What Drives Risk Perceptions? Revisiting Public Perceptions of Food Hazards Associated With Production and Consumption

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What Drives Risk Perceptions? Revisiting Public Perceptions of Food Hazards Associated With Production and Consumption

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Abstract

As food technology continues to advance, the potential for new food products to enter the food market grows, attracting considerable media interest. Whilst previous research has explored public perceptions of food-related hazards, much of this took place over 10 years ago. Continued technological developments have yielded new food products, for which there is no extant research on public perceptions. In light of this, there is a pressing need to update and extend research exploring public perceptions of food-related hazards. Using a psychometric approach, a nationally representative UK sample (n= 907) provided ratings of 11 old and new food hazards on a total of 12 risk characteristics (identified from previous research). Principal components analysis identified two main components: 'dread' and 'knowledge', which explained 80.8% of the variance in perceptions, consistent with past findings. Additives were perceived as the least dreaded and most known of the hazards considered, whereas ractopamine pork, atrazine corn and hormone beef were dreaded the most. 3D printed food and lab-grown meat were perceived as the least known. Our results highlight the importance of knowledge in shaping risk perceptions and have implications for risk management. An understanding of the factors which determine risk perceptions is vital for the development of effective risk management and risk communication strategies.

Keywords: food safety; food technologies; risk perception; psychometric paradigm

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Food risks are a unique type of risk, in that consumers face them on a daily basis (Fischer & De Vries, 2008). Despite this, eating is not typically perceived as particularly hazardous, except during food safety scares[1] or when it involves new food products. As food technology and production techniques continue to advance, new food products will inevitably enter the food chain and, following their introduction, attract considerable media interest. Regardless of the media discussion, the public may not necessarily be fully aware of, nor have considered at any length, the specific properties of these new products, including their associated benefits and risks. This is potentially problematic, given that knowledge (or lack of) has been consistently identified as a driver of risk perceptions towards both hazards in general (Sjöberg, 2001), but also within a food context – the less one knows about a hazard, the higher their risk perceptions (Kirk et al., 2002; Sparks & Shepherd, 1994). In the same vein, the less one knows about the benefits of a hazardous technology, the higher their risk perceptions (e.g., Finucane, Alhakami, Slovic, & Johnson, 2000; Frewer, Howard, & Shepherd, 1998). The present study therefore aimed to extend prior work on risk perception in light of risks and opportunities afforded by new food technologies and production processes, in order to ascertain the public's perceptions of newer food products. We also incorporated older food hazards for comparison.

The current study stems from research using the psychometric paradigm, pioneered by Slovic and colleagues (Fischhoff et al., 1978; Slovic, 1987; Slovic et al., 1986), which aimed to identify the psychological factors which affect how a risk is perceived and its acceptability (Fischhoff et al., 1978). Within this paradigm, individuals are asked not only how a risk is perceived, but also to characterise the 'personality of hazards', by rating them on a series of characteristics thought to be relevant by the researchers, including 'controllability', 'familiarity', 'level of knowledge', 'severity' and 'immediacy of effects'. Principal components analysis (PCA) can then be utilised to categorise this large number of characteristics into a smaller number of sets (termed 'principal components'), which can explain most

[1] Notable food safety scares in the UK include the horsemeat scandal in 2013 and the Bovine Spongiform Encephalopathy (BSE) crisis in the late 80s and 90s. Similar food scares in other countries include the 2008 Chinese baby milk scandal, and the 1993 US 'Jack in the Box' e-coli scandal.

of the variance in the original ratings. Both the initial study (Fischhoff et al., 1978) and later research (Slovic, 1987; Slovic, Fischhoff, & Lichtenstein, 1986) found that perceptions of risk comprised of two components, labelled by the researchers as 'dread' and 'unknown'. The 'dread' component relates to the potential for catastrophic or fatal consequences, a lack of perceived control, and the uneven distribution of risks and benefits. The 'unknown' component relates to those risks which are poorly understood, new, unknown to science and those exposed, unobservable, and have delayed consequences.

The psychometric approach has been adopted within a food context (Cunha et al., 2010; Fife-Schaw & Rowe, 1996, 2000; Kirk et al., 2002; Mccarthy & Henson, 2004; Ohtsubo & Yamada, 2007; Siegrist et al., 2005, 2006; Sparks & Shepherd, 1994). These studies have generally found two- or three-component solutions, which map closely to previous findings in other (non-food) contexts, as outlined above. Typically, solutions in these studies include a 'dread' component, as well as a 'knowledge' component, though their precise labelling (e.g., dread/severity and known/knowledge/familiarity) varies across studies. The former component relates to characteristics such as 'likelihood of causing harm', 'seriousness of harm', 'disastrous consequences', 'worry', 'concern', 'lack of benefits' and 'man-made'. The latter component relates to characteristics such as 'personal/scientific knowledge', 'familiarity', 'newness' and 'level of control'. In the following, we use the term 'knowledge' to encompass all of these characteristics; referring both to a hazard being known, as well as levels of knowledge.

Whilst the above research is invaluable in identifying the factors which influence perceptions of food hazards, it cannot completely address (for many reasons) how the UK public perceives food hazards today. Previous findings may not be reflective of the public's current risk perceptions – studies which included the widest range of food hazards (Fife-Schaw & Rowe, 1996; Siegrist et al., 2006; Sparks & Shepherd, 1994) are (at least) 13+ years old, and thus took place before technologies such as 'lab-grown meat' had been invented, and before technologies such as genetic modification (GM) became 'mainstream'. The current study allows the opportunity to extend more recent research in the food domain, which has either taken place in non-UK populations (e.g., Cunha et al., 2010; Ohtsubo & Yamada, 2007), focused on a small subset of food hazards, or simplified the paradigm, meaning the generalisability of results is limited. Moreover, whilst the paradigm is over 40 years old, its real value lies in "accounting for risk perceptions of novel hazards" (Siegrist & Árvai, 2020, p. 11) – over half of the hazards included in the study had *never* been the subject of prior psychometric research. The study of these is especially pertinent in light of the UK's exit from the European Union and the prospect of trade deals potentially meaning the introduction of new food hazards to the UK food market.

Many have cited the psychometric paradigm as an important part of developing effective risk communication and management efforts (Renn & Benighaus, 2013), given its utility in identifying the characteristics which drive risk perceptions, which can be used to tailor subsequent communication strategies (Frewer et al., 2016; Soby et al., 1994; Starr, 1985; van Kleef et al., 2006). For instance, if a hazard is known to be so dreaded that even risk communication would not reduce it, a risk manager might decide to delay approval of a substance in order to avoid a loss in perceived consumer confidence (Miles et al., 1999). Alternatively, if a hazard is perceived as risky and unknown, a risk communicator might decide to adopt a strategy increasing information detailing the benefits (Frewer et al., 1998; Siegrist et al., 2000).

In light of the above, there is much interest in identifying (a) levels of awareness and knowledge of hazards (both new and old) and (b) how risky these hazards are perceived to be. Using a nationally representative sample, the current pre-registered study (https://osf.io/eafkw/) sought to extend previous psychometric research by incorporating hazards arising from new products and technologies. We aimed to investigate if previous findings (e.g., relating to the two-component solution – dread and knowledge) still hold and whether they apply to newer hazards. We also extended the traditional psychometric approach by examining which characteristics best predicted overall risk judgements for the included hazards, and exploring the relationship between perceived risk and benefits.

Methods

Participants

Given both food risk perceptions and concern levels are influenced by culture (Knox, 2000), and differ across countries (Meagher, 2019), a nationally representative UK sample (on the basis of age, gender, region and social grade) of 1005 participants was recruited via the online survey company Dynata. Ninety-eight failed the attention check question ("How good are you at surviving one hour without oxygen?" c.f. Martire, Kemp, Watkins, Sayle, & Newell, 2013) and were excluded from the study, leaving a final sample of 907 participants. For sample characteristics, see Table 1. The study took approximately 25 minutes to complete and participants were remunerated in the form of points, which could be later redeemed for options such as gift cards and charitable contributions. Ethical approval was granted from the Departmental Ethics Chair for Speech, Hearing and Phonetic Sciences (University College London).

Table 1.

Characteristics of Sample.

