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Review

Motivators and Barriers to Cooking and Refrigerator Thermometer Use among Consumers and Food Workers: A Review

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ABSTRACT

Temperature control prevents the rapid growth of foodborne pathogens during food storage and assures adequate heating to destroy pathogens prior to consumption. The use of thermometers is a recognized best practice among consumer and food worker guidelines; however, compliance with this recommendation is quite low. Eighty-five studies from the past 21 years were reviewed and an analyzed for the knowledge, attitudes, and behaviors associated with thermometer use and the motivators and barriers to cooking and refrigerator thermometer use among consumers and food workers. Barriers to thermometer were categorized into two major groups: "the belief that a thermometer is not necessary" and "the difficulty of selecting and using a thermometer." Each group has its unique aspects. Four barriers were recognized in the "not necessary" group: (i) preference for alternative techniques, (ii) mainstream media and food professionals seldom serve as role models and often negate the need for food thermometers, (iii) limited awareness of potential health issues associated with current practices, and (iv) limited knowledge and awareness related to thermometer usage for specific food groups. Six barriers were recognized in the "difficult to select and use" group: (i) difficulties in selecting the type of food thermometers, (ii) availability of food thermometers, (iii) lack of skills related to the usage of food thermometers, (iv) limited knowledge related to endpoint temperatures, (v) inability to calibrate food thermometers, and (vi) lack of knowledge about food thermometer cleaning and sanitation. These findings will facilitate the development and adoption of effective strategies to increase thermometer use and increase food safety education efficacy with a positive impact on public health.

Key words: Barriers; Consumer behavior; Food safety education; Food worker behavior; Thermometer use

Foodborne illness is a significant public health issue in the United States. One of every six Americans is affected by foodborne pathogens *(105)*. Foodborne illness creates an economic burden to the United States with an estimated annual loss of $51.0 billion to $77.7 billion *(106)*. Temperature control is essential to prevent the rapid growth of foodborne pathogens during storage. The use of cooking thermometers to verify that food is adequately cooked and the use of refrigerator thermometers to control the storage temperature are considered of primary importance to prevent illness caused by major foodborne pathogens such as *Campylobacter jejuni, Salmonella, Escherichia coli* O157:H7, *Toxoplasma gondii, Yersinia enterocolitica, Bacillus cereus, Clostridium perfringens,* and *Staphylococcus aureus (49, 80, 81)*.

People use various methods to determine whether cooked food is ready to eat. The color of meat is frequently mentioned as an indicator of adequate cooking *(65)*. However, color is not a reliable indicator of internal temperature. The internal colors of ground beef patties were the same between cooking temperatures of 151 and 160°F (66 to 71°C), and both colors were nearly brown *(45)*. One of four burgers turned brown before the meat reached 160°F, and some burgers were still pink with an internal temperature higher than 160°F. Microbial assessments have revealed that the color of poultry is not necessarily a valid indicator of the destruction of bacteria *(12)*. Firmness, the color of juices, loose joints, and other methods are commonly found in recipes and cookbooks *(56, 122–124)*; however, most of those methods were not correlated with microbiological safety *(14)*. Measurement of the internal temperature is the most reliable method to determine whether food has been adequately cooked.

Control of temperature through adequate chilling or thorough cooking is an essential component of safe food handling educational programs for food workers *(86)* and consumers *(2, 9, 29, 33, 80, 95, 96, 99, 126)*. Some food safety educational programs focus exclusively on thermometer use *(29, 30, 123)*. In 2001, the U.S. Department of Agriculture (USDA) *(123)* published a report on the effectiveness of a food thermometer education program utilizing social marketing techniques. Edwards et al. *(30)* evaluated a teaching kit for secondary school teachers to motivate students to use a food thermometer with small cuts of meat. Another educational program used an emotion-

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based approach to motivate women in the Women, Infants, and Children program (WIC) to use a food thermometer *(31)*.

Despite efforts in consumer food safety education, consumer ownership and use of refrigerator and cooking thermometers as reported in the U.S. Food and Drug Administration Food Safety Survey did not increase significantly over the past decade *(59–61)* (Table 1). In 2006, 2010, and 2016, 74, 79, and 84% of respondents, respectively, reported not using a refrigerator thermometer when their refrigerator lacked a built-in thermometer. About two-thirds of respondents reported owning a food thermometer; however, reported usage of a thermometer for roasts, chicken parts, and hamburgers has changed little during this 10-year period. In 2006, 2010, and 2016, 36, 37, and 38% of respondents reported that they always used a cooking thermometer for roasts. Fewer respondents used a thermometer for chicken parts; 15% in 2006, 17% in 2010, and 19% in 2016 stated that they used a thermometer to determine whether the chicken was adequately cooked. Fewer still used a thermometer when cooking hamburgers: 8% in 2006, 9% in 2010, and 10% in 2016.

To the best of our knowledge, no longitude studies have been conducted to record the ownership and use of refrigerator and cooking thermometers among professional food workers. This article is a review of the literature on consumers' and food workers' knowledge, attitudes, and behaviors regarding thermometer use to identify motivators and barriers to thermometer use and proposed strategies to increase compliance with safe handling recommendations. Although the food service environment differs from that in the consumer kitchen, food workers are included in this review for a more comprehensive examination of human behavior.

TABLE 1. *Self-reported refrigerator and cooking thermometer use among U.S. consumers from 2006 to 2016*[a]

Self-reported survey item	% respondents		
	2006	2010	2016
Owned a refrigerator thermometer	61	63	51
Refrigerator temperature at 33–41°F (1–5°C)	66[b]	74	40
Owned a cooking thermometer	67	66	67
Thermometer used for roasts (always)	36	37	38
Thermometer used for chicken parts (always)	15	17	19
Thermometer used for egg dishes (always)	3	3	6
Thermometer used for hamburgers (always)	8	9	10

[a] Adapted from FDA consumer food safety survey reports *(59–61)*.
[b] In 2006, reported refrigerator temperature was 30°F (–1°C) to 41°F.

REVIEW METHODS

The peer-reviewed scientific literature was searched to locate relevant articles. Searches were conducted on electronic databases available the from Purdue University library: PsycINFO, Medline, ERIC, CINAHL, Social Science Citation Index, Science Direct, and Web of Science. These searches covered a range of publication years from 1998 through April 2018. For all the databases, the following search strategy was used: [“Food safety” or “Food hygiene”] and [“thermometer*” or “thermometer use” or “educat*”] in any text content of the article, including title, abstract, and the main text. All citations identified by these searches were downloaded and when possible captured and compiled in an EndNote database. In the second step, a supplemental list of articles was identified by consulting the reference lists of the previously selected articles. Only articles that met all selection criteria listed below were considered:

1. population: consumers (elderly, pregnant women, school students, etc.) and professional food workers;
2. date: published after January 1998;
3. language: published in the English language;
4. duplication: duplications and similar publications from the same groups of authors were excluded manually;
5. type of article: peer-reviewed primary research articles (conference abstracts and review articles were excluded);
6. outcomes: reported knowledge, attitude, and behavior outcomes relevant to either cooking thermometer or refrigerator thermometer use.

