



Is visual motivation for cleaning surfaces in the kitchen consistent with a hygienically clean environment?

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ABSTRACT

Cleaning is a method at the disposal of domestic cooks for curtailing the dispersal of foodborne pathogens in the process of preparing food. The observation of visible dirt/soil ‘in the wrong place’ operates as one of the stimuli for action. This paper makes a transdisciplinary contribution to understandings of cleaning as a practice for ensuring safety in the kitchen, and it is mainly focused on the (in)visibility of soil or dirt. The social science research included analysis of a consumer survey in 10 European countries where 9966 respondents were asked about motivations for cleaning in the kitchen. This paper draws also on three microbiological tests. First, Portuguese (n = 7) and Norwegian (6) consumers evaluated the visible cleanliness of 10 surface areas in their kitchens, directly and through the visible residue and total bacterial numbers accumulated on a white cotton swab after swabbing the surface areas. Secondly, 15 Norwegian consumers tested if they could visually detect different types of food soils, as these dried on kitchen surfaces. Finally, the survival of *Campylobacter* and *Salmonella* in the same soil types was tested under lab conditions as the soil dried out. Cleaning food preparation surfaces “after food preparation” (73%), “before preparing food” (53%) and “when they are dirty” (43%) were the three most common self-reported behaviours. Routine was the most common motivation to clean, but this was age dependent. There was low correlation between visual detection of dirt/soil and bacterial enumeration. Visual detection of soils was dependent on type and concentration of food soils and material of the surface; the soils were more easily detected on laminate surfaces than plastic and wood. *Campylobacter* died rapidly, while *Salmonella* survived for at least one week in food soils drying on a countertop laminate surface. Presence of food soils in concentrations that can be detected visually, protected *Salmonella* against drying. In conclusion, selecting materials where soil/dirt can easily be detected visually in the kitchen surfaces, may motivate consumers to clean and will reduce risk, but establishing a habit to clean surfaces soon after food preparation is also important from a food safety perspective.

1. Introduction

Cleaning is one of the methods at the disposal of domestic cooks for curtailing the dispersal of micro-organisms in varying processes of managing and preparing food at home. Domestic cleaning must be understood as a multi-faceted practice that is stimulated by a range of priorities and concerns, involving a complexity of materials and cultural understandings. At least three cleaning concerns may be identified that relate to food preparation. Cleaning for aesthetic considerations that return the domestic environment to a desired state of visual

appearance has been, and is connected with, a broad range of social and cultural concerns (Douglas, 1966; Hoy, 1997; Martens, 2007). When preparing food, a second rationale for cleaning is dealing with the visible dirt (e.g. mud, soil, insects, sliminess and suspect liquids) that is brought into the kitchen with food items, or that enters the kitchen in other ways (Curtis et al., 2003; Wills, Meah, Dickinson, & Short, 2013). The removal of grit and other ‘dirty’ materials from foods before cooking and consumption, and the prevention of foods gathering visible dirt once in the kitchen, is closely guided by experiences of disgust that are associated with understandings of what materials can and should

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not be incorporated into the human body (Curtis, de Barra, & Aunger, 2011). Cleaning is also done for hygiene considerations, when action is undertaken to prevent the spreading of harmful micro-organisms in ways that may jeopardise the health of family members. Whilst micro-organisms have a very real material presence, one of the challenges for dealing with these entities in the domestic environment is that they are invisible to the human eye. A range of technologies are used by professionals to overcome this challenge, such as bacterial enumeration after culturing, ATP tests, visual detection under UV light and protein tests (Moore & Griffith, 2002; Mørtrø & Langsrud, 2017; Whitehead, Smith, & Verran, 2008). However, consumers making food in their kitchens do not have access to these monitoring devices and procedures. As microbial pathogens are invisible to the human eye, yet pose a health hazard, of substantial interest is how consumers understand these entities as they engage with food. Is understanding of pathogens displayed in practices that curtail their spreading? Is awareness of the potential presence of pathogens extrapolated onto specific materials that are perceptible, whether through vision or touch? And does the presence of such materials become inducement to take care and to clean up?

From a food safety perspective, kitchen hygiene is about keeping the numbers of pathogens at safe levels (Bloomfield, Carling, & Exner, 2017). The kitchen environment potentially contains large numbers of bacteria (Cardinale, Kaiser, Lueders, Schnell, & Egert, 2017; Moen, Røssvoll, Måge, Mørtrø, & Langsrud, 2016; Rusin, Orosz-Coughlin, & Gerba, 1998). In most cases these bacteria are harmless, and thus unproblematic from a food safety point of view. However, the pathogens *Listeria monocytogenes*, *Salmonella* and *Campylobacter* have been found in the kitchen environment (Borrusso & Quinlan, 2017; Cogan, Slader, Bloomfield, & Humphrey, 2002). Among these, *Salmonella* and *Campylobacter*, which may be present on various raw foods, can cause illness even at low numbers (Chlebicz & Slizewska, 2018). When transferred from contaminated equipment and surfaces to food, they represent a risk, and several studies have shown that consumers may use contaminated surfaces/equipment when preparing food (Jay, Comar, & Govenlock, 1999; Kennedy et al., 2011; Redmond & Griffith, 2003). As discussed above, consumers have limited possibilities for knowing when their kitchen surfaces are contaminated with pathogens, and the question is therefore if the priorities that initiate cleaning are sufficient to reduce risk.

The kitchen environment may also contain a range of different types of soil. Some types of soil and dirt may be harmful as they may contain pathogens (e.g. vomit, cat litter, meat juices), but not all (e.g. bread crumbs, dust, syrup). How consumers perceive different types of soils and how it affects their motivation to clean is not known and to our knowledge there have been no studies comparing visual evaluation of the cleanliness of kitchen surfaces with bacterial numbers. Elsewhere in the food sector, studies comparing visual inspection of food production/retail/restaurants premises with respective microbial counts have been conducted, and the majority report poor or no correlation (Kassa, Harrington, Bisesi, & Khuder, 2001; Tebbutt, 1991; Tebbutt & Southwell, 1989; Wyatt & Guy, 1980). However, a study from the UK, reports about correlation between hygiene ratings and microbial contamination (Fleetwood et al., 2019). There are reports showing that visual evaluation of the hygienic level is less sensitive than ATP measurement and bacterial enumeration in food industry (Moore & Griffith, 2002) and hospital settings (Griffith, Cooper, Gilmore, Davies, & Lewis, 2000; Mulvey et al., 2011). However, bacterial levels are often several magnitudes higher in domestic kitchens (Haysom & Sharp, 2005; Moen et al., 2016; Rusin et al., 1998) than in food industry and hospitals ($< 10 \text{ cm}^{-2}$ after cleaning and disinfection as recommended by Griffith et al. (2000)). Also, the type of soiling (e.g. food residues vs. blood) and surface materials (e.g. wood vs. steel) may be different between domestic kitchens, food industry and hospitals. Thus the conclusions from commercial food and hospital settings may not be valid for domestic kitchens.