Demographic		National Representative Percentage	Percentage in Study	n
Gender	Male	48.7	48.2	437
	Female	51.3	51.6	468
	Other	N/A	0.1	1
	Prefer not to say	N/A	0.1	1
Age	18 - 24	14.8	14.1	128
	25 - 34	16.6	14.0	127
	35 - 44	17.3	17.8	161
	45 - 54	17.2	18.1	164
	55 - 64	14.6	16.6	151
	65+	19.6	19.4	176
	Prefer not to say	N/A	0	0
Region	England	84.5	84.0	762
	Wales	4.9	5.2	47
	Scotland	8.0	8.4	76
	Northern Ireland	2.6	2.4	22
	Prefer not to say	N/A	0	0
Social Grade	ABC1	54.4	53.5	485
	C2DE	45.6	45.3	410
	Prefer not to say	N/A	1.3	12

Note. ABC1 comprises of: higher managerial/professional/administrative; intermediate managerial/professional/administrative; student. C2DE comprises of: skilled manual worker; semi-skilled and unskilled manual worker; retired and living on state pension only; casual worker – not in permanent employment; housewife/ homemaker; full-time carer of other household member.

Questionnaire

We identified 11 food-related hazards (see Table 2.) from a mixture of sources including the latest Food Standards Agency (FSA) Attitude Tracker (Food Standards Agency, 2019), the Emerging Technologies review (Lyndhurst, 2009), the Eurobarometer survey (European Commission, 2010), as well as some featured in previous psychometric studies of food-related hazards (e.g., Ohtsubo & Yamada, 2007; Siegrist, Keller, & Kiers, 2006; Siegrist et al., 2008; Sparks & Shepherd, 1994). We deliberately sought to include newer hazards such as lab-grown meat and pathogen-treated chicken, which have received relatively little research attention compared with older technologies, and which are of public interest given recent media coverage in light of an EU exit. The older hazards were selected on the basis of their frequency of use in previous psychometric studies. The number of hazards included was higher than the majority of previous food hazard research (Cunha et al., 2010; Fife-Schaw & Rowe, 2000; Kirk et al., 2002; Mccarthy & Henson, 2004; Ohtsubo & Yamada, 2007; Rosati & Saba, 2004; Savadori et al., 2004).

As the food hazards were a combination of particular food processes/production techniques as well as ingredients found within foods, it was decided to express each in terms of 'food' that either contained, or was affected by, the agent/issue of interest (as in Fife-Schaw and Rowe, 2000). This avoided the specification of many different instantiations of a technology (e.g., GM crops vs. GM livestock). Each hazard was presented with a short descriptive sentence to provide context (see Table 2.), though no mention of associated risks or benefits was made. These sentences were based on definitions provided by food safety regulators and food experts (see Table 2 notes).

Table 2.

Hazards and Associated Descriptions (See Below for Sources).

Hazards
Beef from a cow given hormonal growth promotants[1] *Hormonal growth promotants (HGPs) are naturally occurring hormones such as oestrogen, or synthetic alternatives, which are used in cattle to accelerate weight gain.*
Chicken which has undergone pathogen reduction treatment[2] *Chicken which has been treated with antimicrobial rinses, in order to remove harmful bacteria on the meat.*
Corn containing atrazine residue[3] *Atrazine is a herbicide, used on crops such as maize and sweetcorn and kill weeds. Small amounts of residue may remain in or on food after applying the herbicide.*
Food containing additives, colourings and preservatives[4] *Food additives, colourings and preservatives are ingredients added to food to perform particular functions, such as extending shelf life, improving taste and appearance.*
Food from a cloned animal[1] *A cloned animal is an exact genetic copy of an existing animal. Cloned animals are used for breeding purposes, and food is produced from their offspring.*
Food that has been irradiated[4] *During irradiation, food is exposed to electron beams, X-rays or gamma rays, in order to kill bacteria that cause food poisoning.*
Food that has been genetically modified[4] *Genetically modified organisms are plants or animals, in which the genetic material (DNA) has been altered in a way that does not occur naturally. GM foods are foods that contain or consist of GMOs, or are produced from GMOs.*
Food where nano-technology has been used[5] *Nanomaterials, developed using nano-technology, are measured in nanometers — equal to about one-billionth of a meter. These can be used in the production, processing and packaging of food, in order to improve food qualities such as taste, nutritional value and freshness.*
Food that has been 3D printed[6] *3D printing is a digitally controlled, robotic manufacturing process, which produces food that can be customised by shape, colour, flavour, texture and nutrition.*
Lab-grown meat[7] *Lab-grown meat uses stem cell technology, in which tissue is taken from a live animal, and stem cells extracted, which are then grown into muscle fibres in a bioreactor.*
Pork containing ractopamine residue[7] *Ractopamine is a synthetic substance that is used as a veterinary drug in animal feed to promote muscle growth in pigs.*

Notes: 1. Food Standards Australia and New Zealand 2. Federation of American Scientists 3. US Food and Drug Administration 4. Food Standards Agency (England, Wales & Northern Ireland) 5. European Food Standards Authority 6. Sun, Zhou, Huang, Fuh, and Hong (2015). 7. Food and Agriculture Organization of the United Nations

Each hazard was rated on a series of 12 characteristics, using a 7-point Likert scale (as used previously in Cunha et al., 2010; Sparks & Shepherd, 1994). Characteristics were selected on the basis of their frequency of use in previous psychometric studies, as well as in accordance with their loadings on components (e.g., ‘dread’/ ‘knowledge’) previously identified in the literature. The complete list of characteristics and response scales can be found in Table 3. The number of characteristics selected was similar to the number featured in previous food hazard research and the questionnaire was thus comparable in length to Fife-Schaw and Rowe (Fife-Schaw & Rowe, 2000) – approximately 25 minutes.

Participants were also asked to give an overall risk rating for each hazard (as in Bassarak, Pfister and Böhm, 2017; Gardner and Gould, 1989; McDaniels, Axelrod and Slovic, 1995) – “How risky do you consider consuming the above to be?”, rated on a 7 point scale, from 1 (*Not at all risky to consume*) to 7 (*Highly risky to consume*).

Table 3.

Hazard Characteristics. Text in Parentheses Represents Anchor Points of the Likert Scale.

Characteristics
Controllability[2]*   In general, how much control do people have over whether they consume the above? *(No control, to Total control)*
Knowledge (presence)^   How easy is it for you to tell if a food you are about to eat contains, or has been manufactured using the above...? *(You can never tell, to You can always tell)*
Likelihood of harm to health   How likely is it that your health will be damaged by consuming the above? *(Not likely at all, to Extremely Likely)*
Seriousness of harm to health*   How seriously do you think consuming the above may harm your health?   *(Not seriously at all, to Extremely seriously)*
Worry*   How worried are you about potential risks associated with consumption of the above? *(Not worried at all, to Extremely worried)*
Natural/mankind   To what extent are the risks to your health from consuming the above natural, or the fault of mankind? *(They are natural risks, to Man is entirely to blame)*
Knowledge (personal risk)^   To what extent are the risks associated with consuming the above known precisely by those consuming them? *(The risks are not known at all, to The risks are known precisely)*
Knowledge (scientific risk)^   To what extent are the risks associated with consuming the above known to science? *(The risks are not known at all, to The risks are known precisely)*
Familiarity^   I am very familiar with the risks associated with consuming the above *(Strongly disagree, to Strongly agree)*
Newness^   Is the above old or new? (*Extremely old, to Extremely new)*
Immediacy of effects   Would any damage to your health from consuming the above be immediately apparent, or would it only become apparent at a later date? *(Immediate, to Delayed).*
Benefits   How great do you think are the benefits associated with the above? *(No benefits at all, to Very great benefits)*

* relate to dread (emotions are assumed to relate to dread given they arise in anticipation of harm)
^ relate to knowledge

[2] In order to be able to compare across studies we used the same operationalisation of controllability as in previous (food) psychometric research. However, we acknowledge its weakness as a measure, in that all products could be given high scores because people could simply choose not to eat a certain product.

Procedure

The study was run using Qualtrics. Participants were asked to respond to a number of demographic questions, including age, gender, region and social grade (see Table 1). Participants were also asked to indicate if they had any specific dietary preferences, selecting from: none, vegetarian, pescatarian or vegan. If applicable, they were asked how frequently they ate meat, from seven days a week; at least five days a week, at least three days a week; at least one day a week; at least once a fortnight, at least once a month.[3] They then completed a captcha question and an attention check – "How good are you at surviving one hour without oxygen?" (c.f. Martire, Kemp, Watkins, Sayle, & Newell, 2013).

