products.

Contamination rate

In relation to TVC,'s contamination was found on the hands of all 51 participants (100%). In addition, 44 (92%) phones and 28 (55%) tablet devices were contaminated with general bacteria and fungi. In this study, a third (n=16, 31%) of participants' hands were contaminated with *Enterobacteriaceae*. Further, four (8%) participants' phones and three (6%) participants' tablets were contaminated with *Enterobacteriaceae.*

For general bacterial analysis (TVC), we investigated the contamination rate of participants' hands, tablets and phones according to socio-demographic characteristics of age, gender, location and education level. On these demographic data only, the contamination rate of tablets in relation to education level indicated a statistically different relationship (4.331, 1, p=0.037), with a higher percentage of contamination found in respondents with less than university education (74%), compared to those who had completed university (43%). No other significant differences were detected in microbial contamination rate according to socio-demographic data. Due to the small contamination rate of tablets (n=4) and phones (n=3) with *Enterobacteriaceae*, no statistical analysis was conducted on these variables. No statistical differences were detected on the contamination rate of *Enterobacteriaceae* on hands in terms of socio-demographic characteristics. Similarly, statistical analysis of general (TVC) and *Enterobacteriaceae* contamination rates with self-reported behaviours, such as mobile use while preparing a meal, cleaning frequency and cleaning type, uncovered no significant relationships.

An API (Analytical Profile Index) 20E was conducted on VRBG plates to identify members of the *Enterobacteriaceae* family detected. In descending order, the most frequently identified bacteria were *Pantoea* spp. (n=20), *Pasteurella pneumotropica* (n=3), *Aeromonas salmonicioa* (n=2) *Ewingella americana* (n=2), *Rahnella aquatilis* (n=1), *Pseudomonas aryzihabitans* (n=1), *Serratia marcesens* (n=1) and *Enterobacter aerogenes* (n=1).

Microbial load

In relation to TVC, the mean and standard deviation of the microbial load on hands ($\log_{10}$ mean CFU/swab: 2.9 ± 0.75), phones ($\log_{10}$ mean CFU/swab: 2.1 ± 0.75) and tablets ($\log_{10}$ mean CFU/swab: 1.81± 0.74) varied considerably. Lower microbial loads were observed with VRBG analysis: of hands ($\log_{10}$ mean CFU/swab: 2.05 ± 1.00), phones ($\log_{10}$ mean CFU/swab: 1.40 ± 0.38) and tablets ($\log_{10}$ mean CFU/swab: 1.54 ± 0.47).

Based on socio-demographic characteristics (age, gender, location and education level), independent t-tests and One-Way ANOVA statistical analysis were conducted on the microbial load (log_{10} mean CFU/swab) reported on TVC (hands, phones and tablets) and VRBG (hands) (Table 5). Independent t-tests found that there was a significant difference in the microbial load on hands in relation to gender, where males had a significantly higher microbial load (mean log_{10} CFU/Swab: 3.20 ± 0.84) compared to females (mean log_{10} CFU/swab 2.74 ± 0.67), conditions; t (49)=2.14, p=0.037. In addition, statistical analysis found a significant difference in the microbial load on phones in relation to education level, where individuals with an education equivalent to or higher than university education had a significantly lower microbial load (mean log_{10} CFU/swab: 31.57 ± 0.97) compared with participants with less than university education (mean log_{10} CFU/swab: 2.20 ± 1.02), conditions; t (47)=2.18, p=0.034.

Table 5: Significance of differences in microbial load between the socio-demographic groups

Socio-demographic group (n = no of participants)	**Total viable count hands (log10 CFU/ swab)**		**Total viable count of phones (log10 CFU/ swab)**		**Total viable count of tablets (log10 CFU/ swab)**		***Enterobacteriaceae* of hands (log10 CFU/ swab)**	
	Mean log_{10} CFU ± SD	p value	Mean log_{10} CFU ± SD	p value	Mean log_{10} CFU ± SD	p value	Mean log_{10} CFU ± SD	p value
Gender [a]								
Male (n=18)	3.20 ± 0.84	0.037 *	1.76 ± 1.31	0.968	1.10 ± 1.05	0.739	0.69 ± 1.29	0.83

Female (n=33)	2.74 ± 0.67		1.78 ± 0.88		0.99 ± 1.09		0.62 ± 1.03	
Location [a]								
Rural (n=27)	2.95 ± 0.70	0.494	2.03 ± 0.84	0.105	1.03 ± 1.03	0.965	0.64 ± 1.05	0.825
Urban (n=22)	2.80 ± 0.84		1.56 ± 1.18		1.04 ± 1.14		0.57 ± 1.15	
Education [a]								
Less than University (n=19)	2.74 ± 0.60	0.300	2.20 ± 1.02	0.034 *	0.99 ± 1.04	0.835	0.58 ± 1.14	0.888
University (n=30)	2.98 ± 0.85		1.57 ± 0.97		1.06 ± 1.11		0.63 ± 1.07	
Age [b]								
19 – 35 y/o (n=16)	2.59 ± 0.80	0.216	2.02 ± 0.86	0.364	1.23 ±1.08	0.165	0.39 ± 1.20	0.508
36 – 55 y/o (n=14)	3.04 ± 0.72		1.76 ± 1.06		0.59 ± 0.90		0.49 ± 0.72	

55+ (n=16)	2.97 ± 0.74		1.48 ± 1.06		1.17 ± 0.98		0.81 ± 1.13	

[a.] Independent t-test; *p<0.05, significant; ** p< 0.001, highly significant

[b.] One-Way Anova; *p<0.05, significant; ** p< 0.001, highly significant

A comparison of the participants' self-reported behaviours and microbial load (mean $\log_{10}$ CFU/swab) revealed that there was no significant difference between the reported frequency of cleaning and the microbial load on phones and tablets (Table 6). Welch ANOVA found that the cleaning type significantly influenced microbial loads, conditions: $F(2, 40) = 5.12$, P= 0.029. Post-hoc analyses using Bonferroni criteria for significance indicates a statistically significant lower microbial load of using general wipes (mean $\log_{10}$ CFU/swab: 1.61 ± 1.30†) in comparison to using a damp cloth (mean $\log_{10}$ CFU/swab: 2.84 ± 0.71). However, the microbial load of participants using antibacterial products did not significantly differ from the other two groups (Table 6). In addition, when participants were asked "What they do after touching smart devices during meal preparation?", responses were grouped into two categories: improper behaviour (continue preparing food and wipe hands on cloth or towel) and proper behaviours (washing hands). Independent t-test analysis found that there was a significant difference in the microbial load on reported behaviours and the microbial load of tablets; conditions; $t(48) = 2.145$, $p = 0.042$. Individuals that reported proper behaviours (mean $\log_{10}$ CFU/swab: 0.72 ± 0.89) after touching their smart device had a lower microbial load in comparison to participants reporting improper behaviours (mean $\log_{10}$ CFU/swab: 1.35 ± 1.18).

Participants' self-reported handwashing behaviours before meal preparation and after touching chicken were grouped into recommended practices (always washing hands) and less than satisfactory behaviours (participants that washed their hands "often, sometimes, rarely and never"). There was no statistically significant difference found between these groups in relation to contamination rate or the microbial loads of hands.

Pearson's correlation coefficient did not find any significant relationships in relation to the level of contamination for general and *Enterobacteriaceae* and continuous socio-demographic variables of age and level of education.

Table 6: Comparison of mean log_{10} bacteria on smart devices (Colony Forming Units(CFU)/swab) by self-reported behaviours including frequency and type of cleaning.

Self-reported behaviour (n = no of participants)	**Total viable count CFU of phones**		**Total viable count CFU of tablets**	
	Mean log_{10} CFU ± SD	p value	Mean log_{10} CFU ± SD	p value
Frequency of cleaning [a]				
Never/ only when visibly dirty (n=19)	1.92 ± 0.97	0.494	1.36 ± 1.04	0.251
Monthly (n=9)	1.45 ± 1.24		0.69 ± 0.88	
Weekly (n=22)	1.80 ± 1.01		0.86 ± 1.11	
Method of cleaning [b]				
Disinfectant/ antibacterial wipe (n=21)	1.88 ± 0.56	0.029*	1.08 ± 1.20	0.584
General wipe (baby wipe, lens wipe or PC wipe) (n=16)	1.61 ± 1.30†		1.04 ± 1.08	
Damp cloth or tissue with warm water (n=6)	2.84 ± 0.71†		0.55 ± 0.89	

Behaviours after touching device during meal preparation [c]				
Proper – washing hands (n=27)	1.94 ± 1.07	0.115	0.72 ± 0.89	0.042*
Improper – continue preparing food and wipe hands on cloth or towel (n=23)	1.49 ± 0.92		1.35 ± 1.18	

a. One-Way Anova; *p<0.05, significant; ** p< 0.001, highly significant

[b.] One-Way Anova; Welch Statistic as Levene's statistic reported that equal variances are not assumed *p<0.05, significant; ** p< 0.001, highly significant

† Bonferroni post hoc analysis to show differences between groups

[c]. Independent t-test; *p<0.05, significant; ** p< 0.001, highly significant

In-Kitchen Research: Focus Groups

Four themes around food safety and smart device use in food preparation were developed: 1) 'No food poisoning in my home,' 2) 'Behaviours – identification, perceptions, and catalysts,' 3) 'Devices – type and usage,' and 4) 'Bacterial survival and transference.' These themes related to general food safety, how devices are being used in food preparation, and their perceived relationship to food safety. The themes are detailed with illustrative quotes below

No food poisoning in my home

Participants believed the risk of food poisoning in the home environment is extremely low or non-existent. The mentality of 'no one has died yet,' appeared pervasive among the participants.

“We have to have a level of realism. Have you got sick, have you, has anyone in your family got sick over the last 20 years at home? No. So like …” (Ireland Grp 2, Male)

This perception was prevalent across all focus groups, where they had a greater concern about the external environment to their homes, for example, takeaways and restaurants.

“I’d be more worried about takeaways than home.” (Ireland Grp 1, Female).

Behaviours – identification, perceptions and catalysts

The participants were generally able to identify different behaviours (poor versus good behaviours). They noted positive behaviours such as handwashing (with or without soap), general cleanliness levels, one hand touching the chicken, changing boards, changing knives, washing hands when touching devices and hair tied back, and in general that the actor was more organised. The participants tended to be shocked at poorer behaviours: *“Yeah, that’s definitely how not to do it.” (NI Grp 2, Female)*. They identified negative behaviours such as the actor touching a device after touching raw chicken, a lack of cleanliness, washing the chicken, using the same board to chop vegetables as raw chicken, loose hair, sneezing and not washing hands after preparation. While the majority of participants felt their behaviours were similar to the behaviours shown in the good clip, a minority recognised that their behaviours fell somewhere in between the good and poor behaviours or were like the poor behaviours.

Participants also identified that their safety behaviours were dependent on certain catalysts. While time pressures and organisation were mentioned as influencing their behaviours, the most prevalent reported influence was their children distracting them or wanting attention, which led to poorer food safety behaviours.

“There's that incessant noise of ‘Mommy, Mommy, Mommy, is dinner ready?’” (NI Grp 1, Female).

Additionally, some participants acknowledged that they may change their behaviours after their experience in the session, particularly around devices.

Devices – type and usage

The primary reported devices used during food preparation were mobile phones, followed by tablets. A minority of participants noted that they used voice-controlled devices or that they still preferred to use traditional cookbooks. The 'ease of access' to devices was noted in their use; screen size factored into some participants' reasons for using tablets.

The main reason for using devices during food preparation was for searching recipes or following them while preparing food (both reading recipes and watching videos), including taking pictures of recipes from cookbooks or magazines and using the device to follow them. They also used devices to check ingredients or for finding alternative ingredients.

"Well, I used to always use cookery books. Now they're just sitting redundant and me phone's so much handier, but I have to admit I take a photograph of her too [the cookbook] and using it." (NI Grp 1,female)

Finally, devices were used in a passive manner in the kitchen as well as for actively engaging in the cooking process. Participants used devices to listen to music and podcasts while they were preparing food.

Bacterial survival and transference

Participants believed that there was some risk for bacteria on objects, while some felt that everything is 'dirty'. While there was some belief that there was a risk of transference of bacteria from devices to hands and vice-versa, there was a general acknowledgement that there is a need for some bacteria in individuals' lives and *"What doesn't kill you, makes you stronger." (NI Grp 2, Female)*. Furthermore, participants believed that there was a greater awareness around hygiene practices nowadays because of the COVID-19 pandemic, which would lead to generally safer practices and a reduced risk from bacteria: *"I think we're more conscious about using the sanitizer now." (Ireland Grp 2, Male)*.

A sub-theme within this theme revolved around the bacterial risks of devices and cookbooks - the traditional method versus the modern method for following recipes. Initially, the majority of participants believed cookbooks were more risky, mainly due to the perception that cookbooks are not cleaned and there is more surface area in a cookbook.

"Just imagine as well that you know if you get something on the paper and then you close the book and then you put it away in a cupboard and it's nice and warm and dark you could end up with a wee bacterial storm." (NI Grp 1, Female).

However, while some participants instantly perceived devices as riskier for bacterial transference, as the group discussion progressed some participants changed their opinions based on reflection. It was highlighted that devices potentially provide a greater opportunity for bacterial transference due to their mobility, i.e., they do not remain in the kitchen setting, and that multiple individuals are more likely to touch a device.

"I actually think the tablets are very risky, like more risky in the book you close a book and that's it, yeah. I think the tablet because the tablet you're picking a tablet up, you're going to the door handle, wee Johnny's coming to the door handle, turn off the light, turn off the switch." (NI Grp 1, Male).

Online Survey

In total, 520 participants from the IOI (366 people living in Ireland and 154 living in NI) completed the survey. Participants ranged from 18 to 80 years old (mean = 42.70, SD = 15.54). Characteristics of participants are detailed in Table 7.

Table 7: Socio-demographic characteristics of participants in online survey

Description of participants in online survey	Number of participants (n)	Percentage of total participants (percent)
Jurisdiction		
NI	154	29.6
Ireland	366	70.4
Total	**520**	**100.0**
Age		
Mean age (years)	42.70	Not applicable
Gender		
Male	249	47.9
Female	266	51.2
Nonbinary, gender nonconforming or other personal identification	4	1.0
Education		
None or primary school	3	0.6
Secondary school to age 15 or 16 or Irish Junior Cycle Certificate, or UK General Certificate of Secondary Education (GCSE) or General Certificate of Education (GCE) Ordinary Level ("O" Level)	53	10.2
Secondary school to age 17 or 18 or Irish Senior Cycle Leaving Certificate, or UK General Certificate of Education (GCE) Advanced Level ("A" Level)	87	16.7
Additional training (such as UK National Vocational	102	19.6

Description of participants in online survey	Number of participants (n)	Percentage of total participants (percent)
Qualification [NVQ] or Business and Technology Education Council [BTEC] qualification, or Irish Further Education and Training Awards Council [FETAC] or Foras Áiseanna Soathair [FAS] qualification)		
Undergraduate degree or nursing qualification	183	35.2
Postgraduate degree	92	17.7
Occupation status		
Full-time paid work	276	53.1
Part-time paid work	84	16.2
At school or in full-time higher education	30	5.8
Retired	66	12.7
Unemployed	35	6.7
Full-time homemaker	29	5.6
Marital status		
Married	256	49.2
Living with partner	68	13.1
Single	167	32.1
Widowed, divorced or separated	29	5.6
Living situation		
Living with parents	55	10.6

Description of participants in online survey	Number of participants (n)	Percentage of total participants (percent)
Living with parents and sibling(s)	27	5.2
Living with partner	134	25.8
Living with partner and child(ren)	181	34.8
Living with child(ren)	25	4.8
Living with friends or roommates	34	6.5
Living alone	64	12.3

Food safety behaviours and device use

The majority of participants (57.5%) claimed they always wash their hands with soap before starting to prepare or cook food, with almost one quarter (24.8%) doing so 'very often'. Five per cent said they never or rarely wash their hands before starting to prepare or cook food. A greater proportion of participants (68.1%) always wash their hands with soap immediately after handling raw meat, poultry or fish, with five per cent never or rarely doing so. Females wash their hands with soap significantly more frequently both before starting (z = -3.73, p = 0.001) and immediately after handling raw meat etc. (z = -3.76, p = 0.001) than males. Generally, the oldest participants wash their hands with soap more frequently immediately after handling raw meat etc. than the youngest participants (H (5) = 18.44, p = 0.002).

Over one quarter (27.9%) indicated that they use a smart device while cooking or preparing a meal every day or almost every day. Almost four in ten participants (38.7%) use a device when cooking or preparing a meal between two times a month to four times a week. Almost one fifth (19.8%) never use a smart device while cooking or preparing a meal. Females use their device significantly more frequently than males while cooking or preparing a meal ($z = -3.73$, $p = 0.001$). Younger participants were also significantly more likely than older participants to do so (H (5) = 58.81, $p < 0.001$). The device most often used by participants was a mobile phone or smart phone (63.9%), followed by a tablet (8.8%).

Almost one in three participants (31.7%) wash their hands with soap after using their device while preparing food, with a further 15.6% washing with water only. Almost one in five participants (19.2%) continue preparing food immediately after touching their device.

Participants typically clean their mobile phone or tablet screen when it is visibly dirty or something has been spilt on it (26.5%). However, one in ten (10.4%) clean their device daily or almost daily. A further 4.8% never clean their mobile phone or tablet, with males significantly more likely to indicate this than females. Using an antibacterial wipe was the most common method of cleaning devices (56.9% of those who clean their devices use this method), with females significantly more likely to use this method than males (X^2 (1, 490) = 6.92, $p = 0.009$), alongside those aged 25-44 years old.

Food safety knowledge and device bacteria awareness

From the list of nine possible causes of cross-contamination in the kitchen, participants ranked unwashed hands after using the bathroom or touching a pet as the most likely source of contamination (M = 6.44, SD = 2.35, possible score 1 to 9), closely followed by unwashed hands before preparing food (M = 6.38, SD = 2.52) and using the same utensils for raw meat and cooked food without washing in between (M = 6.25, SD = 2.18). Using electronic devices in the kitchen (phones/tablets) was seen as the least likely source of cross-contamination (M = 2.90, SD = 1.82).

Participants' mean food safety score was slightly above the midpoint (M = 5.25, SD = 1.52) on a possible range of 0 to 10. Younger participants (18-34 years old) had a significantly lower mean score (M = 4.95, SD = 1.59) than middle-aged (35-54 years old) (M = 5.32, SD = 1.50, $p = 0.048$) or older participants (55 years old and above) (M = 5.63, SD = 1.35, $p = <0.001$).

Participants' awareness of smart devices as harbouring bacteria was high, with a median score of 3 (possible minimum 0, possible maximum 3). Indeed, the majority of the sample (83.1%) had the highest level of awareness. Younger participants had a significantly lower bacteria awareness level than middle-aged and older participants ($H (2) = 13.44$, $p = 0.001$).

Psychosocial variables and food safety hazard identification

The mean health consciousness score for the sample was 34.12 (SD = 7.92), from a possible minimum score of 8 and maximum score of 56.

The mean cooking skills score for the sample was 69.89 (SD = 18.38, possible minimum score of 0 and maximum score of 98).

Participants had a food poisoning perceived susceptibility mean score of 26.41 (SD = 4.06) and food poisoning perceived severity mean score of 22.81 (SD = 2.87). As both scales had a minimum score of 6 and maximum score of 30, this indicates that participants believed they were relatively highly susceptible to food poisoning and that it is relatively severe.