All articles were managed and analyzed using qualitative data analysis software, NVivo (version 11.4.3 for Mac, QSR International, Melbourne, Australia). The content of each article was reviewed, and information regarding the research objective, methodology, sampling, and key findings with regard to thermometer use was extracted. Information on respondent demographic characteristics, survey region or country, and study methodology also were recorded.

The review generated 85 articles that were analyzed in detail (Tables 2 and 3). The majority of the studies were conducted in Africa (1 study), North America (57 studies), Europe (16 studies), the Middle East (7 studies), Asia-Pacific (2 studies), and South America (2 studies). The sample size ranged from 15 to 2,680, and participants were either food workers or consumers. The methodologies used included interviews, focus groups, surveys, and observation. In more than half of the studies (60%), a self-reported survey was the only measurement tool. In most articles, only knowledge was measured, and knowledge questions often were delivered with true-or-false or multiple-choice responses rather than an open-ended inquiry. One-third of the studies included observation with or without other measurements. Only 10% of the studies included a focus group component, and 17% had an educational intervention to assess the impact of the knowledge and/or behavior on thermometer use.

COOKING THERMOMETERS

The percentage of food workers who knew the correct temperature to hold hot food was 42 to 96% (Table 2). In most studies with food workers, about 40% could identify the recommended internal temperature for cooking poultry and ground beef when the query was phrased as a multiple-choice question *(36, 42, 101, 128)*. The proportion of consumers who knew the correct temperature to determine

TABLE 2. *Food worker knowledge and use of thermometers*

Authors	Year	Origin	Participants	Method[a]	Knowledge[b]	Behavior
Abushelaibi et al. *(1)*	2015	Saudi Arabia	48 Establishments	SS, OB	Self-Report: after the intervention, 72% knew hot food should be kept >60°C (15% increase compared with the pretest)	Observed: after the intervention, 70% kept food thermometer in the kitchen (5% increase compared with the pretest); RE (Observed): after the intervention, 63% kept food <5°C (14% increase compared with the pretest)
Al-Shabib et al. *(5)*	2016	Saudi Arabia	87 Food service employees	SS	45% knew the recommended temp to cook and/or hold food	
Baş et al. *(10)*	2006	Turkey	764 Food service employees	SS	42% knew the recommended temp to hold hot food	
Bolton et al. *(15)*	2008	Ireland	200 Chefs and managers	SS	67% knew the recommended temp to keep hot food; RE: 97% knew the recommended refrigerator temp range to store food	74% (with a Bain Marie) checked the temperature of the food; RE: 92% had thermometers in refrigerators; 80% had thermometers in freezers; 69% had thermometers in cold rooms; 80% monitored temp using a temp probe
Brown et al. *(19)*	2012	United States	420 Restaurants	OB		95% used food thermometers; 40% calibrated it at least once per week; 80% had someone trained to calibrate; 15% did not calibrate the thermometer; 41% did not monitor time or temp during cooking
Choi et al. *(26)*	2016	United States	31 Establishments	OB		RE: 58% consistently calibrated; 94% were within the proper temp range; 45% did not check food temp every 4 h
Finch and Daniel *(35)*	2005	United States	276 Food service employees for emergency food programs	SS, W/T	After the intervention, 87% knew to use a thermometer to check food being held (74% increase compared with the pretest)	
Garayoa et al. *(36)*	2011	Spain	105 employees (SS), 20 establishments (OB)	SS, OB	Self-Report: 35% knew the recommended temp to cook; 78% knew the recommended temp to hold hot food; RE: 91% knew the recommended refrigerator and freezer temp range to store food	Self-Report: 88% used food thermometers; Observed: 68% of dishes were at the recommended temp range; RE (Self-Report): 88% used food thermometers; RE (Observed): 20% of dishes were at the recommended temp range
Green et al. *(42)*	2005	United States	486 Food service employees	SS		53% did not use a thermometer to check food temperature; workers in chain restaurants more frequently reported using thermometers than did workers in independently owned restaurants

TABLE 2. *Continued*

Authors	Year	Origin	Participants	Method[a]	Knowledge[b]	Behavior
Green Brown et al. *(43)*	2013	United States	448 Food service managers	SS	43% knew the recommended temp for cooking chicken	49% calibrated the thermometer at least once per week; 46% used a thermometer to determine when chicken was thoroughly cooked; 47% used appearance
Henroid and Sneed *(48)*	2004	United States	40 Schools	SS, OB		Observed: most did not measure and record food temp; 85% held hot food at the recommended temp range; RE (Observed): 45% held cold food at the recommended temp range; RE (Self-Report): employees did not calibrate thermometers
Jevšnik et al. *(52)*	2008	Slovenia	386 Food service employees	SS	57% knew the recommended temp to hold hot food	
Martins and Rocha *(71)*	2014	Portugal	88 Schools	OB		40% used food thermometers; 78% thought hot food holding temp was above the recommended temp; RE: 94% held cold food below the recommended temp
McIntyre et al. *(76)*	2013	Canada	499 Trained and 199 untrained food service employees	SS, W/T	After the intervention, 71% of trained knew temp to hold hot food (10% increase compared with untrained); 93% knew the recommended final temp for cooking foods (no difference); RE: 89% of trained knew to check refrigerator temp at least once per day (4% increase compared with untrained)	
Niode et al. *(87)*	2011	United States	41 managers of Asian and Mexican restaurants	SS	59% knew the recommended temp for cooking food; RE: 90% knew the recommended temp to refrigerate food	10% of Mexican restaurants and 62% of Asian restaurants did not use food thermometers to check doneness
Osaili et al. *(88)*	2013	Jordan	1,084 Retail food service employees	SS	31% knew to check poultry cooking temp; 37% knew the recommended temp to reheat the leftovers; RE: 48% knew the recommended temp to refrigerate food; 46% knew the recommended temp to freeze food	85% had a food thermometer in the restaurant; 24% relied on cooking instruction time to determine the doneness of foods; 27% relied on appearance to determine the doneness of foods; RE: >90% had thermometers in the refrigerator and freezer

TABLE 2. *Continued*

Authors	Year	Origin	Participants	Method[a]	Knowledge[b]	Behavior
Panchal et al. *(91)*	2013	Switzerland	100 Food service employees	SS	92% knew the recommended part of the meat to insert the thermometer (thickest part); 2% knew the minimum internal temp to cook hamburger; 0% knew the minimum internal temp to cook chicken properly (fill-in-the-blank question); 92% knew the recommended type of thermometer (metal stem thermometer); RE: 43% knew the recommended temp to keep food (≤5°C)	
Panchal et al. *(92)*	2012	United States	508 Food service employees	SS	88% knew the recommended part of the meat to insert the thermometer (thickest part); 17% knew the minimum internal temp to cook hamburger; 20% knew the minimum internal temp to cook chicken properly (fill-in-the-blank question); 68% knew the recommended type of thermometer (metal stem thermometer); RE: 17% knew the correct temp danger zone	
Parry-Hanson Kunadu et al. *(94)*	2016	Ghana	278 Food service employees	SS	RE: 30% thought refrigeration could kill bacteria in foods	
Pichler et al. *(98)*	2014	Austria	234 Retail food service employees	SS	96% knew the recommended part of the meat to insert the thermometer (thickest part); 25% knew the minimum internal temp to cook hamburger; 39% knew the minimum internal temp to cook chicken properly (fill-in-the-blank question); 79% knew the recommended type of thermometer (metal stem thermometer); RE: 77% knew the recommended temp to keep food (≤5°C)	
Robertson et al. *(101)*	2013	United States	78 Employees (SS), 15 establishments (OB)	SS, OB	Self-Report: 38% knew the recommended temp to cook poultry; 87% answered within safe but higher temp range to cook poultry; 96% knew the recommended temp to hold hot food	Observed: touched the tip of the thermometer with hands before placing it into a food product
Rowell et al. *(103)*	2013	United States	15 Stores	SS, OB, W/T	Self-Report: employees knew the steps to calibrate thermometers	Observed: employees did not properly calibrate thermometers in the stores