Firstly, participants were presented with instructions, asking them to consider the following hazards within the context of personal risks (i.e., base your answers on what they mean for you, personally), as risk judgements have been found to vary by context (Hermand et al., 2003; Schutz & Wiedemann, 1998). Participants were asked to provide ratings of the overall riskiness of the hazards, though the order of this question (i.e., whether it came before or after ratings of all of the hazards and characteristics) was counterbalanced. On the next screen, participants were presented with one of the hazards and asked to rate the hazard on 12 characteristics, using 7-point Likert scales (see Table 3). Both hazards and characteristics were presented in a random order, to control for the order effects reported in Fife-Schaw and Rowe (2000). The subsequent screen showed another randomly presented hazard, and so on and so forth, until the participant had rated the full set of hazards. Finally, participants were thanked, debriefed (including links to find out more information about the hazards presented) and re-directed to claim their reward.

[3] Non-meat eaters (n= 105) were not removed from analysis. A broadly similar component structure was found when non-meat eaters were removed from analysis, see Supplementary Materials 1.

Results

Planned Analyses

Given a significant proportion of the hazards featured in our study have not been the focus of psychometric studies before, the majority of our analyses were performed at the aggregate level (i.e., data averaged across individuals) focusing on differences among hazards (see Bronfman, Cifuentes, DeKay, & Willis, 2007). This was done in order to gain a general understanding of the public's perception of these hazards, particularly given over half had never been the subject of prior research.

Data Preparation.

To ensure that the rating scales were all consistent, following Siegrist et al. (2006), we recoded the 'controllability', 'knowledge of hazard presence', 'knowledge of risk (personal and scientific)', 'familiarity' and 'benefit' items, such that higher scores on all characteristics reflected perceptions that have typically been associated with higher risk ratings (as in Siegrist et al., 2006). For example, 'No control' and 'Extremely worried' were both recoded as 7.

Whilst a 'don't know' option was not explicitly included in the study; participants were able to skip questions. As per the pre-registration, we followed the protocol of Fife-Schaw and Rowe (Fife-Schaw & Rowe, 2000) and checked whether any of the hazards had >15% missing responses, though none did (for further details, see Supplementary Materials 2). Given that missing data is problematic for principal components analysis, individual missing values were replaced by the mean value for that item (the specific characteristic of the hazard in question; as in Siegrist et al., 2006).[4]

Principal components analysis.

A correlation matrix was created, featuring all of the variables in the PCA, in order to check that all of the variables had at least one correlation where $r \geq 0.3$ (Field, 2013). All of the variables had at least one correlation above this level. 'Familiarity' ("I am very familiar with the risks associated with

[4] The same component structure is obtained even if participants with missing responses are removed from analysis, see Supplementary Materials 2.

consuming the above") and 'personal knowledge of risk' ("To what extent are the risks associated with consuming the above known precisely by those consuming them?") were highly correlated (*r* = 0.97). In line with Fife-Schaw and Rowe (2000), we excluded the 'familiarity' characteristic, in order to keep both types of knowledge characteristics (e.g., personal and scientific). 'Newness' ("Is the above old or new?") and 'scientific knowledge of risk' ("To what extent are the risks associated with consuming the above known to science?") were also highly correlated (*r* = 0.96). We excluded the 'newness' characteristic to keep both types of knowledge characteristics. Although 'likelihood of harm' ("How likely is it that your health will be damaged by consuming the above?") and 'seriousness of harm' ("How seriously do you think consuming the above may harm your health?") were highly correlated (*r* = 0.98), we kept both characteristics in the analysis as they significantly increased the measure of sampling adequacy (see below).[5]

Secondly, we carried out a Kaiser-Meyer-Olkin measure of sampling adequacy of the aggregated data, which equalled 0.49. We stipulated in our pre-registration that a KMO measure of ≥ 0.6 was a minimum requirement for continuing with PCA (based on Kaiser's [1974] classification). We therefore examined the KMO measures for each individual variable, with a view to eliminating the variables with the lowest values, until the measure for the overall dataset was ≥ 0.6 (as in Eisend, 2006). Removing the 'immediacy' characteristic increased the KMO value to 0.52. Subsequent removal of the 'knowledge of presence' characteristic increase the KMO value to 0.60.

Following this, a principal component analysis (PCA) of the aggregated data of the remaining eight hazard characteristics ('worry', 'seriousness of harm', 'likelihood of harm', 'benefits', 'personal knowledge of risk', 'scientific knowledge of risk', 'control' and 'naturalness') was conducted, using a Varimax rotation. Such a rotation results in more interpretable clusters of factors (DeVellis, 2012) and has been used in previous psychometric studies in the food domain (Cunha et al., 2010; Mccarthy & Henson, 2004; Rosati & Saba, 2004; Siegrist et al., 2008), as well as in the original psychometric

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[5] A three-component structure (with similar 'knowledge' and 'dread' components) is obtained when all hazard characteristics are included, see Supplementary Materials 3.

paradigm study (Fischhoff et al., 1978). On the basis of the eigenvalue over one (Kaiser, 1960), the scree plot (Cattell, 1966) and the proportion of variance criteria, we retained three components, which in total explained 94.0% of the variance. 'Worry', 'control' and 'naturalness' cross-loaded on more than one component. In these instances, we selected the component where the characteristic had the highest loading (see Table 4).

We termed the first component (accounting for 55.2% of the variance) 'dread'. Characteristics loading heavily on 'dread' were 'seriousness of harm' (extremely serious), 'likelihood of harm' (extremely likely to damage health), 'worry' (extremely worried) and 'benefits' (no benefits at all). We termed the second component (accounting for 25.6% of the variance) 'knowledge'. 'Personal and scientific knowledge of risk' (not known at all) loaded heavily on this component. The third component accounted for 14.7% of the variance, with 'control' and 'naturalness' loading on to this component. We did not label this component, given it was unclear as to what it referred to and, as highlighted below, the reliability of the component was low.

As in McCarthy and Henson (2004), we tested the reliability of the factors by using Cronbach's alpha. Component 1 'dread' and component 2 'knowledge' were found to have excellent reliability ($\alpha = .940$, $\alpha = .947$, respectively) (Nunnally, 1978). Component 3 had low reliability, $\alpha = .09$, and thus we retained a two-component solution.

Table 4.

Loadings from the PCA.

Characteristic	Component		
	1 (Dread)	2 (Knowledge)	3
Worry	**.891**	.331	
Seriousness of harm	**.978**		
Likelihood of harm	**.952**		
Benefits	**.796**		
Personal knowledge of risk		**.944**	
Scientific knowledge of risk		**.990**	
Control	.432		**.864**
Natural	.558	.468	**-.600**

We computed component scores for each of the hazards (i.e., original variables multiplied by optimal weights = the score the hazard achieves on the retained component) as in Siegrist et al. (2006, 2008). Figure 1 illustrates that three of the newest hazards (hormone beef, atrazine corn and ractopamine pork) were perceived as highly dreaded.

