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6200 Aurora Ave., Suite 200W, Des Moines, IA 50322-2864

Jeannie Sneed,[1*] Randall Phebus,[2] Diane Duncan-Goldsmith,[3] Donka Milke,[2] Kevin Sauer,[1] Kevin R. Roberts[1] and Dallas Johnson[4]

[1]Dept. of Hospitality Management and Dietetics, Kansas State University, 152 Justin Hall, Manhattan, KS 66506-1403, USA

[2]Dept. of Animal Sciences and Industry, Kansas State University, 223 Call Hall, Manhattan, KS 66506, USA

[3]Dept. of Apparel, Events, and Hospitality Management, Iowa State University, 31 MacKay Hall, Ames, IA 50011-1121, USA (formerly at Kansas State University);

[4]Dept. of Statistics, Kansas State University, Manhattan, KS 66506-1403, USA

Consumer Food Handling Practices Lead to Cross-contamination

ABSTRACT

Consumers engage in food handling practices that can contribute to foodborne illness, and there is interest in improving those behaviors. The purpose of this study was to determine the impact of the "Food Safe Families" clean and separate messages on cross-contamination behaviors of consumers and to determine the impact of external safe food handling cues. Participants (n = 123) were randomly assigned to a control group or to one of two experimental groups (traditional food safety messages or Ad Council public service announcements). Experimental groups were given a defined educational intervention; then all three groups were videotaped preparing a meal with raw chicken or ground beef (inoculated with *Lactobacillus casei*) and a ready-to-eat fruit salad. About 90% of salads were contaminated and 24% were highly contaminated, although levels were lower for the food safety messages group. Handwashing scores were lower for the control group than for the other groups. Cloth towels were the most contaminated contact surface, and towels were frequently handled by participants. A slight positive impact relative to the level of cross-contamination observed was associated with the use of external cues. Cell phone use was observed in the kitchen and should be studied as a source of cross-contamination. An educational intervention had a small impact on some measures, but most participants in all groups used procedures that resulted in cross-contamination.

INTRODUCTION

About 9% of all reported foodborne illness outbreaks occur in private homes, with a median of eight illnesses per outbreak *(15)*. An earlier analysis indicated that 15% of outbreaks resulted from food consumed in a private home *(14)*. For bacterial outbreaks, cross-contamination from raw ingredients of animal origin, bare hand contact by a food preparer, and inadequate cleaning of equipment and utensils were identified as major contamination factors *(7)*.

Consumers have reported food handling practices that could create cross-contamination in home kitchens *(1-3, 5, 8, 16, 19-20, 26)*. Observations of food handling practices showed that consumers do not follow cross-contamination

*Author for correspondence: Phone: +1 785.532.5507; Fax: +1 785.532.5522; Email: jsneed@k-state.edu

prevention behaviors *(6, 18)*. Video observations conducted in a number of states indicate that consumers fail to practice adequate handwashing (including both frequency and appropriate technique), and this failure presents many opportunities for cross-contamination *(4, 10, 17, 18, 22, 24)*.

Several microbiological studies have examined kitchen surfaces as contamination sources. Donofrio et al. *(12)* found high bacterial counts on sponges and the kitchen sink as well as coliforms present on dish sponges, the sink, cutting boards, and countertops. Another study *(9)* concluded that rinsing surfaces in conjunction with use of detergent-based cleaners is essential to cleaning, that antimicrobial agents may be necessary, and that *Salmonella* grows on cloths stored overnight even after they were washed and rinsed.

Several studies have focused on food handling practices and the presence of microbial contamination. Redmond et al. *(23)* videotaped 24 adults preparing meals and found numerous practices contributing to cross-contamination, including using the same preparation area for raw chicken and ready-to-eat (RTE) pasta salad, using a common cutting board or failing to sanitize it, and allowing direct contact of the work surface with raw chicken packaging. Further, inadequate handwashing practices that could lead to cross-contamination were observed. Three studies *(11, 13, 21)* used *Lactobacillus casei,* a non-pathogenic tracer inoculant, to track cross-contamination between raw meats and salads. Most salads were found to contain some tracer bacteria, and a high percentage were heavily contaminated. The researchers concluded that consumer cleaning procedures in the kitchen were not sufficient to prevent cross-contamination, on the basis of observing use of the same cutting board for raw meat and RTE product that would not be further cooked, rinsing of cutting boards and knives with cold water and no soap, and touching of kitchen surfaces with contaminated hands.

Because research strongly indicated a need for improving consumers' food handling behaviors, the USDA Food Safety and Inspection Service (FSIS) developed the *Be Food Safe* campaign "to provide educators with the tools to inform consumers about foodborne illness and raise the level of awareness of dangers associated with improper handling and undercooking of food *(25)*." The campaign focused on four key concepts: clean, separate, cook, and chill. Later, FSIS and the AdCouncil transitioned this campaign to *Food Safe Families,* which focuses on the same four concepts.