In the present transdisciplinary work, motivations for kitchen surface cleaning were examined in a survey among consumers in 10 European countries. Also, consumers' ability to see dried food soils as well as the correlation between visible dirt/soil and bacterial numbers on kitchen surfaces, were studied in practical experiments. Finally, survival of the pathogenic bacteria *Salmonella* and *Campylobacter* was tested in drying and dried food soils.

2. Materials and methods

2.1. Information about consumers' cleaning of kitchen surfaces

A household online survey on food safety was conducted between December 2018 and April 2019 with a total of 9966 participants from 10 European countries: Denmark, France, Germany, Greece, Hungary, Norway, Portugal, Romania, Spain and the UK. The data collection was subcontracted to a professional survey provider (Dynata, formerly Research Now SSI). The survey contained a question (which is addressed in this paper) on household behaviours related to kitchen hygiene: "In general: when would you normally clean your kitchen countertop or other surfaces where you do your food preparation?". The following answers were available: (a) Before preparing food, (b) After preparing food, (c) When they are sticky, (d) When they are dirty, (e) When in contact with something dirty, (f) Before receiving visitors, (g) Other, specify and (h) None of the above.

2.2. Visual evaluation of food soils added to kitchen surfaces

The levels of food soils, dried on cutting boards and countertop surfaces, that could be visually detected by consumers in their own kitchens were tested. Poultry soil (20%) was made by adding 4.8 l of dH_2O to 1200 g minced poultry raw meat, followed by 1 min stomacher treatment and collection of the suspension passing through the stomacher filter. Lettuce soil was made by cutting two iceberg lettuce heads with a food processor for 1 min, and diluting five times with dH_2O (regarded as 20% lettuce soil). A waffle mix powder prepared according to the manufacturer's instructions (Orkla Foods, Norway) was used as egg-based soil. Aliquots of all soils were frozen at -40°C until further use. On the same day as they were handed over to the consumers, soils were thawed, and test solutions made by dilution with dH_2O to 10%, 1%, 0.1% and 0.01%. Dry weight, lipid, protein and sodium chloride of the food soils were analysed as described by (Mørtrø, Normann, Sæbø, & Langsrud, 2019) and results of the analyses are reported in [Supplementary Table S1](#).

Fifteen volunteers from Nofima (Norway) performed the experiments in their own kitchen. Both men ($N = 6$) and women ($N = 9$) were represented as well as people in different ages (< 30 years ($N = 4$), 30–55 years ($N = 7$) and > 55 years ($N = 4$)). The test persons were given a method description for the test together with tubes with soils, disposable plastic drip Pasteur pipettes, a frame ([Supplementary Fig. S1](#)) and a form to fill out results. The tubes with soils (10, 1, 0.1 and 0.01% soil) of three different food soils (poultry, lettuce and egg-based) and three tubes with dH_2O were numbered, but did not contain any information about type of soil or concentrations.

The tests were performed on clean surfaces, one cutting board and the countertop. Three drops (total ca. 100 μl) of soil suspension (or water as control) were applied to the surfaces in a pattern indicated by the application frame in the evening before the visual judgement. The drops were spread using the pipette and left for air drying overnight. The next morning the consumers noted down which drops of food soil they could detect visually (yes/no). They were asked to stand beside the surface as they were going to clean it and with the light in the room as in a normal cleaning situation. Photos of the surfaces with soil were taken and information about and colour of the surface material collected.

2.3. Survival of *Salmonella* and *Campylobacter* in dried food soils

Mixtures of overnight cultures of two *Salmonella* strains (*S. Enteritidis* from hens eggs from Portugal, Teixeira unpublished and *S. Infantis* M2016 ETBI 015346/01 from poultry, National Food chain Safety Office strain collection, Hungary) and two *Campylobacter jejuni* strains (NCTC11168, a human clinical isolate and DFVF1099 from chicken, Denmark (On et al., 2006)) (approximately 7 log/ml) were made with 0.1% and 10% of the three soils, and dH₂O as control. Three drops (approximately 100 µl) of bacteria/soil suspensions were applied with a plastic Pasteur pipette (as done by consumers in home tests) to a laminate countertop material. The suspensions were allowed to dry at room temperature (23 °C). The relative humidity in the test room varied with outdoor conditions, and were in the range 22–60% RH during the experiments. Sampling was performed immediately (when still wet), when visible dry (about 1.5–2 h, drying time varied between replicates) and after 24 h and 7 days, by swabbing of the area where the suspension was applied by use of two cotton swabs. The first swab was pre-moistened in buffered peptone water (BPW) (not at time zero on wet sample). Both swabs were put in same tube with 2.5 ml BPW. Plating after dilutions was performed for total counts on PCA (30 °C, Oxoid), *Salmonella* on XLD (41 °C, Oxoid), and *Campylobacter* on mCCDA (41 °C, microaerophilic incubation, Oxoid). For samples where no colonies were obtained on XLD or mCCDA, a qualitative enrichment test was performed to test whether all the pathogens died. For the *Campylobacter* test, one of the swabs was transferred to a tube with 2 ml Bolton enrichment broth (Oxoid), incubated microaerophilic at 41 °C until next day before the swab was streaked onto mCCDA. For the *Salmonella* test; 2 ml BPW were added to the tube with the remaining swab, incubated at 37 °C until next day when the swab was streaked on XLD, and growth/no growth was observed. The identity of a selection of colonies from PCA plates from the samples air dried for one week was determined with MALDI-TOF (MALDI Biotyper smart, Bruker Daltonik GmbH, Bremen, Germany), according to the manufacturer's instructions.

2.4. Consumer visual evaluation of kitchen cleanliness compared with bacterial enumeration

Visual evaluation of cleanliness of surfaces was performed by six Norwegian and seven Portuguese consumers (volunteers from our working institutions or their family members) in their own kitchens, and compared with bacterial enumeration. The consumers were given swabs, tubes and an instruction (in Norwegian/Portuguese) on how to perform the test. The instructions included a table to fill in evaluations, and a list where eight of ten sample sites were predefined and the two last sites could be chosen by the consumer.

The consumers were asked to perform the test in the morning before going to work. Initially, a test/sample area was inspected visually and rated for cleanliness from a scale from 1 to 4, where 1 was considered as clean. Then the same sample area was swabbed with a white cotton swab (Unil, Oslo Norway or Continente, SONAE, Matosinhos, Portugal). This method was inspired by a Portuguese TV commercial, where white cotton was used to check surfaces after cleaning (Anonymous, 2011). The consumers were instructed to use gloves when handling the swabs. The cotton swab was premoistened in 0.9% NaCl, and an area of 10 × 10 cm (or as large as possible if the sample site was smaller) was swabbed in two directions. After use, the swabs were evaluated visually on a scale from 1 (white, unused moistened swab as control) to 4 (Supplementary Fig. S2). After the rating, the swab was transferred to an empty test tube and transported to the laboratory and kept cool until further assessment. At the lab, the swabs were visually rated for cleanliness by a technician, and transferred to tubes with 2 ml peptone water. The number of viable bacteria was determined after dilution in peptone water and spread plating to PCA, the plates were incubated for 1–2 days at 30 °C.