The mean food safety hazard identification score for the paper recipe video clip was 11.71 (SD = 5.17), the mean score for the device video clip was similar (M = 11.73, SD = 6.14). The overall combined food safety hazard identification mean score was therefore 23.44 (SD = 9.63).

Table 8 summarises the results of predicting the combined food safety hazard identification score. Predictions of potential effects are made using different proposed sets of characteristics, or "models".

Model 1, the baseline hierarchical multiple regression model that investigated the contribution of participants' socio-demographic characteristics as potential predictors of food safety hazard identification, accounted for 8% of the variance explained, with a significant independent contribution 0.081 ($p < 0.001$).

Model 2, which included the number of times participants had played each video, did not add a significant contribution to the variance explained.

Model 3, which included how frequently participants' prepare the main meal for themselves or their households, their frequency of using their device while preparing or cooking a meal, how often they clean their device, awareness of smart devices as potentially harbouring bacteria, cooking skills, perceptions around food poisoning susceptibility and severity, and food safety knowledge score, resulted in a total of 23% of variance. The variables contributing significantly to the final model included gender, the number of times the paper recipe video was watched, awareness of smart devices as potentially harbouring bacteria, perceptions around food poisoning susceptibility and severity, and the food safety knowledge score.

The results of Model 3 showed that (i) females, (ii) participants who had watched the paper recipe video once, (iii) those who had a greater awareness of bacteria on devices, (iv) those who perceived a higher susceptibility to food poisoning, (v) those who perceived the consequences of food poisoning to be less severe, and (vi) had a higher food safety knowledge score, had a higher food safety hazard identification score than (i) males, (ii) participants who had watched the paper recipe video twice, (iii) had a lower awareness of bacteria on devices, (iv) did not believe they were highly susceptible to food poisoning, (v) believed that food poisoning consequences would be severe, and (vi) had a lower food safety knowledge score.

Table 8: Hierarchical multiple regression predicting combined food safety hazard identification score (n = 515). Significance values shown for significant findings only.

Variables	**Model 1**		**Model 2**		**Model 3**	
	B (SE)	Β	**B (SE)**	**β**	**B (SE)**	**β**
Age	0.064 (0.028)	0.105 ($p = 0.021$)	0.072 (0.028)	0.118 ($p = 0.010$)	0.008 (0.028)	-0.13
Country	-1.828 (0.876)	-0.089 ($p = 0.037$)	-1.904 (0.874)	-0.092 ($p = 0.030$)	-1.612 (0.824)	-1.955
Gender	5.633 (0.844)	0.299 ($p < 0.001$)	5.520 (0.843)	0.293 ($p < 0.001$)	3.727 (0.808)	0.198 ($p < 0.001$)
Education	0.383 (0.451)	0.037	0.342 (0.450)	0.033	0.019 (0.418)	0.002
Number of times device video clip watched			-0.993 (1.221)	-0.035	-1.012 (1.140)	-0.036
Number of times paper recipe video clip watched			-2.468 (1.252)	-0.086	-2.429 (1.165)	-0.085 ($p = 0.038$)

Variables	Model 1		Model 2		Model 3	
	B (SE)	Β	**B (SE)**	**β**	**B (SE)**	**β**
Frequency of preparing main meal					0.584 (0.309)	0.079
Frequency of using device while preparing/cooking meal					-0.176 (0.155)	-0.50
Never cleans device					-0.126 (1.843)	-0.003
Cleans device if dirty					0.753 (1.025)	0.035
Cleans device once a month or less					-1.210 (1.136)	-0.051
Cleans device few times a month					-1.505 (1.065)	-0.066
Bacteria awareness					1.644 (0.557)	0.124 (p = 0.003)
Cooking skills score					0.032 (0.023)	0.061

Variables	**Model 1**		**Model 2**		**Model 3**	
	B (SE)	Β	**B (SE)**	**β**	**B (SE)**	**β**
Food poisoning perceived susceptibility					0.216 (0.103)	0.093 ($p = 0.036$)
Food poisoning perceived severity					-0.319 (0.149)	-0.094 ($p = 0.033$)
Food safety knowledge score					1.728 (0.258)	0.279 ($p < 0.001$)
F	12.36 ($p < 0.001$)		9.23 ($p < 0.001$)		10.21 ($p < 0.001$)	
Adjusted R^2	0.081 ($p < 0.001$)		0.088		0.233 ($p < 0.001$)	

p values shown only when statistical significance was found

Project Modifications

There were no modifications made which impacted upon the objectives of the project.

Discussion

This project aimed to understand consumer behaviour and attitudes around the use of smart devices while preparing food in the domestic kitchen, and assess the prevalence of bacteria on smart devices, in addition to assessing the potential for bacterial contamination as a food safety hazard in the kitchen. This research project utilised a combination of behavioural science approaches: qualitative and quantitative methodologies (delivered in four tasks) together with microbial techniques (one task) to obtain a comprehensive and holistic understanding of the use of these devices in the domestic setting, while also ascertaining the potential food-safety risk. This section combines the results from the different studies of the research project.

Literature review

Smart devices have become an indispensable component of our daily lives due to their versatility and mobility. The benefits of these devices are centred on consumer convenience, as a vast number of apps, coupled with the ability to have resources on devices tailored to the individual's own interests and needs, makes for a very efficient device. Unsurprisingly, the younger generation are more receptive to the use of these devices; however, recent studies have demonstrated that the older population are incorporating these devices into their daily lives as well. This is likely due to the design of apps making usage straightforward (Ernsting et al., 2017; Seifert & Schelling, 2015).

Overall, in all clinical studies (n=53), a high incidence of bacterial isolation on personal electronic devices was reported. While the microbial community was diverse, and dominant microorganisms fluctuated, common microorganisms such as CoNS and *Bacillus* species were frequently isolated (Bayraktar et al., 2021; Brady et al., 2011; Jalalmanesh et al., 2017; Simmonds et al., 2020). Additionally, phone characteristics, such as whether it was key-pad or touchscreen operated, and the presence of a cover, influenced the bacterial contamination incidence (Elmanama et al., 2015; Koroglu et al., 2015; Qureshi et al., 2020). Moreover, several studies, while limited, established that the microbial community present on hands and corresponding electronic devices correlated (Badr et al., 2012; Katsuse Kanayama et al., 2017; Shah et al., 2019). Therefore, there is undisputable evidence that personal electronic devices harbour microorganisms, and thus have the ability to significantly contribute to cross-contamination.

Given the understanding that personal electronic devices are reservoirs for microorganisms, it is also important to acknowledge that regular cleaning can significantly reduce the microbial load and flora present on these devices (Egert et al., 2015; Howell et al., 2014; Jones et al., 2020). Poor hygiene practices persisted, despite participants displaying an awareness of risks of cross-contamination from devices, and that they understood regular cleaning would alleviate contamination (Brady et al., 2011; Jalalmanesh et al., 2017; Murgier et al., 2016; Olsen et al., 2021). This finding complimented that of Lando et al., (2018), which found poor hygiene practices relating to devices used in the domestic kitchen. Moreover, studies have indicated that participants share devices, and that such practices can further exacerbate bacterial contamination (Edrees & Al-Awar, 2020; Matthews et al., 2016; Ustun & Cihangiroglu, 2012). Unsurprisingly, due to the increased exposure of a high-risk clinical setting, health care workers had a greater level of microbial contamination in comparison to the general population (Angadi et al., 2014; Koroglu et al., 2015; Sedighi et al., 2015; Simmonds et al., 2020). Moreover, elevated microbial contamination was associated with males, which is likely due to females' increased engagement in good hygiene behaviours, i.e., washing hands (Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Murgier et al., 2016).

Gap identification and justification of experimental design

Several gaps in this review were identified:

- Overwhelmingly, the majority of the research investigating the microbial contamination on personal electronic devices was conducted in a clinical setting. While this is beneficial, as it clearly demonstrated that these devices contribute to cross-contamination, there has been no research to date, to the authors' knowledge, investigating the risk that personal smart devices contribute to cross-contamination in a food production environment. This research gap was addressed in the project.

- Limited research has addressed the influence of hands in relation to cross-contamination and re-contamination resulting from the frequent touching of phones. Therefore, hands were included in the experimental design of this survey to build on previous research.
- The majority of research focused on investigating the contamination incidence and microflora present on smart devices. Additionally, it is well known that fomites can survive on inanimate objects; however, there is little known about the extent to which microorganisms survive on smart devices. This project conducted a preliminary validation study to determine if microbes can survive on the surfaces of these devices.
- The majority of surveys in this area lacked validated measures to ascertain psychometric parameters such as awareness. In addition, there is only one study that investigates the use of smart devices in a food production environment. Lando et al., (2018) utilised survey and focus groups to determine usage behaviours. These studies are beneficial as they provide insight into the use of these devices. The present study incorporated specific in-kitchen pre- and post-surveys, a cooking activity, and microbial analysis of hands, phones and tablets, coupled with focus group discussions. This holistic approach offers a more comprehensive understanding of this issue.

Further justification for study design

- Microbial protocol: The vast majority of studies utilised culture-based approaches to isolate microorganisms on smart devices. Most studies used a general-purpose agar coupled with a selective agar to isolate and identify bacteria to satisfy the overall aims of their experiment. Further identification was completed using additional standardised biochemical tests. For this study, a general-purpose agar was selected; additionally, due to the focus of this project being food safety, a VBRG Agar was selected, as this remains the most popular agar to identify *Enterobacteriaceae*, which is generally considered to indicate the prevalence of food safety bacteria in food establishments.

- Many studies investigated the presence of multidrug resistant microorganisms (MDROs). This is understandable, as clinical settings are considered a reservoir for these microorganisms. Results from the review indicated that these MDROs were isolated from HCW and were rarely isolated on general population groups. Therefore, as the current project involved the general population, there was no need to include microbial techniques to isolate and identify MDROs.

The versatility and portable design of these devices is beneficial, accommodating individual interests and needs. However, the increased use of these devices may also lend itself to cross-contamination in a domestic setting. Therefore, this study was designed to capture the behaviours relating to consumers' usage of smart devices and identify the potential food safety risk of these devices. Such a design enabled a comprehensive exploration and understanding if smart devices are a food-safety hazard in the kitchen.

Observations

To the authors' knowledge, this is the first study to investigate consumers' food safety behaviours centred on using smart devices in the kitchen. The research offers insights into consumers' food safety behaviour in relation to smart devices in the kitchen, in addition to providing recommendations to minimise cross-contamination risk associated with using these devices during meal preparation.

Hand hygiene campaigns are the cornerstone of preventing cross-contamination and have been continuously advocated in food industry (Heard & Ipsos MORI, 2021; Wright et al., 2011). Furthermore, hand hygiene campaigns increased to global scale in response to the COVID-19 pandemic, resulting a surge in engagement with hand hygiene behaviours*.* However, in the wake of the pandemic, research has indicated that handwashing behaviour has not been sustained and individuals are washing their hands less frequently (Heard & Ipsos MORI, 2021). It is a reassuring finding that the majority of participants engaged in the recommended practices of washing hands with soap before meal preparation. Similar findings in other studies demonstrated that absence in handwashing before meal preparation persists, this despite continuous messaging on the importance of hand hygiene from regulatory bodies such as FSA, FSAI and ***safe*****food** (Armstrong et al., 2022; Heard & Ipsos MORI, 2021; Lavelle, McKernan, et al., 2023).

Furthermore, participants in this study demonstrated poor hygiene practices during meal preparation, as a third of participants were observed not washing their hands after touching raw chicken, while the majority (74%) did not wash their hands after touching raw eggs. This finding is a concern, as a recent Irish study found that the majority of participants demonstrated a decent understanding of *salmonellosis* and risk perception related to food handling practices, with the majority of respondents (96%) reporting handwashing with soap and water after touching raw meat (Conway et al., 2023). However, this study found that this self-reported behaviour for handwashing and other food preparation tasks markedly differs from actual reported behaviours, strengthening findings from other research that awareness and knowledge do not translate into actual behaviours, as it has been shown that campaigns focused on hand hygiene have limited success with compliance (Redmond & Griffith, 2004). These findings are echoed in other studies in the UK and US reporting that a substantial proportion of participants do not adhere to recommended food safety practices (Armstrong et al., 2022; Byrd-Bredbenner et al., 2013), indicating that there is a disconnect between perceived behaviour, knowledge of food safety, and actual practices. This may be attributable to research that suggests participants display an optimistic bias. A low perceived risk of food poisoning in the home creates a behavioural challenge whereby safety practices in meal preparation are not a priority (Taché & Carpentier, 2014). Furthermore, Conway et al. (2023), reported that the majority of Irish consumers (>70%) use separate utensils for preparing raw meat and vegetables (Conway et al., 2023). However, participants in this study demonstrated that they somewhat engaged in satisfactory behaviour and either changed or washed their chopping board (73%) and knife (66%).

Studies have reported the use of smart devices as a tool for meal preparation (Jokela et al., 2015; Müller et al., 2012). Furthermore, the utilisation of these devices during food preparation is likely to result in increased food-safety risks due to the increased reliance on smart devices and their increased involvement in meal preparation in the home (Murphy et al., 2021). As previously discussed, there are numerous sources and vehicles that have the ability to contribute to cross-contamination in the domestic environment, for instance, dishcloths (Azevedo et al., 2014; Taché & Carpentier, 2014).

An earlier study in the USA reported that one third of participants reported washing hands after touching the device and before continuing cooking (Lando et al., 2018). Similarly, in the current study approximately a third (37%) of participants washed hands between meal preparation and touching a smart device. This is a concerning finding, as studies have shown that mobile devices can harbour microorganisms, and are thus a reservoir and vehicle for the cross-contamination of pathogenic bacteria (Basol et al., 2014; Foong et al., 2015). Furthermore, in the current study, half of participants washed their hands after touching chicken and before touching the tablet, while only a fifth of participants washed their hands after touching eggs and before touching tablets. Further research in the USA indicated that the majority (80%) of participants expressed the belief that smart devices could harbour microbes and could be a potential food safety risk, and felt that food industry workers should regularly clean devices of this nature. In the current study, only a fifth of participants cleaned their tablet during the cooking activity, with the majority of respondents doing so due to the device being visibly dirty or contaminated with ingredients. These observations are supported by findings from other studies reporting that participants only cleaned devices when they were visibly dirty (Bayraktar et al., 2021; Heyba et al., 2015). On all occasions of cleaning, an unclean teacloth, dishcloth or sleeve was used as a method of cleaning, a finding also echoed in other studies (Jones et al., 2020; Kotris et al., 2017; Lando et al., 2018).

While the use of head camera recording equipment in the project allowed for all participants' actions to be recorded and subsequently analysed in detail, the impact of wearing the headsets and the use of laboratory kitchens may have impacted upon participants' behaviours.

Microbial

Validation study

Studies have demonstrated that pathogens can persist on the surfaces of smart devices for considerable periods of time, posing a significant contamination risk to human health (Kusumaningrum et al., 2003; Mattick et al., 2003). This finding is strengthened by findings in the current study, indicating that pathogenic bacteria *E. coli* and *Salmonella* can survive on the surfaces of tablets for extended periods of time (>24h). These devices tend to be moved from the kitchen shortly after meal preparation and carried around the home, potentially spreading harmful bacteria. Additionally, devices such as tablets tend to be used by multiple people in families, potentially risking multiple-person exposure to bacteria.

It was observed in this study that after cleaning with 70% isopropyl alcohol and chlorhexidine wipes, the microbial load of general (TVC) and potentially pathogenic bacteria (*E. coli* and *Salmonella*) was significantly reduced to levels below the limit of detection (<10 CFU/swab). Similar efficiency of cleaning smart devices with products containing alcohol has been reported in other studies, with an 80-100% effectiveness (Angadi et al, 2016; Singh et al., 2010; Egert et al., 2015; Brady et al., 2011). Studies have found that all methods, such as microfibre cloths, lens wipe, antibacterial wipe containing alcohol and chlorhexidine significantly reduced microbial load and extent of contamination; however, there is a general agreement that products containing alcohol are more effective (Howell et al., 2014; Egert et al., 2015; Jones et al., 2020; Muniz de Oliveira et al., 2019). The findings of the current study demonstrate that despite bacteria being able to survive on smart devices, regular alcohol-based decontamination is a highly efficient and effective way to mitigate food safety concerns. With the continued and increasing use of these devices in the kitchen environment, it is essential to promote the cleaning of devices after meal preparation to minimise food safety risk.

Cooking activity

In this study, all participants' hands (100%), the majority of phones (92%) and 55% of tablets were contaminated with microorganisms, which is unsurprising as microorganisms are ubiquitous. Our findings are consistent with previous studies that have reported high bacterial contamination on phones (Jones et al., 2020; Koroglu et al., 2015; Karkee et al., 2017; Tailor et al., 2019) and hands (Angadi et al., 2014; Shah et al., 2019). Pathogenic contamination rates on devices have been reported to range from 30% to 60% in previous studies (Missri et al., 2019; Walia et al., 2014; Tekerekoglu et al., 2011; Ulger et al., 2009). The current study reported a lower incidence of contamination from potentially pathogenic bacteria - hands (31%), phones (8%) and tablets (6%). The low contamination rates of tablets with general bacteria (55%) and potential pathogenic bacteria (6%) may be partly explained by experimental design, whereby tablets were cleaned with antibacterial wipes containing chlorhexidine between cooking sessions. These wipes are reported to provide disinfecting abilities lasting for up to 12 hours (Badr et al., 2012; Kanayama et al., 2017; Galazzi et al., 2019; Howell et al., 2019).

In 2018, a study conducted in the USA reported that 49% of consumers used smart devices during meal preparation (Lando et al., 2018), while in our study, almost all (80%) participants regularly or often used a mobile phone during meal preparation. It is very likely that the utilisation of these devices has increased in the kitchen as cooking at home has increased during the COVID-19 pandemic, coupled with meal preparation cited as a common use for these devices (Murphy et al., 2021; Lando et al., 2018).

Previous studies indicated that the majority of participants did not engage in hand hygiene practice before or after device usage (Murgier et al., 2016; Singh et al., 2010). In the present study, a third of participants continued to prepare food after touching a smart device without washing their hands. Additionally, those reporting "proper" behaviour (washing hands) while preparing food had significantly lower bacterial loads than those reporting “improper” behaviour (continue preparing food) after touching smart devices. It is possible that the improved engagement and self-reported behaviour with smart devices may be attributable to hygiene campaigns initiating a fundamental shift in hygiene, specifically hand hygiene behaviours, promoted to mitigate the transfer of the SARS-CoV-2 virus during the COVID-19 pandemic, anchored in cross-contamination.

In clinical studies, approximately a third of participants only cleaned devices when they were visibly dirty, which agrees with figures from other studies in Kuwait and Turkey (Bayraktar et al., 2021; Heyba et al., 2015). In the present study, it is reported that the majority of females (60%) cleaned their smart devices at least weekly, whereas the majority of males (67%) cleaned their device annually or when visibly dirty. Furthermore, 59% of females reported using antibacterial products in comparison to only 18% of males. While the microbial load of smart devices (phones and tablets) did not significantly differ by gender, the microbial loads of hands significantly differed, with a higher microbial load found on male hands. Numerous studies report similar statistically significant gender differences in microbial contamination rates, citing that increased female engagement in better practices like handwashing and regular cleaning of devices was expected and found in other studies (Lando et al 2018; Jalalmanesh el al., 2017; Murgier et al., 2016; Qadi et al., 2021; Bodena at al., 2019).