The purpose of this study was to determine the impact of the *Food Safe Families* clean and separate messages (two of the campaign's four key messages), delivered to a targeted group of consumers using two different approaches, on their observed food handling practices during a home meal preparation activity. To compare participants' food safety behaviors objectively, a tracer bacterial inoculant in the final RTE salad was correlated with cross-contamination across the kitchen environment. A secondary objective was to determine if external food safety cues in the kitchen would impact behaviors.

MATERIALS AND METHODS

Sample

The sample consisted of 123 parents (either mother or father, depending on which parent was the family's primary food preparer) who met the following criteria: young parents between 20 and 45 years of age; prepared four or more meals at home each week; had at least one child less than 13 years old in the home; and spoke English. Each individual was randomly assigned to one of three groups (control and two experimental groups). The institutional review board at Kansas State University approved the study protocol. All participants signed consent forms to verify their desire to participate.

Research design

A control group and two experimental (exposure) groups were used. The control group was provided with a 45-minute program on nutrition for children, which contained no food safety messages. The Food Safety Messages Group (FSM) was provided a 45-minute face-to-face educational program on the four *Food Safe Families* messages (clean, separate, cook, and chill), which included a PowerPoint™ presentation, discussion, and activities. A pamphlet on the *Food Safe Families* messages, two magnets, a bookmark, and a food safety quiz were given as handouts. The Ad Council Messages Group (AdCM) participated in a 45-minute session in which participants viewed and discussed each of the four Ad Council public service announcements. Discussion questions included what the ad meant to them and what behaviors they would change after viewing the message. All sessions were presented by a registered dietitian with experience in training. If incorrect information was brought up by participants, the moderator provided the accurate information. After these sessions, participants were invited to participate in a project to develop quick and easy recipes for young children. Those who volunteered prepared a meal consisting of an entrée using raw meat (either ground beef or poultry) and a RTE fruit salad. All meals were prepared in a consumer kitchen equipped with four cameras strategically but inconspicuously placed to record the food handling behaviors of participants. Participants knew they were being videotaped but did not know that a non-pathogenic tracer organism was being used. Participants were asked not to taste anything, and a debriefing was held immediately following data collection. Two refrigerator magnets developed by the FSIS ("Is it Done Yet?" and the clean, separate, cook, and chill messages) were used as food safety cues for half of the participants in each group. After the cooking session, participants were debriefed

about the purpose of the study. A rubric was developed and used for recording observations from the videotaped meal preparation sessions. A total hand washing score and a cross-contamination score were calculated for each participant based on his or her observed behaviors, and these scores were used to determine differences associated with group, type of meal prepared, and whether or not cues were provided. A handwashing score was assigned (0 = no handwashing; 1 = washed less than 20 seconds with no soap; 2 = washed 20 or more seconds with no soap; 3 = washed less than 20 seconds with soap; 4 = washed 20 or more seconds with soap) for each handwashing event (prior to meal preparation, after handling raw meat, after handling raw meat packaging, after throwing away trash, after handling raw egg, and after handling fruits and vegetables). The handwashing score could range from zero to 24. A cross-contamination score was assigned based on eight behaviors (washing hands after handling raw meat, washing hands after handling raw meat packaging, washing counter after handling raw meat, using a common hand towel, using same utensil for raw and cooked meat, using same utensil for raw meat and salad ingredients, washing cutting board between uses, and washing bowls between uses). The cross-contamination score could range from zero to eight, based on yes/no responses to each practice.

Microbiological analysis

Lactobacillus casei (ATCC 334; KWIK-STIK™) was obtained from Microbiologics, Inc. (St. Cloud, MN) to serve as a non-pathogenic "tracer" organism to gauge microbiological cross-contamination associated with handling raw meat. The culture was received at the K-State Food Safety and Defense Laboratory (FSDL) and activated according to the supplier's instructions. The activated culture was transferred onto Tryptic Soy Agar with 5% Sheep Blood (TSA; Remel, Lenexa, KS), incubated at 35°C under anaerobic conditions for 48 h, and stored at 4°C. Biochemical confirmation of the tracer culture as received was done using API 50 CHL test strips (bioMérieux, Inc., Durham, NC) at the time of receipt. This working culture was propagated and biochemically confirmed bi-weekly during the course of the study to ensure continued viability and purity. To prepare a master inoculum for use on each day of food preparation, a single colony of *L. casei* was transferred into 9 ml of de Mann, Rogosa, Sharpe broth (MRS; Oxoid Ltd, Basingstoke, Hampshire, UK) and incubated at 35°C for 24 h. The inoculum was maintained at 4°C and applied to the raw meat product within 12 h of scheduled consumer food preparation activities.