TABLE 2. *Continued*

Authors	Year	Origin	Participants	Method[a]	Knowledge[b]	Behavior
Sneed et al. *(109)*	2004	United States	40 Assisted-living facility for elderly	SS, OB	Self-Report: 33% of chefs did not know the minimum temp to cook the items they have	Self-Report: employees did not calibrate the thermometer before using; stem-type thermometers were most commonly used; Observed: 65% kept hot food within the recommended temp range; 88% used a thermometer when cooking, but only 40% recorded the temperature; RE: 53% kept cold food within the recommended temp range; 93% checked refrigerator temp daily, but only 50% documented refrigerator temp
Soares et al. *(110)*	2012	Brazil	166 Public school employees	SS	58% knew the recommended temp to hold hot food (true and false); RE: 51% knew the recommended temp to hold cold food (true and false)	None used a thermometer to check the doneness of food; RE: 96% thought it was necessary to take refrigerator/freezer temp
Strohbehn et al. *(114)*	2011	United States	16 Retail food service operations	OB, W/T		Observed: after the intervention, 15 operations sanitized food thermometers between cooking items (5 operation increase compared with the pretest)
Strohbehn et al. *(113)*	2014	United States	1,103 Retail food service employees	SS		Mean score 4.6 of 5 (1 = never, 5 = always) for making sure food is within the recommended temp range; 4.4 of 5 for taking the temp of food
Thomas et al. *(117)*	2016	United States	265 Restaurants	SS, OB		Self-Report: 23% of servers said chefs used a food thermometer to determine the doneness of burger
Walker and Jones *(127)*	2002	United Kingdom	70 Restaurants	SS		47% used a thermometer to check cooking temp; 60% used a thermometer to check reheated food temp; RE: 46% measured the food product internal temp when the refrigerating unit air temp was >8°C
Webb and Morancie *(128)*	2015	Trinidad	57 Retail foodservice employees	SS	28% knew the recommended internal temp for cooking poultry; 46% knew the recommended temp to hold hot food; 21% knew range of the temp danger zone; RE: 53% knew the recommended temp to refrigerate food	
York et al. *(131)*	2009	United States	368 Restaurant employees	SS, OB, W/T		Observed: after the intervention that targeted barriers, behavior compliance of thermometer use increased (not significantly)
Youn and Sneed *(132)*	2003	United States	406 Schools	SS		94% reported checking the final temp of cooked foods; RE: 98% had thermometers in all freezers and refrigerators; 66% calibrated thermometer sometimes or always

[a] SS, self-reported paper or face-to-face survey; OB, observation or audit; W/T, with training or educational intervention.
[b] RE, refrigerator thermometer use.

TABLE 3. *Consumer knowledge and use of thermometers*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Anderson et al. *(6)*	2004	United States	99 Consumers	SS, OB	Self-Report: 43% did not know the recommended temp for cooking chicken (mean, 185°F; range, 140–375°F); 44% did not know the recommended temp for cooking ground beef (mean, 178°F; range, 70–450°F); RE: 30% did not know the recommended temp setting for refrigerator	Self-Report: 6% reported using food thermometer often or always in cooking; Observed: 5% used a food thermometer to determine the doneness of the meat, poultry, or seafood; RE (Self-Report): 17% reported they checked their refrigerator temp; RE (Observed): 29% of observed refrigerators had a temp >40°F
Athearn et al. *(7)*	2004	United States	69 Pregnant women	FG, SS		Many said they never used a thermometer (no percentage)
Badrie et al. *(8)*	2006	United States	121 Consumers	SS		87.5% never used a thermometer to check the safe internal temp when cooking large portions of meat; 97% did not use a thermometer to determine the chicken doneness; RE, Self-Report: 18% of refrigerators at home were ≤41°F
Bearth et al. *(11)*	2014	Switzerland	446 Consumers: 13 interviewed and 433 surveyed	SS	Participants exhibited gaps in their knowledge related to temp	Mean score 3.6 of 6 for using a thermometer to check the doneness of a whole chicken; mean score 5.9 of 6 for consuming chicken only when cooked thoroughly
Bermudez-Millan et al. *(13)*	2004	United States	100 Puerto Rican caretakers of young children	SS, OB		Observed: none used a food thermometer to check meat doneness; Self-Report: 4% used a food thermometer
Breen et al. *(17)*	2006	United Kingdom	25 Undergraduate students	OB		RE: 16% had a thermometer in the refrigerator; 33% were>5°C
Brennan et al. *(18)*	2007	Ireland	1,025 "High-risk" consumers	SS, FG	Males >65 yr had the lowest mean knowledge score (no percentage data recorded)	
Bruhn *(20)*	2014	United States	120 Consumers	OB	53% said they knew the recommended temp to cook chicken; 29% said the recommended temp is ≥165°F; RE: 56% did not know the recommended refrigerator temp; only 26% correctly responded; the range of responses was −88 to 70°F	75% said they always or most times used a thermometer to measure when the whole chicken was adequately cooked; 31% said they used it when cooking chicken pieces; <5% voluntarily used a thermometer; 34% used their own thermometer; 40% said chicken was considered cooked when temp was <165°F; RE: 64% were ≤40°F; 12% were ≥45°F; one refrigerator was 60°F

TABLE 3. *Continued*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Burke and Dworkin *(21)*	2016	United States	171 High school students	SS, W/T	After the intervention, 55% knew to use the thermometer to ensure reaching the recommended cooking temp of the frozen chicken breast (43% increase compared with the pretest); after the intervention, 14% knew the recommended temp for cooking ground beef (13.5% increase compared with the pretest (question type: fill-in-the-blank)	
Burke et al. *(22)*	2016	Canada	334 Young adults	SS	39% identified the recommended safe internal temp for cooking chicken; RE: 41% identified the unsafe temp range to hold food as 40–140°F	43% said they regularly used a thermometer to check the internal temp of meats for doneness
Byrd-Bredbenner et al. *(23)*	2007	United States	154 Young adults	OB		7% owned a cooking thermometer; RE: mean temp was 6.1°C for refrigerator and −9.3°C for freezer (both higher than recommended temp)
Cates et al. *(24)*	2004	United States	63 Pregnant women	FG		Many did not use thermometers to check the internal temp
Cates et al. *(25)*	2009	United States	1,140 Older adults	SS		4% said they used food thermometers to check the doneness of small cuts of meat and poultry; 25% used food thermometers to check large cuts of meat and poultry; RE: 32% said they used a refrigerator thermometer to ensure their home refrigerator was ≤40°F
Conley and McPeak *(27)*	2004	United States	32 Families with young children	FG		6% used a food thermometer when cooking small cuts of meat and poultry; one participant started using a food thermometer regularly after a friend's son was diagnosed with salmonellosis
DeDonder et al. *(28)*	2009	United States	21 Adults, 20 adolescents	SS, OB	42.5% said they knew the recommended temp to determine the doneness of poultry; of those, the range of response was 140–450°F	73.2% said they owned a food thermometer; of those, 4.8% reported using it often or always; <20% reported using a thermometer to determine the doneness of raw chicken; Observed: 3 people used thermometer correctly, 2 used it with the cap on
Dharod et al. *(29)*	2004	United States	500 Latino consumers	SS, W/T		After the educational campaign, <1% reported they would use thermometers when cooking hamburger (1% decrease compared with the pretest)