Level of education also influenced engagement with a cleaning method, with higher-educated participants (70%) preferring antibacterial products in comparison to 28% of those less educated. This self-reported behaviour is strengthened by further statistical analysis reporting a higher contamination rate in tablets, coupled with the presence of a higher microbial load in phones, in participants with less than university education. In higher education participants, microbial load was likely lower because they used antimicrobial products to clean phones, which is an effective method, as previously discussed. Interestingly, other studies have found no difference between socio-demographic characteristics (Koroglu et al., 2015; Di Lodovico et al., 2018; Foong et al., 2015; Mushabati el al., 2021) and self-reported behaviours (Loyola et al., 2016; Jones et al., 2020).

To the authors’ knowledge, this is this first research that is specifically focused on ascertaining the food-safety implications in relation to the use of smart devices in the kitchen. In clinical settings, there is limited research on the influence of hands on the microbial profile of smart devices. Therefore, this experiment utilised a holistic approach, swabbing the hands, mobile phones and tablet devices of participants to determine the effect of hands on cross-contamination and re-contamination. The small sample size is a limitation of the study (n=51). A larger study correlating phone behaviour items and swab samples may enable associations between swabbing regions to be identified (hands, phone and devices), in addition to phone behaviours and risk of its contamination. Another limitation in the study design was that participants’ hands and devices were only sampled at one time point (after meal preparation). Therefore, future studies should seek to include swabbing of participants’ hands and devices at different time points (for instance, before and after meal preparation) to obtain a comprehensive view of the microbial profile and to ascertain the food-safety risk.

Focus groups

The focus group discussions provided some insights into participants’ perceptions around food safety in the domestic environment and how devices are used in the kitchen. The participants in this study reflect the literature, in that despite the kitchen being shown as a high-risk environment for bacterial contamination (Flores et al., 2013; Food Standards Agency, 2020), it is perceived as low risk (Byrd-Bredbenner et al., 2007; Food Standards Agency, 2020; Lee et al., 2017; Redmond & Griffith, 2003, 2004). This pervasive optimistic bias creates a barrier to behaviour change and is an area that needs to be counteracted.

The majority of the participants were able to identify good and poor food safety behaviours in general, including particularities of certain behaviours – for example, washing hands with and without soap. While a minority acknowledged that their behaviours may not be at the level of the actor in the ‘good behaviours’ video clip, the majority believed they were similar or better than the clip. This again is supported by the literature, which has acknowledged that consumer knowledge does not equate to the implementation of the food safety behaviours (Abbot et al., 2009; Redmond & Griffith, 2003, 2004; Wilcock et al., 2004), creating a behavioural challenge in the food safety area. Interestingly, in this study the participants recognised the influence of external factors on the level of implementation of their food safety behaviours. Time is a long-established barrier to domestic cooking (Lavelle et al., 2016; Smith et al., 2013; van der Horst et al., 2011; Wolfson et al., 2016), and this research highlights how it may also impact on food safety behaviours. Additionally, the participants identified children as a distraction in the kitchen that influences their food safety behaviours. Children have previously been highlighted as a distraction in a kitchen environment (Lavelle et al., 2019) in terms of cooking. This research adds the additional element that they may distract from food safety. The implications for children distracting parents in the kitchen are multi-fold: 1) they are increasing food safety risk in an already high risk environment; 2) it is a learning environment for children (Lavelle et al., 2016, 2019) and, if present, they are observing and potentially learning poor food safety behaviours; 3) if they are removed from the kitchen to remove the distraction, they are missing an opportunity for learning invaluable life skills (Lavelle et al., 2019). The parent-child dynamic in the kitchen needs further exploration, such as parent-child cooking interventions (Lavelle, Mooney, et al., 2023). However, consideration should be given to food safety practices in these studies. It is worth noting that while participants understood that their behaviours can vary depending on these distractions, none of the distractions were present in the cooking task, and yet there were discrepancies between their actual and reported behaviours.

With the increased consumer reliance on technology and the COVID-19 pandemic catalysing the surge of device use in the kitchen (De et al., 2020; Murphy et al., 2021), it is no surprise that participants reported use of devices during the cooking process, both actively and passively. Ease of access to these devices and their multipurpose use, such as reading/watching recipes, checking ingredient substitution and listening to music, means that continued and increased use of devices is highly likely; therefore, this is an important area to focus on. Even if the devices are used in a passive manner (such as listening to music), there is still the strong possibility that the device could be touched (for changing music), and this needs to be considered. There should be an emphasis on cleaning devices regardless of whether they are used actively or passively in the kitchen.

Participants in this study were aware that some bacteria is needed to support an individual's health and that bacteria was present on all objects. However, they also noted that there was an increased awareness around hygiene practices since the COVID-19 pandemic. This research may illustrate some level of behaviour fatigue, as the observations highlight that there were gaps in handwashing behaviours, despite the reported changes resulting from the advice given during the pandemic. Furthermore, while there was some discussion around the potential for cookbooks to harbour bacteria due to their being stored in a warm environment, a lack of cleaning and their greater surface area, there was a growing consensus that there may be a greater risk from devices due to their multi-function purposes. Devices have the potential to be used by multiple individuals as well moved around the house, increasing opportunities for cross-contamination.

The use of focus groups in the project complemented the in-kitchen studies, allowing for a greater understanding of participants' thoughts and behaviours. These discussions also helped to inform the development of the project survey. However, typical limitations of qualitative work, such as the potential impact of overbearing personalities and non-representativeness, should be borne in mind when considering the results.

Online survey

Smart device use while preparing or cooking food in domestic kitchens is common in the population, with almost 80% of participants doing so to a varying degree. To our knowledge, only one other study has examined the rates of device use while cooking, finding a rate of 49% (Lando et al., 2018). Potential explanations for this difference may be country differences (IOI versus USA) or the gap of seven years between studies, in which device usage has likely increased. The type of device used was similar (mobile phone 64% IOI versus 65% USA; tablet 9% IOI versus 13% USA).

Overall, participants had an average food safety score. Awareness of smart devices as a source of bacteria and cross-contamination was high; however, participants also ranked using devices in the kitchen as the least likely source of cross-contamination. Almost one in five participants continue preparing food immediately after touching their device, with almost one in three participants washing their hands with soap after using their device while preparing food. This compares with 60% who always wash their hands with soap before starting to prepare or cook food, and 68% who always wash their hands with soap immediately after handling raw meat, poultry or fish. Furthermore, only 10% of respondents stated that they clean their devices daily. This is similar to previous research, which found less than optimal levels of device cleaning (Bayraktar et al., 2021; Brady et al., 2011; S. Singh et al., 2010). These results suggest that participants are aware that devices are a source of bacteria but do not translate this awareness to the use of devices in the kitchen, or their behaviours. This is in line with previous research findings that, despite an awareness that devices could be contaminated with microbes, many do not engage in appropriate cleaning (Kotris et al., 2017; Olsen et al., 2021). This also compares with a previous ***safe*food** study (Safefood, 2022) on preprepared convenience foods, which found that participants had awareness of food safety which was not necessarily reflected in their behaviours. Indeed, even observation of professional food handlers (assumed to have good food safety knowledge) identified a lack of handwashing after using a phone (Štefančič & Jevšnik, 2020).

There were significant socio-demographic differences in awareness, knowledge and behaviours. Those who are older were more likely to wash their hands with soap immediately after handling raw meat, etc., use devices less while preparing or cooking food, have higher food safety knowledge, and a higher level of awareness of device-borne bacteria. Meanwhile, females were more likely than males to wash their hands with soap in relation to food preparation or cooking, use their devices more frequently while cooking or preparing food, and use an antibacterial wipe for cleaning their device.

These results were similar to the cooking activity results in the current project, where females reported greater frequency than males of cleaning devices, and doing so with antibacterial products. Gender was also predictive in the regression, with being female a predictor of a higher food safety hazard identification score. These findings could be due to women being more likely to cook than men (Taillie, 2018; Wolfson et al., 2021), and those who are younger having limited exposure to preparing and cooking meals, this due to the fact that over one in five of those aged 25-34 years old in Ireland live with their parents (Eurostat, 2020). These findings suggest that interventions or campaigns to improve awareness, knowledge and behaviours relating to food safety should focus on those who are younger and male. Given the further findings of the regression, i.e., that those with a greater awareness of bacteria on devices and who perceived themselves to have a higher susceptibility to food poisoning had a higher food safety hazard identification score, such interventions should focus on raising awareness of bacteria on devices and emphasise the likelihood of food poisoning occurring.

The online survey method allowed for the findings from the focus groups (as well as other areas of interest) to be explored at a national level. Online surveys are a cost-effective method of reaching individuals across the country. However, the potential limitations of this method include socially desirable responding and not knowing whether individuals are giving their full attention to the research. Efforts were made to minimise such limitations via the exclusion of ‘speeder’ respondents, and attention checks.

Overall, the combination of methods in the project allowed for a thorough and holistic insight into the topic.

Conclusions

- There is limited research in the area of bacterial contamination in the domestic kitchen related to smart device usage. Research is primarily focused on bacterial contamination of devices in clinical settings. However, this highlights the potential for cross-contamination in the domestic and other non-clinical settings.
- The pervasive belief that the kitchen is a low-risk environment for foodborne diseases (FBD) was found in this research.
- Across the studies, participants demonstrated that higher knowledge does not necessarily equate to better behavioural practices.
- Participants acknowledged that external factors, such as time limitation and children, could influence their food safety behaviours. However, these influences were not present when the current studies were conducted.
- For general food safety behaviours: not all participants washed their hands after touching raw chicken and eggs, and a minority of participants conducted risky food safety behaviours such as not changing or washing chopping boards between raw chicken and vegetables, and not changing or washing the knife between these tasks.
- With the continued and increased use of smart devices in the kitchen, both actively (for following recipes) and passively (for listening to music, but where they may still touch the device), the potential for cross-contamination needs to be highlighted.
- *E coli* and *Salmonella* can survive on devices for more than 24 hours; however, the cleaning of devices, with wipes (containing alcohol) can effectively remove the presence of pathogenic bacteria.
- Among the 51 participant, all hands (100%), 44 (92%) phones and 28 (55%) tablet devices were contaminated with general bacteria (TVC).
- A third (n=16, 31%) of participants' hands, four (8%) participants' phones and three (6%) participants' tablets were contaminated with

Enterobacteriaceae, with the mean (SD) microbial load of hands, tablets and phones (reported as $\log_{10}$ mean CFU/swab: 2.05 ± 1.00, 1.54 ± 0.47 and 1.40 ± 0.38 respectively). The results of this study indicated that when using these devices in the kitchen cross contamination is possible, and the use of antibacterial wipes and good food hygiene practices, including regular hand washing, should be encouraged to avoid cross contamination.

- In this study males reported a significantly higher microbial load of general bacteria on hands (mean $\log_{10}$ CFU/Swab: 3.20 ± 0.84) compared to females (mean $\log_{10}$ CFU/swab 2.74 ± 0.67).
- It was found in this study that educational level influences the contamination rate on tablets and the number of bacteria on phones relative to general bacteria (TVC) based on microbial analysis. Higher education individuals had lower levels of tablet contamination. Similarly, individuals with an education equivalent to or higher than university education had significantly lower microbial loads compared with participants with less than university education. Only half of the participants washed their hands after touching raw chicken, and only one fifth after touching raw egg washed their hands before touching devices, clearly demonstrating the potential for contamination. One third of participants continued preparing food after touching devices, illustrating the potential for cross-contamination.
- Both the survey and the focus group discussions highlighted that there was an awareness of cross-contamination with device use in the kitchen, and for the increased opportunity for cross-contamination through the use of devices by multiple people in the household and the removal of the devices from the kitchen. However, the perceived level of risk was low.
- This research has highlighted that foodborne pathogens can survive on devices for greater than 24 hours, that consumers engage in risky behaviours relating to these devices, and that they do not clean the devices frequently to counteract this risk. There is an awareness of the risk of

cross-contamination through the multi-use and mobility of the devices; however, there is a low risk perception of this.

Added value and anticipated benefits

The smart devices in the kitchen project has added value and benefits in a number of different areas, which are classified below using the impact taxonomy developed by the European Science Foundation.

Scientific impact: advances in understanding, method, theory and application

The smart devices in the kitchen project is the first to employ microbial techniques to investigate the potential food safety implications of using these devices in the domestic kitchen. Microbial analysis provided an overview of pathogenic survival on the surface of these devices, and the impact of cleaning the devices. This project is also the first study to conduct behavioural observations on smart device use during meal preparation, advancing the knowledge of consumer use of these devices in a domestic setting and their associated potential food safety implications. The method used for the observations (head video cameras) was also novel. Additionally, the project has reiterated the pervasive finding that consumers believe the domestic kitchen is low-risk for food poisoning, and has shown that this optimistic bias has translated across to smart device use, i.e., consumers believe that there is a low risk for cross-contamination.

Cultural impact: contribution to understanding of ideas and reality, values and beliefs

The smart devices in the kitchen project has gathered insights into consumers' beliefs about their behaviours and highlights potential gaps between their knowledge and behaviours. This publicly available report can increase consumer awareness on the IOI around differences in their knowledge and their behaviours, providing opportunities for consumers to implement safer behaviours. Additionally, as the culture of using devices in the kitchen continues, it highlights potential hazards that can be counteracted with earlier intervention, meaning that devices can be used in a safer manner.

Educational impact: contributing to education, training and capacity building

The smart devices in the kitchen project has identified areas where education should be provided around safe behaviours relating to general food safety behaviours, hand hygiene, device hygiene and cleaning methods. Furthermore, as there has been a decline in domestic cooking, there is a growing promotion of culinary skills and education. The use of video has been highlighted as an effective method for teaching cooking skills (Surgenor et al., 2017). The COVID-19 pandemic has led to an increase in culinary education being provided virtually. The integration of device hygiene and safety should be a key component of these interventions as they are actively promoting the use of devices in the kitchen. These culinary education programmes provide an important opportunity for promoting education around food safety and in particular device safety and hygiene.

Social impact: contributing to community welfare, quality of life, behaviour, practices and activities of people and groups

Foodborne illness is a substantial public health problem, particularly in vulnerable groups such as over 65's, children, and those who are pregnant. Device use is growing across all of these groups and they are additionally targets for culinary interventions as these are key life stages for optimising nutrition. The promotion of device hygiene is particularly important for these groups.

Technological impact: contribution to the creation of product, process and service innovations

The smart devices in the kitchen project highlights the need for device hygiene and in turn supports the need for bacterial-resistant surfaces on devices.

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Glossary of acronyms

ANOVA = Analysis of Variance

CFU=Colony Forming Units

FBD = Foodborne disease

FSA = Food Standards Agency

FSAI = Food Safety Authority of Ireland

HCW = Health Care Workers

IOI = Island of Ireland

IPC = Infection Prevention Control

ISO = International Organisation for Standard

MDRO = Multidrug Resistant Microorganisms

NI = Northern Ireland

PFGE = Pulsed-Field Gel Electrophoresis

POV = Point-of-view

PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analysis

QUB = Queen’s University Belfast

STACS = Saint Angela’s College Sligo

UK = United Kingdom

USA = United States of America

UU = Ulster University

VRBG = Violet Red Blue Glucose (agar)

WHO = World Health Organisation

Appendices

Appendix 1: In-Kitchen protocol (cooking activity protocol)

Summary

Starting Point before cooking task:

Due to the nature of the activity and to capture actual practices, participants are not told of swabbing ahead of activity, as this could influence behaviours. At the beginning of each cooking task, each participant will have the following:

- Their own personal mobile phone (unwashed if that is their normal behaviour. Taking swabs of participants' mobile phones is done to get a true representation of the microbial load of a personal device);
- A sterilised tablet at the beginning of the cooking activity to watch the recipe. (Swabs of the tablet will reflect the participants' individual behaviour during the cooking activity and aims to capture if cross-contamination occurred during the cooking activity);
- Participants are not specifically advised or instructed to take part in any food hygiene practices such as washing hands, changing utensils/chopping boards to emulate normal practices; however, they are shown in the video.

Cooking Activity Protocol

- Participants will wear video recording glasses (to record consumer behaviour) which will be used in the observational study, as direct observation of participants by researchers can cause participants to modify their behaviours as well as cause anxiety, as reported in a previous cooking experiment.
- Preparation of chicken product (tasks will be done to encourage use of smart devices during cooking activity to emulate actual behaviours in the home). The recipe will be provided on a tablet device in video format – a similar format to YouTube cooking channel videos to emulate real-life practices in the kitchen.

The recipe includes the preparation of chicken goujons and a side salad, to assess if participants follow good food safety/hygiene practices. The recipe is provided at the end of the document. Participants will be encouraged to take progress pictures by research fellows (CMK & FL) attending the activity.

- After the cooking activity, a researcher (CMK) who has experience in collecting swabs for microbial analysis will take the following swabs of each participant. Swabs are labelled for each participant and to identify/differentiate between swabbing zones. The swabs will be labelled accordingly.

There will be a total of 150 swabs - three swabs from 50 participants, including:

- x 50 – Hands
- x 50 – Mobile phones (*participants' personal mobile phones - participants are not being told about swabbing ahead of the cooking task as this will likely change behaviours, so if participants do clean their phone beforehand that would be a normal practice for that individual. Taking swabs of participants' mobile phones is done to get a true representation of the microbial load of a personal device. This has been approved by ethics*)
- x 50 – Tablet device (*The tablets belong to QUB and as these tablets are provided at the start of each cooking activity, they will have to be sterilised after swabbing, so the swabs collected reflects that individual's behaviour)*

Cooking Task Recipes

Chicken Goujons Ingredients

- 4 chicken breasts
- 2 eggs
- 50g fresh breadcrumbs
- 50g of porridge oats
- 25g of plain flour

Chicken Goujons Method

1. Pre-heat oven to 180^{o}C
2. Cut the chicken into strips
3. Beat the eggs into a bowl
4. Mix the breadcrumbs and porridge oats together and then scatter on a plate
5. Place flour on a plate
6. Roll the chicken strips in the flour
7. Dip the chicken strips into the beaten egg
8. Roll the chicken strips in the breadcrumb mixture until they are fully coated
9. Cook in the oven for 15-20 minutes until cooked through

Side Salad Ingredients

- Lettuce
- Tomato
- Onion (spring or red onion)

Side Salad Method

- Wash the vegetables
- Chop the vegetables
- Combine vegetables and toss together

Pre-Task Survey (In-Kitchen Study)

Part 1

Participant identification number for kitchen task: __ __

Q1. How frequently are you responsible for the main meal preparation (including purchasing takeaway, cooking from scratch, using convenience meals) for yourself or your household?

Almost every day (5-7 days a week)	
2-4 times a week	
Once a week	
Two to three times a month	
Once a month	
Every 2-3 months	
Once or twice a year	
Never	

Q2. Do you use smart devices (e.g., tablets, mobile phone, laptop) when cooking?

Always	
Very Often	
Sometimes	
Rarely	

Never	

Q3. What is your age?

Q4: Do you or does anyone in your household work in any of the following occupations? Select all that apply.

Teaching		
Banking/finance		
Science		
Farmers and growers/manufacturers/wholesale/retail of food and/or drinks		
Food safety		
Food processing or manufacturing		
Home Economics		
None of these		

Q5. Are you/do you identify as …?