Participants received packages of either two raw boneless skinless chicken breasts or 90% lean ground beef, as predetermined for their assigned treatment group. The raw meat for each recipe was purchased at a local supermarket and stored at 4°C for no more than 3 days prior to inoculation. At the time of inoculation, raw products were removed from their original packaging and placed onto new Styrofoam™ trays with absorbent pads. Two mL of master inoculum was dispensed onto two chicken breasts (0.5 mL to each side) and evenly distributed using a L-shaped cell spreader to achieve a target of 10^{6-7} CFU. A one-pound brick of ground beef was bisected horizontally with a sanitized knife, and both interior (bisected middle) and exterior (top and bottom) surfaces were inoculated evenly with 0.5 mL of culture (total of 2 mL applied) to achieve a target of 10^{6-7} CFU/g. The two inoculated meat portions were joined to re-establish the single brick appearance. The trays of both inoculated chicken breasts and inoculated ground beef were wrapped with plastic film to appear as purchased from a retail market and stored in the refrigerator (4°C) for no longer than 12 h prior to each participant's meal preparation session. In preliminary studies, meat products to be used in the *L. casei* tracer studies with participants were inoculated as described, trays containing the inoculated meat were overwrapped and stored for 24 h at 4°C, and *L. casei* levels were confirmed to consistently achieve the target level of 10^6 CFU/g of meat (data not shown). A standard USDA-mandated safe handling label *(Fig. 1)* was applied to each package. It should be noted that these labels contain the basic food safety messages and so could be considered external cues that all participants received.

Figure 1. Safe handling instructions for meat packages

Detection of tracer *L. casei* in the final prepared fruit salad represented definitive evidence that cross-contamination had occurred directly or indirectly from raw meat into the RTE salad. In preliminary studies, fresh cut fruit used to prepare salads, along with raw chicken and ground beef, was analyzed on multiple occasions, using cultural procedures defined for the formal study. No native background microflora were detected that were indistinguishable from the inoculated *L. casei* culture (i.e., 1 mm, white, round, opaque, raised, smooth colony forming units on anaerobically incubated MRS agar spread plates). After completion of each participant's meal preparation activities, the entire fruit salad was aseptically bagged and labeled, placed in an insulated transport container with blue ice packs and transported to the K-State FSDL for analysis within 24 h. The entire salad was homogenized in a Smasher™ Lab Blender (AES CHEMUNEX; Bruz, France) for 60 s. Twenty-five grams of the homogenate were transferred to a sterile stomacher bag containing 75 mL of sterile 0.1% peptone water (Becton Dickinson, Sparks, MD) and stomached for 60 s. The sample was enumerated for *L. casei* levels by plating serial dilutions (in duplicate) onto MRS agar. Plates were placed in a sealed container with anaerobic gas packs (Pack-Anaero; Mitsubishi Gas Chemical America, Inc., New York, NY) and incubated at 35°C for 48 h. At regular intervals during the study, presumptive *L. casei* colonies on MRS agar plates were confirmed by use of API 50 CHL test strips and Gram staining.

The kitchen environment was sampled for the presence of *L. casei* with surface swabs immediately after completion of each participant's meal preparation activities and thus after any post-food preparation cleaning and sanitizing procedures participants chose to utilize. The specific location on the countertop where food preparation occurred was recorded on a kitchen diagram by a research team member who observed food preparation on a screen in an adjoining room, and two counter sponge (hydrated with 25 mL 0.1% peptone) samples (400 cm^2 each) were taken from those countertop areas. Sterile cotton-tipped swabs in Letheen broth (Hygiena Q-Swab; Camarillo, CA) were used to swab a 15-cm section of the refrigerator handle, faucet, trash cabinet handle, and oven handle, as well as the salt shaker (data were reported based on a per handle or shaker basis). A new dishcloth and hand towel (sterilized by autoclaving prior to each meal preparation session) were available for each participant to use during the meal preparation session. These were collected separately, aseptically bagged, and labeled after each session. All surface samples were placed in an insulated cooler with the fruit salad sample and transported to the laboratory for analysis. Samples were collected after participants left; then the kitchen was thoroughly cleaned and sanitized with a 70% alcohol solution, and supplies were restocked by the research team prior to arrival of the next participant. In this study, 70% alcohol was chosen as the kitchen spray sanitizer provided to participants for their discretionary use and was also used by the study team for disinfecting all kitchen surfaces between participants, to avoid issues with residual sanitizer antimicrobial effects that would compromise our ability to detect cross-contamination by participants. A liberal amount of sanitizer was applied, with a contact time of at least 15 minutes, with focused disinfection efforts made at the defined sampling locations, to ensure no residual *L. casei* within the kitchen environment after each participant's meal preparation activities. For microbiological analyses to enumerate *L. casei*, 250 mL and 350 mL of 0.1% sterile peptone water were added to the bags containing the dishcloth and hand towel, respectively, followed by hand massaging for 1 min. Serial dilutions of all environmental swabs and cloth sample rinses were plated onto MRS agar and incubated under anaerobic conditions at 35°C for 48 hours.

