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Lay-people's knowledge about toxicology and its principles in eight European countries

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ABSTRACT

The procedures of risk assessment related to substances consumed or used by consumers (e.g., food additives, cleaning products) are highly complex and there exists some controversy between experts in regards to the uncertainty linked to it. This contributes to the well documented divergence in experts and lay-people's judgments, particularly for synthetic or man-made chemicals. By investigating lay-people's knowledge gaps and misconceptions related to toxicology, we hope to contribute to facilitating the communication between experts and the lay public. For this, a large-scale survey measuring knowledge of toxicological principles, trust in regulators, the irrational fear of chemicals and health concern was distributed in eight European countries (Total: $N = 5631$). Results suggest that large gaps exist regarding people's knowledge of toxicological principles and that a lack of knowledge is significantly associated with higher levels of chemophobia. Particular attention for future communication efforts should be placed on the stigma associated with the terminology, principles of dose-response associations and the comparability of substances of natural and synthetic origin.

1. Introduction

In one of the articles on experts' and lay-people's perceptions of toxicological principles Kraus, Malmfors, and Slovic (1992) coined the expression “intuitive toxicology:” „Human beings have always been ‚intuitive toxicologists,’ relying on their sense of sight, taste, and smell to detect harmful or unsafe food, water, and air” (p. 215). Due to the inadequacies of this “intuitive toxicology,” the science of toxicology and health risk assessment have been developed to test the safety of chemicals. Chemicals consumed or used by consumers, such as food additives or cleaning products, are put through intensive risk assessments, maximum usage or consumption doses, and usage instructions are set before their approval (Fan et al., 2015). However, these procedures of risk analysis are highly complex and there is some controversy between experts in regards to the uncertainty linked to this risk assessment (Kraus et al., 1992; Slovic et al., 1995; Ueland et al., 2012). This complicates the communication between experts and lay-people, as the latter lack the necessary background information, time and motivation to judge the uncertainty linked to risk assessments themselves (Hartings and Fahy, 2011; Slovic et al., 1997). Research shows that experts and lay-people's judgments of the risks and benefits and acceptance of complex science and technological innovations differ significantly, particularly if they are perceived as synthetic or man-made (e.g., Blok et al., 2008; Hartmann et al., 2018).

The irrational fear of chemicals and everything the term stands for among lay-people can be termed as “Chemophobia” (e.g., Entine, 2011; e.g., Hartings and Fahy, 2011; Royal Society of Chemistry, 2015). The Royal Society of Chemistry (2015) claimed that experts overestimate the degree of chemophobia in the public and its implications for consumer choices and behavior. Other research suggests, however, that misconceptions exist among the lay public (Bearth et al., 2014; Dickson-Spillmann et al., 2011; Nieuwenhuijsen et al., 2005). For instance, consumers underestimate the riskiness of prescription drugs or eco-cleaning products, while the potential hazardousness of food additives (e.g., Aspartame) is overvalued (Bearth et al., 2014; Bearth et al., 2017; Dickson-Spillmann et al., 2009).

The divergence in judgments between lay-people and experts is frequently explained by pointing out the different levels of knowledge and potential misconceptions that lay-people might have, (e.g., Bearth and Siegrist, 2016; Bredahl et al., 1998; Frewer et al., 2013). The differentiation of “risk as analysis” and “risk as feeling” describes that risk judgments might be based on two distinct strategies: First, people's estimation of the risk based on all available data and second, heuristics or other simple decision strategies, such as trust in public authorities, affect or perceived naturalness (Raue et al., 2018; Slovic et al., 2004). Lay-people usually lack the necessary resources (e.g., time, motivation,

Abbreviations: CH, Switzerland; AT, Austria; FR, France; DE, Germany; IT, Italy; PL, Poland; SE, Sweden; UK, United Kingdom

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attention, lack of education) to apply the "risk as analysis" strategy and instead rely on "risk as feelings." For instance, lay-people might be well aware of the safeguards implemented regarding food additives, but might still express worry and reject foods with a particular food additive due to the feelings they have or due to a lack of trust in risk assessors and regulators. Particularly, (a lack of) trust in scientists and risk analysis might contribute as an intuitive factor to the public's acceptance of or skepticism towards "chemicals" (Siegrist, 2008). Also, someone's personal concern with health might have implications how much concern chemicals induce, as a common narrative is that some man-made substances (e.g., Aspartame) are carcinogenic independent of the exposure level (Bearth et al., 2014; Levy et al., 2008; MacGregor et al., 1999; Nieuwenhuijsen et al., 2005).

The goal of the present research was to investigate consumers' knowledge of toxicology and its principles and relate this knowledge, as well as trust and health concern, to the level of reported chemophobia. By focusing on this issue, we hope to contribute to facilitating the communication between experts, such as toxicologists from research and industry, and the lay public. For this, a large-scale survey was distributed to lay-people in eight European countries.

2. Method

2.1. Participants

For this study, subjects from Switzerland, Austria, France, Germany, Italy, Poland, Sweden and the United Kingdom were recruited with the support of a professional provider of consumer panels (respondi in Cologne, Germany). In Switzerland, three of the four national languages were considered (i.e., 70% German-speaking, 24% French-speaking, 6% Italian-speaking participants). Participants who filled out the questionnaire too fast (i.e., half the duration of the median duration of all participants per country), and likely only participated for the incentive offered by the panel provider, were excluded from the final sample (Greszki et al., 2014). On average, this applied to $n = 79$ participants per country. Table 1 presents an overview of the socio-demographics per country with the final samples. As quota-sampling for age and gender was applied (gender: 50:50, age: six groups from 18 to 79 years), no significant differences between countries were expected or uncovered (gender: $\chi^2(7) = 1.17$, $p = .992$; age: $F(7, 5623) = 0.79$, $p = .597$, $\eta^2 = 0.00$). Regarding education ($\chi^2(28) = 1133.135$, $p < .001$) and the number of school-years ($F(7, 5631) = 71.27$, $p < .001$, $\eta^2 = 0.08$) significant differences were found. These differences originate in the different socio-cultural contexts of these countries and should be considered when interpreting this study's findings.

