Food Control 111 (2020) 107069

Contents lists available at ScienceDirect

Food Control

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

Using tactile cold perceptions as an indicator of food safety-a hazardous choice

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ARTICLE INFO

Keywords:
Refrigeration
Food safety
Tactile sensation
Effusivity
Thermal conductivity

ABSTRACT

The safety of many foods is dependent on ensuring the cold chain until the time of consumption. A weak link is the consumer part of the chain as the temperatures of domestic refrigerators are often too high and the users have limited possibilities to monitor and adjust the temperatures. The aim of this work was to evaluate whether common consumer practices for monitoring that food is kept cold are valid. Consumers demonstrated limited ability to assess food and surface temperature by tactile sense with lower precision at 8 °C compared to 4 °C. Almost 20% of the consumers were able to detect the exact food and surface temperature kept at 4 °C, while at 8 °C only 13% detected the exact temperature. A web-based survey mapping consumer practices showed that more than 40% of consumers never checked the temperature in their refrigerators, 38% rely on food coldness to evaluate if the refrigerator is running at adequate temperature and 65% lack knowledge on how to correctly asses temperature in the fridge. Most of the comments emphasized the situations where consumers could be at risk due to misevaluation of refrigerated food and surfaces real temperature indicating the necessity for better monitorization of cold food chain at domestic level.

1. Introduction

A considerable role in good food handling practices at home is played by the capacity of ensuring refrigeration conditions for preventing growth of psychrotrophic pathogens (e.g. *Listeria monocytogenes*, *Yersinia enterocolitica*) and toxigenic bacteria (e.g. some strains of *Clostridium botulinum*, and *Bacillus cereus*) in foods during storage. Consequently, if not properly maintained, refrigerator allows pathogens growth and/or toxin production (Banwart, 2004; Dhama et al., 2013). In fact household setting is the most frequently reported place of exposure associated with food-borne outbreaks, one of the contributing factors being the time-temperature abuse (EFSA & ECDC, 2018). Proper storage of refrigerated food is recommended at temperatures lower than 5 °C for preventing food spoilage and minimizing the risks of food-borne illnesses (FDA, 2017). Various studies indicated that not all consumers follow the instructions regarding time and storage temperature of refrigerated food products (Ceuppens, Van Boxstael, Westyn, Devlieghere, & Uyttendaele, 2016; Marklinder & Erikkson, 2015), whereas many studies highlighted that domestic refrigerators are running at too high temperatures (James, Onarinde, & James, 2017). Additionally, the literature shows a high level of consumers' unawareness regarding the proper refrigerator running temperature and the temperature at which their fridges operate (Garrido, García-Jalón, & Vitas, 2010; Joshi, Banwet, & Shankar, 2010; Prior, Taylor, Smeaton, & Draper, 2013).

As often consumers lack a thermometer, they either do not measure the temperature of their refrigerators or use their hands and tactile sense for doing this or rely on their personal judgment when comes to evaluate the refrigeration (George, Burgess, & Thorn, 2010; Prior et al., 2013). The field observations made in the SafeConsume project in 75 European households revealed that consumers are often touching food items or the inner surfaces of the fridge to evaluate the refrigeration temperature.

Having neural receptors of cold and warmth, skin plays an important role in the perception of the environmental temperature. Psychophysics is the term coined to define the relationship between

Abbreviations: Fw, fridge wall; Gb, glass bottle; Al, aluminum can; Pap, parchment paper; PET, polyethylene terephthalate bottle

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https://doi.org/10.1016/j.foodcont.2019.107069
Received 6 November 2019; Received in revised form 16 December 2019; Accepted 17 December 2019
Available online 18 December 2019

physical stimuli such as cold, sensations and the perceptions in the brain evoked by these stimuli. The complexity of the cold and warm perceptions resides in the absence of the innate thermal sensations that are acquired only later in life, by experience and could be very different from person to person (Lehmuskallio, Hassi, & Kettunen, 2002). Moreover, perception of coldness is influenced by environmental temperature, knowledge acquired in past experiences, cold response or adaptation ability of the body, surface exposed to coldness, duration of exposure, individual sensitivity and age. It is well understood that sensitivity deteriorates with aging. The tactile perception of cold has to take into account that, in general, temperatures lower than 18 °C produce a cold pain sensation, temperatures lower than 12 °C produce numbness and temperatures lower than 8 °C generate the loss of pain sensation (Lehmuskallio et al., 2002).

When skin is in contact with a surface or an object, the perceived temperature is influenced by the thermal properties of the materials among which the most important are the ability to conduct heat (thermal conductivity) and to exchange heat with its surroundings (thermal effusivity). The effusivity of a material is defined as the square root of the product of the material's thermal conductivity and volumetric heat capacity (Bhatta et al., 2019). A strong correlation between coldness perception and effusivity was observed in several studies (Bhatta et al., 2019; Wilkes et al., 2014; Wongsriruksa, Howes, Conreen, & Miodownik, 2012).