TABLE 3. *Continued*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Edwards et al. *(30)*	2005	United States	326 High school students	SS, W/T	After the intervention, 93% responded that using food thermometer is the only way to know the doneness of meat (29% increase compared with the pretest)	After the intervention, 27% reported using a food thermometer (5% increase compared with the pretest)
Evans and Redmond *(32)*	2016	United Kingdom	43 Consumers	SS, OB		RE (Observed): 91% of refrigerators were >5°C; Self-Report: 36% had a thermometer (built-in or after-market) in their refrigerators; 13% checked the temp of their refrigerators
Feng et al. *(34)*	2016	United States	29 Pregnant women, 32 diabetic consumers	FG		RE: one-third of participants from the diabetic group and >40% of the pregnant women reported the top-shelf temp was >40°F
Gilbert et al. *(38)*	2007	New Zealand	127 Consumers	SS, OB	RE (Self-Report): 84% knew the recommended refrigerator temp (<5°C)	RE (Observed): 34% of refrigerators were >6°C and 55% were >5°C
Gold et al. *(40)*	2014	United States	73 Immigrants (English learners)	SS, W/T	After the intervention, 100% knew to use a food thermometer to determine the doneness of meat (70% increase compared with the pretest)	
Gong et al. *(41)*	2011	China	1,393 Consumers	SS		6.2% used a thermometer when cooking meat; RE: 71.2% owned a refrigerator; 43.9% stored meat >5°C
Haapala and Probart *(44)*	2004	United States	178 Middle school students	SS	63% knew to use a meat thermometer to check the doneness (true or false); RE: 59% knew the recommended temp range for a refrigerator (true or false)	
Hassan and Dimassi *(46)*	2014	Lebanon	1,172 Undergraduate students	SS		7% used a thermometer when cooking meat; RE: 54% had a thermometer in the refrigerator
Jevšnik et al. *(53)*	2013	Slovenia	100 Elderly people (6 OB)	SS, OB	RE: 48% knew the recommended refrigerator temp (<40°F)	RE: for 93%, refrigerator temp was >40°F when measured
Kendall et al. *(54)*	2004	United States	79 Graduate students	SS, OB		16% used a thermometer when cooking meat; 89% cooked hamburger to 160°F, 93% cooked chicken to 160°F
Kosa et al. *(57)*	2007	United States	2,060 Consumers	SS		RE: 8.8% of pregnant women, 15.4% of older adults, and 10.7% of total population owned a refrigerator thermometer; for 70.9% of pregnant women, 77.5% of older adults, and 72% of total population, refrigerator temp was <40°F

TABLE 3. *Continued*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Kosa et al. *(55)*	2015 (poultry)	United States	1,504 Consumers	SS		62% owned a food thermometer; 73% of thermometer owners used it to check the doneness of whole turkeys, 57% used it to check whole chickens; 12–26% used a thermometer to check smaller cuts of poultry and ground poultry; 35% used a thermometer to check leftovers
Kosa et al. *(56)*	2015 (eggs)	United States	1,504 Consumers	SS		62% owned a food thermometer; 5.2% of thermometer owners used a thermometer to check the doneness of baked egg dishes
Kwon et al. *(58)*	2008	United States	1,598 WIC participants.	SS	23.7% knew to use a thermometer to ensure the doneness of ground beef	
Lazou et al. *(62)*	2012	Greece	750 Undergraduate students	SS	RE: 44% knew the recommended refrigerator temp	42% owned a food thermometer; 1% used a thermometer when cooking burgers; 5% used a thermometer when cooking poultry; RE: 42% had a thermometer in the refrigerator
Lin *(65)*	2018	United States	1,688 Consumers	SS		5% only used a thermometer when cooking burgers; 20% used a thermometer and other techniques (color, juice, texture, etc.) when cooking burgers
Lum et al. *(67)*	2013	United States	503 Families with young children	SS	70% knew to use a food thermometer to ensure the doneness of chicken; 62% knew to use a food thermometer to ensure the doneness of hamburger	3% always used a food thermometer to test the doneness of chicken; 0% always used a thermometer to test the doneness of hamburger
Majowicz et al. *(68)*	2015	Canada	2,860 High school students	SS	17.3% knew to use a food thermometer to ensure the doneness of hamburger; 56.7% believed color was the indicator to ensure the doneness of hamburger or meat (incorrect)	
Marklinder and Eriksson *(69)*	2015	Sweden	1,812 School students (8–18 yr)	SS		RE: 74% of ground meat was >4°C; >25% of meatball and sausage was >8°C
Marklinder et al. *(70)*	2004	Sweden	102 Consumers	SS, OB	RE (Self-Report): 85% knew the temp should be >8°C; 24% knew the temp of the refrigerator; 41% measured the temp by sensing the food during handling and consumption	RE (Observed): 85% of ground meat was >4°C, 22% was >8°C; 94% of ready-to-eat salad was >4°C, 39% was >8°C; RE (Self-Report): 21% said they measured the temp of the refrigerator

TABLE 3. *Continued*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Maughan et al. *(73)*	2016	United States	101 Consumers	OB		37% used a thermometer when cooking chicken breasts; 22% used a thermometer when cooking turkey patties; 0% used a thermometer when cooking fried or scrambled eggs; 77% of chickens, 69% of turkeys, 77% of scrambled eggs, and 49% of fried eggs were at the safe temp
Maughan et al. *(74)*	2016	United States	155 Consumers	OB, W/T		Observed: after the intervention, 85% used a thermometer when cooking chicken (55% increase compared with the pretest); 58% inserted the thermometer correctly in the chicken (42% increase compared with the pretest); 86% used a thermometer when cooking turkey burger (66% increase compared with the pretest); 76% inserted the thermometer correctly in a turkey patty (63% increase compared with the pretest); Self-Report: 63% owned a thermometer, 54% dial and 42% digital; 52% used a thermometer when cooking large meat cuts; 15% used a thermometer when cooking small cuts; 13% used a thermometer when cooking ground meat
Medeiros et al. *(79)*	2006	United States	293 Older adults (>60 yr)	SS, W/T	Significant increase in knowledge of adequate cooking (no percentage)	Significant increase in cooking behavior and initial use of food thermometers was very rare (no percentage)
Meysenburg et al. *(82)*	2014	United States	72 Families with young children	FG	77.5% knew to use a thermometer to ensure the doneness of chicken; 57% knew to use a thermometer to ensure the doneness of burger	
Murray et al. *(85)*	2017	Canada	2,474 Consumers	SS	29% knew to use a thermometer when cooking meat; 12% knew to use a thermometer when cooking small cuts of meat	
Osaili et al. *(89)*	2011	Jordan	867 Female college students	SS	33% knew the recommended temp for cooking beef; 33% knew the recommended temp for cooking poultry; 8% knew to use a thermometer to determine the doneness of hamburger; RE: 34% knew the recommended refrigerator temp; 21% knew the recommended freezer temp	