Male	
Female	

Non-binary conforming	
Other (please specify):	

Q6. Please select the option most like the area you live in:

Village/countryside (less than 2,250 people)	
Small town (less than 10,000 people)	
Town (greater than 10,000 people)	
City (greater than 75,000 people)	

Q7. What is the highest level of education you have attained?

None	
Primary school	
Secondary school to age 15/16 or Junior Cycle Certificate, GCSE or O-Level	
Secondary school to age 17/18 or Leaving Certificate or A-Level, HNC	
Additional training (e.g. NVQ, BTEC, FETAC, FAS, other)	

University undergraduate / nursing qualification	
University postgraduate	

Q8. What is your current occupation status?

Full-time paid work (30+ hours per week)	
Part-time paid work (8-29 hours per week)	
Part-time paid work (under 8 hours per week)	
Retired	
At school	
In full-time higher education	
Unemployed (seeking work)	
Unemployed (not seeking work)	
Full-time homemaker	

Q9. Are you currently on any of the following diets?

Diabetic diet	
Cholesterol lowering diet	
Vegetarian diet	
Vegan diet	

Slimming diet	
None of the above	

<u>Pre-Task Survey (Part 2)</u>

Q1. How many days in an average week do you or someone in your household cook dinner?

Q2. Please look at the following list. If you have any of the skills, please say how good you are at it on a scale of 1-7, where 1 is very poor, 7 very good. If you don't have a particular skill, tick 'Never/rarely do it':

	Never/ rarely do it	**1 Very Poor**	**2**	**3**	**4**	**5**	**6**	**7 Very Good**
1.Chop, mix and stir foods, e.g., chopping vegetables, dicing an onion, cubing meat, mixing and stirring food together in a pot/bowl								
2. Blend foods to make them smooth, like soups or sauces (using a whisk/blender/food processor, etc.)								

	Never/ rarely do it	1 Very Poor	2	3	4	5	6	7 Very Good
3. Steam food (where the food doesn't touch the water but gets cooked by the steam)								
4. Boil or simmer food (cooking it in a pan of hot, boiling/bubbling water)								
5. Stew food (cooking it for a long time (usually more than an hour) in a liquid or sauce at a medium heat, not boiling) e.g., beef stew								
6. Roast/bake food in the oven, for example raw meat/chicken, fish, vegetables, etc.								
7. Fry/stir-fry food in a frying pan/wok with oil or fat using the hob/gas rings/hot plates								

	Never/ rarely do it	1 Very Poor	2	3	4	5	6	7 Very Good
8. Microwave food (not drinks/liquid) including heating ready-meals								
9. Bake goods such as cakes, buns, cupcakes, scones, bread, etc., using basic/raw ingredients or packet mixes								
10. Peel and chop vegetables (including potatoes, carrots, onions, broccoli)								
11. Prepare and cook raw meat/poultry								
12. Prepare and cook raw fish								
13. Make sauces and gravy from scratch (no ready-made jars, pastes or granules)								
14. Use herbs and spices to flavour dishes								

Q3. Now that you have been told you will be cooking goujons from scratch, how **confident** do you feel at this moment about producing a safe, edible meal?

(Not at all confident) 1	2	3	4	5	6	7 (Extremely confident)

4. At this moment, how **enjoyable** do you think you will find cooking this meal?

(Not at all enjoyable) 1	2	3	4	5	6	7 (Extremely enjoyable)

5. At this moment, how **difficult** do you think it will be to cook this meal?

(Not at all difficult) 1	2	3	4	5	6	7 (Extremely difficult)

6. At this moment, do you think you would **cook this meal from scratch at home**?

(Not at all likely) 1	2	3	4	5	6	7 (Extremely likely)

Post-Task Survey (In-Kitchen Study)

Participant identification number for kitchen task: __ __

1. At this moment, how **confident** do you feel that you have produced a safe, edible meal?

(Not at all confident) 1	2	3	4	5	6	7 (Extremely confident)

2. At this moment, how **enjoyable** would you say cooking this meal was?

(Not at all enjoyable) 1	2	3	4	5	6	7 (Extremely enjoyable)

3. At this moment, how **difficult** would you say cooking this meal was?

(Not at all difficult) 1	2	3	4	5	6	7 (Extremely difficult)

4. At this moment, do you think you would cook this meal from scratch at home?

(Not at all likely) 1	2	3	4	5	6	7 (Extremely likely)

5. At this moment, do you think you have the necessary equipment to cook this meal at home (including pots/utensils/serving dishes, etc.)?

(Not at all likely) 1	2	3	4	5	6	7 (Extremely likely)

At Home

Q6. How often do you wash your hands with soap before starting to prepare or cook food?

Always	
Very often	
Sometimes	
Rarely	
Never	

Q7. How often do you wash your hands with soap immediately after handling raw meat, poultry or fish?

Always	
Very often	
Sometimes	

Rarely	
Never	

Q8. Do you ever use a telephone, mobile phone, smart phone, tablet, laptop or computer while preparing food (for example, to look up recipes or take a call)?

Yes	
No	

Q9. Which device do you handle **most** often while preparing food?

Telephone	
Mobile phone	
Smart phone	
Tablet (e.g., iPad)	
Laptop	
Computer	
Other (please specify):	

Q10. After you touch your most frequently used device while preparing food, what do you usually do next?

Continue preparing the food	
Wipe your hands (e.g., on a cloth or towel)	
Rinse your hands with water	
Wash your hands with soap	
Other (please specify):	

Your Opinions

Q11. On a scale of 1 to 5, where 1 means very unlikely and 5 means extremely likely, how likely, in general, do you think you are to get food poisoning?

1 'Extremely unlikely'	2	3	4	5 'Extremely likely'

Q12. On a scale of 1 to 5, where 1 means very unlikely and 5 means extremely likely, how likely do you think you are to get food poisoning from food you have fully prepared from basic ingredients in your home?

1 'Extremely unlikely'	2	3	4	5 'Extremely likely'

Q13. On a scale of 1 to 5 where 1 indicates that you strongly disagree and 5 indicates that you strongly agree, please say how much you disagree or agree with each of the following statements?

	Strongly Disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly Agree**
If I don’t follow ‘use by’ instructions I will be more likely to develop food poisoning					
If I don't follow 'best before' instructions, I will be more likely to develop food poisoning					
If I don’t use leftovers within 2-3 days, I will be more likely to develop food poisoning					
If I don’t follow the current advice for defrosting food, I will be more likely to develop food poisoning					
If I don’t maintain my fridge temperature within 0-5°C, I will be more likely to develop food poisoning					
If I don't clean my oven regularly (at least once a month), I will be more likely to					

develop food poisoning					
If I don’t clean my fridge regularly (at least once a month), I will be more likely to develop food poisoning					
If I don’t store raw and cooked foods separately, I will be more likely to develop food poisoning					

Q14. On a scale of 1 to 5, where 1 indicates that you strongly disagree and 5 indicates that you strongly agree, please say how much you disagree or agree with each of the following statements?

	Strongly Disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly Agree**
Food poisoning could be serious for me and my household					
Food poisoning could affect my health/the health of my household in the long-term					
Food poisoning can result in hospitalisation					
Food poisoning can be fatal					
Developing food poisoning would **NOT**					

have a major effect on my life					
Developing food poisoning would have serious financial consequences for my household					

Q15. When you have cooked chicken that will be served cold tomorrow, which one of the following should you do?

Put it in the refrigerator while still hot	
Cover it and put it in a cool place for 1-2 hours and then put it in the refrigerator	
Turn off the oven and leave the chicken there for 1-2 hours and then put it in the refrigerator	
Cover it, leave it to cool overnight on the kitchen counter and the put in the refrigerator	

Q16. How often should the inside of a refrigerator be cleaned?

Once a week	
Once a fortnight	
Every month	
Every 3 months	
Every 6 months	
Only if there is a spill	

Other (Please specify):	

Q17. What are the safest two ways to defrost raw meat?

In the sink covered in water	
On the top/bottom shelf of refrigerator	
On the kitchen counter	
In a microwave oven immediately before cooking	
Don’t know	

Q18. Within what timeframe should you cook raw meat/cooked foods after they have been defrosted (thawed)?

Within 24 hours	
Within 48 hours	
Within 72 hours	
Within 96 hours (four days)	
Don’t know	

Q19. Where is the safest place to store raw meat in your refrigerator?

Top shelf	
Middle shelves	

Bottom shelf	
Where there is space	
Don’t know	

Q20. Within what timeframe should you eat refrigerated food that was left over from a cooked meal?

Within 24 hours	
Within 48 hours	
Within 72 hours	
Within 96 hours (four days)	
Don’t know	

Q21. Please select up to two correct responses to the following statement:
‘After the ‘use by’ date a refrigerated food is …?’

Still safe to eat if it looks and smells OK	
No longer safe to eat and should always be discarded	
Safe to eat if it was frozen before the ‘use by’ date and used within 24 hours of being thawed	
Safe to eat if it was frozen before the ‘use by’ date and used within 48 hours of being thawed	

Q22. Please select one correct response to the following statement:

'After the 'best before' date a refrigerated food is …?'

Still safe to eat but it may begin to lose its flavour and texture	
No longer safe to eat and should always be discarded	

Q23. A perishable refrigerated food should be always be thrown away if it is left at room temperature for longer than …?

30 minutes	
1 hour	
2 hours	
3 hours	
Don't know	

Q24. After a food with a 'use by' date has been opened, which two of the following are most important in determining if the food is safe to eat?

'Use by' date	
Look and smell of the food	
Storage instructions on the label, e.g., the number of days to be consumed once open	
'Display until' date	

Don’t know	

Q25. How frequently do you clean your mobile phone?

Never	
Only if it is visibly dirty/something spills on it	
Once or twice a year	
Every 2-3 months	
Once a month	
Two to three times a month	
Once a week	
2-4 times a week	
Almost every day (5-7 days a week)	

Q26. If you clean your mobile phone, how do you clean it?

____

Q27. In general, would you say your health is …?

Excellent	
Very good	

Good	
Fair	
Poor	

Q28. What is your marital status?

Married	
Single (never married)	
Widowed	
Divorced	
Separated	
Living with partner	

Q29. How many children aged under 16 live in your household?

Q30. Including you, how many adults aged over 16 live in your household?

Q31. What is your current living situation?

Living with parents	
Living with parents and siblings	
Living with partner	

Living with partner and child(ren)	
Living with child(ren)	
Living with partner and parents (with or without siblings and/or child(ren))	
Living with friends	
Living with roommates I didn’t know before moving in	
Living on my own	

Q32. Are you responsible for the food and grocery shopping in your household?

Yes – I do most of the food and grocery shopping	
Yes – I am jointly responsible/share responsibility with others	
No – someone else does it	

Q33. How many people (including yourself and other adults and children) do you typically prepare/cook a main meal for?

Mostly for myself	
Mostly for 2 people	
Mostly for 3-4 people	

Mostly for 5-6 people	
Mostly for more than 6 people	

Q34. What is the total annual income of your household from all sources before any tax and National Insurance contributions? If you share your household with individuals unrelated to you (not a family member or your partner), please count only your personal income.

If anyone in your household is currently furloughed or receiving support from a Coronavirus Job Retention Scheme, please select your normal household income.

Include all income from employment and benefits. If you are not sure of your household income, please estimate.

Under £10,000 per annum	
£10,001 - £20,000 per annum	
£20,001 - £30,000 per annum	
£30,001 - £40,000 per annum	
£40,001 - £50,000 per annum	
£50,001 - £60,000 per annum	
£60,001 - £70,000 per annum	
£70,001 - £80,000 per annum	
£80,001 - £90,000 per annum	
£90,001 - £100,000 per annum	
£100,001 - £150,000 per annum	

£150,001 - £200,000 per annum	
£200,001 - £500,000 per annum	
£500,001 or more	
Prefer not to answer	

Appendix 2: In-Kitchen study (observation codebook)

Codebook for video footage relating to smart devices focused on elements related to cross-contamination

Measure: Tally chart (give one point when a participant is observed engaging in a behaviour - therefore a higher score is equivalent to better behaviours)

The structured the tally system was separated into three categories:

- General cross-contamination behaviours (*minimum score = 0, maximum score = 13*)
- Additional cross-contamination behaviours (additional score)
    - ***This score will be general behaviour score + additional score***
- Smart device (scored separately - based on frequency of touching device and behaviour following).

I have provided a table for cross-contamination behaviours:

- ➔ Red Arrow: Considered unsatisfactory behaviour/ poor hygiene practice: 0
- ➔ Orange Arrow: Considered somewhat satisfactory behaviour: 0.5
- ➔ Green Arrow: Considered satisfactory behaviour/ good hygiene practice: 1

Behaviour	Scoring (on a tally basis)	Score
• Washing hands before starting ➔ No hand washing ➔ Quick rinse under water no soap (<15 seconds) ➔ Quick rinse under water with soap (<15 seconds) ➔ Wash under water, no soap (>15 seconds) ➔ Wash hands under water with soap (>15secs)	➔ = 0 tally (**red arrow**) ➔ = 0.5 tally (where participants do behaviours highlighted by **orange arrow**) ➔ = 1 tally (where participants do either of the behaviours highlighted by the **green arrow**)	1
• Drying hands ➔ Drying hands on yourself (using your own clothes) ➔ Drying hands using tea towel provided ➔ Drying hands using kitchen hand towel	➔ = 0 tally ➔ = 0.5 tally ➔ = 1 tally	1
• Moving chicken from plate to chopping board ➔ Use two hands to touch chicken ➔ Using one hand only to touch chicken breast (or using a utensil) ➔	➔ = 0 tally ➔ = 1 tally	1
• Chopping chicken for goujons ➔ Use two hands to touch chicken ➔ Using one hand only to touch chicken breast (or using a utensil)	➔ = 0 tally ➔ = 1 tally	1
• Washing hands before starting ➔ No hand washing ➔ Quick rinse under water, no soap (<15 seconds) ➔ Quick rinse under water with soap (<15 seconds)	➔ = 0 tally ➔ = 0.5 tally ➔ = 1 tally	1

Behaviour	Scoring (on a tally basis)	Score
➔ Wash under water, no soap (>15 seconds) ➔ Wash hands under water with soap (>15secs)		
• Coating chicken strips with flour, eggs and oats ➔ Use two hands to touch chicken ➔ Using one hand only to touch chicken breast (or using a utensil)	➔ = 0 tally ➔ = 1 tally	1
• Washing hands after preparing chicken goujons ➔ No hand washing ➔ Quick rinse under water, no soap (<15 seconds) ➔ Quick rinse under water with soap (<15 seconds) ➔ Wash under water, no soap (>15 seconds) ➔ Wash under water with soap (>15 seconds)	➔ = 0 tally ➔ = 0.5 tally ➔ = 1 tally	1
• Washing hands after cracking eggs ➔ No hand washing ➔ Quick rinse under water, no soap (<15 seconds) ➔ Quick rinse under water with soap (<15 seconds) ➔ Wash under water, no soap (>15 seconds) ➔ Wash under water with soap (>15 seconds)	➔ = 0 tally ➔ = 0.5 tally ➔ = 1 tally	1
• Washing hands before touching tablet, if touched chicken ➔ No hand washing ➔ Quick rinse under water, no soap (<15 seconds) ➔ Quick rinse under water with soap (<15 seconds) ➔ Wash under water, no soap (>15 seconds)	➔ = 0 tally ➔ = 0.5 tally ➔ = 1 tally	1

Behaviour	Scoring (on a tally basis)	Score
→ Wash under water with soap (>15 seconds)		
• Washing hands before touching tablet, if touched egg → No hand washing → Quick rinse under water, no soap (<15 seconds) → Quick rinse under water with soap (<15 seconds) → Wash under water, no soap (>15 seconds) → Wash under water with soap (>15 seconds)	→ = 0 tally → = 0.5 tally → = 1 tally	1
• Changing chopping board and/or washing chopping board before cutting veg → No changing or washing board → Washing board with just water (no soap) → Washing board with soap and water → Changing board	→ = 0 tally → = 0.5 tally → = 1 tally	1
• Changing knife and/or washing chopping board before cutting veg → No changing or washing knife → Washing knife with just water (no soap) → Washing knife with soap and water → Changing knife	→ = 0 tally → = 0.5 tally → = 1 tally	1
Total for general contamination behaviours (Max score)		***13***
The next section is for 'tablet use' behaviours related to cross-contamination.	This will be tallied separately from the main cross-contamination behaviours and additional behaviours score. The reason for this is the ***frequency*** with which participants touch their device. Participants behaviours will be tallied in relation to each time they touch the device.	

Behaviour	**Scoring (on a tally basis)**	**Score**
• Washing hands ***immediately before*** touching **tablet** (based on frequency – it can be many times) → No hand washing → Quick rinse under water, no soap (<15 seconds) → Quick rinse under water with soap (<15 seconds) → Wash under water, no soap (>15 seconds) → Wash under water with soap (>15 seconds)	→ = 0 tally → = 0.5 tally → = 1 tally	1 (based on frequency, can be an infinite no. of times)
• Washing hands ***after*** touching tablet (based on frequency – it can be many times) → No hand washing → Quick rinse under water, no soap (<15 seconds) → Quick rinse under water with soap (<15 seconds) → Wash under water, no soap (>15 seconds) → Wash under water with soap (>15 seconds)	→ = 0 tally → = 0.5 tally → = 1 tally	1 (based on frequency, can be many times)
• Washing hands ***immediately before*** touching ***phones (if used)*** (based on frequency – it can be many times) → No hand washing → Quick rinse under water, no soap (<15 seconds) → Quick rinse under water with soap (<15 seconds) → Wash under water, no soap (>15 seconds) → Wash under water with soap (>15 seconds)	→ = 0 tally → = 0.5 tally → = 1 tally	1 (based on frequency, can be many times)

Behaviour	Scoring (on a tally basis)	Score
• Washing hands ***after*** touching ***phones (if used)*** (based on frequency – it can be many times) → No hand washing → Quick rinse under water, no soap (<15 seconds) → Quick rinse under water with soap (<15 seconds) → Wash under water, no soap (>15 seconds) → Wash under water with soap (>15 seconds)	→ = 0 tally → = 0.5 tally → = 1 tally	1 (based on frequency, can be many times)
The next section is for frequency of ***cleaning*** the tablet	This will be tallied separately from the main cross-contamination behaviours and additional behaviours score. The reason for this is the frequency in which participants touch their device. Participants behaviours will be tallies each time they touch the device. ***In addition only be coding if participants cleaned their device.***	

Behaviour	Scoring (on a tally basis)	Score
Why reason? Visibly dirty **"other"**	Frequency tally:	
Method of cleaning ➔ Unclean teacloths or tea towel ➔ Unused teacloth/ tea towel ➔ Wiped with kitchen roll ➔ Antibacterial spray/ antibacterial wipe "other" write down	➔ = 0 tally ➔ = 0.5 tally ➔ = 1 tally	

Observation: Smart device behaviours

Participant ID: _______

Score:______

The next section is for 'tablet use' behaviours related to cross-contamination.

The next section is for 'tablet use' behaviours related to cross-contamination.	**Frequency touched**			
	Tally (1 Tally = 0)	Tally (1 Tally = 0.5)	Tally (1 Tally = 1)	Score (total)
• Washing hands ***immediately before*** touching ***tablets***				
• Washing hands ***after*** touching ***tablets***				
The next section is for 'phone use' behaviours related to cross contamination.	**Frequency touched**			
	Tally (1 Tally = 0)	Tally (1 Tally = 0.5)	Tally (1 Tally = 1)	Score (total)
• Washing hands ***immediately before*** touching ***phones (if used)***				
• Washing hands ***after*** touching ***phones (if used***) (based on				

frequency – it can be an infinite number of times)				

This will be tallied separately from the main cross-contamination behaviours and additional behaviours score. The reason for this is the frequency in which participants touch their device.