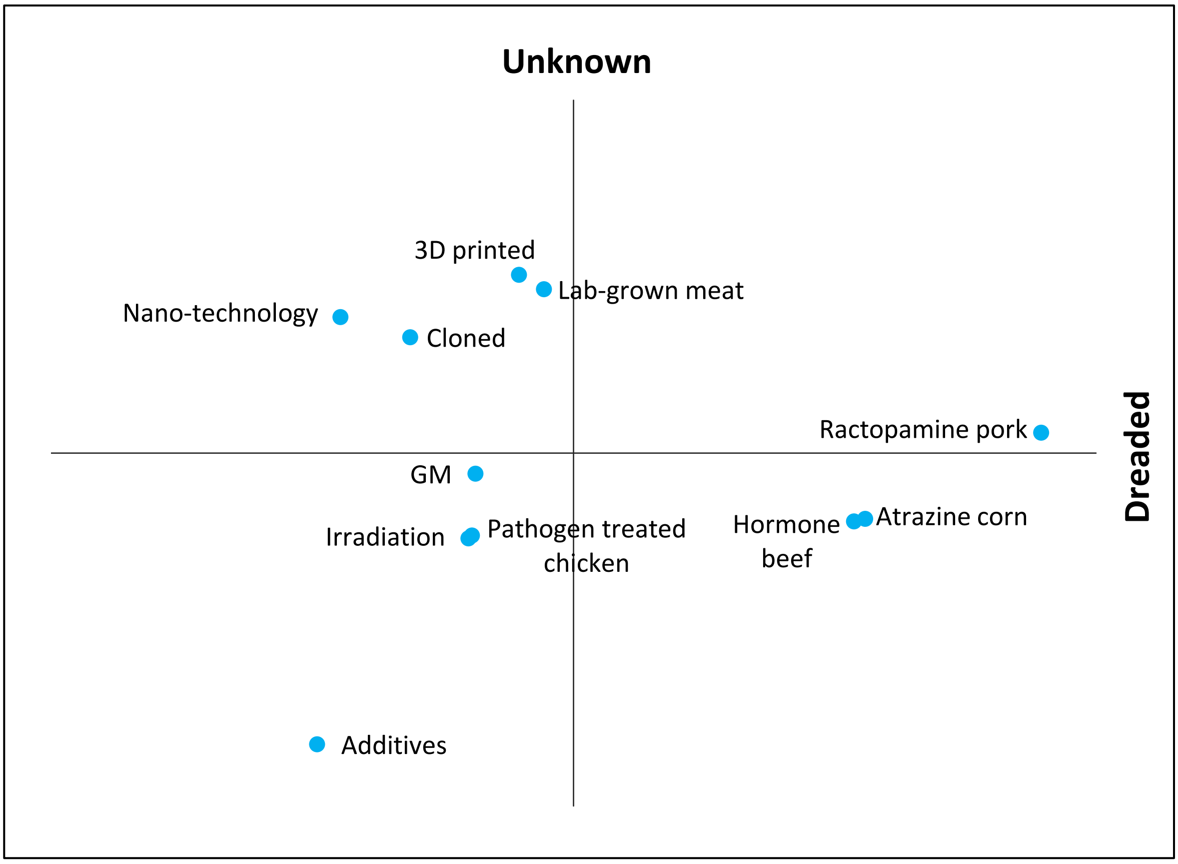
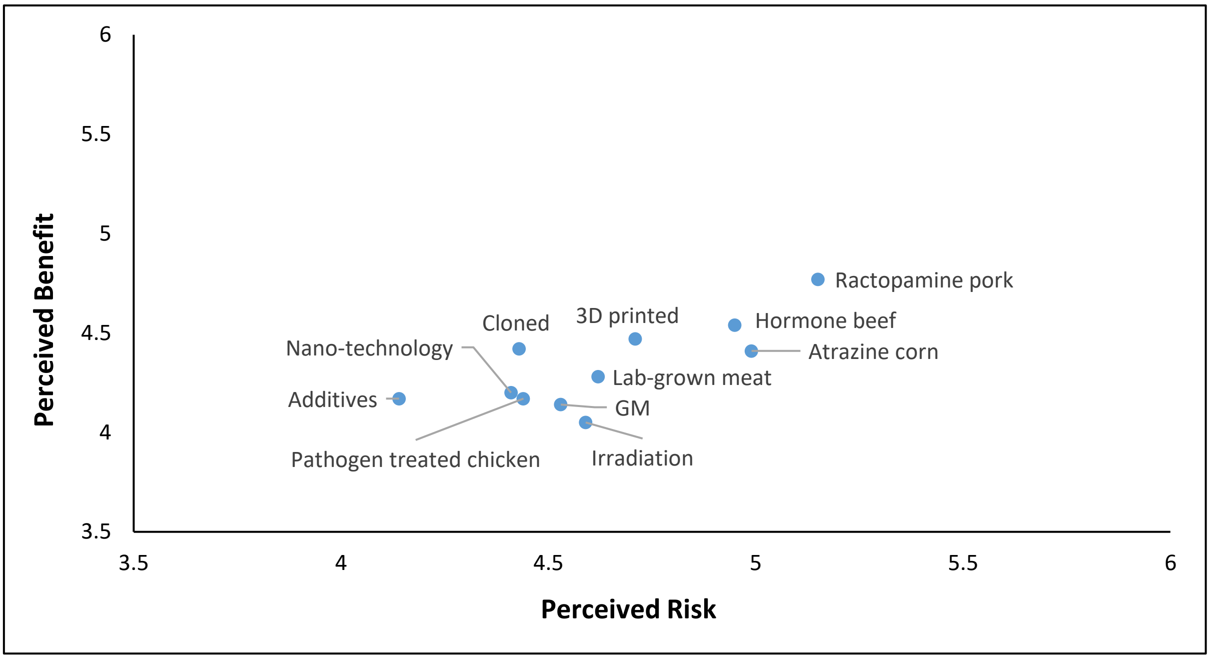


Figure 1. Location of hazards within the two-component space.

Correlation between overall perceived risk and benefits.

Mirroring previous research (Alhakami & Slovic, 1994; Fischhoff et al., 1978; Frewer et al., 1998; Savadori et al., 2004; Slovic et al., 1991, 2007; Starr, 1969), there was a significant positive correlation between overall risk and perceived benefits, $r = .76$, $p = .006$, with greater risks associated with fewer benefits (see Figure 2).



Note: The higher the perceived benefit score, the fewer perceived benefits.

Figure 2. Relationship between perceived risk and perceived benefit.

Individual hazards.

Using the non-aggregated data, for each of the hazards[6] we regressed perceived risk on to the qualitative risk characteristics, as in Bassarak et al., (2017); Gardner and Gould (Gardner & Gould, 1989), and Sjöberg (Sjöberg, 2002), entering them simultaneously into the model. Figure 3 shows a summary of the results of these regressions (see Supplementary Materials 4 for full results), with the heat map's shaded squares indicating characteristics which significantly ($p < .05$) predicted risk ratings.

[6] Note that we only pre-registered analysis of the four newest hazards. We extended (unplanned) analysis to all of the hazards in the interests of completeness.