TABLE 3. *Continued*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Ovca et al. *(90)*	2016	Slovenia	1,272 Young adults	SS, W/T		RE: significant increase in using a thermometer to check refrigerator temp (compared with the pretest, no percentage)
Parra et al. *(93)*	2014	United States	468 Mexican Americans	SS		47% owned a thermometer; 21% used a thermometer to ensure the doneness of meat and poultry
Phang and Bruhn *(97)*	2011	United States	199 Consumers	OB	35% thought they knew the recommended temp for cooking ground beef, but only 13% knew the correct temp; 33% knew how to use a thermometer	4% used a thermometer to check the doneness of burger; 53% owned a meat thermometer; 76% said they would not use a thermometer to check the doneness of burger; RE: >19% of refrigerators tested were >43°F; 3% were >50°F
Sanlier *(104)*	2009	Turkey	1,461 Adults and adolescents	SS	55% of youth and 54% of adults knew to use a food thermometer to check the doneness of meat; 74% of youth and 58% of adults knew to use a food thermometer to check the internal temperature for chicken doneness; RE: 19% of youth and 88% of adults knew the recommended refrigerator temp	
Sinley and Albrecht *(108)*	2015	United States	62 Native Americans and 57 Hispanic caretakers of young children	SS, W/T	After the intervention, 81% of Native Americans knew to use a thermometer to decide the doneness of chicken (39% increase compared with the pretest), and 73% knew to use a thermometer to decide the doneness of hamburger (31% increase compared with the pretest); after the intervention, 84% of Hispanic caretakers knew to use a thermometer to check the doneness of chicken (38% increase compared with the pretest), and 70% knew to use a thermometer to check the doneness of hamburger (37% increase compared with the pretest)	
Stein et al. *(111)*	2010	United States	1,122 Undergraduate students	SS	56% knew to use thermometer to accurately determine the doneness of beef; 46% knew to use a thermometer to accurately determine the doneness of chicken; RE: 40% knew the recommended refrigerator temp	51% said they could use a thermometer to check ground beef

TABLE 3. *Continued*

Authors	Year	Origin	*n*	Method[a]	Knowledge[b]	Behavior
Stenger et al. *(112)*	2014	United States	142 Hispanic families with young children	SS, FG	42% knew to use a thermometer to accurately determine the doneness of hamburger; 39% knew to use a thermometer to accurately determine the doneness of chicken	
Takeuchi et al. *(115)*	2005	United States	295 Consumers	SS, W/T		After the intervention, 48% never used a food thermometer (36% decrease compared with the pretest); 16% used a thermometer regularly or most of the time when cooking small cuts (12% increase compared with the pretest); 73% owned food thermometers (18% increase compared with the pretest)
Towns et al. *(118)*	2006	United States	81 Consumers	SS		RE: 25% had a thermometer inside the refrigerator; 12% had a thermometer in the freezer; of those who had a thermometer, 10% reported that the refrigerator temp was >43°F. Freezer temp ranged from −10 to 20°F
Trepka et al. *(119)*	2006	United States	32 WIC participants	FG		Reported that using a thermometer was the most difficult practice to comply with; 3 of 5 groups did not own a thermometer; some people in each group preferred undercooked egg or meat
Trepka et al. *(120)*	2008	United States	394 WIC participants	SS, W/T	After the intervention, use of a thermometer increased more than any other behavior measured (compared with the pretest, no percentage)	A significant increase in self-reported food thermometer use
Trepka et al. *(121)*	2007	United States	299 WIC participants	SS	58% did not use a food thermometer when cooking poultry; 61% did not use a thermometer when cooking a large piece of meat	88% ate burgers that were still pink or red inside; 72% ate eggs that were soft boiled or had a running yolk; 24% owned a thermometer; RE: 31% used a thermometer in the refrigerator

[a] SS, self-reported paper or face-to-face survey; OB, observation or audit; FG, focus group; W/T, with training or educational intervention.
[b] RE, refrigerator thermometer use.

TABLE 4. *Quotations identifying barriers to food thermometer use among consumers and food workers*

Quotations by theme	Subject	Reference
Not needed for our type of cuisine		
It's different here. We cook on the grill. Others put it [meat] on pots so they use a thermometer. But cooling down after cooking is also important; we make the meats 2 inches in thickness so that there is more surface area for cooling down.	Mexican restaurant manager	*87*
Not really, because the food always has to be in small pieces; each plate is cooked right away, and not kept in a pot.	Asian restaurant manager	*87*
Cook is experienced (or inexperienced)		
In Mexico we don't use that [thermometers], it is a natural thing, one has to know when the food is cooked, and if you can't tell then you don't know how to cook.	Hispanic consumer	*93*
They gave me one for barbequing chicken. But I know when things are done because I've been cooking for 10 years. This is a stupid rule that turns people into robots.	Asian restaurant manager	*87*
I have never given myself food poisoning yet so I must be doing something right.	Consumer	*18*
We know how to cook (no need to use food thermometer).	Asian consumer	*47*
If I can cook it myself, I know what I'm doing.	Consumer	*50*
My family has not gotten sick, I think I do things correctly.	Hispanic consumer	*112*
Cook determines appropriate temperature by other means		
I won't check it [a thermometer]. Just usually by touch you know. [not checking refrigerator temperature]	Consumer	*18*
I wiggle the turkey leg. If it's loose, I guess it's done.	Consumer	*37*
I just look at it, you know, and you can tell it's done. But I don't even know what the real temperature should be.	Consumer	*82*
Do not know how to use a thermometer		
If given a thermometer I would use it, but only if someone teaches me how to use it.	Consumer	*13*

the doneness of meat was 33 to 53% *(6, 20, 22, 28, 89)* (Table 3).

Demographic characteristics related to thermometer knowledge. Knowledge and thermometer usage varied by age, ethnicity group, and country. In nationwide surveys with a large sample size, young participants (<34 years old) tended to have a lower level of knowledge and practice regarding thermometer use *(18, 85)*. Studies conducted among young food workers and high school and middle school students supported these findings *(21, 30, 44, 68),* and fewer than 1% of these participants knew the endpoint internal temperature for cooking meat *(21)*.

Consumers from non-Hispanic White communities tended to be more knowledgeable about recommended endpoint temperatures and the benefits of thermometer use compared with those of other ethnicities *(111)*. Most consumers (70 to 78%) from a primarily non-Hispanic White community responded that using a thermometer is the best way to determine whether the chicken is adequately cooked *(67, 82),* whereas this response was given by only 39 to 46% of Hispanic and Native American U.S. consumers *(108, 112)*.

Most of the studies from countries other than the United States and Canada included different measuring instruments. However, three studies in Austria, the United States, and Switzerland had a similar survey *(91, 92, 98)*. Food workers from Austria had a higher percentage of correct responses (25 to 39%), followed by the United States (17 to 20%) and Switzerland (0 to 2%).