2.2. Questionnaire

The study is part of a Swiss government-funded research project that aims at investigating consumers' perceptions and handling of chemical products. However, for this paper, solely knowledge, chemophobia, trust in public authorities and health concern scales, sociodemographics and control variables will be considered. The questionnaire was translated from German into French, Italian, Polish, Swedish and English and subsequently, back-translated into German by a native speaker. Irregularities were discussed and solved by the first author.

The knowledge scale aimed at measuring people's *Knowledge of Toxicological Principles* with focus on negative health effects. The scale was developed and validated in a previous study with German-speaking Swiss participants (Saleh, Bearth, & Siegrist, submitted). For this new study, items pertaining to regulatory actions were removed as they will likely be closely related to trust in public authorities. Moreover, previously un-scalable items were rephrased. The included knowledge scale comprised seven incorrect and five correct statements and for each, participants were asked to indicate whether they thought the statement was "true," "false" or "do not know," which was subsequently recoded to 1 for correct responses and 0 for the other two responses. Figs. 1 and 2 in the results section present the 12 items.

Chemophobia (5 items) was defined as the irrational fear of chemical substances, such as the wish to live in a chemical-free world. *Health Concern* (5 items) measured how worried participants were about their personal health. *Trust in Public Authorities* (3 items) measured their amount of trust that public authorities in their country protect their health. Responses were measured on a 6-point Likert scale with 1 "do not agree at all" to 6 "strongly agree." The chemophobia and health concern scales were also previously used in the study by Saleh et al. (submitted). Principal component and reliability analyses suggested a one-factor solution for chemophobia, whereas health concern loaded on

Table 1
Socio-demographics per country.

Total	CH	AT	FR	DE	IT	PL	SE	UK
	698	731	708	711	695	693	682	713
Gender *N* (%)								
Female	352 (50.4)	368 (50.3)	364 (51.4)	356 (50.1)	351 (50.5)	349 (50.4)	357 (52.3)	358 (50.2)
Male	346 (49.6)	363 (49.7	344 (48.6)	355 (49.9)	344 (49.5)	344 (49.6)	325 (47.7)	355 (49.8)
Age *M* (*SD*)	50.7 (16.9)	49.5 (16.8)	50.4 (16.9)	50.3 (16.8)	50.2 (16.5)	50.9 (16.8)	51.4 (16.7)	50.7 (17.0)
Years of school *M* (*SD*)	12.1 (5.0)	11.4 (5.1)	10.1 (6.6)	10.8 (6.1)	14.1 (4.7)	14.6 (3.6)	11.1 (5.0)	13.4 (4.4)
Education *N* (%)								
No school completed	1 (0.1)	1 (0.1)	34 (4.8)	5 (0.7)	–	–	–	8 (1.1)
Mandatory school	34 (4.9)	40 (5.5)	79 (11.2)	45 (6.3)	55 (7.9)	24 (3.5)	52 (7.6)	106 (14.9)
Apprenticeship	338 (48.4)	307 (42.0)	94 (13.3)	298 (41.9)	66 (9.5)	80 (11.5)	92 (13.5)	46 (6.5)
High school	233 (13.2)	201 (27.5)	196 (27.7)	150 (21.1)	299 (43.0)	288 (41.6)	274 (40.2)	289 (40.5)
University	233 (33.4)	182 (24.9)	305 (43.0)	213 (30.0)	275 (39.6)	301 (43.4)	264 (38.7)	264 (37.0)
Children in household *N* (%)								
Yes, full time	96 (13.8)	91 (12.4)	126 (17.8)	104 (14.6)	137 (19.7)	181 (26.1)	115 (17.0)	123 (17.3)
Yes, part time	31 (4.4)	35 (4.8)	38 (5.4)	29 (4.1)	42 (6.1)	34 (4.9)	55 (8.1)	45 (6.3)
No	571 (81.8)	605 (82.8)	544 (76.8)	578 (81.3)	516 (74.2)	478 (69.0)	512 (75.1)	545 (76.4)
Household tasks *N* (%)								
Main responsibility	386 (55.3)	414 (56.6)	399 (56.4)	412 (58.0)	433 (62.3)	374 (54.0)	363 (53.2)	403 (56.5)
Shared responsibility	271 (38.8)	276 (37.8)	282 (39.8)	262 (36.8)	227 (32.7)	299 (43.1)	284 (41.6)	268 (37.6)
No responsibility	41 (5.9)	41 (5.6)	27 (3.8)	37 (5.2)	35 (5.0)	20 (2.9)	35 (5.1)	42 (5.9)
Work in industry *N* (%)								
Yes	103 (14.8)	116 (15.9)	96 (13.6)	72 (10.1)	44 (6.3)	79 (11.4)	120 (82.4)	58 (8.1)
No	595 (85.2)	615 (84.1)	612 (86.4)	639 (89.9)	651 (93.7)	614 (88.6)	562 (82.4)	655 (91.9)

Note: CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom.