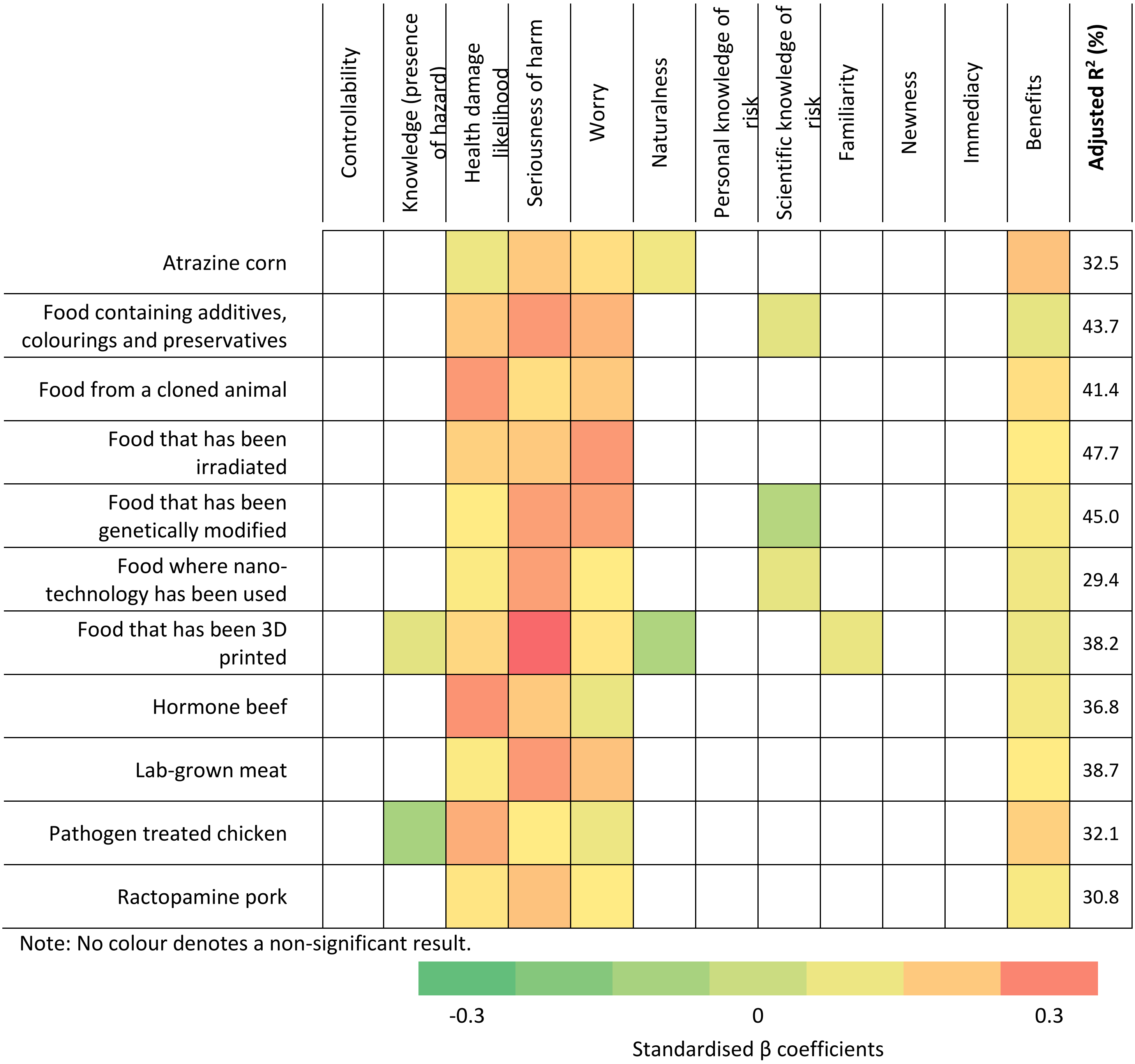


Figure 3. Heat map of significant predictors ($p < .05$) of overall risk ratings for each hazard.

Overall mean risk ratings.

Figure 4 shows the overall risk ratings for each hazard. A one-way ANOVA showed there was a significant difference in overall risk ratings between hazards, $F(10, 9966) = 34.55$, $p < .001$, $\eta_p^2 = .03$. A Tukey HSD post-hoc test showed that additives were perceived as significantly less risky than the other ten hazards (see Table 5). Hormone beef, atrazine corn and ractopamine pork were perceived as significantly riskier than the other hazards, though there was no significant difference between these three. There was no difference in risk ratings between 3D printed food, lab-grown meat, irradiated food and GM food. There was also no difference in risk ratings between nano-technology, food from a cloned animal, chicken which has been given pathogen reduction treatment, GM food, irradiated food and lab-grown meat.

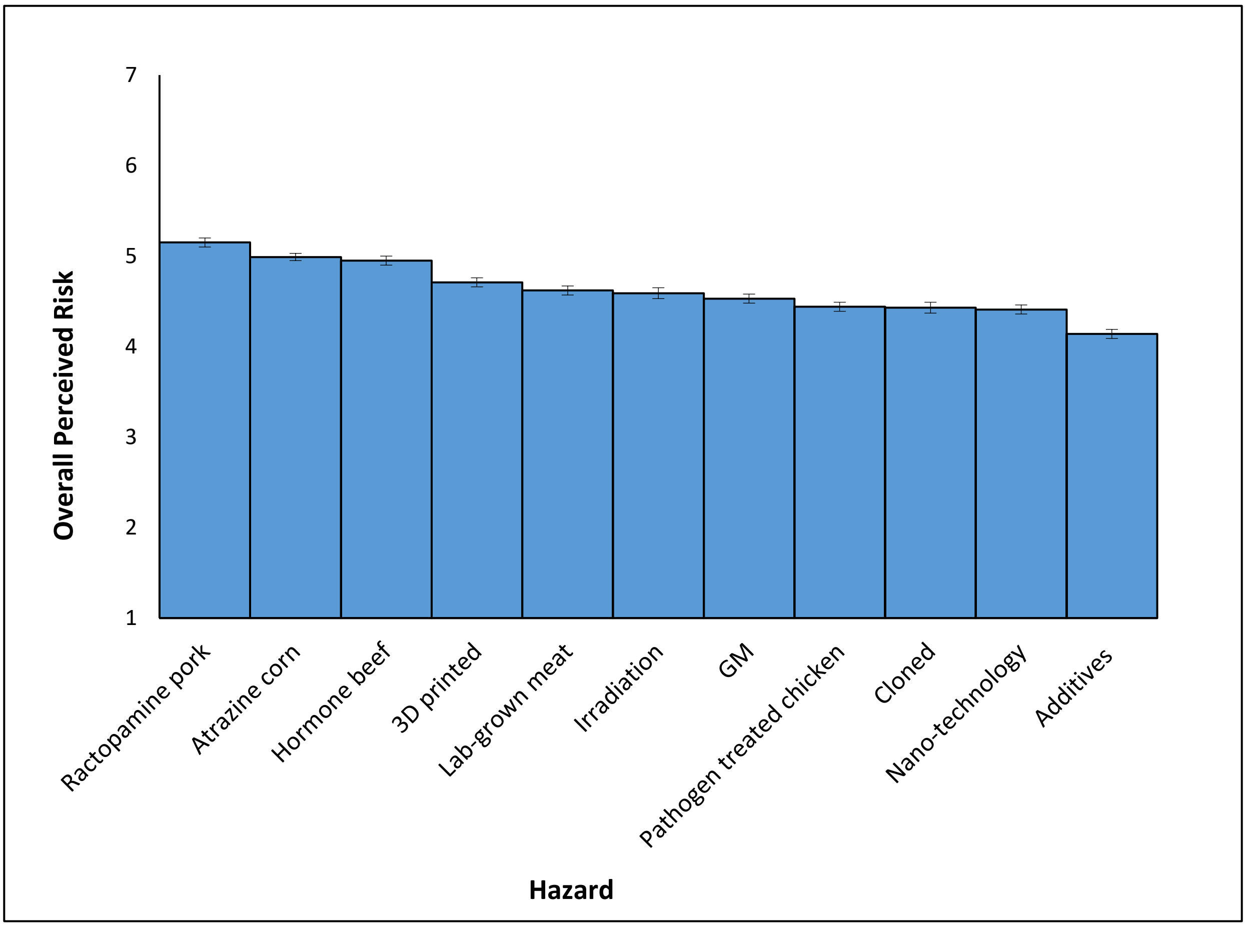


Figure 4. Overall mean risk ratings for each hazard. (Error bars represent ±1 Standard Error [SE]).

Table 5.

Results of Tukey HSD Post- Hoc Test for Overall Mean Risk Ratings.

Hazard	Mean Risk Rating	SD
Additives	4.14[a]	1.51
Nano-technology	4.41[b]	1.42
Cloning	4.43[b]	1.66
Pathogen reduced chicken	4.44[b]	1.56
GM	4.53[bc]	1.60
Irradiation	4.59[bc]	1.67
Lab-grown meat	4.62[bc]	1.56
3D printed	4.71[c]	1.63
Hormone beef	4.95[d]	1.44
Atrazine corn	4.99[d]	1.34
Ractopamine pork	5.15[d]	1.37

Note: Hazards which share a superscript do not have significantly different mean ratings.

General Discussion

The current study supports existing literature which has consistently shown that risk perceptions are complex and relate to many qualitative characteristics such as level of knowledge, likelihood/seriousness of harm to health, as well as to more affective characteristics such as worry. We identified two main components, which we labelled 'dread' and 'knowledge'. These explained a considerable proportion (80.8%) of variance in risk judgements. We successfully replicated the results of previous studies which have found two component solutions relating to 'dread risk' and 'unknown risk' for hazards both in and outside of the food safety domain (Cunha et al., 2010; Fischhoff et al., 1978; Fox-Glassman & Weber, 2016; Kirk et al., 2002; McCarthy & Henson, 2004; Siegrist et al., 2005, 2006, see also Fife-Schaw & Rowe, 1996, 2000; Sparks & Shepherd, 1994 for similar concepts, albeit labelled differently).

Dread and Knowledge

The precise characteristics which contributed to the components were similar to those identified in previous studies. Within a food safety context, 'dread' has consistently been found to comprise of characteristics such as 'likelihood of harm', 'seriousness of harm to health' and 'worry' (Cunha et al., 2010; Kirk et al., 2002; Mccarthy & Henson, 2004). Although these studies did not find 'perceived benefits' contributed to the 'dread' component, benefits were found to contribute to the 'severity' component in Fife-Schaw and Rowe (Fife-Schaw & Rowe, 1996). In line with previous research (Cunha et al., 2010; Kirk et al., 2002; Mccarthy & Henson, 2004), our 'knowledge' component was also made up of 'personal and scientific knowledge'. There were, however, additional characteristics which we did not find contributed to the 'knowledge' component, such as 'familiarity', 'controllability' and 'knowledge of presence'. This arose partly as a result of the high correlations between characteristics and the KMO scores, which meant some of these characteristics were removed. Notably, despite fewer characteristics contributing to the final solution, it explained a greater amount of variance (80.8%) than previous studies with similar solutions, which have found levels of between 43–63% (Cunha et al., 2010; Kirk et al., 2002; Mccarthy & Henson, 2004). In summary, using a comparable design to research from over 40 years ago, the current study indicates that the same 'risk personalities' (e.g., 'dread' and 'knowledge') are of as much relevance now as they were previously, and are found specifically in the context of hazards associated with new food processes/technologies.