The conundrum question is how safe is to assess temperature by tactile sensations and how much information this experience could give. Many studies have investigated the microbiological contamination in the domestic environment (Redmond & Griffith, 2003; Ricci et al., 2018), however only few of them mentioned the use of human tactile perception as a food safety indicator. Assessing temperature by touching objects with hands could be also a hazardous practice if decisions regarding food safety are based on deceptive perceptions. Moreover, adjusting temperature using fridge thermostat could be done using the scale of the thermostat as an indicator for refrigeration temperature, as observed in SafeConsume field studies (safeconsume.eu), and this practice might also expose consumers to the risk of temperature abuse.

This study aimed to evaluate consumers' sensations and perceptions regarding the ability of tactile sense to give valid information on real temperature and their capacity to discriminate the temperature of different packed foods kept refrigerated and refrigerators' walls. The cold sensations and perceptions were evaluated by tactile sense using different food items and surfaces as thermal indicators for temperatures. Two parameters were determined: the discrimination threshold (DT), defined as the smallest difference between temperatures that a person could detect between two thermal stimuli, and the point of subjective equality (PSE) considered the perception of the same coldness of two different thermal stimuli. Additionally, in the current study, an online questionnaire was conducted to assess consumers' knowledge regarding the refrigeration practices with an emphasis on refrigerators' surfaces used as a food safety indicator.

2. Materials and methods

2.1. Experimental part

Seventy persons representing either technical staff or students from the Faculty of Food Science and Engineering from the Dunarea de Jos University of Galati, agreed to participate in the study on tactile cold perceptions.

2.1.1. Tested surfaces and food products

The tested surfaces belonged to the refrigerators' walls (Fw), which are made of polyvinyl chloride, and four differently packed food products: Coca-Cola in glass bottles (Gb), beer in aluminum cans (Al), butter in parchment paper (Pap), and yogurt in polyethylene terephthalate recipients with a polyvinyl chloride cover (PET).

The food products were in duplicate and stored in two refrigerators, one set at 4 °C (EFSA and WHO advise that foods should be refrigerated below 5 °C) and one at 8 °C (a low temperature but above the refrigeration safe zone). The temperature of the tested food and surfaces was measured using a calibrated infrared thermometer (Helium Innovation Ltd., Varna, Bulgaria) before being touched by the participants.

To mimic real life situations, when consumers touched food items to measure temperature, the food was available in its original packaging and the visual sense might also have influenced the perceived temperature reported.

2.1.2. Study procedure

Each of the 70 participants touched once the refrigerators' walls and food items at both temperatures, and in absence of other participants. They were not informed about the temperatures beforehand. Every participant was asked to hold in the palm of his/her hand a food product from one of the refrigerators and estimate the surface temperature of the food. For the temperature estimation of the refrigerators' walls, they went to each refrigerator and touched the interior wall. The contact between skin and surface was 2–3 s. The order in which the surfaces were touched was randomized, either the ones having 4 °C being touched first or the ones stored at 8 °C. With the purpose of maintaining a normal hand temperature for the participants, a pause of 30 s was taken after each temperature evaluation. Since repeated exposure could influence the sensory perception (Hutchings, de Casanove, Schlich, & O'Riordan, 2017) and change the response, this experiment was conducted only once for each participant.

2.2. Consumer practice data collection

The questionnaire included six questions about food safety knowledge and was developed as an online survey. Compared to face to face interviews, the online surveys are faster and easier to be self-administered (Odeyemi et al., 2019). The anonymity that the Internet provides allows collection of responses that closely match reality (Lagendijk, Asséré, Derens, & Carpentier, 2008). The study was conducted between September 2019 and October 2019, on 320 consumers in the framework of the SafeConsume project. Three variant Likert scale responses (I agree, I do not agree, I do not know) were available for each question.

2.3. Data analysis

2.3.1. Experimental data

The experimental results were evaluated using descriptive statistics available on Office Excel 19 (Microsoft Corp., Redmond, Washington, USA). The normality of the data was assessed by Ryan-Joiner test using Minitab 19 and a cumulative Gauss distribution function was fitted to the experimental values with Excel 19 tools. Coefficients such as RMSE and R^2_{adj} were calculated to demonstrate the goodness of fit accuracy. The point of subjective equality (PSE) determined at 50% response level and the capacity to discriminate between the cold surfaces, considered as the 25% response level, were calculated as indicated by Bhatta et al. (2019). In addition, the probability of indicating a certain range of temperature and the chance to consider perceived temperature values lower than the real one and as such to be *at risk* were estimated.