2.5. Calculations

Statistical analysis of the survey data was conducted using appropriate software (IBM SPSS Statistics 25) and focused on the construction of frequency tables, and, for the association tests on the construction of chi-square (χ^2). In these tests we were concerned to examine, first, the relative values, and also to demonstrate statistically significant associations resulting from a cross between categories of variables, with reference to the degree of error of less than 5% or statistical significance ($p < 0.05$).

For the consumer test on visual judgment of different soils on surfaces, each positive reported detection was given a score of one and negative detection scored zero. Based on this, the percentage of the consumers who detected water and the different concentrations of soils were determined. To develop a metric for visually detectable soil, the sum of scores for the three controls was subtracted from the sum of scores for the three soil samples (1% soil) (Microsoft Excel 365, version 1909, www.microsoft.com). The number of positive differences (defined as visible soil) and differences of zero or less (defined as soil not detected visually) was counted for groups (consumers, materials) using the pivot table function. Fisher's exact test was used to calculate the statistical significance of differences between groups of consumers and material types (<https://www.langsrud.com/fisher.htm>).

For the consumer tests with swabbing kitchen surfaces, the bacterial numbers were log transformed and the scores for visual cleanliness reported as categorical data from 1 to 4. The statistical significance of differences between groups was calculated using the general linear model in Minitab (Minitab 18.1, 2017, www.minitab.com).

For the inactivation tests, bacterial numbers were log transformed and mean values and standard error of the mean calculated in Minitab. One-way ANOVA was used to calculate statistical differences between means.

3. Results and discussion

3.1. In which situations do consumers clean their kitchen surfaces?

Forty-three percent of the 9966 participating consumers in the 10 different countries reported that they clean food preparation surfaces *when they are dirty* (Fig. 1). This was the third most commonly reported behaviour, following *cleaning after food preparation* (73%) and *before preparation of food* (53%). Further analyses showed differences between age groups, with the age group 16–25 years more often reporting that they clean when the kitchen surface is dirty (45.9%) compared to the consumer group of > 65 years (36.7%). On the other hand, the > 65 years consumer group reported that they more often clean before food preparation (58.4%), compared to the 16–25 years group (39.6%) (data not shown). In the survey, multiple answers were allowed, and a small proportion of consumers across the countries (5.3%, country range 4.4–7.1%) reported cleaning kitchen surfaces only *when they are dirty*. This suggests that motivations to clean surfaces are diverse.

We continued by dividing the options for cleaning motivation into three categories, which we call 'routine cleaning' (cleaning that is done before and after food preparation), 'stimulated cleaning' that is based on perception during food handling (when dirty, when in contact with something dirty, and when sticky) and cleaning for social reasons (before having visitors). Routine cleaning was very common (83.4% of respondents). Almost half (42.9%) cleaned both before and after preparing food, and more consumers cleaned only after (30.2%) than only before (10.3%) preparing food. Overall, the responses from the consumers indicate that most consumers use several motivations for cleaning. There may be a change towards cleaning being more motivated by sensory perception during food handling, as suggested by Martens (2007), as younger persons' cleaning was motivated more in this way compared with older consumers.

Stimulated cleaning was common, and there are also other studies

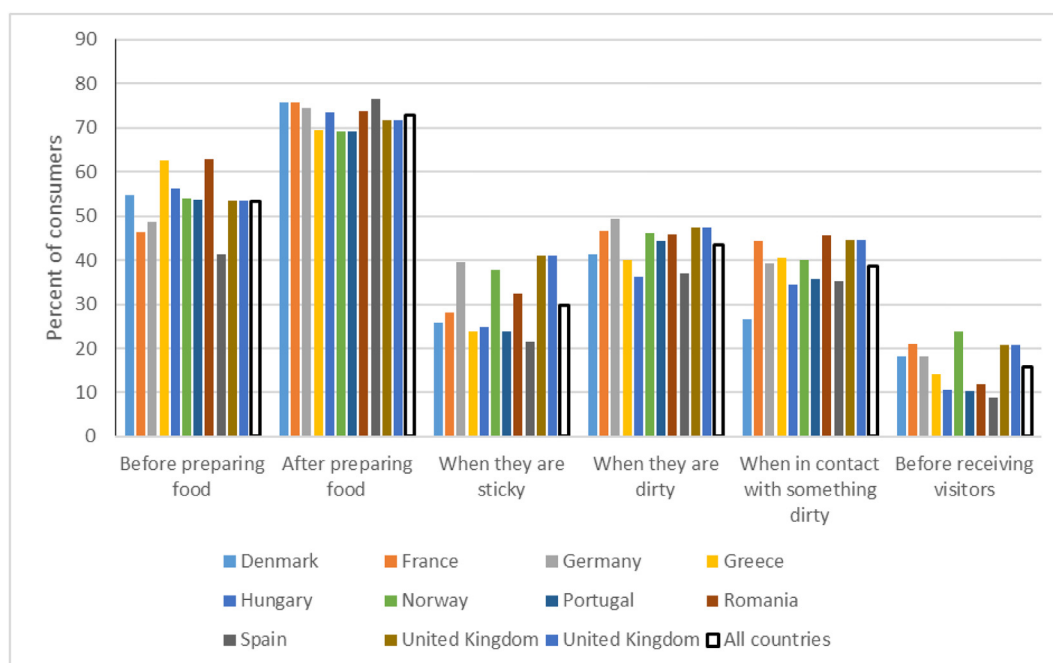


Fig. 1. Self-reported behaviour in a web based survey among 9966 European consumers on the question: “In general, when would you normally clean your kitchen countertop or other surfaces where you do your food preparation?” Multiple answers were allowed. The responses to the alternatives “other”/“none of the above” (both < 2%) not shown in figure.

indicating that consumers may base their cleaning frequency on evaluation of cleanliness of surfaces. In an observational study among 10 households in England, consumers reported that most home cleaning was motivated by the sight of dirt (Curtis et al., 2003). In a large survey from 12 countries world-wide with 12239 consumers, it was found that surface cleaning was linked to having a cleaning routine and to the perception that one is living in a dirty environment, and that women and children clean more frequently than men (Aunger et al., 2016). As some consumers clean their food preparation surfaces based on visual cleanliness it can be asked whether it is safe or sufficient to clean only when it is visually dirty. To answer this question, knowledge about the sensitivity of visual detection of food soils, as well as whether the visual perception of cleanliness is linked to bacterial numbers, is necessary.

3.2. Consumers' visual perception of surface contamination with food spills

We wanted to test to what degree the visibility of dirt depends on the type of soil that is considered in conjunction with surface materials.