DATA ANALYSIS

An observation rubric was developed for scoring the videotaped food preparation sessions to enumerate when hand washing was supposed to occur and when it actually did occur, as well as instances of behaviors that could lead to cross-contamination. SPSS (IBM SPSS, ver. 20, Armonk, NY) was used to analyze all observational data, with descriptive statistics to characterize each variable and ANOVA to determine differences among groups. A total handwashing score and a total cross-contamination score were calculated. All microbiological data were analyzed using SAS/STAT (ver. 13.1, Cary, NC). Descriptive statistics were calculated for counts for each sampling location and ANOVA was used to determine differences among groups. For samples for which *L. casei* was below the detection limit by direct plating, one-half of the calculated detection limit was used for purposes of statistical analyses. Each kitchen sampling location was separated into three levels of contamination: low was within the lowest quartile; medium was between 25% and 75%; and high the highest quartile. Chi-square tests were used to detect associations between various treatments and the likelihood that the RTE fruit salad was contaminated. A 10% significance level was used for all tests. There has been little similar research to provide guidance; thus, this significance level was selected so that important food safety issues would not be missed.

RESULTS

Sample

Of the total of 123 individuals recruited to participate in the study, about 90% were female, all but one fell within the 20 to 45 age range, and 70% had either a Bachelor's or a Master's degree. Approximately 92% held higher education degrees (Associate or higher). Most participants reported that they were white, with about 20% being Asian or African-American.

Video observations

The frequency distributions for each handwashing event by group, meal, and cues are presented in *Table 1*. In many instances, hands were not washed or the techniques used were inadequate. A surprisingly large number did not wash their hands before beginning meal preparation, and

TABLE 1. Frequency and technique of handwashing by group, meal, and cues (n = 123)

Handwashing event	Group[a]			Meal[b]		Cues[c]	
	Control	FSM	AdCM	Beef	Chicken	Yes	No
Washed hands prior to meal preparation							
No	14	7	14	18	17	19	16
< 20 s, no soap	0	0	0	0	0	0	0
≥ 20 s, no soap	0	0	0	0	0	0	0
< 20 s, with soap	6	7	8	16	15	17	14
≥ 20 s, with soap	20	17	20	30	27	26	31
Washed hands after handling raw meat							
No	1	0	0	0	1	0	1
< 20 s, no soap	6	4	2	4	8	8	4
≥ 20 s, no soap	6	2	3	4	7	6	5
< 20 s, with soap	12	13	20	21	24	21	24
≥ 20 s, with soap	12	18	14	26	18	23	21
Washed hands after handling raw meat packaging							
No	21	22	24	26	41	34	33
< 20 s, no soap	3	2	3	4	4	3	5
≥ 20 s, no soap	13	16	13	30	12	20	21
< 20 s, with soap	0	0	0	0	0	0	0
≥ 20 s, with soap	3	1	2	4	2	4	2
Washed hands after throwing away trash							
No	19	23	19	31	30	35	26
< 20 s, no soap	10	4	7	11	10	12	9
≥ 20 s, no soap	3	4	8	9	6	4	11
< 20 s, with soap	5	8	7	11	9	9	11
≥ 20 s, with soap	2	2	0	1	3	1	3
Washed hands after handling raw egg							
No	16	14	9	15	24	18	21
< 20 s, no soap	13	3	14	15	15	18	12
≥ 20 s, no soap	0	0	1	1	0	1	0
< 20 s, with soap	10	23	17	33	17	24	26
≥ 20 s, with soap	1	1	0	0	2	1	1

Table 1 continued on next page

TABLE 1. Frequency and technique of handwashing by group, meal, and cues (n = 123) (cont.)

Handwashing event	Group[a]			Meal[b]		Cues[c]	
	Control	FSM	AdCM	Beef	Chicken	Yes	No
Washed hands after handling fruits and vegetables							
No	12	11	9	17	15	19	13
< 20 s, no soap	21	17	17	30	25	25	30
≥ 20 s, no soap	4	7	8	9	10	9	10
< 20 s, with soap	3	5	6	7	7	7	7
≥ 20 s, with soap	0	0	2	1	1	1	1

[a]Participants were assigned to one of three groups: control; Food Safety Messages (FSM); and Ad Council Messages (AdCM).
[b]Participants were randomly assigned to prepare either a recipe with raw ground beef or chicken.
[c]Half of the participants in each group were randomly provided food safety cues on refrigerator magnets.

TABLE 2. Frequency of cross-contamination behaviors by group, meals, and cues (n = 123)

Practices related to cross-contamination	Group[a]			Meals[b]		Cues[c]	
	Control	FSM	AdCM	Beef	Chicken	Yes	No
Washed counter after handling raw meat							
No	35	34	39	59	49	59	51
Yes	5	7	3	5	10	5	10
Used common cloth for drying hands							
No	9	10	6	12	13	15	10
Yes	31	31	34	51	45	46	50
Used common cloth for drying equipment							
No	9	12	13	21	13	15	19
Yes	31	29	27	42	45	46	41
Used same utensils for raw meat and cooked meat without wash between uses							
No	39	38	41	63	55	57	4
Yes	1	3	1	1	4	61	1
Used same utensils for raw meat and salad prep without wash between uses							
No	38	40	42	63	57	61	59
Yes	2	1	0	1	2	1	2

[a]Participants were assigned to one of three groups: control; Food Safety Messages (FSM); and Ad Council Messages (AdCM).
[b]Participants were randomly assigned to prepare a recipe with either raw ground beef or chicken.
[c]Half of the participants in each group were randomly provided food safety cues on refrigerator magnets.