2.3.2. Survey data

The survey results were analyzed using SPSS (BM SPSS Statistics 20.0 Inc., Chicago, IL) in terms of descriptive statistics, or cross-tabulation and chi-square tests (when searching for relationships among qualitative variables). The validity test was conducted with a reference group of 13 individuals working in the area of food safety from the Faculty of the Food Science and Engineering, Galati, Romania, who were not included in the final study. The Cronbach's alpha for the

Table 1
The socio-demographic profile of the respondents (n = 320).

Variable	Frequency	Percentage (%)
Gender		
female	248	77.5
male	72	22.5
Place of living		
urban	238	74.4
rural	82	25.6
Age		
< 35	187	58.4
35–45	72	22.5
45–65	56	17.5
> 65	5	1.6
Educational level		
high school	99	30.9
bachelor degree	118	36.9
master degree and above	103	32.2
Income		
Minimum	67	20.9
Medium	137	42.8
High	116	36.3

constructs of food safety knowledge was at 0.78, which was considered to be acceptable (Ruby, Ungku Zainal Abidin, Lihan, Jambari, & Radu, 2019).

Table 1 shows the demographic characteristics of the interviewed persons. It can be seen that from a total of 320 respondents, 77.5% of the respondents were female, 74.4% were from urban areas, 58.4% were less than 35 years old, 69.1% had at least a bachelor's degree, and 42.4% had a medium monthly income of less than 2720 lei (less than 573 euro). In Romania, near 20% of inhabitants have bachelor degree (Eurostat, 2016), however it should be mentioned that the survey results are not necessarily representative for the Romanian population as a whole, but allowed the identification of correlations between consumers' refrigeration practices.

3. Results and discussion

3.1. Assessing temperature by tactile sense

Median values and interquartile range of the perceived temperatures (N = 70) at 4 °C and 8 °C are shown in Fig. 1. At 4 °C the reported perceived temperature range presented a higher spread for the refrigerator walls (−1‒13 °C, IQR = 4) than for the packed food items. For example, for the aluminum cans the range was (−2‒5 °C, IQR = 2.25) while for paper and PET similar temperature ranges (−2‒8 °C, IQR = 3) were reported (Fig. 1a). This implies that participants shared more common temperature perceptions for the aluminum cans than for the fridge walls. Three of the surfaces shared the same estimated median (2 °C) namely glass bottle, aluminum can and paper.

The distribution of the temperatures reported for the samples kept at 8 °C is represented in Fig. 1b. The perceived temperature range of the fridge wall at 8 °C (1‒11 °C, IQR = 3) was close to the one reported for the fridge wall at 4 °C. The median of the fridge wall temperature perception (6 °C) is the closest one to the real temperature (8 °C) in comparison with the other packed foods. The glass bottle displayed the highest spread of the temperature values (−1‒12 °C, IQR = 4). Aluminum can had the lowest median (3 °C) and shared similar spread of temperature range perceived with paper (−2‒8 °C, IQR = 3). PET displayed a median of 5 °C, and comparable spread values with the fridge wall (1‒10 °C, IQR = 3).

After removing the outliers with the most numerous ones registered at 8 °C for fridge wall, the normality of the data distribution for each tested surface containing no less than 63 estimated temperature values was checked by the Ryan-Joiner test. Subsequently, confirmation ($p > 0.1$) of Gauss distribution was applied for interpreting the results.

In Fig. 2 the cumulative curves of the tested products (normal distribution) are shown whereas correlation parameters for the model (R^2_{adj} and RMSE), presented in Table 2, indicate a good model fit with significant correlation between the experimental values and the model curve and low values of the RMSE at 4 °C and 8 °C.

PSE at 50% response level indicates that consumers perceives the aluminum cans with 2 °C lower than the real temperature (4 °C), while the temperature perceived after touching paper and glass bottle was equal, and with 1 °C lower than the actual temperature. The PSE perceived for PET was 3.5 °C and 4.5 °C for the fridge wall. A significant difference ($p < 0.05$) was registered between the refrigerator wall and the aluminum can that was perceived with 2.5 °C lower that the former. Effusivity could explain why a significant difference in the perceived temperature was registered between refrigerator wall and aluminum can but also why the cold sensation after touching glass bottle and paper felt almost similar (Table 3). As demonstrated by Bhatta et al. (2019), the larger the differences in thermal properties of materials the easier the task to discriminate among them. The cold perceptions also vary from person to person. Hence, persons with a low thermal effusivity of hands will feel surfaces colder than persons with higher thermal effusivity (Obata, Takeuchi, Furuta, & Kanayama, 2005). Moreover, an increased humidity of the palms is corelated with an increased value in thermal effusivity (Yoshida, Kagata, & Yamada, 2010). For food and surface kept at 4 °C all the temperatures perceived by consumers were lower than the actual temperature, except for the fridge wall. This could suggest that consumer perceived all the tested food surfaces as being colder than in reality. It can be noticed that at 50% response level, PSE varied in the range 2‒4.5 °C for all materials (Fig. 2a).