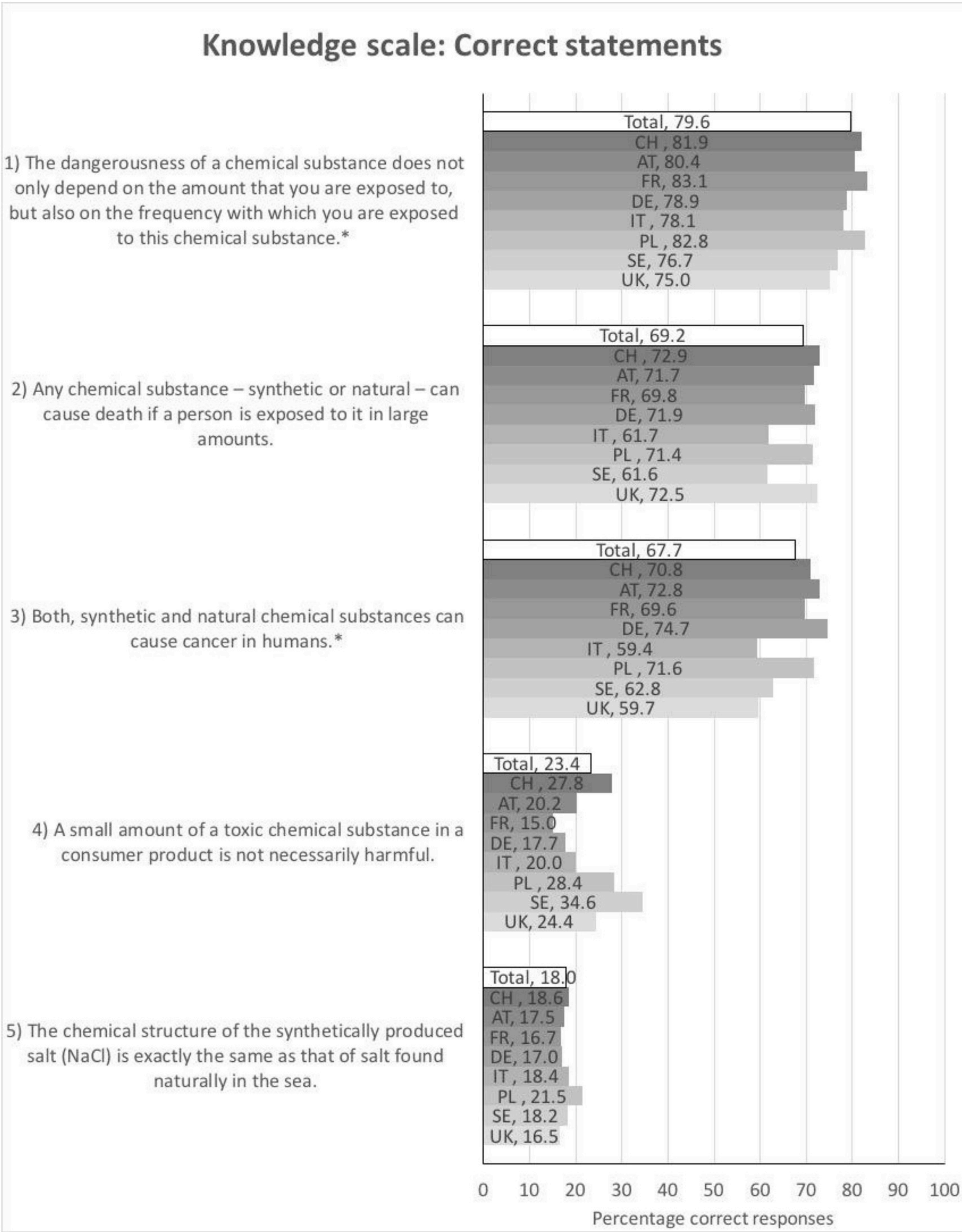

Fig. 1. Correct statements of the knowledge scale (Total N = 4943; CH: Switzerland (N = 698); AT: Austria (N = 731); FR: France (N = 708); DE: Germany (N = 711); IT: Italy (N = 695); PL: Poland (N = 693); SE: Sweden (N = 682); UK: United Kingdom (N = 713); *: included in the Mokken scale).

two separate factors in all eight countries. Thus, health concern was split into two scales: *Health concern* and *Health Worry,* with the latter focused more strongly on the fear of potential illness. The three trust items loaded on one factor. Table 2 presents all scales and their corresponding items with means and standard deviations.

Lastly, sociodemographics and control variables were assessed, namely gender, age, level of education and school years, whether they worked in an industry that handles chemical products.

2.3. Data analysis

Descriptive analyses, bivariate correlations, regression analyses and Chi^2-Tests and ANOVAs (two-tailed) to compare data from the different countries were conducted in SPSS 25 (IBM Corp, 2017). The scalability of the knowledge items was assessed with an approach from the probabilistic test theory, more specifically Mokken scale analysis (Mokken and Lewis, 1982). It is based on the assumption that the knowledge items can be ordered according to their difficulty and that each person's probability to give the correct response depends on the item's difficulty and the person's ability. A Mokken scale is a collection of ability items, ordered according to difficulty, that measure an underlying latent construct (i.e., knowledge of toxicological principles). It is a more stringent test for one-dimensionality than classical test theory. Loevinger's scalability coefficient H indicates the scale's quality, where