I will be able to tally their behaviours to each time they touch the device.

Appendix 3: In-Kitchen research (focus group topic guide)

Topic	**Questions**
Introduction and ice-breaker	• *Introduction to discussion, reminder of use of voice recorders and verbal consent* • How did you find that whole cooking experience?
Using devices while cooking in general	• Would you usually use devices while cooking? • How do you (or why don't you often) use these devices? • Is there anything that would make you use them more?
Vignettes (good behaviours/poor behaviours – shown in random to groups)	*Clip 1* • What are your first impressions of the clip? • What do you think about the person's behaviours? • Do you think that level of cleaning is needed? • Approximately, how many times do you think the person touched their tablet? *Clip 2* • What are your first impressions of that clip? • What do you think about the person's behaviours? • Do you think that level of cleaning is needed? • Approximately, how many times do you think that person touched their tablet? • Thinking about both those clips, what are the biggest differences you noticed? • Which person behaves more like you? How come?

Topic	**Questions**
	• Person 1 touched their tablet a few times, do you think it matters?
Food safety risks of devices	• In clip X, the person doesn't wash their hands after touching their device, what do you think about this? • Is there anything else they should do after touching the device? What are your thoughts on that? • If I told you that bacteria has been shown to last on inanimate objects such as door handles for up to months, would that change (make your opinions stronger) your opinion? In what way? • Do you believe there is a high risk of bacteria transferring from the food to your hands and devices, and vice versa? How do you feel about this? • How does this make you feel about the risk of food poisoning in your home? • Do you think using devices in the kitchen is any more risky than using traditional methods like a cookbook? How come? • Seeing the clips today and hearing about potential for bacteria transference, would any of you change your behaviours? In what way?
Interview close	*Summarise and clarify key points from the discussion.* • Is there anything else you would like to add about cooking and using smart devices that you don't think we have covered? *Thank participants and close*

Appendix 4: Consumer survey

Q1. What is your age? *(under 18/over 80 - close)*

Q2: Do you, or does anyone in your household, work in any of the following occupations? Select all that apply.

Teaching		
Banking/finance		
Farmers and growers/manufacturers/wholesale/retail of food and/or drinks		
Food safety		*close*
Food processing or manufacturing		*close*
None of these		

Q3. How frequently are you responsible for the main meal preparation (including purchasing takeaway, cooking from scratch, using convenience meals) for yourself or your household?

Never	*Close*
Once or twice a year	

Every 2-3 months	
Once a month	
Two to three times a month	
Once a week	
2-4 times a week	
Every day or almost every day (5-7 times a week)	

Q4. How frequently do you use a smart device (e.g., a tablet, mobile, laptop) while cooking or preparing a meal?

Never	
Once or twice a year	
Every 2-3 months	
Once a month	
Two to three times a month	
Once a week	
2-4 times a week	
Every day or almost every day (5-7 days a week)	

Q5. Please look at the following list. If you **utilise the skill,** please **say how good you are at it** on a scale of 1-7 where 1 is very poor, 7 very good. If you don't utilise a skill, tick 'Never/rarely do it':

	Never/ rarely do it	**1 Very Poor**	**2**	**3**	**4**	**5**	**6**	**7 Very Good**
1.Chop, mix and stir foods, e.g., chopping vegetables, dicing an onion, cubing meat, mixing and stirring food together in a pot/bowl								
2. Blend foods to make them smooth, like soups or sauces (using a whisk/blender/food processor, etc.)								
3. Steam food (where the food doesn't touch the water but gets cooked by the steam)								
4. Boil or simmer food (cooking it in a pan of hot, boiling/bubbling water)								

	Never/ rarely do it	1 Very Poor	2	3	4	5	6	7 Very Good
5. Stew food (cooking it for a long time (usually more than an hour) in a liquid or sauce at a medium heat, not boiling) e.g., beef stew								
6. Roast/bake food in the oven, for example, raw meat/chicken, fish, vegetables, etc.								
7. Fry/stir-fry food in a frying pan/wok with oil or fat using the hob/gas rings/hot plates								
8. Microwave food (not drinks/liquid) including heating ready-meals								
9. Bake goods such as cakes, buns, cupcakes, scones, bread, etc., using basic/raw ingredients or packet mixes								

	Never/ rarely do it	1 Very Poor	2	3	4	5	6	7 Very Good
10. Peel and chop vegetables (including potatoes, carrots, onions, broccoli)								
11. Prepare and cook raw meat/poultry								
12. Prepare and cook raw fish								
13. Make sauces and gravy from scratch (no ready-made jars, pastes or granules)								
14. Use herbs and spices to flavour dishes								

INSTRUCTIONS TO PARTICIPANTS: YOU WILL NOW BE SHOWN TWO VIDEO CLIPS OF MEAL PREPARATION. PLEASE CONSIDER EACH CLIP **CAREFULLY** AND ANSWER THE QUESTIONS THAT FOLLOW BASED ON WHAT YOU SAW IN THAT CLIP.

YOU WILL HAVE TO OPPORTUNITY TO REPLAY THE VIDEO CLIP A SECOND TIME.

****CLIP ONE****

Q6: Please indicate the number of times you watched the video.

Once	
Twice	

Q7. From the video clip shown, please select as many **food safety problems** that you spotted

Tied hair up before beginning	
Hair loose	
Washed hands before beginning	
Did not wash hands before beginning	
Did not wash hands with soap	
Dried hands on tea towel	
Did not remove jewellery	
Washed chicken breast	
Shook chicken after washing	
Touched mobile phone, without washing hands before	
Touched mobile phone, without washing hands after	
Sneezed over food	

Sneezed over food and did not wash hands after	
Sneezed over food and did not wash hands with soap after	
Washed hands after touching chicken	
Used the same knife for cutting chicken and vegetables	
Used the same chopping board for cutting chicken and vegetables	
Did not wash hands after touching chicken	
Washed hands after touching chicken but did not use soap	
Used different chopping boards for chicken and vegetables	
Touched the chicken chopping board after washing hands	
Washed hands after touching tablet	
Touched tablet without washing hands before	
Touched tablet without washing hands after	
Put recipe on chicken chopping board	
Put tablet on chicken chopping board	

****CLIP TWO****

Q8: Please indicate the number of times you watched the video.

Once	
Twice	

Q9. From the video clip shown, please select as many **food safety problems** that you spotted

Tied hair up before beginning	
Hair loose	
Washed hands before beginning	
Did not wash hands before beginning	
Did not wash hands with soap	
Dried hands-on tea towel	
Did not remove jewellery	
Washed chicken breast	
Shook chicken after washing	
Touched mobile phone without washing hands before	
Touched mobile phone without washing hands after	

Sneezed over food	
Sneezed over food and did not wash hands after	
Sneezed over food and did not wash hands with soap after	
Washed hands after touching chicken	
Used the same knife for cutting chicken and vegetables	
Used the same chopping board for cutting chicken and vegetables	
Did not wash hands after touching chicken	
Washed hands after touching chicken but did not use soap	
Used different chopping boards for chicken and vegetables	
Touched the chicken chopping board after washing hands	
Washed hands after touching tablet	
Touched tablet without washing hands before	
Touched tablet without washing hands after	
Put recipe on chicken chopping board	

Put tablet on chicken chopping board	

Q10. On a scale of 1 to 5, where 1 indicates that you strongly disagree and 5 indicates that you strongly agree, please say how much you disagree or agree with each of the following statements?

	Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
If I don't follow 'use by' instructions I will be more likely to develop food poisoning					
If I don't use leftovers within 2-3 days, I will be more likely to develop food poisoning					
If I don't follow the current advice for defrosting food, I will be more likely to develop food poisoning					
If I don't maintain my fridge temperature within 0-5°C I will be more likely to develop food poisoning					
If I don't clean my fridge regularly (at least once a month) I will be more likely to develop food poisoning					
If I don't store raw and cooked foods separately, I will be more likely to develop food poisoning					
I am more likely to get food poisoning from a meal prepared outside the home, e.g., from a takeaway or restaurant					

Q11. On a scale of 1 to 5, where 1 indicates that you strongly disagree and 5 indicates that you strongly agree, please say how much you disagree or agree with each of the following statements?

	Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
Food poisoning could be serious for me and my household					
Food poisoning could affect my health/the health of my household in the long-term					
Food poisoning can result in hospitalisation					
Food poisoning can be fatal					
Developing food poisoning would **NOT** have a major effect on my life					
Developing food poisoning would have serious financial consequences for my household					

Q12. How often do you wash your hands with soap before starting to prepare or cook food?

Never	
Rarely	
Sometimes	
Very Often	

Always	

Q13. How often do you wash your hands with soap immediately after handling raw meat, poultry or fish?

Never	
Rarely	
Sometimes	
Very often	
Always	

REMINDER: The following questions are in relation to smart device usage in the kitchen, i.e., smart phone, tablet, laptop devices

Q14. Do you ever use a telephone, mobile phone, smart phone, tablet, laptop or computer while preparing food (for example to look up recipes or take a call)?

Never	*If "never" skip to Q15*
Rarely	
Sometimes	
Very Often	
Always	

Q15. Generally, which device do you handle **most** often while preparing food?

Telephone	
Mobile phone	
Smart phone	
Tablet (e.g., iPad)	
Laptop	
Computer	
Other (please specify):	

Q16. After you touch your most frequently used device while preparing food, what do you usually do next?

Continue preparing the food	
Wipe your hands (e.g., on a cloth or towel)	
Rinse your hands with water	
Wash your hands with soap	
Other (please specify):	

Q17. How frequently do you clean your mobile phone/tablet device?

Never	

Only if it is visibly dirty/something spills on it	
Once or twice a year	
Every 2-3 months	
Once a month	
Two to three times a month	
Once a week	
2-4 times a week	
Every day or almost every day (5-7 days a week)	

Q18. If you clean your mobile phone, how do you clean it?

Damp cloth	
Wipe (i.e., lens wipe, baby wipe, pc wipe)	
Antibacterial Wipe	
Tissue	
Warm water and soap	
None of the above <specify other>	

Q19. How often do you share your phone with other people (i.e., family member, children, friends)?

Never	
Rarely	
Sometimes	
Very often	
Always	

Q20. Please select ‘yes‘ or ‘no’, for the following statements

	Yes	***No***

Electronic devices harbour bacteria (that could make you sick)		
Phones/tablets can be a source of cross-contamination in the kitchen		
General cleaning of smart devices can reduce bacteria		

Definition: *Cross-contamination is the process by which bacteria and other microorganisms are unintentionally transferred from one person, place or object to another with harmful effect. Common controls for cross-contamination include effective cleaning and sanitation of individuals and the environment, in addition to correct storage of food products, including the separation of raw and ready-to-eat foods.*

Q21. Please list the following items you consider as a likely source/cause of cross-contamination in the kitchen (1 = most likely and 9 = least likely)

Unwashed hands before preparing food	
Unwashed hands after using the bathroom/ touching pet	

Using the same utensils for raw meat and cooked food without washing in between	
Using the same chopping board to prepare raw meat and vegetables without washing in between	
Washing raw meat, i.e., chicken	
Storing raw and cooked/ready to eat food together	
Door handles	
Using electronic devices in the kitchen (phones/tablets)	
Using unwashed dishcloths and sponges repeatedly	

Q22: In general, would you say your health is …?

Excellent	
Very good	
Good	
Fair	
Poor	

Q23: On a scale of 1 to 7, 1 being strongly disagree and 7 being strongly agree, please rate your agreement with the following statements:

	1 – Strongly disagree	**2**	**3**	**4**	**5**	**6**	**7 – Strongly agree**
1. The healthiness of food has little impact on my food choices.							
2. I am very particular about the healthiness of food I eat.							
3. I eat what I like and I do not worry much about the healthiness of food.							
4. It is important for me that my diet is low in fat.							
5. I always follow a healthy and balanced diet.							
6. It is important for me that my daily diet contains a lot of vitamins and minerals.							
7. The healthiness of snacks makes no difference to me.							

	1 – Strongly disagree	2	3	4	5	6	7 – Strongly agree
8. I do not avoid foods, even if they may raise my cholesterol.							

Q24. Please choose **one** item which best matches how you typically prepare or cook your meals.

Buy it ready-made and reheat it	
Use mostly pre-prepared ingredients and I assemble the dish	
Use mostly pre-prepared ingredients and some fresh, basic or raw ingredients	
Use mostly fresh, basic or raw ingredients and some pre-prepared ingredients	
Use only fresh, basic or raw ingredients	
I do something else not listed here	

Q25: Which of the following are high risk in terms of food poisoning risk? Select all that apply.

Raw meat/poultry	
Milk	
Cooked meats	
Fruit and vegetables	
Yogurt	
Fruit juice	
Ready-to-eat salads	
Cheese	
Leftover rice	
Ready meals	
Smoked fish	
None of the above	

Q26: After cooking a chicken that will be served cold tomorrow, which one of the following should you do?

Put it in the refrigerator while still hot	
Cover it and put it in a cool place for 1-2 hours and then put it in the refrigerator	
Turn off the oven and leave the chicken there for 1-2 hours and then put it in the refrigerator	

Cover it, leave it to cool overnight on the kitchen counter and then put in the refrigerator	

Q27: At a minimum, how often should the inside of a refrigerator be cleaned?

Once a week	
Once a fortnight	
Every month	
Every 3 months	
Every 6 months	
Only if there is a spill	
Other (please specify):	

Q28: What are the safest two ways to defrost raw meat?

In the sink covered in water	
On the top/bottom shelf of refrigerator	
On the kitchen counter	
In a microwave oven immediately before cooking	
Don’t know	

Q29: When raw meat or cooked foods have been defrosted (thawed), within how long should they be cooked to be considered safe?

Within 24 hours	
Within 48 hours	
Within 72 hours	
Within 96 hours (four days)	
Don’t know	

Q30: Where is the safest place to store raw meat in your refrigerator?

Top shelf	
Middle shelves	
Bottom shelf	
Where there is space	
Don’t know	

Q31: What is the maximum amount of time that refrigerated food that was left over from a cooked meal can be eaten for it to be considered safe?

Within 24 hours	
Within 48 hours	

Within 72 hours	
Within 96 hours (four days)	
Don’t know	

Q32: Please select **<u>up to two</u>** correct responses to the following statement:

‘After the ‘use by’ date a refrigerated food is …?’

Still safe to eat if it looks and smells OK	
No longer safe to eat and should always be discarded	
Safe to eat if it was frozen before the ‘use by’ date and used within 24 hours of being thawed	
Safe to eat if it was frozen before the ‘use by’ date and used within 48 hours of being thawed	

Q33: Please select one correct response to the following statement:

After the ‘best before’ date a refrigerated food is …?’

Still safe to eat but it may begin to lose its flavour and texture	
No longer safe to eat and should always be discarded	

Q34: A perishable refrigerated food should be always be thrown away if it is left at room temperature for longer than …?

30 minutes	
1 hour	
2 hours	
3 hours	
Don’t know	

Q35: After a food with a ‘use by’ date has been opened, which two of the following are most important in determining if the food is safe to eat?

‘Use by’ date	
Look and smell of the food	
Storage instructions on the label, e.g., number of days to be consumed once open	

‘Display until’ date	
Don’t know	

Q36. Are you/do you identify as?

Male	
Female	
Non-binary conforming	
Other (please specify):	

Q37: What is your marital status?

Married	
Single (never married)	
Widowed	
Divorced	
Separated	
Living with partner	

Q38: What is your current living situation?

Living with parents	

Living with parents and siblings	
Living with partner	
Living with partner and child(ren)	
Living with friends	
Living with roommates I didn't know before moving in	
Living on my own	*Skip to Q41*

Q39: How many children aged under 16 live in your household?

Q40: Including you, how many adults aged over 16 live in your household?

Q41: Are you responsible for the food and grocery shopping in your household?

Yes – I do most of the food and grocery shopping	

Yes – I am jointly responsible/share responsibility with others	
No – someone else does it	

Q42: What is the highest level of education you have attained?

None	
Primary school	
Secondary school to age 15/16 or Junior Cycle Certificate, GCSE or O-Level	
Secondary school to age 17/18 or Leaving Certificate or A-Level, HNC	
Additional training (e.g., NVQ, BTEC, FETAC, FAS, other)	
University undergraduate / nursing qualification	
University postgraduate	

Q43. What is your current occupation status?

Full-time paid work (30+ hours per week)	
Part-time paid work (8-29 hours per week)	
Part-time paid work (under 8 hours per week)	

Retired	
At school	
In full-time higher education	
Unemployed (seeking work)	
Unemployed (not seeking work)	
Full-time homemaker	

Q44: What is the total annual income of your household from all sources before any tax and National Insurance contributions? If you share your household with individuals unrelated to you (not a family member or your partner), please count only your personal income.

Include all income from employment and benefits.

If you are not sure of your household income, please estimate.

NI

Under £10,000 per annum	
£10,001 - £20,000 per annum	
£20,001 - £30,000 per annum	
£30,001 - £40,000 per annum	
£40,001 - £50,000 per annum	
£50,001 - £60,000 per annum	
£60,001 - £70,000 per annum	
£70,001 - £80,000 per annum	
£80,001 - £90,000 per annum	
£90,001 - £100,000 per annum	
£100,001 - £150,000 per annum	

£150,001 - £200,000 per annum	
£200,001 - £500,000 per annum	
£500,001 or more	
Prefer not to answer	

Ireland

Less than €20,000 per annum	
€20,001 – €40,000 per annum	
€40,001 – €60,000 per annum	
€60,001 – €80,000 per annum	
€80,001 – €120,000 per annum	
€120,001 – €160,000 per annum	
€160,001 - €200,000 per annum	
€200,001 - €400,000 per annum	
€400,001 - €800,000 per annum	
€800,001 or more per annum	
Prefer not to answer	

Q45. How many people (including yourself and other adults and children) do you typically prepare/cook a main meal for?

Mostly for myself	
Mostly for 2 people	
Mostly for 3-4 people	
Mostly for 5-6 people	
Mostly for more than 6 people	

Q46. Which county do you live in?

Ireland

Carlow	
Cavan	
Clare	
Cork	
Donegal	
Dublin	
Galway	
Kerry	
Kildare	
Kilkenny	
Laois	
Leitrim	
Limerick	
Longford	
Louth	
Mayo	
Meath	

Monaghan	
Offaly	
Roscommon	
Sligo	
Tipperary	
Waterford	
Westmeath	
Wexford	
Wicklow	

NI

Antrim	
Armagh	
Derry/Londonderry	
Down	
Fermanagh	
Tyrone	

Appendix 5: Literature review

This critical review is separated into two sections; Part A, *"Consumer use and behaviour surrounding the use of smart devices while preparing food in the domestic kitchen"* and Part B, *"The prevalence of and possibility of bacterial contamination on smart devices, in addition to the survival of microbial contaminants on the surfaces of electronic/smart devices".*

Part A: "**Consumer use and behaviour surrounding the use of smart devices while preparing food in the domestic kitchen".** A total of eight articles were found in the searches and retained for this portion of the review. It is important to acknowledge that research on this issue is limited, with the majority of articles providing general insights into the use of these devices in a domestic setting. Only one peer-reviewed article published investigated consumer use of smart devices specifically in the kitchen. The paucity of research in this area only strengthens the urgent need for the research proposed in this study. Research was conducted in six countries: USA (n=2), UK (n=1), Switzerland (n=1), Finland (n=1), Germany (n=1) and India (n=1). Methodology included quantitative approaches such as surveys in addition to qualitative approaches, including video recordings, observation, written diaries, interviews and focus groups. The majority (n=7) of studies utilised a mixed-methods approach, incorporating components of both quantitative and qualitative data collection. Interviews were the most popular method (n=5), followed by written diaries (n=4), surveys (n=4), video diaries (n=3), observations (n=2) and focus groups (n=1).