The DT values at 25% response level, give the temperature range out of which consumers could reliable discriminate between materials. The difference between PSE and DT was 1 °C for aluminum can, 1.2 °C for glass bottle, 1.8 for paper, 1.5 °C for PET and 1.2 °C for the fridge wall. Thus, the window of equality (Bhatta et al., 2019) considered the interval at which consumer is unable to reliable discriminate the real temperature based on the tactile cold sensations of the materials, according to the cumulative distribution curves, for surfaces at 4 °C was estimated to be in the range: 1‒3 °C for aluminum can, 1.8‒4.2 °C for glass bottle, 1.2‒4.8 °C for paper, 2‒5 °C for PET, and 3.3‒5.7 °C for refrigerator wall. This also demonstrates that overlapping between the estimated temperatures could easily occur when it comes to evaluating the temperatures by tactile sensations in the 1‒5.7 °C temperature range. If the probability to detect the exact temperature by hand touching refrigerator wall and packed food kept at 4 °C is considered, then it is noticeable that for all the tested materials the values are relatively low, but very close one to another, in the 16.17‒18.89% range (Table 4).

When the same experiment was performed at 8 °C, three packaging materials of different foods registered very close PSE-values: 3.5 °C for aluminum cans, 3.5 °C for paper and, 3.9 °C for glass bottle. In the case of PET, the temperature at 50% response level was 4.9 °C and for the refrigerator wall, 5.8 °C, with significantly different perceived temperature values compared to all the other reported values of temperature ($p < 0.05$).

It is interesting to notice that the same pattern of tactile sensations was registered at 4 °C and at 8 °C, so aluminum can was perceived as the coldest surface and fridge wall as the warmest surface, with PET as an intermediary in the cumulative distribution curve (Fig. 2). However, at 8 °C all the PSE values were lower than the actual temperature, so consumers could easily be misled by their senses to trust their food is safe. Here consumers could be *at risk* if based on their tactile sense consider the food products safe while the actual temperature is above the recommended temperature for refrigeration. Moreover, many studies have demonstrated that at 8 °C an accelerated growth of the pathogens is most probable, thus considerably reducing food shelf life