TABLE 3. Mean log colony forming unit (CFU) *L. casei* counts recovered at each kitchen location sampled after participants completed all meal preparation activities

Variable	N[a]	Mean	Std. Dev.	Min.[c]	Max.
Sink handle[1]	123	1.04	0.72	<-0.30[b] (13)	2.61
Fridge handle[1]	123	0.81	0.73	<-0.30[b] (14)	2.64
Oven handle[1]	122	0.61	0.65	<-0.30[b] (21)	2.48
Salt shaker[1]	122	0.59	0.78	<-0.30[b] (36)	2.69
Trash handle[1]	122	1.01	0.91	<-0.30[b] (16)	3.61
Small Towel[1]	121	3.74	1.13	<2.10[b] (20)	5.93
Large Towel[1]	121	4.43	1.13	<2.24[b] (6)	6.44
Countertop 1[2]	123	-0.44	0.78	<-1.51[b] (27)	1.63
Countertop 2[2]	123	-0.43	0.76	<-1.51[b] (22)	1.23
Salad[3]	123	1.81	0.86	<0.30[b] (12)	3.76

[a]Total number of participant observations collected.

[b]No *L. casei* contamination was detected by direct plating; therefore, one-half of the calculated detection limit was recorded for purposes of statistical analyses.

[c]Value in parentheses indicates number of observations showing no *L. casei* contamination detected.

[1]*L. casei* counts reported as log CFU per item tested (i.e., handle, towel or shaker).

[2]*L. casei* counts reported as log CFU/cm^2. A total of 400 cm^2 of surface area was sponge sampled at each countertop location. These two areas were chosen based upon observations by research personnel regarding areas of the countertop in which participants conducted the majority of their meal preparation activities.

[3]*L. casei* counts reported as log CFU/g of finished fruit salad.

even more did not wash hands after handling raw meat packaging and trash. The numbers of participants who washed their hands with soap for 20 s was very low. The overall ANOVA model for handwashing was significant ($F = 2.36$, $P < 0.0106$), with group, meal, and meals x cues interactions being significant. Handwashing scores were highest for the food safety messages group (1.83) and lowest for the control group (1.52). The lowest handwashing scores were for the group that prepared chicken and had external food safety cues.

The frequencies of cross-contamination behaviors by group, meal, and cues are summarized in *Table 2*. After handling raw meat, most participants washed their hands with soap, but often for less than the recommended 20 s. About three-fourths used a common towel for drying hands. Few people used the same cutting board for raw meat and fresh fruit.

ANOVA comparing groups, meals, cues, and interactions found that cross-contamination scores were different only for the meal prepared. The least squares means for meals containing beef ($M = 1.02$) and chicken ($M = 0.87$) were different ($P < 0.01$), indicating that more cross-contamination behaviors were observed in participants preparing meals utilizing raw chicken than in those preparing meals using ground beef.

TABLE 4. Pair-wise comparisons of mean *L. casei* log counts at different kitchen sampling locations by category

Category	Dependent Variable	Source	Mean (log CFU)	*P*-value
Group[a]	Oven Handle	Control	0.77	0.061
		FSM	0.49	
Group by Meal[b]	Sink Handle	AdCM Chicken	1.22	0.064
		FSM Chicken	0.79	
	Salad	AdCM Chicken	1.96	0.083
		FSM Chicken	1.47	
	Salt Shaker	FSM Beef	0.78	0.039
		FSM Chicken	0.27	
Cues[c]	Sink Handle	No Cues	1.16	0.091
		Yes Cues	0.94	
Group by Cues	Small Towel	AdCM No Cues	3.87	0.089
		AdCM Cues	3.25	
	Small Towel	AdCM Cues	3.25	0.089
		FSM Cues	3.92	
	Oven Handle	Control No Cues	0.98	0.041
		Control Cues	0.56	
Meal by Cues	Sink Handle	Beef No Cues	1.22	0.065
		Beef Cues	0.88	
	Large Towel	Beef Cues	4.73	0.058
		Chicken Cues	4.17	
	Small Towel	Chicken No Cues	4.01	0.093
		Chicken Cues	3.50	
Group by Meal by Cues	Small Towel	AdCM Chicken No Cues	3.95	0.059
		AdCM Chicken Cues	2.95	
	Small Towel	AdCM Chicken Cues	2.95	0.080
		FSM Chicken Cues	3.88	
	Oven Handle	Control Chicken No Cues	1.03	0.047
		Control Chicken Cues	0.45	
	Salt Shaker	FSM Beef Cues	0.88	0.059
		FSM Chicken Cues	0.23	
	Fridge Handle	AdCM Chicken No Cues	1.03	0.047
		FSM Chicken No Cues	0.45	

[a]Participants were assigned to one of three groups: control; Food Safety Messages (FSM); and Ad Council Messages (AdCM).
[b]Participants were randomly assigned to prepare a recipe with either raw ground beef or chicken.
[c]Half of the participants in each group were randomly provided food safety cues on refrigerator magnets.