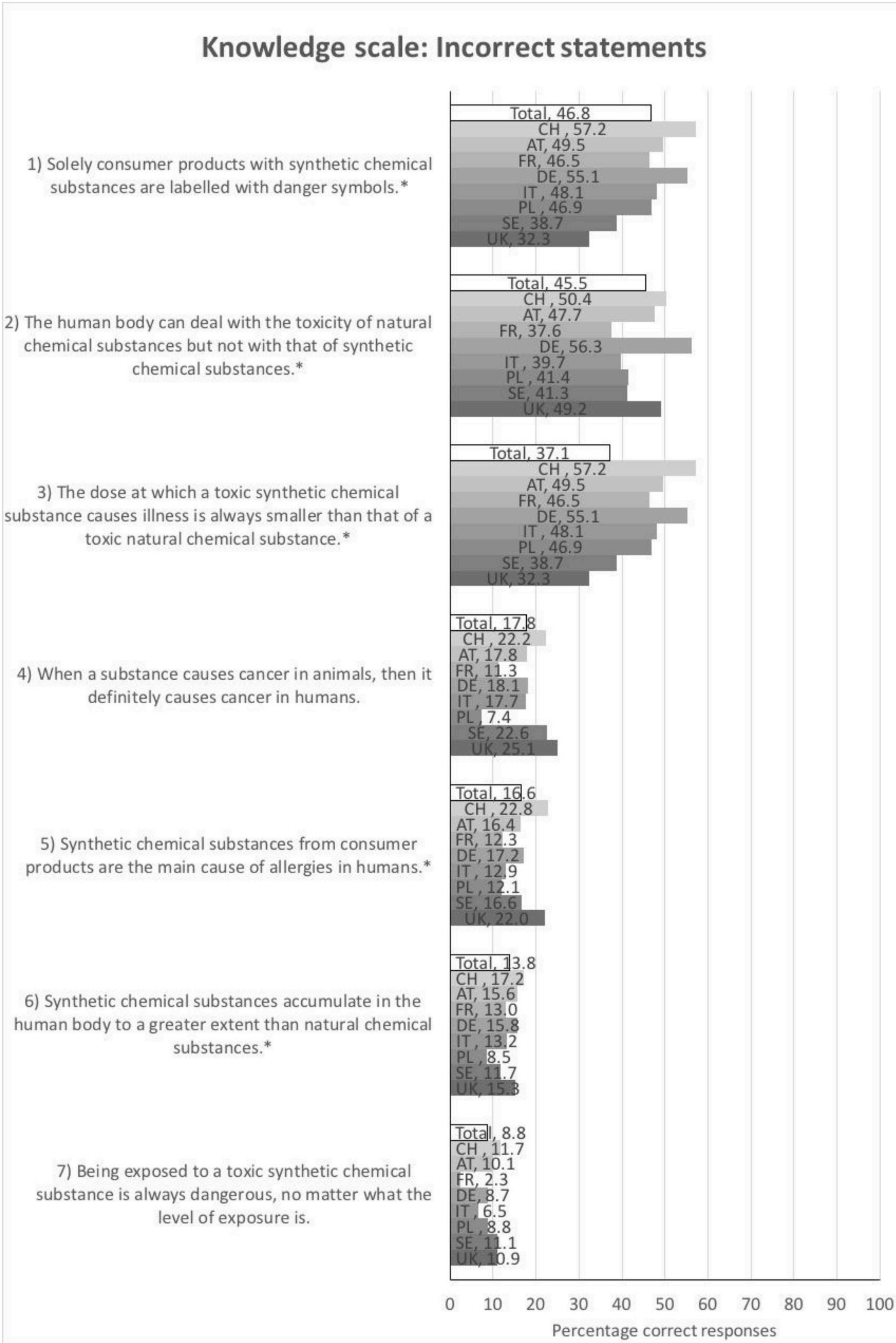

Fig. 2. Incorrect statements of the knowledge scale (Total N = 4943; CH: Switzerland (N = 698); AT: Austria (N = 731); FR: France (N = 708); DE: Germany (N = 711); IT: Italy (N = 695); PL: Poland (N = 693); SE: Sweden (N = 682); UK: United Kingdom (N = 713); *: included in the Mokken scale).

Table 2
Chemophobia (Means, Standard Deviations; 1 do not agree at all – 6: strongly agree).

	CH		AT		FR		DE		IT		PL		SE		UK	
	N = 698		N = 731		N = 708		N = 711		N = 695		N = 693		N = 682		N = 713	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Chemophobia (α = .86)	**3.63**	**1.21**	**3.55**	**1.22**	**4.33**	**1.09**	**3.70**	**1.23**	**4.30**	**1.14**	**4.16**	**1.16**	**3.70**	**1.20**	**3.41**	**1.18**
Chemical substances scare me.	3.27	1.52	3.03	1.59	4.05	1.55	3.25	1.56	4.09	1.49	3.75	1.6	3.52	1.56	3.18	1.55
I do everything I can to avoid contact with chemical substances in my daily life.	3.94	1.51	3.68	1.54	4.38	1.39	3.81	1.52	4.55	1.32	4.28	1.46	3.43	1.49	3.69	1.55
I would like to live in a world where chemical substances don't exist.	3.61	1.64	3.51	1.69	4.42	1.50	3.60	1.65	4.18	1.56	3.86	1.70	4.01	1.64	3.59	1.60
I believe that chemical substances are the main reason why people suffer from cancer.	3.42	1.43	3.42	1.41	4.13	1.39	3.64	1.45	4.01	1.41	4.14	1.42	3.52	1.43	2.91	1.45
I believe that chemical substances are the reason for most environmental problems.	3.90	1.46	4.13	1.45	4.68	1.25	4.18	1.42	4.63	1.32	4.75	1.35	4.04	1.40	3.69	1.45
Trust in public authorities (α = .65)	**4.44**	**1.19**	**3.98**	**1.38**	**3.46**	**1.48**	**3.72**	**1.37**	**4.18**	**1.15**	**3.75**	**1.28**	**4.07**	**1.27**	**4.21**	**1.18**
I think that the legislations on chemical household products in my country are strict enough.	4.47	1.29	3.99	1.50	3.53	1.53	3.80	1.50	4.04	1.34	3.73	1.36	3.94	1.46	4.08	1.38
I trust the public authorities in my country regarding the authorization and control of chemical household products.	4.50	1.33	4.06	1.53	3.46	1.62	3.77	1.54	4.07	1.37	3.82	1.46	4.20	1.42	4.31	1.33
I trust the public authorities in my country that they do everything they can to protect the health of consumers.	4.35	1.35	3.89	1.53	3.40	1.65	3.58	1.50	4.43	1.35	3.70	1.50	4.07	1.45	4.24	1.35
Health concern (α = .65)	**4.51**	**1.01**	**4.41**	**1.05**	**4.61**	**1.07**	**4.48**	**1.04**	**4.67**	**0.95**	**4.72**	**1.03**	**4.45**	**1.01**	**3.92**	**1.11**
I am very concerned about my health.	4.53	1.21	4.44	1.26	4.50	1.29	4.44	1.25	4.70	1.14	4.47	1.31	4.16	1.31	3.65	1.50
I hardly ever worry about my health.	2.31	1.43	2.39	1.48	2.10	1.41	2.32	1.40	2.28	1.44	2.30	1.50	1.90	1.26	2.79	1.48
I protect myself as much as possible from getting even slightly sick.	4.30	1.37	4.17	1.43	4.42	1.38	4.32	1.35	4.60	1.18	5.01	1.20	4.09	1.44	3.89	1.45
Health worry (α = .87)	**3.34**	**1.52**	**3.30**	**1.56**	**3.98**	**1.55**	**3.74**	**1.52**	**4.33**	**1.39**	**4.66**	**1.33**	**3.67**	**1.59**	**3.71**	**1.52**
I worry a lot about getting a serious disease (e.g., cancer).	3.44	1.65	3.37	1.67	4.16	1.70	3.87	1.64	4.38	1.45	4.65	1.43	3.73	1.70	3.59	1.64
I am afraid of getting a chronic disease.	3.24	1.58	3.24	1.64	3.79	1.62	3.62	1.62	4.28	1.47	4.67	1.40	3.60	1.68	3.83	1.64