As expected, the higher the concentration of food in the soil, the more likely consumers were able to detect it visually (Fig. 2). Similar scores were obtained for the lowest two dilutions as for water. For the two highest concentrations (1% and 10% soil) about 40% and > 60%, respectively, reported that they could see the soil applied on the surface. Differences in total scores given for 1% soil were not significant (between 40 and 60% of samples with 1% soil scored higher than controls). However, soil was more often detected when applied on smooth surfaces (1% soil detected on 11 out of 12 surfaces of laminate, stone surfaces or glass) compared with more rough surfaces (1% soil detected on 5 out of 18 surfaces made of plastic or wood) ($p = 0.001$). Soils were more easily detected on countertops than cutting boards ($p = 0.004$), but this was likely because the majority (11 of 15) of countertops were made of laminate or stone and the majority of cutting boards were of wood or plastic (14 of 15).

All consumers detected 10% egg-based soil, which appeared opaque/white after drying on all surfaces. Colour of the soil and surface may influence the detection, e.g. green salad was difficult to spot on green cutting board but easier to spot on white cutting board. In

addition, particle size may play a role, soils with particles may be more easily spotted visually than fully dissolved soils. As the density (% dry weight) of the different food soils varied (Supplementary Table S1), it is not possible to compare the detection limit for the different soils directly. For consumers that report visually dirtiness as a motivation for cleaning, the cleaning frequency will increase with a surface/material where dirt is easily detectable. To our knowledge this is not a parameter included in standards for hygienic design for the food industry, and we are not aware of standards for hygienic design for products intended for home kitchens. In a popularised article on hygienic design, Moerman (2010) states that walls and ceilings should be light-coloured because that permits fast detection of dirt and soil on their surfaces. In the literature on the history of kitchen and domestic design, as per example in Forty (1986), there is a lot of discussion on the introduction of artificial interior design surfaces with the potential to demonstrate clean lines and cleanliness, e.g. formica and linoleum. The results from the present study indicated that it seems to be difficult to detect dirt/soil on wood. Wood has long term history for use as material for food contact surfaces, but it is disputed whether its porosity is positive or negative for food safety and the use of wood as a food contact material is consequently limited in the food industry (Aviat et al., 2016).

3.3. Survival of *Salmonella* and *Campylobacter* in food soils dried on surfaces

The bacteria on the surfaces died over time, but *Salmonella* survived drying significantly better than *Campylobacter*. When the bacteria were suspended in dH₂O before drying for 24 h, there were surviving salmonellae, but no *Campylobacter*. For *Campylobacter*, survivors were observed in about half the samples (0.7–3 log per sample) directly after drying (1.5–2 h). There was no effect of food soils on survival of *Campylobacter* at time 1.5–2 h (data not shown). Surviving *Campylobacter* were not detected beyond 2 h of incubation, in neither quantitative nor qualitative tests. *Campylobacter* has been reported to enter a viable but non-culturable state (VBNC) when exposed to stress conditions (Jackson et al., 2009). However, in the present study, *Campylobacter* appear to die during drying, as the prolonged

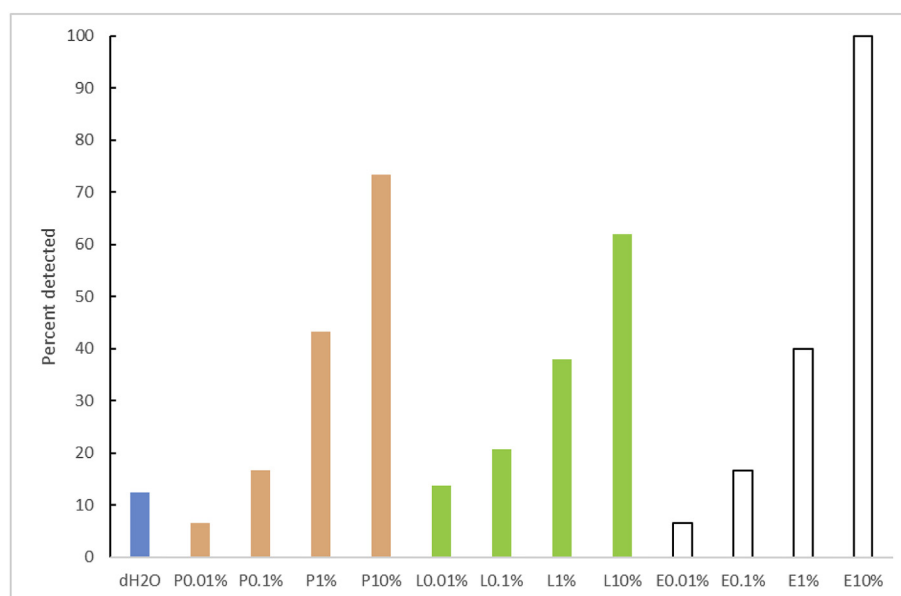


Fig. 2. Average percent visual detection from 15 consumers of food soils and water dried on countertops and cutting boards. Poultry (P), Lettuce (L) and Egg-based (E) soils were tested in different concentrations, water as control. Each consumer stated whether the different food soils or water could be visually detected or not.

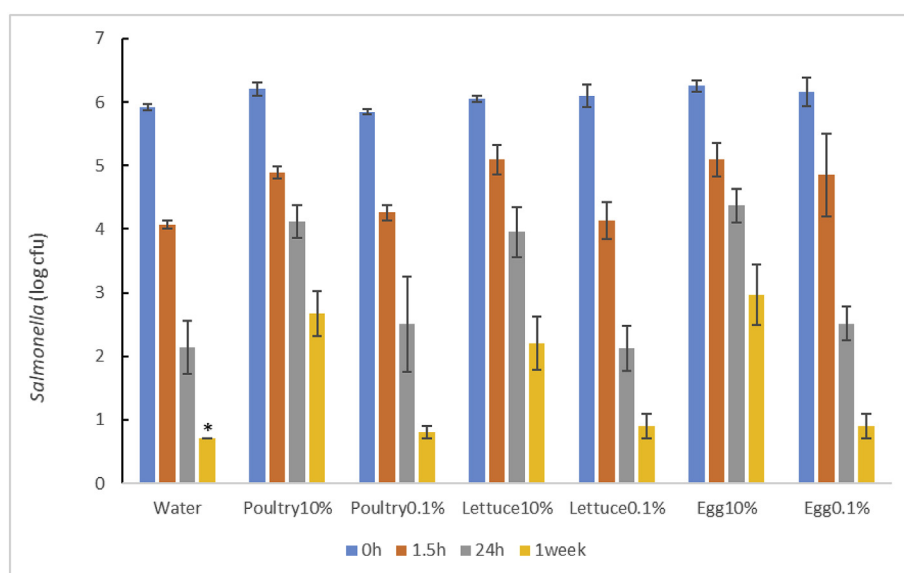


Fig. 3. Survival of *Salmonella* suspended in water and food soils (0.1% and 10%) applied wet (time = 0 h) on a laminate countertop, directly after appearing visibly dry (about 1.5 h) and after 24 h and 7 days air drying. Means and standard errors of three replicates are shown. Asterisk indicate that *Salmonella* was detected in the qualitative, but not in the quantitative test (detection limit 0.7 log).

enrichment period included before plating to selective agar (qualitative test), did not result in culturable campylobacters. Presence of 10% food soils (all three types) compared to water increased the survival of *Salmonella* after 24 h ($p < 0.05$), and after 7 days (Fig. 3). At 1.5 h, a protective effect against drying in 10% poultry soil and 10% lettuce was observed ($p < 0.05$). There were no protective effect of 0.1% food soils ($p > 0.05$). The bacterial numbers on PCA plates were similar to those on XLD, and MALDITOF analysis confirmed that the colonies appearing after 7 days on PCA were *Salmonella*.