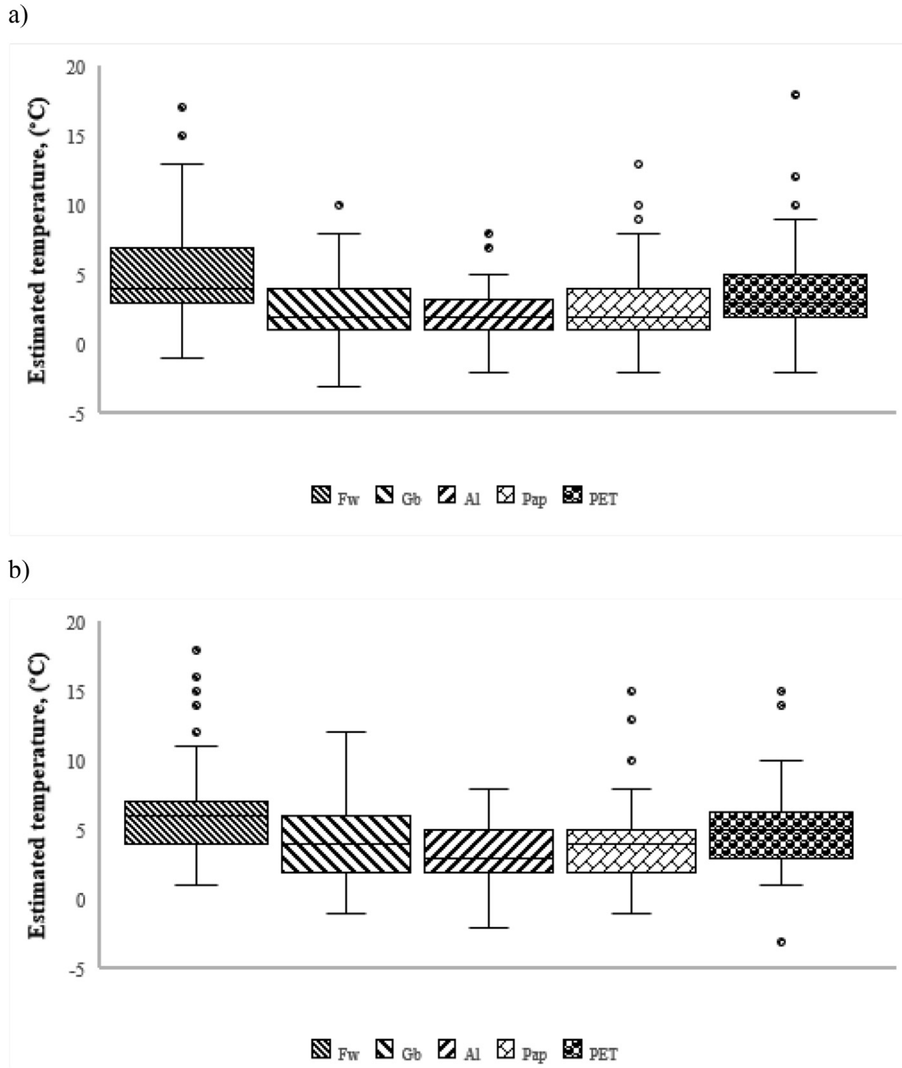

Fig. 1. Boxplots of the temperature values perceived by participants by tactile sense of food items and surfaces at: a) 4 °C and b) 8 °C. Fw - fridge wall, Gb - glass bottle, Al - aluminum can, Pap - parchment paper, PET-polyethylene terephthalate bottle.

(Ceuppens et al., 2016; Garrido et al., 2010; Pal, Labuza, & Diez-Gonzalez, 2008). The probability to give the exact temperature value after touching a surface or food kept at 8 °C is very low and varies from 2.25% for paper up to 12.35% for the refrigerator wall (Table 4). So, it could be more complicated to rely on tactile senses to determine the actual temperature when foods and surfaces are kept at 8 °C compared to 4 °C, probably because the differences between the skin temperature and the tested surface are smaller.

Even if the temperature of the packed food items and refrigerator wall was similar, the sensations were clearly different not only due to the different thermal conductivity of the materials, but also due to differences in effusivity (Bhatta et al., 2019). When the temperature is 8 °C the capacity of surfaces touched by participants to extract heat from the palm skin has a lower rate than at 4 °C and it is interesting to notice that PSE at 8 °C was with almost 1.5 °C higher than PSE at 4 °C and the same difference applies for aluminum can, PET and refrigerator wall. The differences in PSE values for paper and glass bottle at 8 °C compared to 4 °C were smaller than 1.5 °C.

DT values estimated at 8 °C allowed setting the window of equivalence in the range: 1.7−5.3 °C for aluminum can; 1.55−6.25 °C for glass bottle; 1.6−6.2 °C for paper; 1.6−8.2 °C for PET, and 1.6−10 °C for refrigerator wall. Although for all the estimated temperature, refrigerator wall surface was the warmest and closest to the reference value (8 °C), the large range of the interval PSE ± DT underlines the difficulty to estimate the surface temperature by tactile sense for food and surfaces kept at 8 °C.

3.2. Consumer knowledge related to refrigerator practices

As shown in Table 5, six questions were asked to test consumers' knowledge related to refrigerator practices in their homes. The answers demonstrate that 43.4% of the respondents never checked the fridge temperature, while more than a half of those who do the check mentioned that they do not recall when the most recent check was performed. In a survey conducted in the UK, 42% of the respondents mentioned that they never check the fridge temperature and about half (48%) do check the fridge temperature at least once a week (Prior et al., 2013). In a French survey, only 37% of the respondents monitored refrigerator temperatures (Lagendijk et al., 2008). FAO recommends checking temperature regularly: at least once a week (Joshi et al., 2010). On the other hand, even if consumers use a thermometer to check the fridge temperature, often they do not know where to place it in the fridge (Anon, 2015). Some studies recommend to perform the temperature measurement in two to three locations (at the top, middle and bottom part of the fridge) to be able to correctly place the most sensitive foods in the coldest part of the refrigerator (George et al., 2010). Food and Drug Administration (FDA, 2017) recommends placing the thermometer in an easy-to-read location such as the middle of the