Our findings relating to perceptions of the newer food hazards are particularly relevant given that they have not been the subject of previous risk perception research. Ractopamine pork, atrazine corn and hormone beef scored most highly on the 'dread' component. This is in line with past research where pesticides and hormone residues have scored highly on dread (Fife-Schaw & Rowe, 1996, 2000).

The high dread scores may have been a result of the media coverage, meaning they sprung to mind more easily and were perceived as more likely (e.g., Lichtenstein, Slovic, Fischhoff, Layman, & Combs, 1978). Although pathogen treated chicken has been the subject of media interest, much of the media referred to the product as 'chlorinated chicken', and thus the public might not have realised these were one and the same products.

The importance of knowledge as a driver of risk perceptions has been consistently highlighted in the literature, both in and outside of food safety contexts (Kirk et al., 2002; Sjöberg, 2001; Sparks & Shepherd, 1994). The current study provided the opportunity to extend prior work on risk perceptions of food hazards and, along with it, the chance to examine whether increased knowledge/familiarity (relative to the newer hazards) was associated with lower risk perceptions. Whilst past studies found GM technology scored highly on unknown dimensions (Kirk et al., 2002; Mccarthy & Henson, 2004; Sparks & Shepherd, 1994) and was perceived as unfamiliar (Ohtsubo & Yamada, 2007), this was not the case here, at least relative to the hazards included in the present study. [7] Figure 1 shows that GM foods are located much closer to the mid-points of the 'dread' and 'knowledge' scales, in line with findings from more recent research which has observed lower levels of dread regarding GM technology (Cunha et al., 2010). This could be a result of the technology becoming more widespread and thus familiar, as well as the assumption that scientists would be aware of side effects by now – a key driver of initial concerns about the technology (Finucane & Holup, 2005; Miles & Frewer, 2001; Savadori et al., 2004).

Overall Perceived Risk and Its Predictors

Our focus on food hazards meant that differences in overall risk ratings were always likely to be small, given that eating is an everyday event (Fischer & De Vries, 2008). Nevertheless, the comparison of risk ratings of the different hazards yielded patterns of significance consistent with those seen for the PCA, specifically for the dread scores. The same three, novel, food hazards (ractopamine pork, atrazine corn

[7] The nature of principal components analyses means that one can only state the standing of the hazard relative to the other hazards included (which differ to those featured in previous studies).

and hormone beef) received the highest risk ratings, which were significantly predicted by the characteristics: 'likelihood of harm to health', 'seriousness of harm to health', 'worry' and 'perceived benefits'. This is unsurprising given the contribution of the first three characteristics to the component 'dread'. Notably, whilst the relationship between perceived risk and level of knowledge has been put forward in the past (Sjöberg, 2001), in the current study neither 'personal' nor 'scientific knowledge of risk' significantly predicted perceived risk ratings for these hazards (or indeed for the majority of those included in the study).

Surprisingly, 3D printed food was perceived as the fourth most risky food hazard (out of 11), despite the fact that 3D printing technology has been used in food design for around 10 years (Godoi et al., 2016). Given 3D printed food was also scored as the most unknown hazard, it is clear that consumers are not familiar with the nature of this technology. In addition, inspection of the data revealed that it received the second lowest rating on the 'knowledge of presence' characteristic, indicating that consumers do not believe that it is easy to tell if food has been manufactured using 3D printing technology. 'Knowledge of presence' is inevitably linked with low knowledge – if consumers cannot tell that food has been manufactured using the technology, then they have no way of knowing that the technology is widespread.

A similar picture emerges for perceptions of lab-grown meat, which received comparable risk ratings to 3D printed food and also scored highly on the 'knowledge' component. Whilst lab-grown meat is still in its infancy and too expensive for consumers currently (Mattick & Allenby, 2013), this will not always be the case. However, for products such as lab-grown meat to become accepted by the public, risk perceptions need to be lowered. Identifying which characteristics significantly predict risk perceptions means that risk communication strategies can be tailored so as to increase awareness and knowledge of these products (Miles & Frewer, 2001).

Risk and benefits.

The relationship between perceived risk and benefits, whereby higher risks are associated with fewer benefits, has been consistently observed in previous research (Alhakami & Slovic, 1994; Fischhoff et al., 1978; Frewer et al., 1998; Savadori et al., 2004; Slovic et al., 1991, 2007; Starr, 1969). Such a relationship has been demonstrated in a variety of contexts, including for food hazards such as pesticides/herbicides, GM technology, irradiation and high-fat foods. In line with these findings, the results from the regression analyses provide further support for the association between perceived risk and benefit ratings. These results have implications for risk communicators – providing the public with, or increasing the level of, information about benefits of the food product/technology may reduce risk perceptions (Frewer et al., 1998; Siegrist et al., 2000).

Further Considerations

One criticism that has been levelled at the psychometric paradigm is its reliance on aggregate data (Siegrist et al., 2005), which in our study was aggregated across individuals, rather than hazards. We did this because we were interested in the *overall* perceptions of hazards and the question of why particular hazards might be perceived differently. This method was also the most appropriate for gaining an initial understanding of the newer hazards, over half of which had never been the focus of research before. Doing so, however, meant that we had a limited number of units for analysis, though this was comparable and larger than that used in previous food hazard research. Adopting the same aggregation method as previous research (e.g., Cunha et al., 2010; Fife-Schaw & Rowe, 1996, 2000; Kirk et al., 2002; McCarthy & Henson, 2004; Ohtsubo & Yamada, 2007; Sparks & Shepherd, 1994) also meant that we could more easily draw comparisons to this literature.

Implications

The utility of the psychometric paradigm in characterising the 'personality of hazards' has been well established in the literature since its inception over 40 years ago. Consistent with this literature, our findings highlight that risk perceptions are influenced by a variety of qualitative factors, which are not directly related to objective measures of risk (e.g., probability of occurrence). We find similar results to previous research examining perceptions of food-related hazards – a two component solution featuring 'dread' and 'knowledge' is appropriate and explains a large proportion of variance in the public's risk perceptions. Our findings have implications for risk management, particularly for the management of those newer hazards which may not be familiar or have fully entered the food chain. A thorough understanding of the factors which contribute to risk perceptions means that risk communications can be tailored according to the characteristics of the hazard in question, thus increasing their efficacy.

Declarations

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Supplementary Materials 1 – Excluding Non-Meat Eaters – Exploratory Analysis

Table S6.

Dietary Preferences of Sample.

Dietary Preference	Percentage of Sample	n
None	88.4	802
Pescatarian	3.4	31
Vegetarian	6.1	55
Vegan	2.1	19

If non-meat eaters are removed from analysis (n= 105), we found a three-component solution, which in total explained 93.7% of the variance. 'Worry', 'seriousness of harm', 'damage' 'benefits', 'control' and 'naturalness' cross-loaded on more than one component (see Table S2). In these instances, we selected the component where the characteristic had the highest loading.

We termed the first component (accounting for 55.9% of the variance) 'dread'. Characteristics loading heavily on 'dread' were 'seriousness of harm' (extremely serious), 'likelihood of harm' (extremely likely to damage health) and 'worry' (extremely worried). We termed the second component (accounting for 23.2% of the variance) 'knowledge'. 'Personal and scientific knowledge of risk' (not known at all) loaded heavily on this component. The third component accounted for 14.5% of the variance, with 'benefits' (no benefits at all) and 'naturalness' loading on to this component.

As in McCarthy and Henson (2004), we tested the reliability of the factors by using Cronbach's alpha. Component 1 'dread' and component 2 'knowledge' were found to have good/excellent reliability (α = .849, α = .950, respectively) (Nunally, 1978). Component 3 had low reliability, α = .518, and thus we retained a two-component solution.

Table S7.

Loadings from the PCA.