Note: CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom.

H = 0.3–0.4 is considered a still acceptable scale, H = 0.4–0.5 is an average scale and H = 0.5–1.0 is a strong scale. The individual coefficients of the items are required to be higher than $H_i = 0.3$ to include this item in the scale (Mokken and Lewis, 1982). The Mokken scale analysis was done in R, utilising the Mokken package (R Core Team, 2018; van der Ark, 2007).

3. Results

3.1. Knowledge of toxicological principles

Figs. 1 and 2 present the five correct and seven incorrect statements of the knowledge of toxicological principles scale, and the frequency distribution of correct responses. For most knowledge items, responses exhibited significantly different distributions between the countries ($\chi^2(7) > 26.21, p < .001$). An exception was the statement regarding the chemical structure of synthetically manufactured and naturally occurring salt, $\chi^2(7) = 8.47$, $p = .293$. Overall, the easiest item pertained to the interdependence of amount and frequency of exposure for potential harmful effects of a substance (75% or more correct responses). Furthermore, more than half of the participants responded correctly to the statements related to the fatalness of large amounts of any chemical substance and that both synthetic and natural substances can be carcinogen. The incorrect statements regarding the labelling of consumer products, the ability of the human body to deal with natural and synthetic substances, and the dose at which these substances might cause illness exhibited correct response rates between 30% and 50%. The most difficult correct statements were related to the harmfulness of having a small amount of toxic chemical substance in a consumer product and the chemical structure of synthetically produced and naturally occurring salt (less than 25% correct responses). Incorrect statements that exhibited the lowest correct response rates were related to the transferability of insights from animals to humans, causes of allergies, accumulation in the human body and the dose-response relationship between being exposed to a toxic substance and the substance actually causing harm (less than 20% correct responses).

Mokken scale analysis with the total sample showed that seven of the 12 knowledge items were scalable on one dimension with a $H_i > 0.30$. Table 3 presents the scalability coefficients for this scale with the seven items for the total sample and separately for the eight countries. It shows that the scale did not work equally well in all countries. Particularly, in Poland, the scalability coefficient was slightly below the acceptable value of H = 0.30. In Germany, the item regarding the frequency of exposure performed poorly, but the whole scale was good. Therefore, for comparability the same scale was used for all eight countries by summing up the correct responses. This knowledge index had a range of 0–7, with higher scores suggesting a higher knowledge of toxicological principles. The mean knowledge score for the total sample was $M = 3.07$ ($SD = 1.75$). A one-way ANOVA showed that knowledge differed significantly between the eight countries, $F(7, 5623) = 15.00$, $p < .001$, $\eta^2 = 0.02$. The highest knowledge score was observed for Germany ($M = 3.45$, $SD = 1.73$), Switzerland ($M = 3.42$, $SD = 1.83$) and Austria ($M = 3.21$, $SD = 1.79$). Lower knowledge scores were observed for Italy ($M = 2.97$, $SD = 1.73$), Poland ($M = 2.95$, $SD = 1.51$), France ($M = 2.91$, $SD = 1.67$), and the UK ($M = 2.87$, $SD = 1.82$). The lowest knowledge score had participants in Sweden ($M = 2.79$, $SD = 1.81$).

ANOVAs were conducted to check whether education, gender or working in an industry that manufactures, imports, trades or uses chemical products influence knowledge scores. First, an ANOVA was conducted with all variables entered as fixed variables. As there were no interaction effects, the results of separate one-way ANOVAs are reported. There was a significant effect of education ($F(2, 5628) = 69.38$, $p < .001$, $\eta^2 = 0.02$): The highest knowledge score was observed for participants with the highest level of education (university; $M = 3.41$, $SD = 1.78$), followed by medium levels of education (high school, apprenticeship; $M = 2.93$, $SD = 1.71$) and the lowest level of education (no education or mandatory school; $M = 2.58$, $SD = 1.69$). There was a significant gender effect ($F(1, 5629) = 62.85$, $p < .001$, $\eta^2 = 0.01$); Men ($M = 3.26$, $SD = 1.78$) exhibited higher knowledge scores than women ($M = 2.89$, $SD = 1.71$). Also, the professional background had a significant effect on knowledge ($F(1, 5629) = 33.06$, $p < .001$,

Table 3
Knowledge of toxicological principles (Loevinger's scalability coefficient H for scale and H_i items and reliability coefficient (rho)).