Microbiological results

Simple statistics were calculated for *L. casei* counts recovered at the different sampling locations to determine the average overall spread of contamination throughout the kitchen. The pooled results for all treatment groups *(Table 3)* show the most common kitchen locations or items contaminated by participants during meal preparation. Regardless of participant treatment group, 90.2% of all 123 prepared salads had some level of contamination with the tracer culture, and 24.4% of all participants contaminated the fresh salad heavily, with over 2.4 log CFU/g (75th percentile). The largest source of cross-contamination during meal preparation was the small dishcloth and large cloth towels, which harbored mean levels of 3.74 and 4.43 log units of *L. casei* contamination per towel, respectively.

ANOVA tables and mean pairwise comparisons for *L. casei* counts were developed for each sampling location for groups, meals, cues, and interactions ($P \leq 0.10$; *Table 4*). The oven handle counts differed ($P = 0.061$) for the control and FSM groups (0.77 and 0.49 log CFU/handle, respectively). This could be because no food safety concepts *per se* were provided to the control group in their pre-meal preparation informational session, while the FSM group had an informational session covering the basic food safety messages of clean, separate, cook, and chill. No significant differences ($P > 0.10$) were found in contamination levels at any sampling location between participants who cooked entrees containing chicken versus beef.

Differences in contamination levels were observed for sink handles ($P = 0.064$) and in the finished RTE fruit salad ($P = 0.083$) between the AdCM and FSM participant groups who prepared entrees containing chicken. In each case, the FSM participant group exhibited a lower contamination level (approximately 0.5 log cycle) than the AdCM group.

Both entrée recipes required participants to add salt to the entrée during preparation. It is interesting that within the FSM participant group only, a significantly higher ($P = 0.039$) contamination level was observed on the surface of the saltshaker for participants who utilized ground beef as a recipe ingredient than for those who used chicken. The ground beef-containing recipe required participants to form meatballs, which likely resulted in more extensive handling of the raw meat product using either their hands or a kitchen utensil such as a dipper. The handling/slicing of raw chicken breasts and placing them into a bag of breading may have required less direct hand contact, and perhaps led to less transfer of contamination to the salt shaker. However, this difference was observed only in the FSM group and not in the control or AdCM groups.

When participants across all groups who received cues or no cues were compared, a significant difference was observed only for sink handle contamination. Participants who received external food safety cues tended to demonstrate slightly lower contamination on sink handles ($P = 0.09$), but the actual difference in counts (1.16 versus 0.94 log CFU/handle) was of little practical relevance.

Comparing participant groups by cues, small differences ($P \leq 0.10$) in contamination rates were observed only for the small cloth towel and the oven handle. The mean *L. casei* count for the small towel was 0.62 log CFU/towel lower for AdCM participants who received cues than for AdCM participants not receiving cues. A difference ($P = 0.089$) in small towel counts between AdCM participants receiving cues and FSM participants receiving cues was noted, with the AdCM group resulting in slightly lower contamination levels (0.67 log cycle difference). Finally, a difference ($P = 0.041$) was observed in *L. casei* contamination levels for the control group between participants receiving cues and those not receiving cues (mean levels of 0.56 and 0.98 log CFU/handle, respectively). Although not a strong indication, there may be a slight positive impact associated with the use of external cues (i.e. refrigerator magnets) relative to lessening cross-contamination events during meal preparation.

Comparing participant meals by cues, small differences ($P \leq 0.10$) in contamination rates were observed for the sink handle, small cloth towel, and the large cloth towel only. The mean *L. casei* count for the sink handle was 0.34 log CFU/handle lower for participants cooking beef when cues were present versus when cues were absent. A difference ($P = 0.058$) in large towel counts between participants who handled beef while cues were present versus participants who handled chicken with cues present was noted, with the presence of cues resulting in slightly lower contamination levels (0.56 log CFU/towel difference). Finally, a difference ($P = 0.093$) was observed in *L. casei* contamination levels on the small towel for participants who cooked chicken with or without cues (mean levels of 3.50 and 4.01 log CFU/towel, respectively). Again, this may show a slight positive impact associated with the use of external food safety cues relative to the level of cross-contamination during meal preparation.

When the participant groups by meal by cues interaction was compared, differences ($P \leq 0.1$) in contamination rates were observed for the small cloth towel, oven handle, salt shaker, and refrigerator handle. The mean *L. casei* count for the small dish cloth was 1.0 log CFU/towel lower for participants in the AdCM group who were cooking chicken with external cues present versus when cues were not present. There was also a difference ($P = 0.080$) in the small dish cloth counts between the AdCM group and the FSM group when both were cooking chicken with cues present, with the AdCM

group having a 0.93 log CFU/towel lower contamination level. A difference ($P = 0.047$) in oven handle counts for the control group who handled chicken with and without external cues was observed, with the presence of cues resulting in slightly lower contamination levels (0.58 log difference). Within the FSM participant group who received external cues, a difference ($P = 0.059$) in *L. casei* counts was noted on the salt shaker for participants preparing entrees containing beef and chicken (0.88 and 0.23 log CFU/shaker, respectively). Finally, a difference ($P = 0.047$) was observed in *L. casei* contamination levels on the refrigerator handle between the participants from the AdCM and FSM groups who received no external cues while preparing a chicken-based entrée (mean levels of 1.03 and 0.45 log CFU/handle, respectively).

