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"Chemophobia" Today: Consumers' Knowledge and Perceptions of Chemicals

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This mixed-methods study investigated consumers' knowledge of chemicals in terms of basic principles of toxicology and then related this knowledge, in addition to other factors, to their fear of chemical substances (i.e., chemophobia). Both qualitative interviews and a large-scale online survey were conducted in the German-speaking part of Switzerland. A Mokken scale was developed to measure laypeople's toxicological knowledge. The results indicate that most laypeople are unaware of the similarities between natural and synthetic chemicals in terms of certain toxicological principles. Furthermore, their associations with the term "chemical substances" and the self-reported affect prompted by these associations are mostly negative. The results also suggest that knowledge of basic principles of toxicology, self-reported affect evoked by the term "chemical substances," risk-benefit perceptions concerning synthetic chemicals, and trust in regulation processes are all negatively associated with chemophobia, while general health concerns are positively related to chemophobia. Thus, to enhance informed consumer decisionmaking, it might be necessary to tackle the stigmatization of the term "chemical substances" as well as address and clarify prevalent misconceptions.

KEY WORDS: Chemicals; chemophobia; knowledge; risk perception; toxicology

1. INTRODUCTION

Laypeople's perception of chemicals tends to be rather negative and is generally founded on misconceptions and fear (Kraus, Malmfors, & Slovic, 1992). In previous studies involving British and Canadian consumers, specific misconceptions were identified concerning the dose–response relationship, the exposure assessment, and the use of animal testing (Kraus et al., 1992; Neil, Malmfors, & Slovic, 1994; Slovic, Malmfors, Mertz, Neil, & Purchase, 1997). Additionally, previous studies have shown that laypeople often perceive "natural" chemicals more positively, meaning that they are considered to be less risky when compared to synthetic chemicals (Hartmann, Hübner, & Siegrist, 2018; Rozin et al., 2004; Rozin, Fischler, & Shields-Argeles, 2012; Siegrist, Hübner, & Hartmann, 2018). Moreover, other studies have investigated consumers' risk perceptions concerning chemicals and their preferences for natural products, particularly chemicals found in food and household cleaning products (Bearth, Miesler, & Siegrist, 2017; Dickson-Spillmann, Siegrist, & Keller, 2011; Kraus et al., 1992). Furthermore, it has been suggested that chemophobia, which is defined as the irrational fear of chemicals, could fuel laypeople's negative perceptions of chemical-containing products and their fear of synthetic chemicals (Entine, 2011; Francl, 2013). This fear could lead to individuals rejecting certain beneficial innovations and products (e.g., vaccines) or even to endangering themselves by disregarding other risks (e.g., eco-labeled cleaning products) (Bearth et al., 2017; Ropeik, 2012). However, there is currently a lack of research regarding chemophobia and its determinants (Entine, 2011; Michaelis, 1996).

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Thus, understanding factors that can reduce chemophobia might help address laypeople's negative perceptions and reactions to chemicals. Therefore, this study aims to extend upon prior research by investigating consumers' knowledge of natural and synthetic chemicals in terms of basic toxicological principles and then relating that knowledge to their attitudes toward these chemicals. Overall, the findings of this study could help communicators and regulatory bodies plan and implement risk management strategies and messages concerning the risks of chemicals by addressing laypeople's misconceptions and irrational fears of chemicals.

2. THEORETICAL BACKGROUND

2.1. Risk Perceptions and Affect

Laypeople's risk perceptions (e.g., concerning innovative technologies) are not solely based on facts, with affect having been shown to play an important role (Alhakami & Slovic, 1994; Finucane, Alhakami, Slovic, & Johnson, 2000; Slovic et al., 1997). The affect heuristic postulates that consumers' feelings regarding a given product drive their risk evaluations (Finucane et al., 2000; King & Slovic, 2014). Indeed, if consumers experience positive affect toward a certain hazard, they are inclined to judge its benefits as high and its risks as low and- vice versa (Finucane et al., 2000; King & Slovic, 2014; Slovic, Finucane, Peters, & MacGregor, 2004).