	Total H = .379	CH H = .410	AT H = .411	FR H = .405	DE H = .353	IT H = .344	PL H = . 292	SE H = .429	UK H = .380
	5631	698	731	708	711	695	693	682	713
Synthetic chemical substances accumulate in the human body to a greater extent than natural chemical substances.	.427	.492	.482	.427	.467	.336	.307	.399	.416
The dose at which a toxic synthetic chemical substance causes illness is always smaller than that of a toxic natural chemical substance.	.421	.483	.461	.432	.410	.364	.321	.461	.414
The human body can deal with the toxicity of natural chemical substances but not with that of synthetic chemical substances.	.402	.441	.435	.449	.386	.404	.311	.459	.409
Both, synthetic and natural chemical substances can cause cancer in humans.	.379	.372	.447	.429	.322	.289	.311	.465	.364
Solely consumer products with synthetic chemical substances are labelled with danger symbols.	.366	.398	.400	.396	.383	.376	.285	.384	.332
Synthetic chemical substances from consumer products are the main cause of allergies in humans.	.322	.348	.306	.314	.343	.298	.167	.406	.325
The dangerousness of a chemical substance does not only depend on the amount that you are exposed to, but also on the frequency with which you are exposed to this chemical substance.	.304	.294	.299	.325	.134	.280	.296	.400	.411
Reliability coefficient (rho)	**.69**	**.71**	**.70**	**.68**	**.68**	**.68**	**.57**	**.72**	**.70**

Note: CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom.

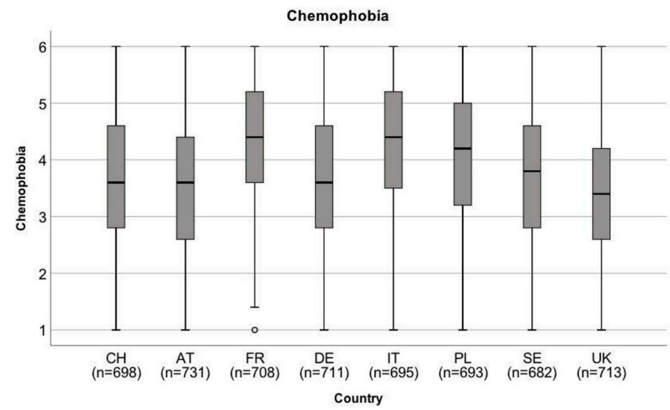

Fig. 3. Boxplots of chemophobia per country (Different superscript letters denote significant differences according to Bonferroni post hoc tests: CH: Switzerland[cd], AT: Austria[d], FR: France[a], DE: Germany[c], IT: Italy[a], PL: Poland[b], SE: Sweden[c], UK: United Kingdom[c]).

$\eta^2 = 0.01$), with higher levels for people who work with chemicals ($n = 688$; $M = 3.43$, $SD = 1.87$), than other people ($n = 4943$, $M = 3.02$, $SD = 1.73$). Bivariate correlation analyses revealed very small, positive correlations between knowledge of toxicological principles and age ($r = 0.05$, $p < .001$) and school years ($r = 0.15$, $p < .001$).

3.2. Relationships with trust in public authorities, health concern and chemophobia

First, a one-way ANOVA was conducted to check for significant differences in chemophobia among participants from different countries. There were significant differences between the mean chemophobia among the eight countries, $F(7, 5623) = 90.50$, $p < .001$, $\eta^2 = 0.08$ (cf. boxplots in Fig. 3). The highest levels of chemophobia were observed in France, Italy and Poland. Germany, Austria, Switzerland, Sweden and UK exhibited lower levels of chemophobia.

In separate linear regression analyses for each country, the effect of socio-demographics, health concern, trust and knowledge on chemophobia was investigated (cf. Table 4). In all countries, the knowledge of toxicological principles was significantly, negatively related to people's levels of chemophobia with the strongest associations in Sweden, Germany and Italy (B = −0.10) and the weakest association in the UK (B = −0.04). Health concern and worry was significantly, positively related to chemophobia for all countries. Thus, people that were more concerned for their health and worried more about getting ill expressed more chemophobia. Trust in public authorities was significantly associated solely in the German-speaking countries and France, but not in the other countries. The negative association suggests that more trust was significantly related to a lower level of chemophobia in the respective countries. Regarding the sociodemographics, particularly higher age was significantly associated with more chemophobia in some countries (Switzerland, Austria, Germany, Poland). In Switzerland, the women expressed significantly more chemophobia than men (B = −0.28). Regarding education, solely in Italy a significant relationship between having a higher education and expressing less chemophobia could be observed (B = −0.56).

4. Discussion

The knowledge scale used in this study did uncover a number of prevalent misconceptions and knowledge gaps among lay-people related to toxicology and its principles. The response patterns also resonates the findings of the original intuitive toxicology papers (Kraus et al., 1992; Slovic et al., 1995): Lay-people exhibit particular insecurities regarding the dose-response relationship, synthetic versus

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Table 4
Linear regression analysis with chemophobia as dependent variables.