The most relevant findings from the Chi-square test were associated with the final RTE fruit salad as the sampling point. Again, presence of the tracer microorganism, *L. casei,* in the final salad indicated cross-contamination from handling raw meat or poultry. A significant difference in salad contamination occurred when meal preparation involved handling raw ground beef rather than raw chicken breasts. For fruit salad contamination level designations, the 25% quartile was contaminated at a level of ≤ 1.20 log CFU/g and the 75% quartile was at ≥ 2.45 log CFU/g.

The estimated probability of final salad contamination levels being within the two middle quartiles (moderate contamination) was 0.52 for ground beef and 0.45 for chicken. However, larger probability differences in final salad contamination levels were observed between ground beef and chicken for the lowest and highest quartiles. The estimated probability of ground beef observations falling into the lowest quartile was 0.11, while the estimated probability of chicken observations falling into the lowest quartile was 0.43. The estimated probability of ground beef falling into the upper quartile was 0.37 and the estimated probability of chicken falling into the upper quartile was 0.12. This suggests that participants who cooked chicken prepared a larger proportion of RTE salads with lower contamination levels compared to participants who prepared a ground beef dish. On the other hand, participants who cooked ground beef entrees had a much larger proportion of highly contaminated salads compared to those who cooked the chicken entree.

The estimated probability of fruit salad contamination levels being within the moderate range was 0.52 when participants were provided external cues (refrigerator magnets), compared with 0.45 when no cues were provided. However, there were differences between the lower and upper quartiles. The estimated probability of "cues" observations falling into the lowest quartile was 0.16, while the estimated probability of "no cues" observations falling into the lowest quartile was 0.38. The estimated probability of a "cues" observation falling into

TABLE 5. Association between log counts for *L. casei* on various contact surfaces and in salad with observed handwashing behaviors and cross-contamination (n = 123)

Logs	Handwashing		Cross-contamination	
	Correlation[a]	Probability[b]	Correlation[a]	Probability[b]
Sink Handles	-0.23195	0.0098	-0.11664	0.1989
Refrigerator Handle	-0.17513	0.0527	0.00901	0.9212
Oven Handle	-0.10557	0.2471	-0.26654	0.0030
Salt Shaker	0.04821	0.5980	0.06997	0.4438
Trash Handle	-0.23249	0.0100	-0.10053	0.2705
Small Towel	-0.21884	0.0159	-0.31962	0.0004
Large Towel	0.07755	0.3979	0.06136	0.5038
Countertop (Location 1)	-0.20566	0.0225	-0.05116	0.5742
Countertop (Location 2)	0.01165	0.8982	0.05341	0.5574
Salad	-0.01149	0.8996	-0.07753	0.3940

[a]Pearson Correlation Coefficients
[b]Prob > |r| under H0: Rho=0

the upper quartile was 0.32 and the estimated probability of a "no cues" observation falling into the upper quartile was 0.17. This shows that the proportion of the "no cues" observations falling into the lowest quartile was greater than the proportion of those with "cues," while the proportion of the "no cues" observations falling into the upper quartile was much smaller than the proportion of those with "cues." In other words, participants who were not provided with external food safety cues had a larger proportion of salads with low contamination levels and a smaller proportion of salads with high contamination, compared to participants who were provided with cues.

Relationship between observations and microbiological analysis

Pearson Correlation coefficients were calculated to identify associations between hand washing and cross-contamination and the level of contamination of *L. casei* on several contact surfaces in the kitchen and in the RTE fruit salad that participants prepared *(Table 5)*. Handwashing was associated with the tracer organism counts on the sink handle, trash handle, small towel, and the main countertop used for food preparation. The oven handle and the small towel were the surfaces associated with the cross-contamination scores of participants.

DISCUSSION

Ninety percent of the RTE fruit salads prepared by participants across the three treatment groups were contaminated at some level with *L. casei,* and about 24% were highly contaminated. There was a high frequency and level on kitchen contact surfaces due to the food handling practices of participants. Fischer et al. *(13)* found that 42% of the variance in log reductions in a finished salad could be explained by cross-contamination practices of participants. Nauta et al. *(21)* concluded that most of the participants in their study were unable to prepare a salad without contaminating it with the tracer organism.

There were several potential sources of cross-contamination. Many instances were observed when hands were not washed or where the techniques used were inadequate, including at the beginning of food preparation and after handling raw meat packaging and trash. Handwashing consistently has been identified as a shortcoming in studies in which consumer activity was videotaped *(4, 17, 22, 24)*.