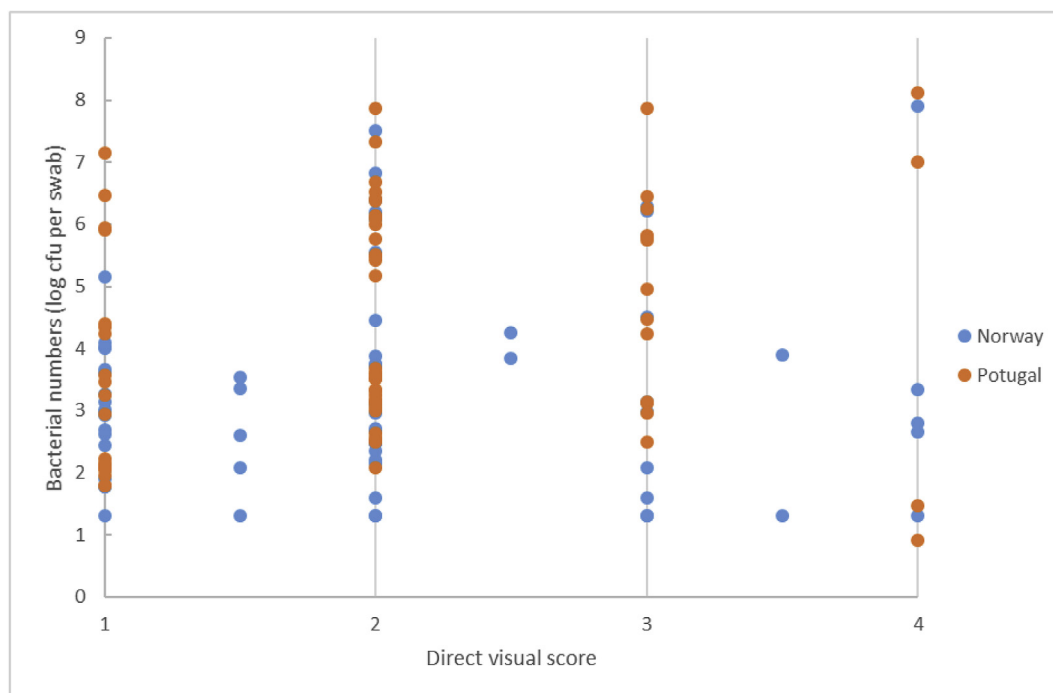
As the pathogens die off during drying, the risk of cross contamination of pathogens from surfaces will be highest directly after contamination of the surface and decrease over time. Thus cleaning will have the highest effect on reducing risk if performed directly after potential contamination (i.e. food preparation). As food residues protect pathogens against drying, visible clean conditions are likely to reduce the survival of *Salmonella* remaining after the cleaning procedure. Insufficient cleaning may lead to higher initial counts of pathogens, and also to the better survival of *Salmonella* against drying. In line

with the results in the present study, it has previously been shown that proteins and sugars (food residues) can protect bacteria, including *Salmonella*, against drying at surfaces (Burgess et al., 2016). *Salmonella* is generally regarded as tolerant to desiccation, e.g. survival at dry conditions on stainless steel has been reported for > 4 weeks (Margas, Meneses, Conde-Petit, Dodd, & Holah, 2014), while *Campylobacter* is regarded as sensitive to drying (Burgess et al., 2016).

3.4. Visual evaluation of kitchen surfaces compared to microbial enumeration

Overall, there was no correlation between direct visual evaluation and bacterial counts on surfaces, and similarly no correlation between visual evaluation of swabs (consumer or lab) and bacterial counts (cfu/swab). Of the surfaces scored as clean (score = 1) and dirty (score = 4) in the direct visual test the range in bacterial counts was < 1.2–6.5 log cfu/swab and < 1.2–3.5 log cfu/swab, respectively (Fig. 4A). For surfaces where the swab test was scored as clean (score 1) and dirty (score

A.



B.

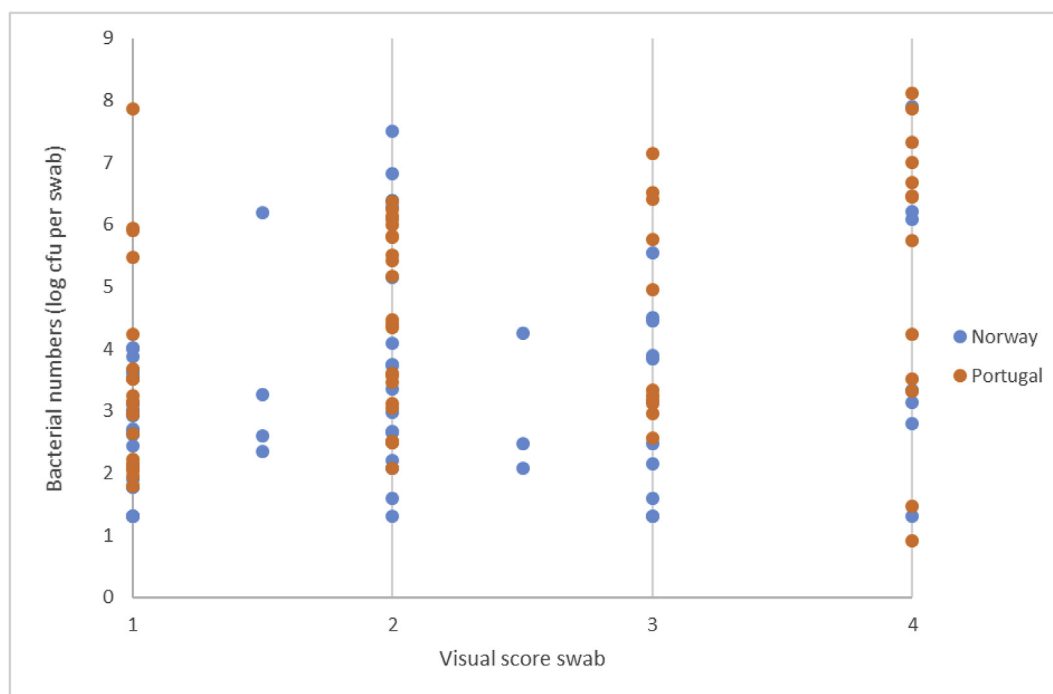


Fig. 4. Direct visual score of surface (A) and visual score of swab (B) (scales from 1 (clean) to 4 (dirty). by Norwegian and Portuguese consumers compared to bacterial numbers in swabs used to swab the same kitchen surfaces (n = 133).