Part B: "**The prevalence of and possibility of bacterial contamination on smart devices, in addition to the survival of microbial contaminants on the surfaces of electronic/smart devices**." The 53 articles relevant for this critical review were published between 2010 - 2021. Research was conducted across 27 different countries; the majority of this research was conducted in Asian regions (44%) followed by European regions (30%), Oceania (8%), Africa (8%), North America (6%) and South America (4%). Furthermore, the majority of these studies were completed in a clinical setting (98%), therefore health care workers (HCW) are frequently investigated. However, studies occasionally investigated the prevalence of microbial contamination with control groups, primarily consisting of patients, visitors and administrative staff.

Part A: Consumer use and behaviour surrounding the use of smart devices while preparing food in the domestic kitchen

Prevalence in the population

It is evident that smart devices are ubiquitous and considered an indispensable tool that many individuals depend on for their daily lives. The explosion of apps available for these devices further enables consumers to have limitless and individualised access to many parts of their lives, i.e., mobile banking, social media, emails, internet, health and games. As a result, the information available on these devices, coupled with its portable nature, makes them extremely convenient for the general population. Studies have demonstrated that smart devices are integrated into society and thus are a common tool to easily access information of interest (Chitakunye & Takhar, 2014; Ernsting et al., 2017; Müller et al., 2012). A German study found that over 60% of users had a smart phone and associate significant benefits with these devices. Unsurprisingly, smart phone users were younger, with a university degree and more engaged in health literacy (Ernsting et al., 2017). In 2015, a Swiss study found that 32% of >65-year-olds owned a smart phone and 26% owned a tablet, with many participants considering the internet and associated devices as a useful tool to assist with daily living (Seifert & Schelling, 2015). In contrast, the older generation showed a reluctance to embrace such devices, although this study demonstrated that older people were happy to use the devices to supplement their lifestyle. Chitakunye & Takhar (2014) found that the transformation and use of these devices in family settings has evolved and enriched familial relationships, contradicting narratives that electronic devices have had a detrimental effect on relationships and family life (Chitakunye & Takhar, 2014).

Intervention studies have encouraged the use of smart devices and app interfaces to assist and promote positive behaviour change, such as healthy living, cooking, smoking cessation and energy conservation during meal preparation (Ernsting et al., 2017;

Müller et al., 2012). Moreover, a study looking into unused devices within the household found that old devices could be adopted for more specialised roles, i.e., an old tablet could be permanently attached to the kitchen wall to support cooking activities (Jokela et al., 2015). These alternative uses can help to reduce contamination from a high-risk environment while simultaneously alleviating technology waste.

Device uses

This section of the review investigates if, and the extent to which, smart devices are used in the kitchen. While there is limited research focusing specifically on the use of smart devices in the kitchen, several studies sought to understand the preferred purposes of tablet devices (Jokela et al., 2015; Müller et al., 2012). Results showed that the majority of participants used a tablet primarily for personal use, such as checking emails, social networking, searching for information (i.e., news and weather), shopping, listening to music, watching TV/videos or reading a book (Jokela et al., 2015; Müller et al., 2012). Interestingly, these studies reported that using smart devices was common during meal preparation/cooking for a variety of reasons, including playing music and finding, following, and checking recipes (Jokela et al., 2015; Lando et al., 2018; Müller et al., 2012). Moreover, participants saw using a smart device while cooking as beneficial as they did not have to print recipes, this in addition to the flexibility and mobility of a tablet, i.e., not having to plug it in and being able to have it close to the cooking/preparation areas (Müller et al., 2012). Furthermore, participants described how these devices could be moved around the house and not be restricted to one environment. For instance, a tablet could be used in the kitchen while preparing a meal, and later used to read a book/check emails in the living room (Jokela et al., 2015). This demonstrated the potential for cross-contamination around the various areas of the house. In addition, studies found that sharing electronic devices with trusted individuals, i.e., a significant other or family members, is common, contributing further to cross-contamination via smart devices (Matthews et al., 2016).

A single article published in 2018 focused on establishing consumer behaviours in relation to personal electronic devices and food hygiene practices (Lando et al., 2018). Lando et al (2018) reported that 49% of consumers used smart devices during meal preparation/while cooking. Younger participants with a college degree were more likely to use a smart device during meal preparation, with mobile phones being the preferred device compared to tablets and laptops (Lando et al., 2018). Interestingly, Lando et al. (2018) reported that only a third of participants wash their hands after touching a smart device, with participants being more concerned about washing their hands before touching other high-risk products in the kitchen, including eggs, raw meat and chicken (Lando et al., 2018). Overall, respondents displayed awareness that personal devices could be dirty from general daily usage. Subsequently, many participants developed their own strategies to prevent cross-contamination, such as using elbows or knuckles to swipe devices (Lando et al., 2018). Moreover, approximately half of participants were more concerned with "*transferring bacteria from phone to food*", while the other half was more concerned with "*transferring bacteria from food to phone*". This crucial paper is the first to explore and provide valuable insights on the use of smart devices in the kitchen, reporting varied usage and behaviours with these devices and poor food hygiene practices. While the results of this study are beneficial, it is important to mention the absence of analytical techniques such as microbiology to assess and determine the risk of cross-contamination and food safety risk. Therefore, further research is needed to evaluate and explore the potential for cross-contamination in relation to food safety risk.

Part B: The prevalence of and possibility of bacterial contamination on smart devices and the survival of microbial contaminants on the surfaces of electronic/smart devices

Methods

Sampling technique

Microbial analysis was included in the experimental design of the majority of the articles (96%, 51/53). An additional two articles were included in this review despite the absence of microbial analysis, as they provided insights into the use of these devices relating to cross-contamination. The majority of the research included (50 out of 51 studies) investigated the microbial community on personal mobile devices. One article specifically investigated the influence of cleaning techniques on iPads (Howell et al., 2014). Numerous studies swabbed specific regions of the phone, such as the ear section (Hadi et al., 2019; Hikmah & Anuar, 2020; Kuriyama et al., 2021; Tekerekoğlu et al., 2011), microphone (Bayraktar et al., 2021; Hadi et al., 2019; Tekerekoğlu et al., 2011), and the front and back of phones (Badr et al., 2012; Bayraktar et al., 2021; Egert et al., 2015; Hadi et al., 2019; Koroglu et al., 2015; Murgier et al., 2016; Pal et al., 2013; Shah et al., 2019; Sharma et al., 2015; Walia et al., 2014; White et al., 2012), while other studies specifically sought to determine if there was any difference in the microbial community of touch and keypad devices (Dorost et al., 2018; Edrees & Al-Awar, 2020; Koroglu et al., 2015; Pal et al., 2015; Pal et al., 2013; Volkoff et al., 2019). In addition, studies included determining the microbial community of hands (Angadi et al., 2014; Foong et al., 2015; Katsuse Kanayama et al., 2017; Shah et al., 2019) and nasal transfer (Brady et al., 2011; Murgier et al., 2016).

Laboratory methods

Culture-dependant and culture-independent approaches were employed to isolate, identify and enumerate the microbial community on personal mobile devices, to ascertain the risk these devices pose in transferring pathogenic microbes to individuals. Culture-dependant approaches remain the most popular method, with 76% (n=39/51) of experimental design utilising methods such as plate counts. To a lesser extent, culture-independent methods and approaches using both methods accounted for 6% (n=3/51) and 18% (n=9/51) of studies, respectively.

Twenty different agar plates were utilised in the articles retained for this review. General purpose agars such as blood agars, chocolate agar, Brain Heart Infusion (BHI) agar, nutrient agars and Tryptone were commonly selected *(see Table 9 for references of agars*). General purpose agars are commonly selected as they are suitable for the cultivation of several fastidious strains of bacteria, fungi and yeasts. Furthermore, a range of selective media was also observed, for instance, McConkey Agar, which is selective and differential for gram negative bacteria and is frequently used in the differentiation of lactose fermenting and lactose non-fermenting bacteria. Mannitol Salt

Agar selective medium for *Staphylococcus*, Harlequin *E.coli*/Coliform Agar for the selection of *E.coli* and coliforms and Baird-Parker Agar selective for the enumeration of *Staphylococcus aureus*. The most popular agars selected are blood agars (n=28) and McConkey's (n=21). It is also worth noting that the majority of papers used a combination of different plates to satisfy the overall aims of their research. See Table 9 for a summary of the frequency in which these agars were used, in addition to the articles that utilised these agars.

Table 9: The types and frequency of agars used in articles retained and the relevant references.

Type of Agar	**Frequency**	**Reference**
Blood Agar	28	(Abd-Ulnabi et al., 2020; Badr et al., 2012; Bayraktar et al., 2021; Bodena et al., 2019; Brady et al., 2011; Di Lodovico et al., 2018; Dorost et al., 2018; Edrees & Al-Awar, 2020; Foong et al., 2015; Galazzi et al., 2019; Heyba et al., 2015; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Karkee et al., 2017; Kotris et al., 2017; Kuriyama et al., 2021; Lubwama et al., 2021; Mushabati et al., 2021;. Pal et al., 2015; Pirko et al., 2019; Sadat-Ali et al., 2010; Shah et al., 2019; Sharma et al., 2015; Simmonds et al., 2020; S. Singh et al., 2010; Smibert et al., 2018; Ustun & Cihangiroglu, 2012; Walia et al., 2014)
McConkey's Agar	21	(Abd-Ulnabi et al., 2020; Angadi et al., 2014; Badr et al., 2012; Bodena et al., 2019; Di Lodovico et al., 2018; Edrees &

Type of Agar	Frequency	Reference
		Al-Awar, 2020; Foong et al., 2015; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Karkee et al., 2017; Loyola et al., 2016; Lubwama et al., 2021; Mushabati et al., 2021; Pal et al., 2015; Pirko et al., 2019; Sedighi et al., 2015; Shah et al., 2019; Sharma et al., 2015; Tailor et al., 2019; Walia et al., 2014; White et al., 2012)
Tryptone Soy Agar/Plates	6	(Bayraktar et al., 2021; Di Lodovico et al., 2018; Egert et al., 2015; Jones et al., 2020; Sedighi et al., 2015; White et al., 2012)
Brain Heart Infusion Agar	6	(Bayraktar et al., 2021; Dorost et al., 2018; Galazzi et al., 2019; Karkee et al., 2017; Pirko et al., 2019; Ustun & Cihangiroglu, 2012)
Mannitol Salt Agar	5	(Abd-Ulnabi et al., 2020; Brady et al., 2011; Di Lodovico et al., 2018; Simmonds et al., 2020; White et al., 2012)
Eosin-methylene blue agars	3	(Bayraktar et al., 2021; Dorost et al., 2018; Simmonds et al., 2020)
Sabourad Dextrose Agar	3	(Bayraktar et al., 2021; Di Lodovico et al., 2018; Tailor et al., 2019)
Chocolate Agar	3	(Edrees & Al-Awar, 2020; Heyba et al., 2015; Mushabati et al., 2021)

Type of Agar	Frequency	Reference
Nutrient Agar	3	(Abd-Ulnabi et al., 2020; Pal et al., 2013; Shah et al., 2019)
Oxide Brilliance MRSA Agar	2	(Howell et al., 2014; Smibert et al., 2018)
Dextrose Agar	1	(Koroglu et al., 2015)
Baird-Parker Agar	1	(White et al., 2012)
Bile Esculin Azide Agar	1	(Simmonds et al., 2020)
Brilliance UTI Agar	1	(White et al., 2012)
C. difficile-selective Agar	1	(Howell et al., 2014)
Cetrimide Agar	1	(Di Lodovico et al., 2018)
ESBL Agar	1	(Smibert et al., 2018)
Harlequin *E.coli* Agar	1	(Smibert et al., 2018)
CHROMagar Orientation plate (BD)	1	(Katsuse Kanayama et al., 2017)
VRE Brilliance Agar	1	(Howell et al., 2014)

In addition to the completing agar plates, the vast majority (n=28) of studies completed additional biochemical tests to further identify bacteria. Methods such as the morphological appearance of the colonies, gram stain, coagulase test, and oxidase and catalase reactions were used (Abd-Ulnabi et al., 2020; Angadi et al., 2014; Badr et al., 2012; Bayraktar et al., 2021; Bodena et al., 2019; Brady et al., 2011; Edrees & Al-Awar, 2020; Foong et al., 2015; Galazzi et al., 2019; Heyba et al., 2015; Hikmah & Anuar, 2020; Karkee et al., 2017; Kotris et al., 2017; Lubwama et al., 2021; Mushabati et al., 2021; Pal et al., 2015; Pal et al., 2013; Qadi et al., 2021; Sedighi et al., 2015; Shah et al., 2019; Sharma et al., 2015; S. Singh et al., 2010; Tailor et al., 2019; Ustun & Cihangiroglu, 2012; Walia et al., 2014; White et al., 2012). A further five studies used Vitek 2 automated system using GPI, GNI or ANC cards for further identification of selected microorganisms (Bayraktar et al., 2021; Brady et al., 2011; Di Lodovico et al., 2018; Galazzi et al., 2019; Koroglu et al., 2015; Smibert et al., 2018).

Aforementioned culture-independent approaches were employed to a lesser extent (n=12), either solely as culture-independent or in conjunction with culture-dependant approaches. In Japan, chromosomal DNA was prepared for pulsed-field gel electrophoresis (PFGE), and DNA fragments were separated by electrophoresis (Katsuse Kanayama et al., 2017). In Iraq, PCR and specific primer for (Methicillin-resistant Staphylococcus aureus) MRSA was utilised (Hadi et al., 2019). In France and Israel, Real-Time quantitative PCR (RTqPCR) was utilised to ascertain the presence of Virus nucleic acids (Cavari et al., 2016), and Enteric virus RV/NV (Pillet et al., 2016). Numerous studies used MALDITOF mass spectrometry analysis for further bacterial identification (Egert et al., 2015; Kuriyama et al., 2021; Missri et al., 2019; Smibert et al., 2018). In the USA and Wales, DNA extraction Illumina MiSeq analysis was completed on the total genomic region of the V3-V4 region of 16S rRNA region (Simmonds et al., 2020; Volkoff et al., 2019), and multiplex qPCR of select antimicrobial resistant genes (Volkoff et al., 2019). In Italy, AFLP analysis was used to study the DNA fingerprinting of samples to evaluate the presence of micro- or macroevolutions induced by electromagnetic waves (Di Lodovico et al., 2018).

Antimicrobial resistance is a global health concern that diminishes treatment efficiency and endangers the future of medical treatment (World Health Organisation, 2015). Clinical settings are considered a source and reservoir for pathogenic bacteria and, more significantly, MDROs. Noncompliance with hygiene protocols means that the clinical setting is an environment with elevated risk for the potential of interchangeable transfer from hospital staff, equipment and patients (World Health Organisation, 2015).

Given the serious implications associated with MDROs , coupled with the high-risk clinical environment, it is understandable that a substantial number of articles (57%, n=29/51), incorporated the detection of MDRO strains such as methicillin-resistant *Staphylococcus aureus* (MRSA) and methicillin-sensitive *Staphylococcus aureus* (MSSA). The majority of studies (n=27/29, 93%) used the Clinical and Laboratory Standards Institute method referred to as the Kirby-Bauer disc diffusion method to assess the presence of MDRO (Abd-Ulnabi et al., 2020; Badr et al., 2012; Bayraktar et al., 2021; Bodena et al., 2019; Edrees & Al-Awar, 2020; Foong et al., 2015; Galazzi et al., 2019; Hadi et al., 2019; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Karkee et al., 2017; Koroglu et al., 2015; Kotris et al., 2017; Kuriyama et al., 2021; Loyola et al., 2016; Muniz de Oliveira et al., 2019; Mushabati et al., 2021; Pal et al., 2013; Qadi et al., 2021; Qureshi et al., 2020; Sedighi et al., 2015; Sharma et al., 2015; A. Singh & Purohit, 2012; Tekerekoğlu et al., 2011; Ustun & Cihangiroglu, 2012; Walia et al., 2014), while other studies chose to use Oxoid Brilliance MRSA Agar and BRILLIANCE VRE Agar (*Resistant Enterococci*) (Howell et al., 2014; Smibert et al., 2018).

Questionnaire

In addition to the microbial analysis, approximately half of the articles distributed questionnaires (n=29/53, 55%) (Badr et al., 2012; Bodena et al., 2019; Brady et al., 2011; Cavari et al., 2016; Edrees & Al-Awar, 2020; Elmanama et al., 2015; Foong et al., 2015; Galazzi et al., 2019; Heyba et al., 2015; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Jones et al., 2020; Koroglu et al., 2015; Kotris et al., 2017; Kuriyama et al., 2021; Lando et al., 2018; Loyola et al., 2016; Lubwama et al., 2021; Murgier et al., 2016; Mushabati et al., 2021; Olsen et al., 2021; Pillet et al., 2016; Qadi et al., 2021; Qureshi et al., 2020; Sadat-Ali et al., 2010; A. Singh & Purohit, 2012; S. Singh et al., 2010; Ustun & Cihangiroglu, 2012). The composition of these questionnaires varied and could be categorised into three groups, including demographics (n=18), general phone use and cleaning behaviours (n=28), while others included items to ascertain psychological parameters such as awareness, knowledge, perceptions and attitudes (n=5). The most popular questionnaire configuration included the participants' socio-demographics coupled with general phone use, type and cleaning behaviours (59%, n=17) (Bodena et al., 2019; Brady et al., 2011; Cavari et al., 2016; Edrees & Al-Awar, 2020; Elmanama et al., 2015; Heyba et al., 2015; Hikmah & Anuar, 2020; Jones et al., 2020; Kotris et al., 2017; Kuriyama et al., 2021; Loyola et al., 2016; Olsen et al., 2021; Pillet et al., 2016; Qureshi et al., 2020; Sadat-Ali et al., 2010; S. Singh et al., 2010). Survey design including three elements (socio-demographics, general phone use and physiological aspects) which were investigated by four articles (Badr et al., 2012; Jalalmanesh et al., 2017; Lando et al., 2018; Lubwama et al., 2021; A. Singh & Purohit, 2012)), and one study used a focus group (Lando et al., 2018). While it is beneficial to understand the demographics and phone usage, the majority of the surveys lacked validated measures to ascertain psychometric parameters.