Discrepancies between self-reported knowledge and behavior compliance. Knowledge attainment does not always impact behavior. The discrepancy between self-reported knowledge and behavior compliance was noted in multiple studies. Many people, 24 to 69%, agreed that using a food thermometer is the best way to tell when meat has been cooked thoroughly *(20, 22, 30, 40, 44, 58, 67, 82, 89, 104, 108, 111, 112)*. However, when observed, only 0 to 5% of consumers used a thermometer when cooking meat *(6, 13, 20, 67, 97)*.

Barriers to thermometer use. Barriers to the use of thermometers can be attributed to many factors *(75, 113)*. After review of both qualitative and quantitative research articles, 10 barriers to thermometer use were identified. Those barriers were separated into two major groups: "belief that a thermometer is not necessary" and "difficulty of selecting and using a thermometer." Each group has its unique aspects. Four barriers included in the group of "belief that a thermometer is not necessary": (i) preference for alternative techniques, (ii) mainstream media and food professionals seldom serve as role models and often negate the need for food thermometers, (iii) limited awareness of potential health issues associated with current practices, and (iv) limited knowledge and awareness related to thermometer use for specific food groups. Six barriers were included in the group of "difficulty of selecting and using a thermometer": (i) difficulties in selecting the type of food thermometer, (ii) availability of food thermometers, (iii) lack of skills related to use of food thermometers, (iv) limited knowledge related to endpoint temperatures, (v)

TABLE 5. *Educational intervention for thermometer use*

Authors	Educational model	Thermometer provided	Thermometer as the only content	Delivery form	Effective
Food worker–focus studies					
Finch and Daniel *(35)*		No	No	In-person one-time food safety training session	A significant increase in knowledge of food thermometer use
McIntyre et al. *(76)*		No	No	Control group: untrained workers from FoodSafe program; treatment group: trained workers from FoodSafe program	Significant higher knowledge scores in most knowledge related to temperature control
Rowell et al. *(103)*		No	No	SafeMark course from the Food Marketing Institute	No significant difference in knowledge and practice of food thermometer use
Strohbehn et al. *(114)*		No	No	3-yr interventions focused on minimizing cross-contamination	A significant increase in observed food thermometer sanitization
York et al. *(131)*		No	No	Control group: pretest; treatment 1: 4-h ServSafe class with thermometer use as one of the three topics delivered; treatment 2: kit included food thermometers, incentive program and persuasive signs; treatment 3: treatments 1 and 2 together	Increase in observed food thermometer use after the intervention but the difference was not significant
Consumer-focus studies					
Burke and Dworkin *(21)*		No	No	A comic book and a 2-h curriculum; food thermometer use is one of many topics covered	Significate increase in knowledge of food thermometer use and cooking temperature
Dharod et al. *(29)*		No	No	FightBac media campaign	No significant difference in self-reported food thermometer use
Edwards et al. *(30)*	Health Belief Model and Transtheoretical Model of Change	Yes (both food and refrigerator thermometers)	Yes	Teacher food thermometer use kit included four 50-min lesson plans, homework activities, cooking experiments, four classroom posters, a 15-min video, five illustrated recipe cards	A significant increase in both knowledge and self-reported practices
Gold et al. *(40)*		Yes	No	2-h discussion about food safety map, hands-on activities, and visual demonstrations; food safety kit for participants included a refrigerator magnet with recommended temperature, a cutting board, a vegetable brush, a mirror cling, and a gift card	A significant increase in knowledge of food thermometer use
Maughan et al. *(74)*		Yes	No	Recipes emphasized food thermometer use	A significant increase in both observed thermometer use and self-reported ownership
Medeiros et al. *(79)*	Transtheoretical Model of Change	Yes	No	Three 30-min in-person lessons with one lesson focused on food thermometer use	A significant increase in both knowledge and self-reported practices
Ovca et al. *(90)*		No	No	45-min workshop with four food safety topics, including temperature control	A significant increase in refrigerator thermometer use
Sinley and Albrecht *(108)*	Conceptual Change Teaching Method	Yes (only refrigerator thermometer)	No	3-h class with food safety topics; food safety kit included dish soap and cutting boards	A significant increase in knowledge of food thermometer use

TABLE 5. *Continued*

Authors	Educational model	Thermometer provided	Thermometer as the only content	Delivery form	Effective
Takeuchi et al. *(115)*	Transtheoretical Model of Change	No	Yes	Food thermometer use kit included a brochure, a 15-min video, five illustrated recipe cards, a refrigerator magnet	A significant increase in self-reported food thermometer use and ownership
Trepka et al. *(120)*	Health Belief Model	No	No	Control group: three pamphlets; treatment group: computer kiosk program with five modules; food thermometer use one of many topics covered	A significant increase in self-reported food thermometer use

inability to calibrate food thermometers, and (vi) lack of knowledge of food thermometer cleaning and sanitation.

Belief that a thermometer is not necessary. ***(i) Preference for alternative techniques*****.** Many consumers (47 to 51%) responded that it is unnecessary to use a cooking thermometer to check the doneness of an egg or meat dish *(30, 93, 97)*. The most frequently reported alternative to food thermometer use was use of color to determine the doneness of the meat *(13)*. Consumers also determined the doneness of egg or meat dishes by touch, taste, recipe cooking time, inserted a knife to examine the internal texture, inserting a toothpick or other utensil to see whether it came out clean, or other indications of texture, such as shaking an egg dish and considering it done when the item was firm *(20, 34, 56, 73)*.

(ii) Mainstream media and food professionals seldom serve as role models and often negate the need for food thermometers**.** Food workers indicated they were less likely to use a food thermometer when the managers were perceived as not caring about or monitoring this activity; some workers reported that their managers were bad examples when using thermometers *(51)*. Food workers who were less likely to use a thermometer also believed that their boss, coworkers, customers, and the health inspector would not support thermometer use *(99)*. Some culinary preparations seldom incorporate temperature measurement. Young Asian consumers reported not seeing a food thermometer used in their daily lives *(47)*.

Use of a cooking thermometer is seldom mentioned in recipes developed for consumers. Printed recipes describe cooking time and oven temperature but rarely list recommended endpoint internal temperature. A recent evaluation of popular cookbooks revealed that only 8% of the recipes containing raw meat included an endpoint temperature, and in 28% of those recipes the temperature provided was incorrect *(64)*. Some information sources are not current. For example, 180°F (82°C), the previously recommended endpoint temperature for poultry, is still listed in some cookbooks and on some thermometers *(20)*.

Chefs on television cooking shows or in videos often do not use a food or refrigerator thermometer on their programs. A content analysis of 100 cooking show episodes revealed that 75% of the episodes did not show use of a cooking thermometer *(72)*. Another analysis of 59 episodes revealed that 45% did not show use of a cooking thermometer, and only 12% mentioned the correct cooking temperature *(130)*.

(iii) Limited awareness of potential health issues associated with current practices**.** Many consumers do not believe thermometers are necessary. They are confident in their cooking skills because they have "cooked for years without once getting food poisoning" *(122)*. Some regard incorporating thermometers as part of the meal preparation as unrealistic *(47),* or they believe that they can control risks by using their current practices *(50)*. Many popular ethnic dishes require long cooking times. Consumers preparing

these dishes feel that they are unlikely to serve undercooked meat, and therefore food thermometers are not needed in their kitchen *(93)*.