4) by the consumers, the bacterial count was in the range < 1.2 – $6 \log$ cfu/swab and < 1.2 – $8 \log$ cfu/swab, respectively (Fig. 4B).

Overall, the bacterial counts were higher ($p = 0.001$) in Portuguese kitchens sampled compared to Norwegian kitchens (Fig. 5). The variation in counts between different types of surfaces were larger between Norwegian kitchens than between Portuguese kitchens. As expected, low bacterial counts were found in dry areas (e.g. inside kitchen

ventilator) and in the stove despite visual soil, since bacteria will not grow at dry conditions and will be killed due to the high temperature in the stove. The observed bacterial counts were within the range previously reported for US and Norwegian kitchens (Moen et al., 2016; Rusin et al., 1998).

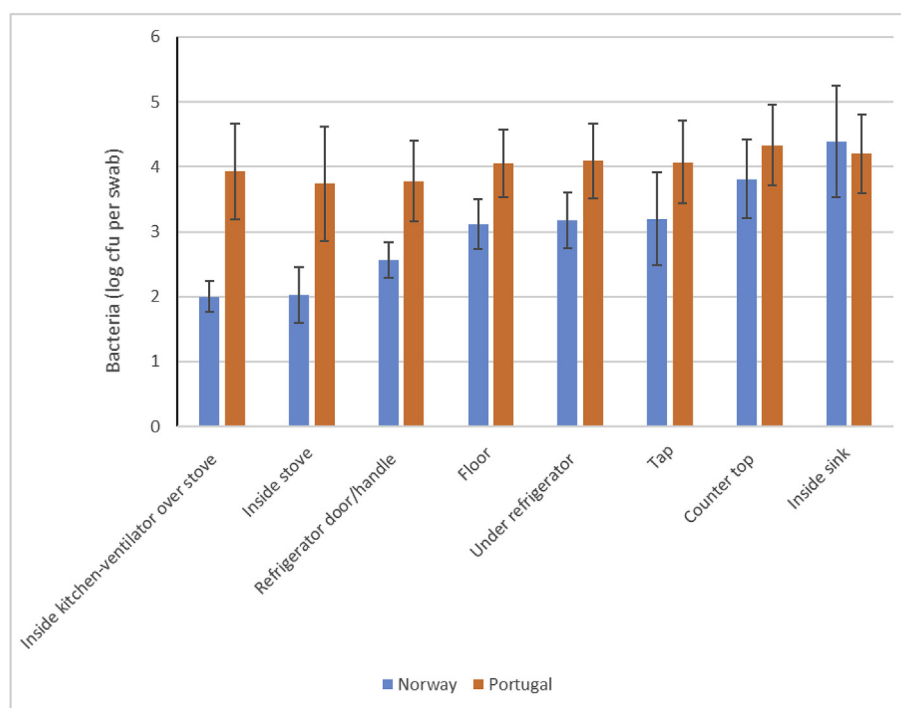


Fig. 5. Total bacterial counts in swabs used on kitchen surfaces. Mean values and standard errors of common surfaces sampled in six Norwegian and seven Portuguese kitchens (n = 104).

3.5. How will different motivations and practices affect the risk of cross contamination?

According to our findings, for most domestic cooks, especially elderly, cleaning kitchen surfaces are a habitual practice performed primarily after cooking, secondary before cooking or both. To assess the risk reducing effect of cleaning is not straightforward, as little is known about the levels of pathogens in kitchen before and after food preparation, and it is probably that the variation is substantial both over time within a household and between households. In a UK study with twenty consumers, about half of the kitchen surfaces sampled were positive for *Campylobacter* or *Salmonella* (very few over 25 cfu cm⁻²) after preparation of a meal from fresh chicken (Cogan et al., 2002). Cleaning during and immediately after preparation eliminated *Campylobacter*, but not *Salmonella*. The spread of pathogens from eggs and vegetables during preparation has not been studied yet, as far as we know. In raw chicken, levels of 10³–10⁴ cfu g⁻¹ or up to 10⁸ cfu per carcass of *Campylobacter* and up to 10³ cfu g⁻¹ of *Salmonella* have been reported (European Food Safety Authority, 2010; Huang, Zong, Zhao, Zhu, & Jiao, 2016; Luber, 2009; Luber & Bartelt, 2007; Wang et al., 2013). A meta-analysis reported concentration of *Salmonella* in lettuce in the range of 0.054–218 cfu g⁻¹ (Elias, Noronha, & Tondo, 2019). Storage of eggs at low temperature will usually keep the concentration of *Salmonella* low, if eggs are contaminated, but it has been reported that concentrations as high as 10⁸–10¹⁰ cfu ml⁻¹ of *S. Enteritidis* can be obtained after storage for 3 weeks at 25 °C (Clay and Board, 1991). From this, it is likely that a habitual cleaning to remove pathogens, especially after preparing raw eggs (if not *Salmonella* free) or chicken, will also contribute to a hygienically clean kitchen, if done properly. However, to avoid cross-contamination also during preparation, cleaning visible (and invisible) spills while preparing food (represented by cleaning when something is dirty or in contact with something dirty) is crucial.

About 40% of the respondents claimed that visible dirt and stickiness motivated them to clean. This raises the question whether cleaning based on visual judgement alone would be a safe practice. Our results showed that most consumers could visually detect the 10% samples of

soil, roughly containing 0.01 g chicken/lettuce/waffle batter. Therefore, in a worst-case scenario with highly contaminated food entering the kitchen, most people will be able to spot a drop of chicken soil containing in total maximum 1000 cfu of *Campylobacter* (maximum 10 cfu *Salmonella*) and waffle batter with eggs containing maximum 10⁷ *Salmonella* if spilled on smooth surfaces. 10% lettuce soil will probably contain very low numbers of *Salmonella* or *Campylobacter* (but may contain other pathogens, as Norovirus and cannot be disregarded). When taking into account the initial levels of pathogens in food soils and the reduction rates obtained in the present study, it is likely that *Salmonella* may survive in relatively high numbers for more than one week in dry egg soil, even in soil levels that are not visible for many consumers. Both *Campylobacter* and *Salmonella* are likely to be reduced to too low levels to cause a food safety threat from dried poultry and lettuce soils. Therefore, cleaning motivated by stickiness/visible dirt may reduce risk of foodborne infection, but should be combined with a habit of cleaning before and after preparing food.