There were several instances in which the treatment impacted cross-contamination. The control group had lower mean handwashing scores than either the AdCM group or the FSM group. Further, contamination on oven handles was lower for the FSM group than for the control group. Differences in contamination levels were observed on sink handles and RTE salads between the FSM and AdCM groups, and in both cases the FSM group was lower.

Towels were commonly observed to be used multiple times after people washed their hands, often with no soap and/or using very short, ineffective handwashing techniques. This could be one of the most critical findings of this study, as cloth towels can quickly become contaminated at significant levels with microorganisms originating from raw meat and poultry as consumers often use and re-use the towels to wipe or dry their hands after ineffective handwashing. This finding is consistent with those of Cogan et al. *(9)* and Redmond et al. *(23)*, who found significant towel contamination after the preparation of a chicken meal. Cross-contamination events, such as using the towel to wipe up water from work surfaces and for drying/wiping unwashed hands, were identified *(23)*. It should also be noted that some participants chose to use paper towels in lieu of the provided cloth towels to dry their hands. Although the used paper towels were not analyzed in our study, they sometimes were re-used by participants multiple times during the meal preparation and likely served as a source of cross-contamination in the same manner as observed with the cloth towels.

Generally, the spread of *L. casei* contamination throughout the kitchen during meal preparation, as indicated by swabbing appliance, sink, and cabinet handles, showed that raw meat and poultry commonly serve as a food safety risk because of consumers' propensity to cross contaminate. Handles throughout the kitchen commonly became contaminated, sometimes at rather high levels (approaching or exceeding 3 log CFU/area swabbed), during the meal preparation. Our study monitored these surfaces only at the end of consumer preparation activities; thus, in some cases these handles may have become and remained contaminated during the meal preparation but could have been sanitized during a final clean up by the participant. In such cases, our data may not be entirely indicative of the extent to which kitchen handles contribute to cross-contamination of ready-to-eat food dishes by potentially harmful foodborne pathogens. A majority (> 82%) of participants, regardless of their assigned treatment group, left meat-originating contamination on sink, refrigerator, oven, and/or trash cabinet handles. The observed contamination levels on these handles were typically low (< 1 log CFU/ handle); however, in some instances contamination levels approached 3 logs. The handle of the trash can cabinet was left contaminated by 86.9% of participants, with a maximum level of 3.61 log CFU/area swabbed being observed. Similarly, the sink faucet handle was contaminated by 89.4% of participants (mean level of ca. 1 log CFU/handle), with a maximum observed contamination level of 2.61 log CFU/handle. Video observation of participants' meal preparation activities indicated a very broad set of behaviors (many risky) relative to disposing of raw meat packages, touching trash can cabinet and sink faucet handles, and subsequent cutting of fruit salad components. Participants frequently handled

and opened raw meat packages, removed the meat, and used their contaminated hands to open the trash cabinet to discard the used package. This directly transferred the tracer contamination from participants' hands onto the trash can cabinet handle. A majority of participants then made some effort to wash or rinse their hands by touching the sink faucet handle and subsequently drying their hands on either a cloth or paper towel, likely spreading the contamination from the original meat package.

L. casei contamination was not restricted to kitchen surfaces which inoculated raw meat directly contacted. The very low *L. casei* counts found on the two countertop locations indicated that on average < 1 CFU/cm^2 was detected after participant activities were completed, including final kitchen cleanup. However, it is important to consider that during actual entrée preparation using the raw meat, and associated raw fruit salad preparation, the countertop areas may have become contaminated at higher levels with the tracer culture and ultimately spread to the RTE salad, contributing to the high percentage of participants overall who contaminated their salad. It is very interesting to note that, even after meal preparation was finished and participants had cleaned the kitchen prior to leaving (if they chose to do so), 80% of the 246 total countertop sponge samples revealed presence of the tracer contamination at levels up to 1.63 log CFU/cm^2. This contamination, if it included foodborne pathogens, could serve as an extended source of direct or food-vectored contamination potentially resulting in human illness. The same would hold true for residual contamination in the kitchen associated with cabinet and appliance handles, utensils, and other surfaces such as seasoning containers.

A few unique observations made in this study deserve followup. First, participants were observed frequently handling towels, including paper towels, even when not using them for drying. Towels were determined to be the most contaminated of all sources examined. Second, we observed several individuals handling cell phones during the food preparation process and not washing hands or disinfecting the surfaces of the electronic device. The increased use of electronic devices for obtaining recipes, personal communications or entertainment, etc., adds a potentially important source of contamination to the kitchen environment.

This study and many others *(11, 13, 21, 23)* using a tracer organism to track cross-contamination have found that RTE foods are contaminated using food handling practices typically used by consumers. Our study indicates that educational messages can have some impact, although it is inconsistent, but cross-contamination continues to be a significant issue. At this point, the question remains how to best impact food handling behaviors to reduce cross-contamination. Research is needed on what motivates consumers to change behaviors to reduce the risk of foodborne illnesses and what messages have been effective.

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