	CH		AT		FR		DE		IT		PL		SE		UK	
	N = 698		N = 731		N = 708		N = 711		N = 695		N = 693		N = 682		N = 713	
	$F(8, 689) = 38.15$ $p < .001$		$F(8, 722) = 37.75$ $p < .001$		$F(8, 699) = 43.13$ $p < .001$		$F(8, 702) = 46.03$ $p < .001$		$F(8, 686) = 30.09$ $p < .001$		$F(8, 684) = 22.95$ $p < .001$		$F(8, 673) = 35.04$ $p < .001$		$F(8, 704) = 28.19$ $p < .001$	
	$R^2 = .31$		$R^2 = .30$		$R^2 = .33$		$R^2 = .34$		$R^2 = .26$		$R^2 = .21$		$R^2 = .29$		$R^2 = .24$	
	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t	B (95% CI)	t
Constant	2.61 (1.97,3.25)	8.01***	2.21 (1.64,2.78)	7.63***	2.77 (2.33,3.22)	12.25***	1.86 (1.30,2.42)	6.52***	2.39 (1.8,2.97)	8.02***	1.97 (1.29,2.65)	5.67***	2.50 (1.87,3.13)	7.77***	1.57 (1.02,2.11)	5.65***
Sex[a]	-0.28 (-0.44,-0.13)	-3.60***	-0.24 (-0.39,-0.09)	-3.12**	-0.21 (-0.34,-0.07)	-3.00**	-0.11 (-0.26,0.04)	-1.48	-0.14 (-0.29,0.01)	-1.90	-0.23 (-0.39,-0.07)	-2.86**	-0.24 (-0.40,-0.08)	-3.00**	-0.10 (-0.26,0.05)	-1.29
Age	0.01 (0.01,0.02)	4.77***	0.01 (0.01,0.02)	6.02***	0.01 (0.00,0.01)	3.10**	0.01 (0.01,0.01)	4.34***	0.01 (0.00,0.01)	2.83**	0.01 (0.00,0.01)	3.54***	0.01 (0.00,0.01)	2.05*	0.01 (0.00,0.01)	2.96**
Education medium[c]	-0.06 (-0.41,0.29)	-0.34	0.00 (-0.33,0.33)	-0.02	-0.08 (-0.28,0.11)	-0.83	0.09 (-0.20,0.39)	0.61	-0.24 (-0.52,0.05)	-1.65	0.12 (-0.32,0.56)	0.54	-0.14 (-0.44,0.16)	-0.93	0.08 (-0.14,0.30)	0.70
Education High[c]	-0.49 (-0.86,-0.12)	-2.62**	-0.45 (-0.80,-0.10)	-2.49*	-0.27 (-0.47,-0.06)	-2.57*	-0.12 (-0.44,0.20)	-0.74	-0.56 (-0.85,-0.27)	-3.79***	-0.07 (-0.52,0.37)	-0.32	-0.44 (-0.75,-0.13)	-2.78**	-0.09 (-0.32,0.14)	-0.74
Knowledge	-0.09 (-0.14,-0.05)	-4.32***	-0.09 (-0.13,-0.04)	-3.89***	-0.07 (-0.11,-0.03)	-3.29**	-0.10 (-0.14,-0.05)	-4.37***	-0.10 (-0.14,-0.05)	-4.41***	-0.05 (-0.10,0.01)	-1.77	-0.10 (-0.15,-0.06)	-4.68***	-0.04 (-0.09,0.00)	-2.02*
Trust	-0.12 (-0.18,-0.05)	-3.61***	-0.15 (-0.21,-0.10)	-5.51***	-0.10 (-0.14,-0.05)	-4.13***	-0.15 (-0.20,-0.09)	-5.18***	0.04 (-0.03,0.10)	1.06	0.04 (-0.02,0.11)	1.41	-0.04 (-0.10,0.02)	-1.43	0.01 (-0.06,0.07)	0.15
Health concern	0.26 (0.18,0.34)	6.5***	0.33 (0.26,0.40)	8.91***	0.30 (0.23,0.37)	8.19***	0.32 (0.24,0.39)	7.82***	0.23 (0.14,0.31)	5.38***	0.17 (0.09,0.25)	4.05***	0.25 (0.17,0.34)	6.09***	0.23 (0.14,0.32)	5.09***
Health worry	0.22 (0.17,0.27)	8.25***	0.17 (0.12,0.22)	6.75***	0.22 (0.17,0.26)	8.91***	0.25 (0.20,0.30)	9.40***	0.28 (0.23,0.34)	10.10***	0.27 (0.20,0.33)	8.38***	0.24 () 0.19,0.29)	9.06***	0.22 (0.16,0.29)	6.64***

Note. [a] 0: female; 0: low education; CH: Switzerland, AT: Austria, FR: France, DE: Germany, IT: Italy, PL: Poland, SE: Sweden, UK: United Kingdom; ***: $p < .001$, **: $p < .01$, *: $p < .05$.

natural chemicals and the circumstances that might lead to harmful effects of a particular substance. The notion among experts is that a basic understanding of toxicology, the dose-response relationship, and the risk assessment process would enable lay-people to retrace risk-and-benefit analyses and might improve their ability to make fact-based decisions related to chemicals (Entine, 2011; Royal Society of Chemistry, 2015; Smith, 2011). Previous research also suggests that appropriately presented information about the risk assessment process is associated with lower risk perception of chemicals (Bearth et al., 2016; Shim et al., 2011). While it might be helpful to find ways to convey these concepts, it might be even more important to address the differences in terminology of what constitutes a “chemical” and the non-existent differentiation between “natural” and “synthetic” in science communication efforts (Royal Society of Chemistry, 2015). Science does not differentiate between chemicals of artificial and natural origin; any substance can be harmful depending on the dose or exposure (Fan et al., 2015). Lay-people on the other hand have a rather narrow definition of the term “chemical,” as a man-made substance, usually dangerous or harmful to health. Previous research showed that lay-people report more negative affect towards the term “synthetic chemical substance” than towards the term “natural chemical substance,” despite having received a definition of both terms beforehand (Saleh et al., submitted). This tendency among lay-people, to prefer natural substances or rather, substances perceived to be natural, is well-documented in the literature (Bearth et al., 2016; Dickson-Spillmann et al., 2011; Ropeik, 2012; Rozin et al., 2012; Scott and Rozin, 2017).