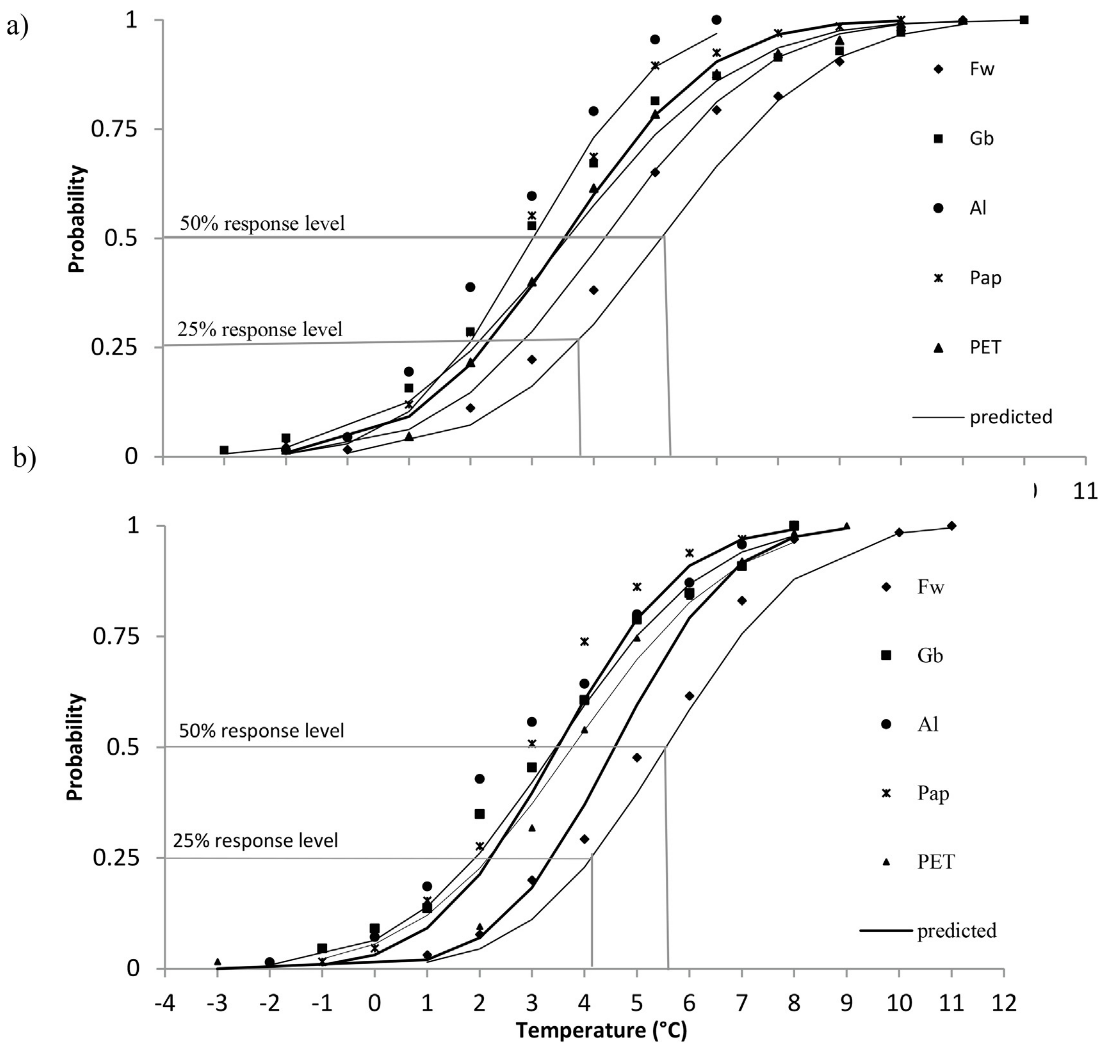

Fig. 2. Experimental temperatures perceived and predicted model curves based on cumulative Gaussian distribution of food items and surfaces maintained at: a) 4 °C and b) 8 °C Fw - fridge wall, Gb - glass bottle, Al - aluminum can, Pap - parchment paper, PET-polyethylene terephthalate bottle.

Table 2
Goodness of fit coefficients.

	RMSE	R^2_{adj}	RMSE	R^2_{adj}
	4 °C		8 °C	
Fw	0.079	97.38	0.062	99.09
Gb	0.059	98.25	0.065	98.66
Al	0.078	98.70	0.078	97.38
Pap	0.077	97.77	0.070	98.52
PET	0.078	97.31	0.090	97.02

Fw - fridge wall, Gb - glass bottle, Al - aluminum can, Pap - parchment paper, PET-polyethylene terephthalate bottle.

refrigerator and wait between 5 and 8 h before reading the temperature.

Near 39% of the Romanian respondents mentioned that they rely on food temperature for testing the real temperature of the fridge and this finding was in line with the field observations made within SafeConsume project at European level (safeconsume.eu). In a recent study conducted in Ireland, about 60% of the participants who checked their fridge temperature, actually checked how cold is the food and only 2% of the participants reported having a fridge thermometer (Anon, 2015).