Although the presence of bacteria in itself is not necessarily a health threat, one could argue that bacterial pathogens are seldomly introduced into the kitchen as pure cultures, but together with soil and other bacteria, and that high bacterial numbers indicate a niche where pathogens may have been introduced and could survive. As our results suggests, visible soil is not a universal indicator for a niche with high bacterial numbers or pathogens, and on the contrary, lack of visible soil is not an indicator of low bacterial numbers or absence of pathogens. Therefore, a narrow approach aiming to keep the kitchen aesthetically clean, is not an effective strategy to reduce the risk of foodborne infection. On the other hand, choosing material surfaces that are light, smooth and signalling cleanliness will aid the domestic cook in spotting spills.

From a food safety view and in an effort to reduce time and chemicals used for cleaning, motivation for cleaning linked to avoiding spread of invisible numbers of pathogens can be seen as ideal. However, such a targeted hygiene approach demands high expertise on the occurrence of pathogens in different foods (and other materials entering the kitchen), how they spread, how and when to break the chain of infection, and the vulnerability of family members and guests

(International Scientific Forum on Home Hygiene, 2015). Changing people's habitual practices is a big challenge, and information and education should start before habits are established. The benefit of a highly educated population would mean that it would be more robust towards new threats. However, one should not underestimate the role of other priorities in life, that could come in conflict with a targeted hygiene approach, such as beliefs connected to the hygiene hypothesis and the harmfulness of cleaning chemicals and practices such as selecting surface materials that are not easy to keep clean.

4. Conclusions

Cleaning in the kitchen, and countertops in particular, usually takes place in routine ways before and after food preparation whilst also stimulated by sensory perception through vision and touch. Cleaning that is stimulated when cooking suggests that domestic cooks pay attention and make decisions during food preparation about when the need to clean arises. Whereas the survey results suggest that 'stimulated cleaning' is not as common as 'routine cleaning', it is possible that the differences are not so distinct, as research has shown that domestic practitioners bracket the practices they engage in sequentially, such that cooking and cleaning follow one another rather than co-occur. Domestic cooks are therefore less likely to think about cleaning whilst preparing food as 'cleaning'. From a food safety perspective, stimulated cleaning that relies on sensory input while food is being prepared is especially interesting, as it suggests cooks do work to prevent cross-contamination.

To develop understanding of how effective reliance on visual input is for hygienic cleaning in the domestic kitchen, during and after food preparation, and how *Campylobacter* and *Salmonella* survive in food soils, three experiments were conducted. There was little correlation between visual cleanliness and the level of bacteria in the kitchen environment in general. For food soils, specifically, consumers could detect relatively low concentrations on smooth surfaces (glass, stone, laminate), but not on rough surfaces (wood, plastic cutting boards). While *Campylobacter* was inactivated quite rapidly in food spills during drying, *Salmonella* could survive for at least a week in dried food spills. In rare events, where highly contaminated foods are introduced to the kitchen, the consumer would not necessarily be able to spot spills with high (10^6 cfu) numbers of pathogens.

As a conclusion, all motivations and habits for cleaning reported by European consumers will contribute to reduce the risk of cross-contamination from food in the kitchen. A combination of establishing cleaning habits before and after making food with cleaning surfaces that have been in contact with raw foods, should be promoted. The latter strategy requires good understanding of how microbes spread or the use of smooth kitchen materials where low levels of soil can be detected by the eye.

CRedit authorship contribution statement

Trond Mørseth: Conceptualization, Methodology, Visualization, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition. **Lydia Martens:** Conceptualization, Writing - original draft, Writing - review & editing, Funding acquisition. **Paula Teixeira:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition. **Vânia B. Ferreira:** Conceptualization, Methodology, Investigation, Writing - original draft, Funding acquisition. **Rui Maia:** Formal analysis, Visualization, Writing - original draft. **Tove Maugesten:** Methodology, Investigation. **Solveig Langsrud:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodcont.2019.107077>.

References

- Anonymous. <https://www.youtube.com/watch?v=pY-ayXoYbQw>: Sonasol 2019.
- Aunger, R., Greenland, K., Ploubidis, G., Schmidt, W., Oxford, J., & Curtis, V. (2016). The determinants of reported personal and household hygiene behaviour: A multi-country study. *PLoS One*, 11(8).
- Aviat, F., Gerhards, C., Rodriguez-Jerez, J. J., Michel, V., Le Bayon, I., Ismail, R., et al. (2016). Microbial safety of wood in contact with food: A review. *Comprehensive Reviews in Food Science and Food Safety*, 15(3), 491–505.
- Bloomfield, S. F., Carling, P. C., & Exner, M. (2017). A unified framework for developing effective hygiene procedures for hands, environmental surfaces and laundry in healthcare, domestic, food handling and other settings. *Gms Hygiene and Infection Control*, 12.
- Borruso, P. A., & Quinlan, J. J. (2017). Prevalence of pathogens and indicator organisms in home kitchens and correlation with unsafe food handling practices and conditions. *Journal of Food Protection*, 80(4), 590–597.
- Burgess, C. M., Gianotti, A., Gruzdev, N., Holah, J., Knøchel, S., Lehner, A., et al. (2016). The response of foodborne pathogens to osmotic and desiccation stresses in the food chain. *International Journal of Food Microbiology*, 221, 37–53.
- Cardinale, M., Kaiser, D., Lueders, T., Schnell, S., & Egert, M. (2017). Microbiome analysis and confocal microscopy of used kitchen sponges reveal massive colonization by *Acinetobacter*, *Moraxella* and *Chryseobacterium* species. *Scientific Reports*, 7.
- Chlebicz, A., & Slizewska, K. (2018). *Campylobacteriosis*, *salmonellosis*, *yersiniosis*, and *listeriosis* as zoonotic foodborne diseases: A review. *International Journal of Environmental Research and Public Health*, 15(5).
- Clay, C. E., & Board, R. G. (1991). Growth of *Salmonella* Enteritidis in artificially contaminated hens shell eggs. *Epidemiology and Infection*, 106(2), 271–281.
- Cogan, T. A., Slader, J., Bloomfield, S. F., & Humphrey, T. J. (2002). Achieving hygiene in the domestic kitchen: The effectiveness of commonly used cleaning procedures. *Journal of Applied Microbiology*, 92(5), 885–892.
- Curtis, V., Biran, A., Devereux, K., Hughes, C., Bellamy, K., & Drasar, B. (2003). Hygiene in the home: Relating bugs and behaviour. *Social Science & Medicine*, 57(4), 657–672.
- Curtis, V., de Barra, M., & Aunger, R. (2011). Disgust as an adaptive system for disease avoidance behaviour. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1563), 389–401.
- Douglas, M. (1966). *Purity and danger. An analysis of the concepts of pollution and taboo* (1st ed.). London, UK: Routledge.
- Elias, S. D., Noronha, T. B., & Tondo, E. C. (2019). *Salmonella* spp. and *Escherichia coli* O157:H7 prevalence and levels on lettuce: A systematic review and meta-analysis. *Food Microbiology*, 84.
- European Food Safety Authority (2010). Analysis of the baseline survey on the prevalence of *Campylobacter* in broiler batches and of *Campylobacter* and *Salmonella* on broiler carcasses in the EU, 20081 Part A: *Campylobacter* and *Salmonella* prevalence estimates. *EFSA Journal*, 8, 1503 03.
- Fleetwood, J., Rahman, S., Holland, D., Millson, D., Thomson, L., & Poppy, G. (2019). As clean as they look? Food hygiene inspection scores, microbiological contamination, and foodborne illness. *Food Control*, 96, 76–86.
- Forty, A. (1986). *Objects of desire: Designs and society 1750-1980*. London: Thames & Hudson.
- Griffith, C. J., Cooper, R. A., Gilmore, J., Davies, C., & Lewis, M. (2000). An evaluation of hospital cleaning regimes and standards. *Journal of Hospital Infection*, 45(1), 19–28.
- Haysom, I. W., & Sharp, A. K. (2005). Bacterial contamination of domestic kitchens over a 24-hour period. *British Food Journal*, 107(7), 453–466.
- Hoy, S. (1997). *Chasing dirt – the American pursuit of cleanliness*. Oxford: Oxford University Press.
- Huang, J. L., Zong, Q., Zhao, F., Zhu, J. Q., & Jiao, X. A. (2016). Quantitative surveys of