The present study demonstrates that knowledge of toxicological principles is important for people not to experience and express irrational fears of chemicals. Thus, efforts of informing consumers and increasing their knowledge about toxicology and its principles is a promising way to reduce chemophobia, but a focus on just the analytical aspect of risk judgments falls short (Hartings and Fahy, 2011; Slovic et al., 2004). For instance, trust has been discussed to be particularly important in the absence of knowledge or when a risk is complex and of high uncertainty. Based on the trust literature (e.g, Earle et al., 2007; Siegrist and Cvetkovich, 2000; Siegrist et al., 2000), trust in regulatory bodies could potentially be improved by providing believable and transparent information or by providing cues that suggest high competence or similar values as the recipient of the information. Furthermore, health concern and worry were more strongly related to chemophobia in all countries. The strong impact of health concern and worry could be explained by the association of chemical substances with cancer, chronic illnesses or other diseases that cause a large amount of dread (Lee et al., 2005; Levy et al., 2008). Thus, participants that are particularly worried about contracting a dreadful disease, also exhibit more chemophobia, which might be caused by the perception that chemical substances are the main source of disease.

Inspecting the particularly difficult knowledge items, two concepts from risk research might play a role in lay-people's perceptions of chemicals: First, the concept of “contagion,” which denotes that the attributes of a disgusting or otherwise negatively connoted object can permanently transfer to a neutral or positive object. Second, man-made chemical substances, despite offering a multitude of benefits for consumers, suffer from “technological stigma.” Introduced by Gregory et al. (1995), the term denotes that for stigmatized technologies, such as use of chemicals or nuclear power, public discourse focuses much more on the potential risks than on the benefits. Previous research has for instance shown that people evaluate a human-caused oil spill more negatively than a natural oil spill; similar results were uncovered for energy systems (Siegrist and Sütterlin, 2014). Thus, lay-people's perceptions of risk of man-made chemicals are amplified, benefits are underestimated. This is largely fueled by the negative associations and imagery that the term “chemicals” raises (Bush et al., 2001; Loewenstein et al., 2001; Saleh et al., submitted). Related to our findings, consumers believe that the chemical structure of synthetically produced salt cannot be the same as salt found naturally in the sea, as one is man-made and “tainted” by human intervention (correct statement #5). This could also explain the frequently uncovered dose-response insensitivity, as they believe that a negative or dangerous object (i.e., chemical) causes harm, independent of the dose (correct statement #4, incorrect statements #6–7; Kraus et al., 1992; MacGregor et al., 1999). Thus, information provision might be insufficient, as lay-people reject synthetic chemicals and products containing synthetic chemicals purely for being man-made.

While the stigmatization related to the terms “chemicals” is well-documented in the literature, little effort has been undertaken to experimentally investigate how stigmatization could be reduced in communication and educational efforts. This is desirable as chemophobia might not only impede individual informed decision making, but also might hinder technological advancements via market boycotts, lobbying or other forms of public protest. It might be difficult to remove stigma by renaming and using different, non-stigmatized terms, but nonetheless it could be fruitful to investigate how the expression “everything's chemical” is understood by consumers and what effects this piece of information has on their perceptions and decision making. Furthermore, specific and personally relevant benefits could be addressed or an alternative world without man-made chemical substances could be evoked, to reduce stigmatization. More generally, chemophobia is an example of distrust in science and low scientific literacy and thus, intolerance of scientific uncertainty (Boele-Woelki et al., 2018; Fasce and Pico, 2019). Communicating risk-benefit considerations and scientific uncertainty is complex and a more intensive educational approach might be necessary to improve people's abilities to make informed decisions. This matches the calls for including a more intensive education in the sciences (i.e., chemistry, toxicology) in school curriculums at all educational levels (Boele-Woelki et al., 2018).

Chemophobia was higher in France, Italy and Poland than in Switzerland, Austria, Germany, Sweden and the UK. It might be important to inform and educate consumers everywhere, but regional differences might need to be taken into account when communicating or educating the public on toxicological principles. For instance, in France, chemophobia might be strongly related to a lack of trust in public authorities, as the French participants reported the lowest trust and it was significantly related to their chemophobia. In Italy, trust in public authorities was not significantly related to chemophobia, but knowledge and education, as well as health concern and worry were. Lastly, in Poland, other variables than the ones included in this survey were relevant for people's chemophobia. Thus, communication and educational efforts should be adjusted accordingly.

In terms of limitations, the concept of chemophobia should be reconsidered in future research, as the current scale comprises potentially rational items. In line with the experts' definition of a chemical substance, it makes no sense to agree to “I would like to live in a world where chemical substances do not exist.” However, the argument that chemical substances are the main reason why people suffer from cancer or are the reason for most environmental problems depends on the chemical that respondents think of (i.e., chemicals in cigarettes, CO_2). There is strong support in the literature that the majority of lay-people do not think of particular chemicals when confronted with the term “chemical substance,” but rather more general, negative associations (Bearth et al., 2014, 2017; Dickson-Spillmann et al., 2011; Kraus et al., 1992; Saleh et al., submitted). Nonetheless, particular care should be taken in the future to methodically differentiate between people's actual irrationality regarding chemical substances and issues related to a misunderstanding or different understanding of words.

To sum up, informing and educating consumers about toxicological principles and the risk assessment of chemical substances might improve trust in the executing authorities and lead to lower levels of chemophobia. This paper indicates in which areas particular misconceptions are more prevalent. Nonetheless, a purely informational and educational approach might not be the solution for all of the issues, as a more intuitive layer of influential factors might also play a role. An important first step to improve the communication between toxicologists and lay-people, could be to find a common wording of the term "chemical" or at least to clarify what exactly these terms mean to someone.

Author contributions

Angela Bearth was project leader (study design and implementation, data analysis, writing article), Rita Saleh provided input regarding the questionnaire based on her original study and Michael Siegrist provided expert feedback through all project stages.

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Appendix A. Supplementary data

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