Temperature inside fridge may vary between shelves, and it is known that heat rises upward, generating higher temperatures at the top of refrigerators (James et al., 2017). The temperature distribution in the fridge varies with type, size, position of the evaporator and the amount of stored food (Marklinder, Lindblad, Eriksson, Finnson, & Lindqvist, 2016). In this study, fridge door was considered inappropriate by more than 60% of the respondents, results that are in agreement with other studies (James et al., 2017). About half of the respondents mentioned fridge wall and middle shelf as being appropriate surfaces to indicate the real temperature of the fridge. In the study conducted by Anon (2015), 43% of the respondents mentioned that the bottom shelf is the coldest part of the refrigerator and 38% of respondents did not know which the coldest part of the fridge is. Respondents who considered that food temperature does not indicate the real temperature of the refrigerator are more likely to indicate that refrigerator surfaces such as door, upper shelf, bottom shelf ($p < 0.01$) are inappropriate to evaluate the refrigerator temperature which demonstrates an understanding of the temperature variations in the refrigerator. The questionnaire results showed that gender exerted a significant influence among the respondents in choosing the surface that better indicates the fridge temperature; men are more likely ($p < 0.05$) to consider middle shelf as a good temperature estimator of the fridge. Respondents from urban areas believe that fridge door ($p < 0.01$) is not a good surface to indicate the real temperature of the fridge, whereas respondents from rural areas believe that fridge wall ($p < 0.05$) better indicates the real temperature of the fridge. On the

Table 3
Thermal conductivity and thermal effusivity of different body parts, materials and food products.

		Thermal conductivity (W/mK)	Thermal effusivity $Ws^{0,5}/(m^2K)$	Reference
Body part	Human skin	0.37	1120	Marín (2006)
	Palm		1300 ± 40	Yoshida et al. (2010)
	Finger		1470 ± 120	Yoshida et al. (2010)
Material	Refrigerator wall	0.12	535	https://thermtest.com/materials-database-popup/
	Glass	1.3	1523	https://thermtest.com/materials-database-popup/
	Aluminum (3004-H19)	160	20079	https://www.makeitfrom.com/material-properties/3004-H19-Aluminum
	Parchment paper (paper + paraffin wax)	0.21	605	Sivasamy, Devaraju, & Harikrishnan, (2018)
	PET + PVC (cover)	0.15–0.4	557	http://www.Goodfellow.com/E/Polyethylene-terephthalate.html
Food product	Coca-Cola	0.6	–	https://www.physicsforums.com/threads/heat-transfer-refrigeration-problem.623035/
	Beer	0.55	–	Macovei (2000)
	Butter	0.19–0.23	–	Macovei (2000)
	Yogurt	0.45	–	Macovei (2000)

Table 4
Probability to precisely perceive the tested food and surfaces at 4 °C and 8 °C, based on Gauss distribution.

Probability (%)		
Surface	4 °C	8 °C
Fw	17.93	12.35
Gb	17.62	4.93
Al	16.17	3.67
Pap	18.27	2.25
PET	18.89	5.78

Fw - fridge wall, Gb - glass bottle, Al - aluminum can, Pap - parchment paper, PET-polyethylene terephthalate bottle.

Table 5
Food safety knowledge among respondents (n = 320).

Question	Percentage (%)		
1. I check the refrigerator temperature			
Using a thermometer or the refrigerator display	39.5		
Using tactile sensations	17.5		
I don't check	43.4		
2. How often do you check the refrigerator temperature?			
Weekly	28.1		
Monthly	19.1		
I do not know	52.8		
3. Do you think that food temperature from your fridge indicates the real temperature of your refrigerator?			
No	41.9		
Yes	38.4		
I do not know	19.7		
4. ***The surface that indicates best the real temperature of my fridge is:***	I agree (%)	I disagree (%)	I do not know (%)
Fridge door	15.3	63.7	20.9
Fridge wall	42.2	42.5	15.3
Upper shelf	35.9	43.1	20.9
Middle shelf	50.3	28.7	20.9
Bottom shelf	33.1	45.9	20.9
Aluminum can	29.4	42.2	28.4
Glass bottle	34.7	41.3	24.1
PET bottle	14.7	57.5	27.8
5. How do you adjust the refrigerator temperature?			
Using a thermometer or the refrigerator temperature display	85.9		
I do not adjust	14.1		
6. The reason for which I adjust the refrigerator temperature:	I agree (%)	I disagree (%)	I do not know (%)
Season change	51.2	34.1	14.7
The fridge has been cleaned	56.9	28.7	14.4
The foods from my refrigerator are not cold as they should be	70.9	14.4	14.7
The fridge is full	56.6	25	18.4