(iv) Limited knowledge and awareness related to thermometer use for specific food groups. The decision of whether to use a food thermometer differs by the food being prepared. Consumers perceive different levels of risk associated with various foods. Consumers are more likely to use a food thermometer for large pieces of meat or poultry than for small cuts, for roasts rather than for ground meat, and for whole chicken rather than for beef *(20, 30, 115, 116)*. Consumers and food workers cooking ethnic cuisines are more difficult to convince regarding the benefits of thermometer use because of the method of cooking and the lack of a tradition of thermometer use. Selected quotations from qualitative studies are included in Table 4.

Difficulty of selecting and using a thermometer. ***(i) Difficulty in selecting the type of food thermometer.*** Edwards et al. *(30)* reported that choosing the right type of thermometer was one of the most challenging aspects for consumers. Although the USDA has an information sheet for consumers, which compares 10 different thermometers *(125),* and two research articles included discussions different types of thermometers *(66),* very limited information has been developed to effectively inform the consumers how to choose the appropriate thermometer for home kitchen use. Some researchers and most food workers consider stem thermometer the most effective type of food thermometer *(91, 92, 94)*.

(ii) Availability of food thermometers. People who did not intend to use a thermometer reported that they do not have a thermometer or that they need reminders for recommended endpoint temperatures *(99)*. Gettings and Kiernan *(37)* noted lack of a thermometer as a major barrier to thermometer use. After being given a food thermometer and shown how to use it, 81% of consumers said they were likely to use thermometer to determine when a whole chicken is adequately cooked *(20)*. However, this compliance rate may be overstated because people with thermometers still do not use them. Food workers reported that they were unable to use a cooking thermometer because one was not available in their workplaces *(128)*.

(iii) Lack of skills related to use of food thermometers. Based upon observed behavior, consumers knew where to insert the thermometer; however, some attempted to obtain the temperature of the cooked chicken while the case was still on the thermometer *(19, 27)*. One participant said, "If given a thermometer I would use it, but only if someone teaches me how" *(13)*.

(iv) Limited knowledge related to endpoint temperatures. Both consumers and food workers lack knowledge about the recommended cooking endpoint temperatures and cooling temperatures. A high percentage of consumers and food workers knew that using a food thermometer is recommended for cooking meat and poultry, but few knew the recommended endpoint internal temperatures *(20)*. Most (96%) of food workers knew where food thermometers should be inserted to accurately check meat temperature, but only 25% knew the recommended internal endpoint temperature for hamburger and 39% knew the endpoint temperature for chicken *(98)*. In a study of 120 consumers who frequently cooked chicken, 75% said they always or most times use a thermometer to determine when whole chicken is adequately cooked, but only 53% replied that they knew the recommended temperature *(20)*.

(v) Inability to calibrate food thermometers. Food workers recognize that use of a food thermometer to measure food temperature is very important (mean score, 4.8 of 5) *(113)*. Although food workers knew how to calibrate thermometers based upon their knowledge test, they did not properly perform this task when observed in the workplace *(103)*. Bruhn *(20)* reported that consumers were surprised that thermometers needed to be calibrated; the difference between the reading on the consumer's home thermometer and the researcher's thermometer (Fisher Scientific, Waltham, MA) was often $>10°F$ (6°C).

(vi) Lack of knowledge of food thermometer cleaning and sanitation. Only 5% of consumers cleaned their thermometers after use *(28)*. Previous research revealed that food thermometers can be the source of cross-contamination when not cleaned and sanitized *(63)*. Food workers also failed to sanitize thermometers before use. Food workers were observed cross-contaminating foods when using a food thermometer by touching the tip of the thermometer with their hands before use, and 3 of 15 workers picked the thermometers up off the floor before using it in ready-to-eat food *(101)*.

Motivators for thermometer use. The most frequently cited motivators for thermometer use were to protect those for whom the food is prepared and to improve food quality. Food workers perceived "keeping customers safe from food-related diseases" as the strongest motivator for them to practice safe food handling recommendations, and "having a thermometer" was also a motivator for using a food thermometer to check the doneness of food *(113)*. Among consumers, respondents reported greater attention to safe food handling when preparing food for their children; 8% reported using a food thermometer to determine the doneness of chicken cooked for their children and only 3% used a thermometer when cooking for themselves *(67)*. Relating the practice of safe food handling to health maintenance can also motivate older adult consumers to use a thermometer *(79)*. Edwards et al. *(30)* found that after exposure to a curriculum that addressed both safety and quality as reasons to use food thermometers, 84% of participants thought use of a food thermometer could improve the quality of cooked meat.

REFRIGERATOR THERMOMETERS

A refrigerator thermometer can be used to monitor whether cold storage is at the recommended temperature for chilled food. The knowledge, attitude, and behavior of consumers and food workers toward the use of a refrigerator thermometer was evaluated in the articles reviewed. Responses of consumers and food workers regarding knowledge of recommended refrigerator temperatures differed by question design, participant characteristics, and county or region. Between 19 and 88% of consumers *(6, 53, 62, 104, 111)* and 17 and 97% of food workers *(15, 36, 87, 88, 92, 98, 128)* stated that they knew the recommended temperature for a refrigerator. However, people often overestimated their knowledge. When asked to identify the recommended temperature of a refrigerator, only 21 to 34% responded correctly *(89)*.

Food establishments were more likely to have a refrigerator thermometer than were home kitchens. More than 90% of the food establishments *(15, 88, 132)* had a thermometer in the refrigerator, but only 11 to 54% *(46, 57, 62, 118)* of consumers reported having a refrigerator thermometer. However, thermometer ownership does not mean food workers and consumers use them to check the temperature of the refrigerator. Only one-third of consumers stated that they checked the refrigerator temperature *(25, 121)*.

Refrigerators are more likely to be operating at the correct temperature in food establishments than in consumer homes. In observation studies, one-third (19 to 36%) of home refrigerators were operating at a temperature higher than recommended, whereas 45 to 94% of food establishment refrigerators were within the recommended temperature range *(20, 34, 97)*.

Not all the food establishments calibrated their refrigerator thermometers. In one study, 15% of the 420 restaurants surveyed did not calibrate refrigerator thermometers *(19),* whereas in another study none of the 42 schools surveyed kept calibration records for their refrigerator thermometers *(48)*. In two other studies, 58 and 66% of the participating food workers said that they sometimes or always calibrated their refrigerator thermometers regularly *(26, 132)*. To date, no studies have included the frequency of refrigerator thermometer calibration among consumers.

EDUCATIONAL INTERVENTION

Fifteen of the 85 articles reviewed included an educational intervention (Table 5). Most of these 15 studies addressed food thermometer use for cooking (13 studies) and the rest (2 studies) focused on refrigerator thermometer use or use of both thermometer types. Educational interventions were developed to meet the needs of a wide range of target audiences from high school students to minority consumer groups to food service employees.