Characteristic	Component		
	1 (Dread)	2 (Knowledge)	3
Worry	**.804**	.345	.396
Seriousness of harm	**.906**		.409
Likelihood of harm	**.928**		.335
Benefits	.435		**.753**
Personal knowledge of risk		**.932**	
Scientific knowledge of risk		**.958**	
Control	**.853**	.309	-.378
Natural		.334	**.865**

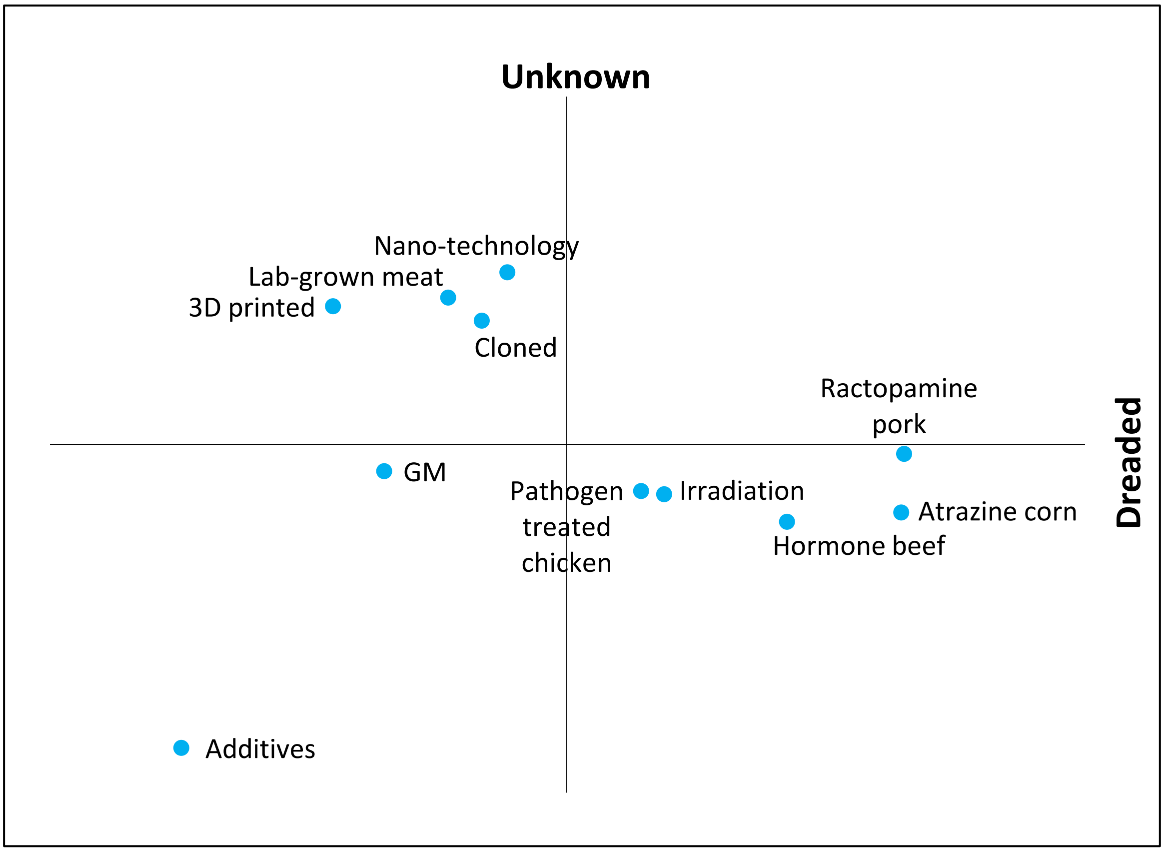

Figure S5. Location of hazards within the two-component space (non-meat eaters excluded).

Supplementary Materials 2 – Excluding Missing Data – Exploratory Analysis

Participants were asked to provide 13 ratings of 11 items in total and 97.6% responses were complete. 9.04% of participants had missing values on one or more items. For missing responses by hazard, see Table S8.

Table S8.

Missing Responses by Hazard.

	% of missing responses
Atrazine corn	2.9
Food containing additives, colourings and preservatives	2.2
Food from a cloned animal	2.0
Food that has been irradiated	2.1
Food that has been genetically modified	2.5
Food where nano-technology has been used	2.2
Food that has been 3D printed	2.5
Hormone beef	2.8
Lab-grown meat	2.3
Pathogen treated chicken	2.6
Ractopamine pork	2.8

Similar results to those reported in the main text are found if participants with missing data are removed from analysis – we found a three-component solution, which in total explained 93.5% of the variance. ‘Worry’, ‘benefits’, ‘control’ and ‘naturalness’ cross-loaded on more than one component (see Table S4). In these instances, we selected the component where the characteristic had the highest loading.

We termed the first component (accounting for 54.4% of the variance) 'dread'. Characteristics loading heavily on 'dread' were 'seriousness of harm' (extremely serious), 'likelihood of harm' (extremely likely to damage health), 'worry' (extremely worried) and 'benefits' (no benefits at all). We termed the second component (accounting for 23.8% of the variance) 'knowledge'. 'Personal and scientific knowledge of risk' (not known at all) loaded heavily on this component. The third component accounted for 15.6% of the variance, with 'control' (no control) and 'naturalness' (man is entirely to blame') loading on to this component.

As in McCarthy and Henson (2004), we tested the reliability of the factors by using Cronbach's alpha. Component 1 'dread' and component 2 'knowledge' were found to have excellent reliability (α = .939, α = .946, respectively) (Nunally, 1978). Component 3 had low reliability, α = .112, and thus we retained a two-component solution.

Table S9.

Loadings from the PCA.

Characteristic	Component		
	1 (Dread)	2 (Knowledge)	3
Worry	**.904**	.349	
Seriousness of harm	**.992**		
Likelihood of harm	**.974**		
Benefits	**.766**		-.304
Personal knowledge of risk		**.952**	
Scientific knowledge of risk		**.984**	
Control	.499		**.804**
Natural	.479	.468	**-.714**