other hand, respondents with high income and high level of education (master degree or above) believe that the middle shelf is more appropriate ($p < 0.05$) than other fridge surfaces to indicate the real fridge temperature, whereas respondents with high school and low incomes think that bottom shelf of the fridge ($p < 0.05$) and fridge wall ($p < 0.01$) may indicate the real temperature of the fridge. The results reported in several studies are contradictory, as the coldest part of the fridge has been considered the bottom shelf (Anon, 2015; Geppert & Stamminger, 2010), the top shelf (or the region where ice appeared) (Ovca & Jevšnik, 2009) or the middle shelf (Marklinder et al., 2016). Sometimes, the temperature difference between shelves from the same refrigerator can reach up to 5 °C (James et al., 2017). However, those consumers who rely mainly on their senses to assess if the fridge is running at the appropriate temperature fail to implement food safety actions that could protect them from the potential risk of foodborne illnesses. In the UK, the Food Standards Agency (2015) recommends consumers to store ready-to-eat foods such as dairy products, cream cakes, cooked meats, leftovers-covered on the top and middle shelves, to use the bottom shelves for raw meat, poultry, and fish, while keeping in the salad drawer the vegetables, fruits, and salads.

The respondents who mentioned the glass bottles as not being the appropriate surface to indicate the real temperature of the fridge are more likely to believe aluminum cans ($R^2 = 0.751; p < 0.001$) and PET bottles ($R^2 = 0.655; p < 0.001$) as being inappropriate surfaces to measure the fridge temperature showing that this category is more aware of the tactile sense limitations when it comes to assessing food temperature. Although most respondents do not believe that PET bottles can indicate the fridge temperature, from Table 5 can be seen that for aluminum cans and glass bottles, more than 56% of the respondents agreed or did not know what to answer indicating consumer lack of knowledge regarding the use of these surfaces to evaluate the fridge temperature. These consumers could be at risk and the results indicate the necessity to inform consumer by food safety campaigns that are specifically targeted on domestic food refrigeration practices and it is worthwhile to mention that no such campaigns were conducted up to know in some countries, including Romania.

On the other hand, most of the respondents (85.9%) said that they adjust the fridge temperature using the fridge thermostat or fridge display, when season change (51.2%), food is not cold (70.9%), or fridge loading level is high (56.6%) (Table 5). Season change was not considered the right reason for adjusting temperature, because, if correctly set, refrigerators are supposed to ensure constant temperature regardless of how cold or hot it is outside; therefore, this practice indicated a knowledge gap of respondents regarding how to properly maintain the fridge. In the study conducted by Anon (2015), 61% of the respondents mentioned adjusting the fridge temperature if the weather gets hotter and 34% if the weather gets colder, 23% mentioned changing the setting if the food is not cold, and 14% based on how full the fridge was. Compared to men, women from this study are more likely ($p < 0.01$) to adjust the fridge temperature if the fridge was just cleaned (but not defrosted).

The results of this survey indicate that consumers should improve their food safety knowledge to properly use and maintain the domestic refrigerators. Training can improve the householder awareness and practices; however, it is important that these changes may last in consumers practice.

4. Conclusions

This is the first study designed to understand consumers' tactile perceptions in relation with assessing refrigeration temperature of their food and food safety aspects. The subjective experience of tactile coldness when skin is in contact with refrigerated foods is mostly related with the thermal properties of packaging materials, and it could easily misguide or even expose consumer *at risk* when considering this experience, a way of measuring the real refrigeration temperature. Thus, consumers should not rely on their tactile senses to measure temperature of different refrigerated foods/surfaces, especially when products are kept at 8 °C when the growth of certain pathogens is accelerated compared to 4 °C. This study provides a strong argument against evaluating refrigeration temperature by tactile sense demonstrating that it is very difficult to discriminate the temperature of foods and surfaces and that the equivalent perceived temperature for the same intensity of coldness sensation is different for different foods and surfaces. The survey indicated that a high percentage of the interviewed consumers lacks knowledge regarding good practices for measuring fridge temperature (60.9%) and/or misbelieve that certain food (58.1%) or specific fridge surfaces such middle shelf (50.3%) could indicate the actual fridge temperature and this could pose them to a serious food safety risk. Such a study supports the necessity to launch educational campaigns on good food refrigerator practices, especially for countries where such actions have never been held.

Author contribution

Daniela Borda: writing, methodology, software;
Octavian-Augustin Mihalache: data collection, writing;
Anca Ioana Nicolau: conceptualization, supervision and editing;
Paula Teixeira: manuscript review;
Solveig Langsrud: manuscript review;
Loredana Dumitrascu: software, writing and editing.

Acknowledgment

This research was supported by the Horizon 2020 project SafeConsume (Grant Agreement No. 727580). All the members of the WP1 of SafeConsume, which was led by Silje Elisabeth Skuland, are acknowledged for the field observations made in the 75 European households.

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