Twelve educational interventions were developed by the same group of researchers. Three studies were conducted to evaluate existing food safety education programs: FoodSafe, SafeMark, and FightBac *(29, 76, 103)*. Five of the consumer-focused interventions were developed based on theoretical educational or social science models such as the Health Belief Model, Transtheoretical Model of Change, and Conceptual Change Teaching Method *(30, 79, 108, 115, 120)*. In most of the studies, increased thermometer use was reported after the intervention. In only two studies (1 of 10 consumer studies and 1 of 5 food worker studies) was there no significant increase of thermometer use between pre- and postintervention measurements *(29, 131)*.

DISCUSSION

Study designs. Responses to knowledge questions differ by question format. A higher percentage of correct responses are produced when the answer is phrased as true or false or multiple choice than when the response is open ended. Because most studies include true-or-false or multiple-choice questions and thus the response can be correct by chance, results may overstate actual knowledge. Future studies should use validated tools to measure knowledge and evaluate the effectiveness of educational interventions.

Self-reported behavior was accepted as reflecting actual practices, even though more recent research based upon observations has revealed that actual behavior differs significantly from self-reported behavior. Observation study results indicate that many consumers and food workers fail to use food and refrigerator thermometers. Because attitudes, intentions, and self-reported practices do not correspond to observed behaviors, observational studies likely provide a more realistic indication of thermometer use in food preparation *(100)*.

Challenges for food safety educators. Food thermometer use has been a challenge for food safety educators. Some professionals teaching in the WIC program believe clients cannot afford food thermometers *(107)*. Some educators believe that high-risk consumers, such as pregnant women, will not follow recommendations to use food thermometers to cook meat *(83, 119)*. Some health care providers indicate that they prefer visual techniques to using a thermometer. One researcher concluded that permanent behavior changes (increase thermometer use), even with proper education, may not be possible and recommended that women use food thermometers at least during pregnancy, which is a temporary life stage *(121)*. Despite the barriers educators perceive that their clients might face in using food thermometers, consumers, especially those in high-risk populations, should know and follow food safety recommendations.

Food safety education programs. Effective consumer and food worker training and education addressing thermometer use is needed. At this time, several consumer food safety education materials include thermometer use as a topic, such as Healthy Baby, Health Me *(9),* a food safety curriculum for pregnant women, Safeology *(129),* a food safety curriculum for high school students, and the FightBac campaign *(29)*. Two food safety education materials featured food thermometer use: a USDA food thermometer

education campaign *(27, 122–124)* and a curriculum on food thermometer use with small cuts of meat *(30, 115, 116)*. However, increases in the use of a food thermometer are difficult to achieve, even after education interventions *(114)*.

An assessment of audience interest could increase compliance with recommended practices. Robertson et al. *(101)* noted that their target audience (food workers) was interested in learning how to calibrate a thermometer and learning the temperature danger zones and endpoint cooking temperatures. For this audience, a training module addressing these points could enhance food workers' compliance behaviors and should be developed and evaluated.

Behavior change models. Behavior change theories *(3, 102)* also suggest that knowledge increase, which is often the focus of conventional education materials, is not sufficient for behavior change. Perceived behavioral control, attitudes, and subjective norms are theorized to be the most powerful factors leading to behavior change *(3)*.

The barriers elicited from the literature confirm the importance of using behavior change models to develop and evaluate education materials. The predictors of intention for using thermometers were attitudes, subjective norms, and perceived control ($P < 0.001$) *(99)*. Knowledge alone predicted only 4% of intention and 1.4% of behavior *(84)*. Perceived behavior control and intention accounted for an additional 24% of the variance in behavior.

Recommendations for increasing the use of cooking and refrigerator thermometers.

1. Include the correct endpoint internal temperature in all recipes. A recent review revealed that cooking endpoints were available in government publications as early as 1984 but cookbooks did not start to incorporate this information until 2005 *(4)*. Consumers do not rely on only cookbooks. All communications including cookbooks, on-line recipes, and other media should provide the endpoint temperature first, then indicate (perhaps in parentheses) the approximate time and cooking temperature to reach this internal temperature *(64, 74)*. Cookbooks and on-line recipes should also be reviewed, and outdated information, especially endpoint temperatures, should be corrected. When recommended temperatures are not consistent, consumers become confused. One peer-reviewed article included 160°F as an adequate internal cooking temperature for chicken *(54)*.
2. Encourage role models, such as parents, celebrity chefs, and television personalities, to use a thermometer and reference endpoint internal temperatures in their communications *(16, 122, 130)*. Studies indicate that consumers modeled television chefs and shows to learn about food handling *(39, 130)*.
3. Direct food safety education toward health professionals such as dietitians and nurses. At-risk population groups prefer that health care providers deliver food safety information *(24)*. Education programs directed toward pregnant women, people with diabetes, and other high-risk groups should include food safety information, including thermometer use.
4. When describing recommended practices, provide background information that supports the recommendation. Consumers and food workers want to know why the specific behavior is recommended. Thus, simply stating a recommendation is less effective for changing behavior than providing the rationale for the recommendation *(34, 129)*.
5. When delivering food safety recommendations, let people practice the behavior. When participants conduct "homework" or "self-inspection," i.e., recording the temperature in three places in their refrigerator and the internal temperature of two cooked or heated items, they found the exercise easy and interesting *(17, 34, 129)*. These take-home tasks reinforced the concepts discussed, provided an opportunity for participants to practice the recommended behaviors, and increased participants' reported intention to use a thermometer in the future.
6. Create and reference easy-to-access videos in which thermometer selection and calibration are discussed. For example, the North American Meat Institute created videos for thermometer use in the kitchen *(77, 78)*.
7. Food safety educators need to engage with populations other than those traditionally targeted. More training should be developed and tailored to address the needs and barriers of consumers or food workers in specific groups, such as high-risk populations (e.g., pregnant women and elderly and immunocompromised persons), ethnic groups (e.g., new immigrants, refugees, and other non–English-speaking communities), and socioeconomic communities with limited resources.
8. Food microbiologists and food engineers can encourage thermometer use compliance by validating and optimizing the temperature recommendations and developing user-friendly and cost-effective temperature control sensors. One chef claimed that the current recommended cooking temperatures resulted in overcooking and lowered the sensory quality of meat. Validation of cooking techniques, such as sous vide, and optimization of temperature control protocols may make thermometer use more acceptable to culinary leaders and the public. Some newer temperature measurement tools have been recently introduced, such as thermometer probes recording continuous temperatures via Bluetooth. With these devices, users do not need to hold a conventional thermometer in a hot environment in the oven or over a barbecue to wait for a reading; the temperature can be checked on a smartphone connected to the device. More user-friendly and cost-effective tools can be developed to encourage behavior compliance for thermometer use.

CONCLUSIONS

Key opportunities for future primary research on consumer and food worker food safety interventions include (i) studies based on behavior change or education theories, such as the Theory of Planned Behavior and the Health Belief Model; (ii) engagement of the target population in the

research by understanding and overcoming unique barriers; and (iii) use of validated instruments to measure outcomes. Continuing efforts are needed among consumers and food workers regarding food and refrigerator thermometer use to ensure cooking effectiveness in the home and in commercial kitchens. Results of this review can be used to prioritize future primary research and decision making in this area.

By identifying and highlighting the barriers and motivators for thermometer use among consumers and food workers, this review offers a priority list for future studies and areas of research. These findings should facilitate the development and adoption of effective strategies to increase thermometer use and food safety education efficacy with a positive impact on public health.

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