- Salmonella* and *Campylobacter* on retail raw chicken in Yangzhou, China. *Food Control*, 59, 68–73.
- International Scientific Forum on Home Hygiene (2015). *Developing hygiene practice for the home – the IFH risk-based approach to home hygiene*. (targeted hygiene). Available: <https://www.ifh-homehygiene.org/factsheet/developing-hygiene-practice-home-%E2%80%93-ifh-riskbased-approach-home-hygiene-targeted-hygiene>.
- Jackson, D. N., Davis, B., Tirado, S. M., Duggal, M., van Frankenhuyzen, J. K., Deaville, D., et al. (2009). Survival mechanisms and culturability of *Campylobacter jejuni* under stress conditions. *Antonie Van Leeuwenhoek International Journal of General and Molecular Microbiology*, 96(4), 377–394.
- Jay, L. S., Comar, D., & Govenlock, L. D. (1999). A video study of Australian domestic food-handling practices. *Journal of Food Protection*, 62(11), 1285–1296.
- Kassa, H., Harrington, B., Bisesi, M., & Khuder, S. (2001). Comparisons of microbiological evaluations of selected kitchen areas with visual inspections for preventing potential risk of foodborne outbreaks in food service operations. *Journal of Food Protection*, 64(4), 509–513.
- Kennedy, J., Nolan, A., Gibney, S., O'Brien, S., McMahon, M. A. S., McKenzie, K., et al. (2011). Determinants of cross-contamination during home food preparation. *British Food Journal*, 113(2–3), 280–297.
- Luber, P. (2009). Cross-contamination versus undercooking of poultry meat or eggs - which risks need to be managed first? *International Journal of Food Microbiology*, 134(1–2), 21–28.
- Luber, P., & Bartelt, E. (2007). Enumeration of *Campylobacter* spp. on the surface and within chicken breast fillets. *Journal of Applied Microbiology*, 102(2), 313–318.
- Margas, E., Meneses, N., Conde-Petit, B., Dodd, C. E. R., & Holah, J. (2014). Survival and death kinetics of *Salmonella* strains at low relative humidity, attached to stainless steel surfaces. *International Journal of Food Microbiology*, 187, 33–40.
- Martens, L. (2007). The visible and the invisible: (De)regulation in contemporary cleaning practices. In B. Campkin, & R. Cox (Eds.). *Dirt: New geographies of cleanliness and contamination* (pp. 34–48). London: I.B. Taurus & Co Ltd.
- Moen, B., Rossvoll, E., Måge, I., Mørretro, T., & Langsrud, S. (2016). Microbiota formed on attached stainless steel coupons correlates with the natural biofilm of the sink surface in domestic kitchens. *Canadian Journal of Microbiology*, 62(2), 148–160.
- Moerman, F. (2010). Hygienic design of food processing facilities. *Food safety magazine*.
- Moore, G., & Griffith, C. (2002). A comparison of traditional and recently developed methods for monitoring surface hygiene within the food industry: An industry trial. *International Journal of Environmental Health Research*, 12(4), 317–329.
- Mørretro, T., & Langsrud, S. (2017). Residential bacteria on surfaces in the food industry and their implications for food safety and quality. *Comprehensive Reviews in Food Science and Food Safety*, 16(5), 1022–1041.
- Mørretro, T., Normann, M. A., Sæbø, H. R., & Langsrud, S. (2019). Evaluation of ATP bioluminescence-based methods for hygienic assessment in fish industry. *Journal of Applied Microbiology*, 127(1), 186–195.
- Mulvey, D., Redding, P., Robertson, C., Woodall, C., Kingsmore, P., Bedwell, D., et al. (2011). Finding a benchmark for monitoring hospital cleanliness. *Journal of Hospital Infection*, 77(1), 25–30.
- On, S. L. W., Dorrell, N., Petersen, L., Bang, D. D., Morris, S., Forsythe, S. J., et al. (2006). Numerical analysis of DNA microarray data of *Campylobacter jejuni* strains correlated with survival, cytolethal distending toxin and haemolysin analyses. *International Journal of Medical Microbiology*, 296(6), 353–363.
- Redmond, E. C., & Griffith, C. J. (2003). Consumer food handling in the home: A review of food safety studies. *Journal of Food Protection*, 66(1), 130–161.
- Rusin, P., Orosz-Coughlin, P., & Gerba, C. (1998). Reduction of faecal coliform, coliform and heterotrophic plate count bacteria in the household kitchen and bathroom by disinfection with hypochlorite cleaners. *Journal of Applied Microbiology*, 85(5), 819–828.
- Tebbutt, G. M. (1991). Development of standardized inspections in restaurants using visual assessments and microbiological sampling to quantify the risks. *Epidemiology and Infection*, 107(2), 393–404.
- Tebbutt, G. M., & Southwell, J. M. (1989). Comparative study of visual inspections and microbiological sampling in premises manufacturing and selling high-risk foods. *Epidemiology and Infection*, 103(3), 475–486.
- Wang, J. Q., Wu, H. Y., Song, M., Li, F. Q., Zhu, J. H., Xi, M. L., et al. (2013). Prevalence and quantitative detection of *Salmonella* in retail raw chicken in Shaanxi, China. *Journal of Food Protection*, 76(11), 1958–1962.
- Whitehead, K. A., Smith, L. A., & Verran, J. (2008). The detection of food soils and cells on stainless steel using industrial methods: UV illumination and ATP bioluminescence. *International Journal of Food Microbiology*, 127(1–2), 121–128.
- Wills, W., Meah, A., Dickinson, A., & Short, F. (2013). Domestic kitchen practices: Findings from the 'kitchen life' study. Unit report 24. *Social science research unit*. UK: Food Standards Agency.
- Wyatt, C. J., & Guy, V. (1980). Relationships of microbial quality of retail meat samples and sanitary conditions. *Journal of Food Protection*, 43(5), 385–389.