Bacteria isolated

The aforementioned analysis was completed on various demographic groups such as health care workers (nurses, doctors), dentists, the general population and university staff. When collapsing those categories, the sample size of personal devices ranged from 30-444, and the incidence of microbial contamination ranged from 44-100% (Abd-Ulnabi et al., 2020; Angadi et al., 2014; Bodena et al., 2019; Brady et al., 2011; Di Lodovico et al., 2018; Edrees & Al-Awar, 2020; Elmanama et al., 2015; Foong et al., 2015; Galazzi et al., 2019; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Jones et al., 2020; Karkee et al., 2017; Koroglu et al., 2015; Kotris et al., 2017; Kuriyama et al., 2021; Lubwama et al., 2021; Missri et al., 2019; Mushabati et al., 2021; Pal et al., 2015; Qadi et al., 2021; Qureshi et al., 2020; Sadat-Ali et al., 2010; Sedighi et al., 2015; Shah et al., 2019; Sharma et al., 2015; Simmonds et al., 2020; A. Singh & Purohit, 2012; S. Singh et al., 2010; Tailor et al., 2019; Tekerekoğlu et al., 2011; Ustun & Cihangiroglu, 2012; White et al., 2012). Moreover, over half (54%) of the articles indicated that bacteria were isolated on >90% of the devices, indicating a high incidence of contamination (Abd-Ulnabi et al., 2020; Angadi et al., 2014; Bodena et al., 2019; Di Lodovico et al., 2018; Galazzi et al., 2019; Hikmah & Anuar, 2020; Jones et al., 2020; Karkee et al., 2017; Koroglu et al., 2015; Missri et al., 2019; Qureshi et al., 2020; Sedighi et al., 2015; Shah et al., 2019; Simmonds et al., 2020; A. Singh & Purohit, 2012; S. Singh et al., 2010; Tailor et al., 2019; Tekerekoğlu et al., 2011; Ustun &

Cihangiroglu, 2012; White et al., 2012). In addition to providing the microbial contamination incidence, studies frequently reported the profile of contamination by categorising the microbial community on mobile devices as monomicrobial or polymicrobial (Brady et al., 2011; Edrees & Al-Awar, 2020; Galazzi et al., 2019; Hikmah & Anuar, 2020; Karkee et al., 2017; Murgier et al., 2016; Shah et al., 2019; A. Singh & Purohit, 2012; Tailor et al., 2019; White et al., 2012). Several studies reported monomicrobial contamination as the dominant status (Brady et al., 2011; Edrees & Al-Awar, 2020; Shah et al., 2019; S. Singh et al., 2010). For instance, in India microbial analysis was completed on the hands and phones of 150 HCW (n=300); monomicrobial organisms were recovered from 247 samples and polymicrobial organisms were isolated from 42 samples (Shah et al., 2019). In comparison, numerous studies reported that polymicrobial contamination was dominant (Galazzi et al., 2019; Koroglu et al., 2015; Murgier et al., 2016; A. Singh & Purohit, 2012; Tailor et al., 2019; White et al., 2012). For example, more than one type of microorganism was isolated from 407 out of the 444 cultured samples obtained from different surfaces of the phones (Simmonds et al., 2020). In Italy, polymicrobial contamination was evident on 72% of phones at the beginning of the shift and 66% of phones at the end of the shift. Additionally, 38% of mobile microbial community changed during shift, with 19% of participants acquiring an additional microorganism; however, no statistically significant differences in bacterial types and burden was found, demonstrating that bacteria can survive change during a 12-hour shift (Galazzi et al., 2019). Volkoff et al. (2019) reported no obvious change in the microbial community of mobile devices at the beginning and end of a shift; however, the presence of MDROs decreased. Volkoff et al. (2019) suggested that this may be as a result of increased compliance with hygiene protocols due to an awareness of the purpose of the research.

Types of bacteria

The microbial community isolated and reported in the retained articles for this review varied extensively. While microbial diversity is evident, several types of bacteria are reported more frequently than others. Gram-positive *Staphylococci* (Di Lodovico et al., 2018; Egert et al., 2015; Qureshi et al., 2020) were frequently reported, as coagulase-negative *Staphylococci species* (CoNS) (Angadi et al., 2014; Badr et al., 2012; Bayraktar et al., 2021; Bodena et al., 2019; Brady et al., 2011; Dorost et al., 2018; Foong et al., 2015; Galazzi et al., 2019; Hadi et al., 2019; Heyba et al., 2015; Hikmah & Anuar, 2020; Karkee et al., 2017; Koroglu et al., 2015; Kotris et al., 2017; Kuriyama et al., 2021; Lubwama et al., 2021; Missri et al., 2019; Murgier et al., 2016; Mushabati et al., 2021; Pal et al., 2015; Pirko et al., 2019; Qadi et al., 2021; Qureshi et al., 2020; Sedighi et al., 2015; Shah et al., 2019; Simmonds et al., 2020; A. Singh & Purohit, 2012; S. Singh et al., 2010; Tailor et al., 2019; Tekerekoğlu et al., 2011; Walia et al., 2014; White et al., 2012) (i.e., *S*taphylococcus epidemics (Bayraktar et al., 2021; Edrees & Al-Awar, 2020; Jalalmanesh et al., 2017) or coagulase-positive *staphylococcus aureus* (Abd-Ulnabi et al., 2020; Angadi et al., 2014; Badr et al., 2012; Bayraktar et al., 2021; Bodena et al., 2019; Brady et al., 2011; Edrees & Al-Awar, 2020; Elmanama et al., 2015; Hadi et al., 2019; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Karkee et al., 2017; Katsuse Kanayama et al., 2017; Kotris et al., 2017; Missri et al., 2019; Mushabati et al., 2021; Pal et al., 2015; Pal et al., 2013; Pirko et al., 2019; Sedighi et al., 2015; Sharma et al., 2015; Simmonds et al., 2020; A. Singh & Purohit, 2012; Tailor et al., 2019; White et al., 2012). Other gram-positive bacteria reported include *Bacillus* species (Abd-Ulnabi et al., 2020; Badr et al., 2012; Di Lodovico et al., 2018; Dorost et al., 2018; Egert et al., 2015; Foong et al., 2015; Galazzi et al., 2019; Hadi et al., 2019; Hikmah & Anuar, 2020; Jalalmanesh et al., 2017; Kuriyama et al., 2021; Mushabati et al., 2021; Pal et al., 2015; Pirko et al., 2019; Qadi et al., 2021; Qureshi et al., 2020; Shah et al., 2019; Tailor et al., 2019; Walia et al., 2014) more specifically *Diphtheroids* (Bayraktar et al., 2021; Foong et al., 2015; Koroglu et al., 2015; Pal et al., 2015), *Micrococcus* (Bayraktar et al., 2021; Egert et al., 2015; Hadi et al., 2019; Heyba et al., 2015; Jalalmanesh et al., 2017; Karkee et al., 2017; Pal et al., 2015; Qureshi et al., 2020; Tailor et al., 2019; White et al., 2012), *Enterococcus* (Bayraktar et al., 2021; Hadi et al., 2019; Jalalmanesh et al., 2017; Karkee et al., 2017; Koroglu et al., 2015; Pal et al., 2015; Simmonds et al., 2020), and *Streptococcus* (Edrees & Al-Awar, 2020; Foong et al., 2015; Jalalmanesh et al., 2017; Koroglu et al., 2015). Gram-negative bacteria were isolated less frequently, such as *Pseudomonas*

(Abd-Ulnabi et al., 2020; Edrees & Al-Awar, 2020; Koroglu et al., 2015; Mushabati et al., 2021; Pal et al., 2015; Sedighi et al., 2015; Simmonds et al., 2020; A. Singh & Purohit, 2012; Tailor et al., 2019; Walia et al., 2014) and *Enterobacteriaceae* (Dorost et al., 2018; Edrees & Al-Awar, 2020; Karkee et al., 2017; Koroglu et al., 2015; Loyola et al., 2016; Simmonds et al., 2020; Tailor et al., 2019; Walia et al., 2014). More specifically, numerous articles isolated and identified several bacteria within *Enterobacteriaceae*, including *Klebsiella* (Badr et al., 2012; Bayraktar et al., 2021; Bodena et al., 2019; Egert et al., 2015; Jalalmanesh et al., 2017; Karkee et al., 2017; Koroglu et al., 2015; Loyola et al., 2016; Mushabati et al., 2021; Shah et al., 2019; A. Singh & Purohit, 2012; Tailor et al., 2019), coliforms (Foong et al., 2015; White et al., 2012) more specifically reported as *E.coli* (Edrees & Al-Awar, 2020; Egert et al., 2015; Hadi et al., 2019; Karkee et al., 2017; Koroglu et al., 2015; Loyola et al., 2016; Mushabati et al., 2021; Sharma et al., 2015; A. Singh & Purohit, 2012; Tailor et al., 2019), *Acinetobacter* (Angadi et al., 2014; Bayraktar et al., 2021; Egert et al., 2015; Karkee et al., 2017; Koroglu et al., 2015; Lubwama et al., 2021; Mushabati et al., 2021; Pal et al., 2015; Shah et al., 2019; Simmonds et al., 2020; Tailor et al., 2019), *Salmonella* (Hadi et al., 2019), *Citrobacter* (Edrees & Al-Awar, 2020), and *Proteus* (Mushabati et al., 202). Yeasts/fungi *Candida spp* were also reported (Abd-Ulnabi et al., 2020; Jalalmanesh et al., 2017; Lubwama et al., 2021). Figure 6 illustrates the frequency with which these microorganisms are reported in the literature.

Figure 6: Frequency (number) with which microorganisms are reported in the literature

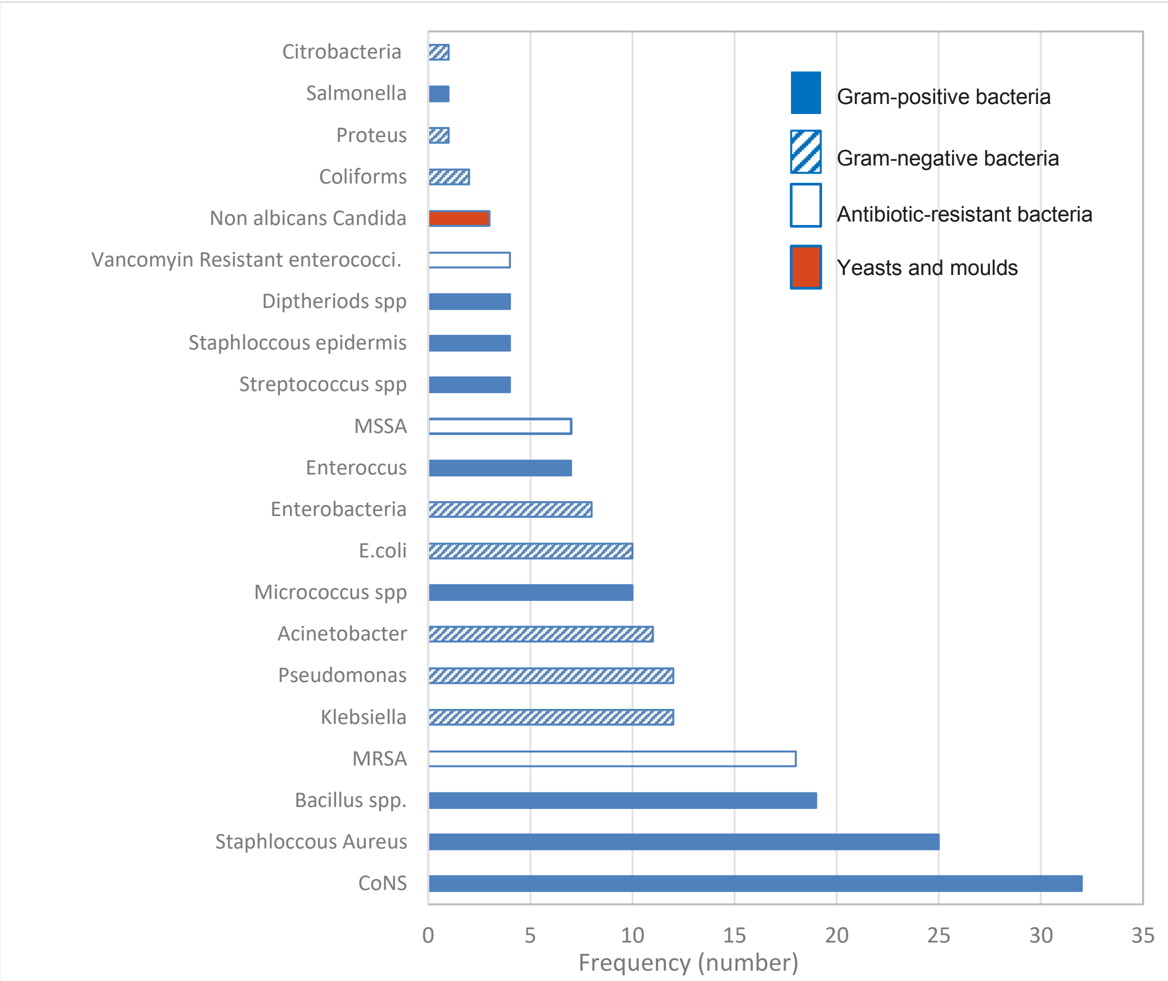

Figure description: Gram-positive bacteria such as Coagulase-negative *Staphylococci* (CoNS), *Staphylococcus* aureus, and *Bacillus* spp. were most commonly reported in the literature. Gram-negative bacteria such as *Klebsiella*, *Pseudomonas*, *Acinetobacter*, *E.coli*, and *Enterobacteriaceae* were also relatively frequently reported.

It was evident that the distribution and structure of the microbial community fluctuated; for instance, in Zambia CoNS isolates were dominant (50%) followed by *Staphylococcus aureus* (24.5%) and Bacillus spp. (14.3%) (Mushabati et al., 2021). By comparsion, in Pakistan and India CoNS isolates dominated, followed by Micrococcus species; however, the prevalence of remaining isolated bacteria differed significantly (Karkee et al., 2017; Qureshi et al., 2020). Meanwhile, studies completed in Fiji and Malaysia identified the *Bacillus* species as the most dominant (Hikmah & Anuar, 2020; Tailor et al., 2019). Due to the fluctuating microbial distribution reported in studies, and in order to obtain awareness of the most common dominant microbes present in the studies in this review, the author collated the top two dominant isolates reported in the literature. From this, it is evident that CoNS dominated the microflora (n=23), followed by *Staphylococcus* aureus (n=12) and *Bacillus* (n=8) (Abd-Ulnabi et al., 2020; Angadi et al., 2014; Bayraktar et al., 2021; Bodena et al., 2019; Brady et al., 2011; Di Lodovico et al., 2018; Dorost et al., 2018; Edrees & Al-Awar, 2020; Egert et al., 2015; Elmanama et al., 2015; Foong et al., 2015; Galazzi et al., 2019; Hadi et al., 2019; Heyba et al., 2015; Hikmah & Anuar, 2020; Karkee et al., 2017; Kotris et al., 2017; Lubwama et al., 2021; Missri et al., 2019; Murgier et al., 2016; Mushabati et al., 2021; Qadi et al., 2021; Sedighi et al., 2015; Shah et al., 2019; Sharma et al., 2015; Simmonds et al., 2020; S. Singh et al., 2010; Tailor et al., 2019; Tekerekoğlu et al., 2011; Walia et al., 2014).

The prevalence of MDROs was high in Eastern Ethiopia, Peru and Zambia (Bodena et al., 2019; Cavari et al., 2016; Loyola et al., 2016; Mushabati et al., 2021). MRSA (Angadi et al., 2014; Elmanama et al., 2015; Galazzi et al., 2019; Hadi et al., 2019; Heyba et al., 2015; Katsuse Kanayama et al., 2017; Koroglu et al., 2015; Missri et al., 2019; Mushabati et al., 2021; Pal et al., 2013; Qadi et al., 2021; Qureshi et al., 2020; Shah et al., 2019; Simmonds et al., 2020; A. Singh & Purohit, 2012; S. Singh et al., 2010; Smibert et al., 2018; Ustun & Cihangiroglu, 2012; Walia et al., 2014), MSSA (Angadi et al., 2014; Bayraktar et al., 2021; Foong et al., 2015; Hadi et al., 2019; Qadi et al., 2021; Shah et al., 2019; A. Singh & Purohit, 2012) and Vancomycin-resistant *Enterococcus* (VRE) (Karkee et al., 2017; Pal et al., 2013; Qureshi et al., 2020; Smibert et al., 2018) were most commonly reported (see Figure 6). In the UK, 13% of phones grew either MRSA or VRE, with keypad phones being contaminated with multi drug resistant organisms (MRDOs) (more frequently than touch screen (Pal et al., 2013). In Wales, Palestine and Pakistan, approximately a third of *Staphylococcus aureus* isolate were Methicillin-resistant (Angadi et al., 2014; Elmanama et al., 2015; Pal et al., 2015; Simmonds et al., 2020). In India, MRSA was isolated on >50% of mobile phones and hands of HCW, and >30% MSSA (Angadi et al., 2014). Studies in Palestine, Pakistan and India reported that a high prevalence of gram-positive cocci such as *Staphylococcus* aureus were resistant and sensitive to penicillin (Elmanama et al., 2015; Karkee et al., 2017) and sensitive to Vancomycin (81.9%) and Ciprofloxacin (88%) (Karkee et al., 2017). However, in Turkey and Palestine MSSA dominated (Bayraktar et al., 2021; Qadi et al., 2021), and the prevalence of MRSA was absent in Turkey and was at significantly low levels in Palestine and Japan (<2%) (Bayraktar et al., 2021; Katsuse Kanayama et al., 2017; Qadi et al., 2021). Variable resistance to Oxacillin was reported; in Malaysia, Oxacillin-resistant *Staphylococcus aureus* accounted for 6%; by comparison, there was 54% resistance among CoNS species reported in Pakistan (Hikmah & Anuar, 2020; Qureshi et al., 2020). Meanwhile gram-negative bacteria displayed sensitivity to Ciprofloxacin, Amikacin and amoxicillin clavulanic acid (Karkee et al., 2017; Pal et al., 2015).

Phone characteristics

Numerous studies investigated the microbial contamination of different types of phones, primarily those with touchscreen and keypad screens (Dorost et al., 2018; Edrees & Al-Awar, 2020; Koroglu et al., 2015; Pal et al., 2015; Pal et al., 2013; Volkoff et al., 2019). Several studies found evidence that the microbial contamination incidence and load was considerably higher in keypad devices when compared to touchscreens (Dorost et al., 2018; Pal et al., 2015; Pal et al., 2013). For instance, Pal et al. (2015; Pal et al., 2013) (2013, 2015) found that the presence of bacterial contamination of keypad phones was 94% when compared to touchscreen phones at 68% (Pal et al., 2015); similarly, the median colony count for keypad phones was significantly higher than touchscreen phones, 0.77 and 0.09 CFU/cm^2, respectively (Pal et al., 2013). In contrast, several other studies indicate high bacterial contamination rates in touchscreen devices (Edrees & Al-Awar, 2020; Jalalmanesh et al., 2017; Volkoff et al., 2019). A Turkish study observed a similar rate of contaminated devices with keypad and touchscreen devices at 98.3% and 97.9%, respectively. Despite similar contamination incidence rates, the extent of contamination differed.

Although both touchscreen and keypad devices showed similar contamination incidence rates, there was a notable difference in the level of contamination. Touchscreens exhibited significantly higher microbial loads compared to keypad devices, with mean CFU values of 46.2 (median CFU: 34) and 36.8 (median CFU: 21.5) respectively. Furthermore, Koroglu et al.(2015) noted a generally greater microbial diversity on touchscreen devices across four different types of microbes. A significantly higher microbial load was observed in touchscreens when compared to keypad deceives (mean CFU: 46.2, median CFU: 34) and (mean CFU: 36.8, median CFU: 21.5), respectively. .Koroglu et al. (2015) suggested that the greater microbial load and diversity present on touchscreen devices compared to keypad devices may be attributable to the generally larger phone size, while higher bacterial contamination on keypad phones could be due to the crevasses in the keypad, which make it more difficult to clean and enable microorganisms to survive and proliferate in these regions.