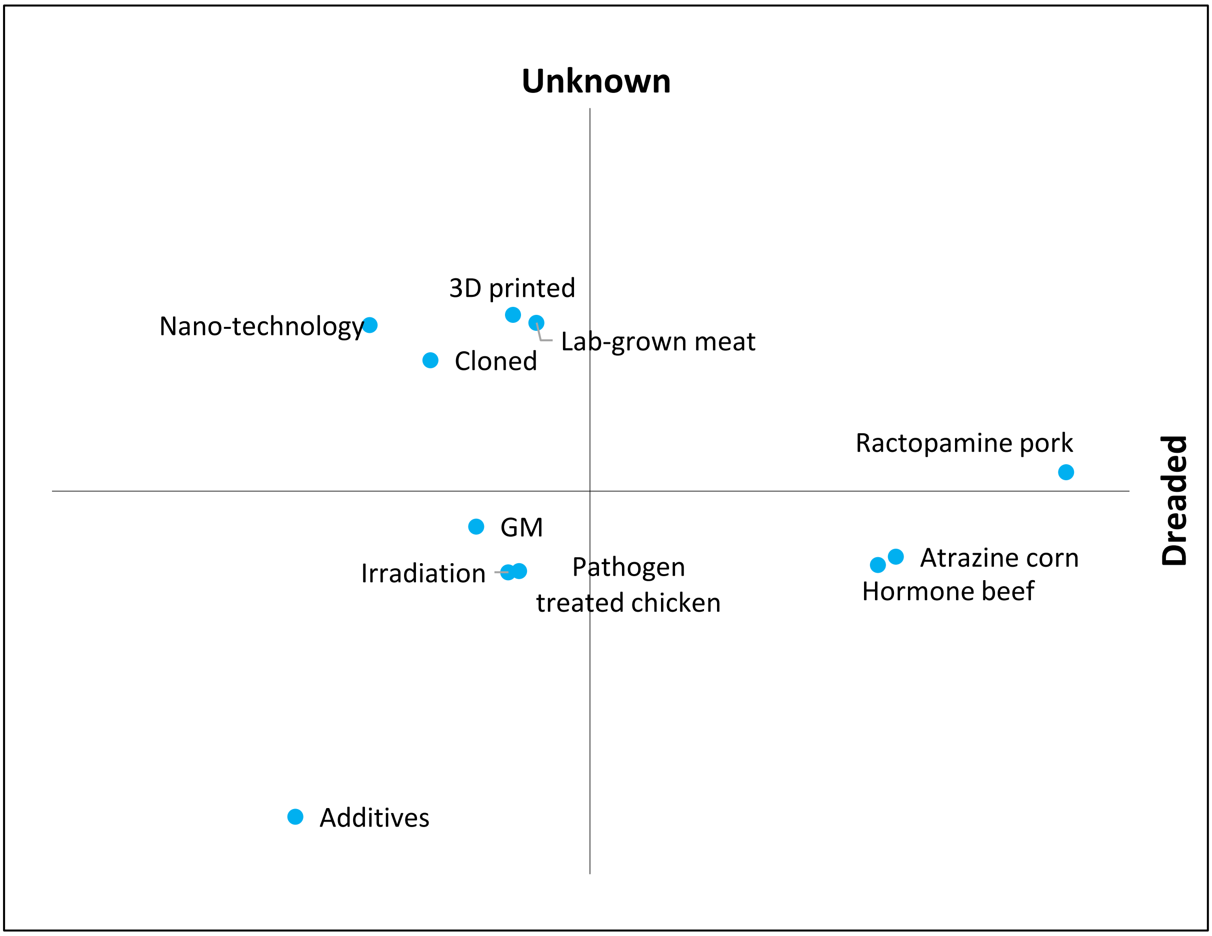

Figure S6. Location of hazards within the two-component space (missing data excluded).

Supplementary Materials 3 – Including All Hazard Characteristics – Exploratory Analysis

We stipulated in our pre-registration that we would exclude highly correlated characteristics (*r* > 0.95) and would only proceed with a PCA given a minimum KMO measure of ≥ 0.6 (based on Kaiser's [1974] classification). However, in the interests of completeness, we present the results of an exploratory PCA including all characteristics (N.B. The resulting correlation matrix was non-positive definite and thus a KMO statistic could not be calculated).

We find a three-component solution, which in total explained 89.9% of the variance. 'Worry', 'personal and scientific knowledge of risk' , 'familiarity', 'worry', 'seriousness of harm', 'likelihood of harm', 'benefits', 'naturalness' and 'knowledge of presence' cross-loaded on more than one component (see Table S5). In these instances, we selected the component where the characteristic had the highest loading.

We termed the first component (accounting for 49.4% of the variance) 'knowledge'. Characteristics loading heavily on 'knowledge' were 'personal and scientific knowledge of risk' (not known at all), 'familiarity' (not familiar) and 'newness' (extremely new). We termed the second component (accounting for 27.1% of the variance) 'dread'. 'Worry' (extremely worried), 'seriousness of harm' (extremely serious), 'likelihood of harm' (extremely likely to damage health), 'benefits' (no benefits at all) and 'naturalness' (man is entirely to blame) loaded heavily on this component. The third component accounted for 13.5% of the variance, with 'control' (no control) and 'knowledge of presence' (you can never tell) loading on to this component, which we termed 'control'.

As in McCarthy and Henson (2004), we tested the reliability of the factors by using Cronbach's alpha. All three components, 'dread', 'knowledge' and 'control' were found to have excellent reliability (α = .915, α = .905, α = .953 respectively) (Nunally, 1978).

Table S10.

Loadings from the PCA.

Characteristic	Component		
	1 'Knowledge'	2 'Dread'	3
Personal knowledge of risk	**.914**		.331
Scientific knowledge of risk	**.986**		
Familiarity	**.895**		.369
Newness	**.914**		
Worry		**.802**	.455
Seriousness of harm		**.886**	.428
Likelihood of harm		**.823**	.489
Benefits	.314	**.784**	
Naturalness	.470	**.736**	- .383
Immediacy	- .313		
Knowledge of presence	.360		**.872**
Control			**.959**

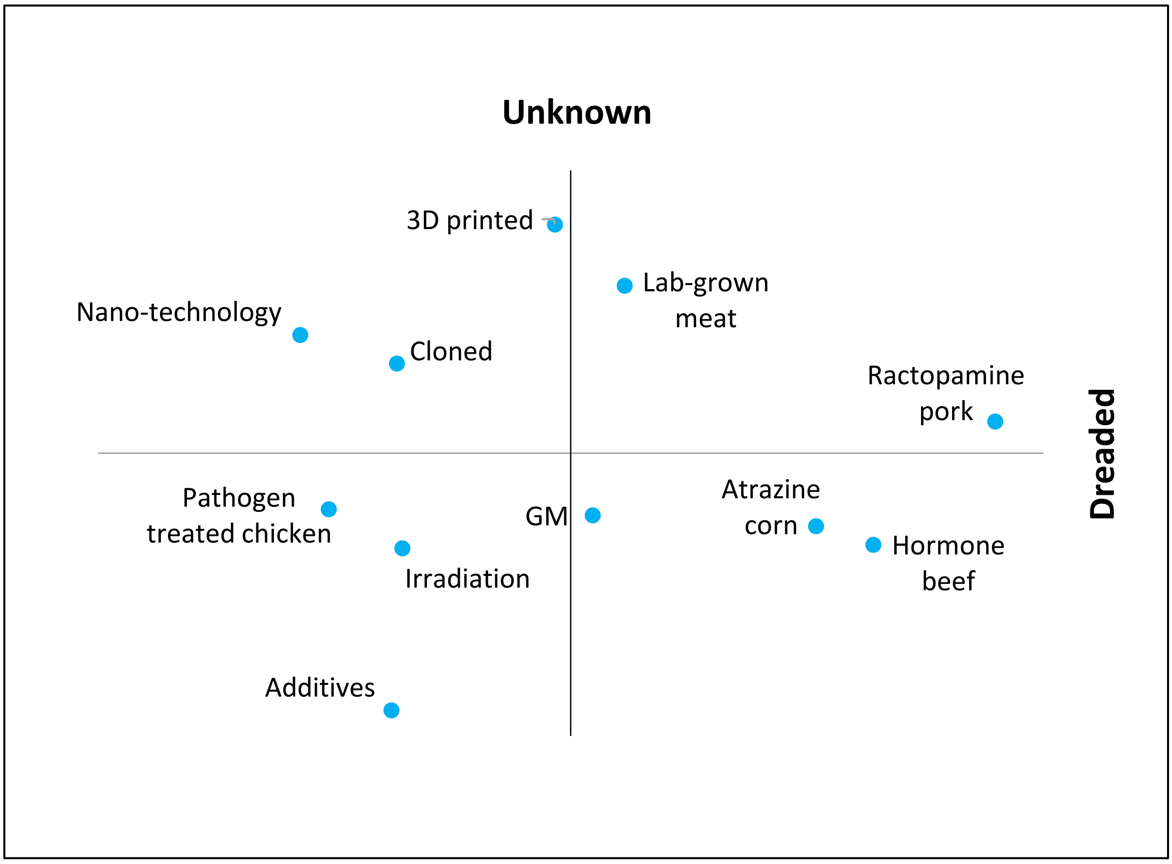

Figure S7. Location of hazards within the two-component space (including all hazard characteristics).

Supplementary Materials 4.

Table S11. Beta Scores of Significant Predictors (p < .05) Of Overall Risk Ratings For Each Hazard

	Characteristics (β)												
	Controllability	Knowledge (presence of hazard)	Health damage likelihood	Seriousness of harm	Worry	Naturalness	Personal knowledge of risk	Scientific knowledge of risk	Familiarity	Newness	Immediacy	Benefits	Adjusted R^2 (%)
Atrazine corn			0.10	0.20	0.17	0.11						0.21	32.5
Food containing additives, colourings and preservatives			0.20	0.27	0.23			0.07				0.08	43.7
Food from a cloned animal			0.27	0.17	0.20							0.17	41.4
Food that has been irradiated			0.19	0.20	0.27							0.15	47.7
Food that has been genetically modified			0.15	0.26	0.26			-0.06				0.13	45.0
Food where nano-technology has been used			0.14	0.26	0.15			0.08				0.11	29.4
Food that has been 3D printed		0.07	0.18	0.34	0.16	-0.08			0.09			0.10	38.2
Hormone beef			0.28	0.20	0.09							0.12	36.8
Lab-grown meat			0.14	0.27	0.21							0.15	38.7
Pathogen treated chicken		-0.10	0.24	0.15	0.10							0.19	32.1
Ractopamine pork			0.16	0.21	0.15							0.13	30.8