An Iranian study investigated the bacterial contamination of the different sections of the mobile device and reported that the highest contamination was present on the surface of the phone (keypad or touchscreen) at 58.74%, followed by the earpiece at 26.7% and the mouthpiece at 14.83% (Hadi et al., 2019). A Turkish study observed a similar incidence of bacterial or fungal contamination of the surface of the device (touch or keypad) and the posterior surface (>89%) (Koroglu et al., 2015). In contrast, Kuriyama et al. (2021) found that the posterior surface of mobile phones was significantly more frequently contaminated than the front surface (46% and 32%, respectively). Phone covers are a common accessory for phones, and studies in Palestine and Pakistan reported that the risk of contamination increased with covers and cracks on the phone's screen (Edrees & Al-Awar, 2020; Elmanama et al., 2015; Qureshi et al., 2020). In contrast, studies in the USA and Eastern Ethiopia found that participants with a device cover had a marginally higher incidence rate of contamination; however, this was not statistically significant (Bodena et al., 2019; Jones et al., 2020).

Hands

Hands are generally considered a vehicle of contamination, which is why hand hygiene is considered the cornerstone of good hygiene practice to prevent the spread of disease. While extensive work has been done to understand the microbial community on mobile devices, there is little research available on the relationship between the microflora of hands and its relation to smart devices. In India, of 300 samples tested, 144 (96%) mobile phones and 145 (96.66%) dominant hands showed contamination with one or more types of microorganisms (Shah et al., 2019). Another study conducted in India compared the microbial community on the hand and phones of healthcare workers (n=30) and a control group of visitors (n=30). Results demonstrated that hands with a higher microbial load correlated with a higher microbial load on the phone (Angadi et al., 2014). Similarly, studies in India and Australia reported that the microflora isolated from the hands and corresponding device were comparable (Angadi et al., 2014; Foong et al., 2015). Studies in Japan and Egypt emphasise the importance of investigating microflora on hands and mobile devices. These studies demonstrated that even if handwashing is adhered to, rapid recontamination of hands can occur due to contact to mobile phones (Badr et al., 2012; Katsuse Kanayama et al., 2017).

There is unequivocal evidence that personal mobile devices are a source of contamination in a clinical setting. Therefore, it stands to reason that these devices could also pose a cross-contamination risk in a domestic environment. The microbial community in studies retained for this review fluctuated substantiality; however, several studies have ascertained several characteristics that influence the microbial load and community on phones. These characteristics include the presence of a cover, whether the phone is a keypad or touchscreen device, and specific areas of the devices. Furthermore, studies have demonstrated a significant correlation between hand and phone microflora. Regularly touched contaminated surfaces such as a mobile phone can contribute to the transmission of bacteria in domestic settings.

Effect of cleaning

Many studies focused on isolating, identifying and enumerating the microflora present on personal mobile devices, providing evidence that personal devices are a source of contamination. Due to the identified cross-contamination risk of these devices, it is understandable that studies have also investigated the most appropriate cleaning approaches to address this issue (Badr et al., 2012; Egert et al., 2015; Howell et al., 2014; Jones et al., 2020; Missri et al., 2019; Muniz de Oliveira et al., 2019; Murgier et al., 2016).

A German and an American study investigated and compared the effect of various cleaning methods (new microfibre cloth and alcohol-based wipes) on the surface of touchscreen phones (Egert et al., 2015; Jones et al., 2020). In both studies, the two types of cleaning methods (cloth and wipe) significantly reduced the bacterial contamination of mobile devices, indicating that proper cleaning can reduce the bacteria on phones substantially (Egert et al., 2015; Jones et al., 2020). However, the American study indicated that there was no significant difference between treatment types (Jones et al., 2020). In comparison, the German study indicated that the alcohol-based product proved more effective, as the bacterial load for microfibre cloth and alcohol wipes was 0.22±0.10 CFU/cm^2 and 0.06±0.02 CFU/cm^2, respectively, compared to the mean bacterial load of uncleaned touchscreens, which was 1.37±0.33 CFU/cm^2 (Egert et al., 2015). Studies in the UK and Brazil investigated the effectiveness of various cleaning methods on pre-contaminated devices, reporting that chlorhexidine digluconate gel-based products are extremely effective at eliminating bacterial contamination while preserving smart devices (Howell et al., 2014; Muniz de Oliveira et al., 2019). Moreover, the UK study found that the residual antimicrobial effect of using chlorhexidine digluconate gel-based products lasted for six hours, preventing recontamination without additional sanitation (Howell et al., 2014). In France, studies investigated the effectiveness of a bactericidal wipe (Missri et al., 2019) and that of 0.25% Surfanios disinfecting product (Murgier et al., 2016) to sanitize mobile phones. With both treatments the bacterial load was significantly reduced, and was coupled with a significant reduction in the isolation of pathogenic bacteria (Missri et al., 2019; Murgier et al., 2016). In Italy, research investigated suggested that electromagnetic waves, emitted from a phone's surface when a phone is turned on, has the ability to the reduce the microbial growth (Di Lodovico et al., 2018). Several studies investigated the influence of alcohol-based wipes, with many studies reporting a significant (80-100%) effect in reducing bacterial load (Angadi et al., 2014; Egert et al., 2015; Elmanama et al., 2015; Foong et al., 2015; S. Singh et al., 2010). Unsurprisingly, studies in India and Germany reported that the microbial load (CFU) was reduced after decontamination with an alcohol-based product (Angadi et al., 2014; Egert et al., 2015). In addition, studies in Australia and India found zero pathogenic growth with routine use of alcohol wipes (Foong et al., 2015; S. Singh et al., 2010).

Overall, cleaning of any description significantly reduced the load and extent of contamination. Therefore, future hygiene protocols should incorporate suitable approaches to cleaning handheld devices to reduce the transmission of bacteria.

Effect of participant behaviours

Cleaning

Survey data endeavoured to obtain a better understanding of the extent of phone use and associated cleaning practices and habits. Previous research has demonstrated that mobile phones are a reservoir for contamination, and therefore a potential source of cross-contamination. That research has also unequivocally proven that participation in the routine cleaning and disinfection of devices can significantly reduce microbial contamination rates, the microbial community present, and the microbial load, thus reducing the potential spread of pathogenic organisms.

Broadly, research has indicated that the practice of cleaning/disinfecting phones was unsatisfactory (Badr et al., 2012; Bayraktar et al., 2021; Brady et al., 2011; Galazzi et al., 2019; Lando et al., 2018; Loyola et al., 2016; Mushabati et al., 2021; Olsen et al., 2021; Pillet et al., 2016; A. Singh & Purohit, 2012; S. Singh et al., 2010; Ustun & Cihangiroglu, 2012). In several studies, the majority of participants (51-97%) admitted to never cleaning their devices (Bayraktar et al., 2021; Brady et al., 2011; Loyola et al., 2016; Olsen et al., 2021; Simmonds et al., 2020; S. Singh et al., 2010; Ustun & Cihangiroglu, 2012). To a lesser extent, participants (12-78%) indicated that mobile phones were cleaned occasionally (monthly/weekly) (Brady et al., 2011; Foong et al., 2015; Kotris et al., 2017; Lando et al., 2018; Murgier et al., 2016; Mushabati et al., 2021; Simmonds et al., 2020). The frequency of daily cleaning ranged from 6-13% (Bayraktar et al., 2021; Brady et al., 2011; Simmonds et al., 2020). Meanwhile, 23% of participants in Turkey and the majority of participants in Kuwait only cleaned their phone when it was visibly dirty (Bayraktar et al., 2021; Heyba et al., 2015). Washing hands is an established method to alleviate microbial contamination incidence; however, the majority of participants reported that they did not wash their hands before or after touching these devices (Badr et al., 2012; Galazzi et al., 2019; Murgier et al., 2016; Pillet et al., 2016; S. Singh et al., 2010), which supports the previous finding that mobile phones could recontaminate hands (Badr et al., 2012; Katsuse Kanayama et al., 2017). Methods reported for cleaning devices ranged from alcohol-based wipes, lens cleaning wipes, "my shirt", damp cloths and dry cloths (Brady et al., 2011; Jones et al., 2020; Kotris et al., 2017; Lando et al., 2018). In Saudi Arabia, Turkey and Australia, a minority of participants used alcohol-based wipes to clean phones despite the proven effectiveness of this method (Foong et al., 2015; Olsen et al., 2021; Sadat-Ali et al., 2010; A. Singh & Purohit, 2012; Ustun & Cihangiroglu, 2012). However, in Pakistan 55% of participants reported using alcohol-based wipes (Qureshi et al., 202). Several studies observed that increased engagement in cleaning significantly correlated with reduced bacterial contamination (Bodena et al., 2019; Heyba et al., 2015; Jalalmanesh et al., 2017; Jones et al., 2020; Qureshi et al., 2020; Simmonds et al., 2020). In Australia, participants who cleaned their mobile phones with alcohol wipes daily had significantly reduced pathogenic growth (Foong et al., 2015; Olsen et al., 2021). Similarly, in Wales, daily cleaning of phones significantly reduced contamination load, while the CFU on devices never cleaned was much higher (($P<0.001$; mean daily 72.3 +/- 11.8 SE, mean never 918.1 +/-66.5 SE) (Simmonds et al., 202).

In an American study, the majority of participants believed that mobile devices have the ability to harbour harmful microorganisms and that using a mobile phone while working with food is a potential health risk (Jones et al., 2020). Interestingly, in Israeli and Iranian studies, the majority of participants (>88%) were aware that mobile phones can harbour microbes and could be a source of contamination (Cavari et al., 2016; Jalalmanesh et al., 2017). However, behaviours in relation to this reported awareness differed. Despite the high level of awareness of the risk in Israel, only 13% of participants disinfected their phone regularly (Cavari et al., 2016). In contrast, Iranian university students were also aware that contamination could be prevented by regular cleaning, with the majority (87%) of students engaging in daily cleaning of phones (Jalalmanesh et al., 2017). In Uganda, a survey was administered to ascertain medical students' awareness, understanding and practice of WHO infection prevention Control (IPC) programmes centred on hand hygiene. Results reported that students' awareness scores (77%) exceeded IPC practical scores (34%), indicating a need for the curriculum to include IPC-related topics which incorporate practical skills (Lubwama et al., 2021). Similarly, in Australia and Croatia, despite >80% of respondents reporting an awareness that phones could be contaminated with microbes, over half did not engage in appropriate sanitisation methodologies and frequency (Kotris et al., 2017; Olsen et al., 2021).

Phone use

Participants reported many different reasons for using phones, including, but not limited to, checking the time, taking phone calls, browsing on the internet, as a tool, e.g., as a torch (Badr et al., 2012; Lubwama et al., 2021; Murgier et al., 2016; Pillet et al., 2016; S. Singh et al., 2010). In France and Australia, the majority (>80%) of health care workers (HCW) considered mobile phones to be an important tool for their profession (Murgier et al., 2016; Olsen et al., 2021). In addition to HCW believing that the utilisation of mobile phones was necessary, the majority of patients (94%) also supported the use of mobile phones during inpatient stay (Brady et al., 2011). Studies in Peru, Italy, Israel and Wales indicated that frequent habitual use of the mobile phone during working hours was evident (Cavari et al., 2016; Galazzi et al., 2019; Loyola et al., 2016; Simmonds et al., 2020). In Peru, 47% of participants used their phones >5 times during an intensive care unit shift (Loyola et al., 2016). In Italy, of the 91% of participants who used their phone in the workplace, 37% of these used it on an hourly basis ((Galazzi et al., 2019). In Uganda and Egypt, all participants use the same phone in work and at home, and the majority (>90%) of respondents used their phone while rotating wards ((Badr et al., 2012; Lubwama et al., 2021). In France, two studies reported that mobile phones were routinely used during care, and participants regularly answered phones whilst in the operating theatre (Murgier et al., 2016; Pillet et al., 2016). In India, only 18% of participants reported using their phones when with patients (Singh et al., 2010). The Australian study also found that the majority of participants believed that mobile phones could harbour harmful bacteria. Despite this belief, over 50% of staff used their mobiles in the bathroom, an unhygienic environment renowned for its high microbial exposure. This finding is of concern, as this study also reported that 57% did not clean/disinfect their phones frequently enough or using adequate procedures (Olsen et al., 2021). The suggestion that use of the mobile phone in the bathroom increases microbial load was strengthened by a study in Palestine reporting that phone use in bathrooms was significantly associated with microbial contamination (Qadi et al., 2021). Interestingly, studies identified that HCW frequently shared phones with other individuals, including family members, children and partners (Edrees & Al-Awar, 2020; Ustun & Cihangiroglu, 2012). Edrees et al., (2020) found that high rates of bacterial contamination correlated with the increased sharing with others and frequency of usage.

Unsurprisingly, extensive and frequent usage of personal mobile devices is evident with many participants considering it as an essential tool. However, research has also demonstrated that overall cleaning behaviours are poor despite an awareness that these devices could harbour harmful microorganisms. The lack of engagement in cleaning may be attributable to optimism bias, causing an individual to underestimate the possibility of a negative event in the future whereby they believe that they themselves are less likely to experience a negative event (Sharot, 2011), or perceived social norms and habits, where it is considered shared standard practice to not clean these devices (Thomas & Sharp, 2013).

Socio-demographics

Occupation/Groups

Numerous studies reported fluctuating bacterial load and community present on mobile devices in various different HCW groups including, nurses, physicians and surgeons (Abd-Ulnabi et al., 2020; Murgier et al., 2016; Pal et al., 2015; Sadat-Ali et al., 2010; Shah et al., 2019; Ustun & Cihangiroglu, 2012). In Turkey, nurses' (51.4%) mobile phones had the highest occurrence of bacterial contamination, followed by other healthcare staff (31.1%) and laboratory personnel (17.5%) (Ustun & Cihangiroglu, 2012). In contrast, a study completed in Saudi Arabia reported that of the 44% contaminated cell phones, physicians' phones more frequently tested positive for bacteria in comparison to nurses (51% and 42% respectively) (Sadat-Ali et al., 2010). In India, the rate of bacterial contamination of resident doctors, support staff and nursing staff's phones and hands were similar, ranging from 31 – 33% (Shah et al., 2019). Similarly, in Australia, a high level of bacterial contamination was reported (74%), with similar organisms found on mobile phones and participants' dominant hands. Being a member of the junior medical staff was associated with increased microbial proliferation (Foong et al., 2015).

Other studies investigated and compared the bacterial load, contamination rates and microbial communities between HCW and other groups, including administrative staff, the general public, patients and visitors. Numerous studies observed that the bacterial contamination rate and load was higher in the HCW group in a hospital setting, in comparison to HCW in a community setting, students, patients and administrative staff (Angadi et al., 2014; Dorost et al., 2018; Elmanama et al., 2015; Koroglu et al., 2015; Sedighi et al., 2015; Sharma et al., 2015; Simmonds et al., 2020). In France, all mobile phones from the HCW group and the administrative group were colonized. A higher number of bacterial species per phone for the HCW was reported, even though the pathogenic colonization on phones did not significantly differ between groups (Missri et al., 2019). In Wales, high levels of bacterial colonization were evident from both hospital staff and a control group comprised of the general public (99% and 97% respectively). Microbial diversity was similar across the two groups, with 152 detected genera present in the two groups. However, 11 genera were unique to the control group, and 34 were unique to the hospital staff group. In addition, the operational taxonomic unit richness and microbial load was significantly higher in the hospital group (Simmonds et al., 2020). In Iraq, Iran and India, research indicated a considerable difference in the isolates identified from HCW and university personnel, with higher pathogenic isolates recovered from HCW mobile phones (Abd-Ulnabi et al., 2020; Sedighi et al., 2015; Sharma et al., 2015). In contrast, two Turkish studies observed significantly higher levels of pathogenic contamination, including MDRO, on patients and a visitor group when compared to HCW (Koroglu et al., 2015; Tekerekoğlu et al., 2011). A Croatian study observed no difference in the number of isolated bacteria between HCW and students' mobile phones (Kotris et al., 2017). Numerous studies reported that MRDOs, such as MRSA and VRE, were only detected on the phones and hands of HCW and not in the control groups (Missri et al., 2019; Qadi et al., 2021; Simmonds et al., 2020; Walia et al., 2014), and only on one visitor's phone in India (Angadi et al., 2014). These studies demonstrate that the presence of handheld devices in a clinical setting raised the probability of MRDO on hands and subsequent mobile phones. Given that the focus of the current project is consumers, however, it is unlikely that MDROS will present as an issue, and therefore including antimicrobial testing in this research is not necessary.

Gender

Many studies reported that gender influences the bacterial load, contamination rate and microbial community present (Bodena et al., 2019; Dorost et al., 2018; Elmanama et al., 2015; Hikmah & Anuar, 2020; Karkee et al., 2017; Murgier et al., 2016). Numerous studies observed a higher bacterial load/CFU and microbial contamination rate count in males in comparison to females (Bodena et al., 2019; Murgier et al., 2016; Qadi et al., 2021). In Turkey, despite there being no statistical gender differences in microbial contamination, the microbial load of males' phones was considerably higher than those of females (Koroglu et al., 2015). In Italy, there was no difference between the rates of microbial growth on smartphones belonging to males or females (Di Lodovico et al., 2018). In Eastern Ethiopia, gender and frequency of cleaning devices was associated with mobile phone contamination (Bodena et al., 2019), a finding strengthened by studies in Iran and the USA that found females cleaned phones more frequently and the microbial contamination of phones was significantly higher for males (Jalalmanesh et al., 2017; Lando et al., 2018). In India, while the pathogenic bacterial growth was higher for males (82.5%) in comparison to females (66.7%), no significant difference was found between genders (Karkee et al., 2017). In contrast, higher levels of bacterial contamination were reported for females in comparison to males in Baghdad (Pirko et al., 2019).

In Turkey, socio-demographic parameters including age, gender, occupation and educational status were investigated for microbial contamination rate and microbial load. No statistical differences were observed for the microbial contamination; however, the microbial load significantly increased as educational level and age decreased (Koroglu et al., 2015). In Australia, data sets were adjusted to investigate the effect of gender, phone use frequency, routine cleaning, cleaning in the past 24 hours, the type of phone and presence of phone cover; the adjusted data displayed no statistically significant associations with the presence of cultivation, pathogenic bacteria present or microbial load (Foong et al., 2015). Similarly, in Zambia, no significant association was observed between socio-demographic characteristics such age, gender, profession and microbial analysis (Mushabati et al., 2021).

Unsurprisingly, due to the increased exposure of a high-risk environment, the bacterial contamination rate, community and load was generally higher amongst HCW when compared to groups consisting of the general population. Moreover, the microbial community on males' personal devices was higher in comparison to females, likely due to an elevated female engagement with hygiene recommendations such as washing hands and regularly cleaning devices.

Publications

The following are conference presentations:

- Proceedings of the Nutrition Society , Volume 81 , Issue OCE4: Irish Section Conference 2022, 15–17 June 2022, Impact of nutrition science to human health: past perspectives and future directions , 2022 , E158. DOI: https://doi.org/10.1017/S0029665122001872

- Proceedings of the Nutrition Society , Volume 82 , Issue OCE1: Winter Conference 2022/23, 24–25 January 2023, Architecture of food: processing, structure and health , 2023 , E8 DOI: https://doi.org/10.1017/S0029665123000162