The use of affect is both automatic and quick and can prove more efficient than analytical and cognitive evaluations (Finucane et al., 2000; Gigerenzer & Gaissmaier, 2011). However, relying on affect for decisionmaking does not necessarily produce decisions that are in the individual's best interests, and it might, in some cases, even lead to biased and dangerous behavior (Ropeik, 2011; Slovic et al., 2004; Slovic, Finucane, Peters, & MacGregor, 2002). For instance, some consumers could be influenced by irrelevant individual or environmental stimuli (Slovic et al., 2004; Slovic, Finucane, Peters, & MacGregor, 2007) that could fuel misconceptions and over- or underestimations of a product's risks. Additionally, this could even lead to the inappropriate handling of certain consumer products (Wilkinson, Rowe, & Lambert, 2004). For products containing chemicals, consumers might regard irrelevant cues featured on a given product's labeling as indicators of its risk level. For example, eco-labeled cleaning products are generally perceived as being safer than conventional cleaning products, which might lead to individuals being less careful in terms of using these products (Bearth et al., 2017). This indicates that consumers might not always, or solely, refer to the textual and graphical safety information featured on the packaging of products when judging the risks associated with those products (Bearth et al., 2017; Hinks et al., 2009; Riley, Fischhoff, Small, & Fischbeck, 2001). Several individual factors (e.g., misconceptions, attitudes, etc.) and situational cues (e.g., packaging of consumer products, distractions, etc.) are thought to comprise part of the reason why consumers do not always comply with the instructions and safety information found on potentially dangerous chemical-containing products (Basso et al., 2014; Kovacs, Small, Davidson, & Fischhoff, 1997). Hence, to ensure the safe handling of consumer products, it is necessary to further understand laypeople's risk perceptions of chemicals as well as how such perceptions are formed.

2.2. Knowledge and Trust

Research has shown that a significant proportion of laypeople associate even minor doses of, and exposure to, toxic chemicals with the almost certain likelihood of harm (Mertz, Slovic, & Purchase, 1998; Slovic et al., 1995), causing them to view chemicals as either safe or dangerous. Hence, consumers frequently express high levels of concern about the use of chemicals as well as a desire to reduce the risks associated with chemicals at any cost (Dickson-Spillmann et al., 2011; Kraus et al., 1992; Slovic et al., 1995). This dose–response insensitivity might influence consumer risk perceptions while also causing overreactions to stories featured in the media that lead to taking inappropriate actions (Wilkinson et al., 2004). When laypeople's concerns arise from a comparably minor risk, the risk management authorities will still have to respond and manage that risk, which could lead to detrimental societal and economic impacts such as increased public distrust of authorities and the wasting of financial resources (Monro, 2001; Ropeik, 2012). In fact, public distrust of the authorities managing the chemical risks might also hold implications for people's risk perceptions of these chemicals. When people do not possess sufficient technical knowledge for judging a certain risk, their trust in risk regulation bodies often guides their judgments and decisions instead (Earle & Cvetkovich, 1995; Siegrist & Cvetkovich, 2000; Siegrist, Connor,

& Keller, 2012). If they trust these regulators, they are less concerned and less prone to overreact to chemicals because they believe the risk regulators do their work appropriately and provide accurate assessments (Ropeik, 2011; Siegrist & Cvetkovich, 2000). Nevertheless, if consumers become familiarized with the dose–response principle, their knowledge regarding chemicals might be enhanced, and limit their negative perceptions and overreactions to chemicals (Dickson-Spillmann et al., 2011). In fact, a greater understanding of the risk assessment process is associated with a lower risk perception of chemicals, particularly in the case of synthetic chemicals (Dickson-Spillmann et al., 2011; Kraus et al., 1992; Shim et al., 2011). Consequently, consumers probably require a basic knowledge of chemical and toxicology principles to enable them to make fact-based decisions regarding chemical-containing products (Bearth, Cousin, & Siegrist, 2016; Dickson-Spillmann et al., 2011; Dickson-Spillmann, Siegrist, Keller, & Wormuth, 2009; Kraus et al., 1992; Shim et al., 2011).

2.3. Chemophobia

When consumers express concerns about the chemicals used in consumer products, they may avoid or reduce their exposure, especially to synthetic chemicals such as artificial additives in food (Bearth, Cousin, & Siegrist, 2014; Dickson-Spillmann et al., 2011). Concerned consumers primarily associate chemicals with death, cancer, and toxicity and tend to be afraid of chemicals. This irrational fear has been called "chemophobia" (Entine, 2011; Ropeik, 2015; Rozin et al., 2004). On the one hand, chemophobia might cause people to avoid chemical-containing products that could actually prove beneficial (e.g., medication) or support groups that advocate for the removal of different chemicals from the market without considering the scientific evidence regarding those chemicals' safety (Entine, 2011). On the other hand, consumers might neglect the risks associated with chemicals of a natural origin due to perceiving them as being less threatening than synthetic chemicals (Ropeik, 2012; Rozin et al., 2004, 2012). For example, consumers might endanger themselves via the less vigilant use of products with chemicals of a natural origin, such as natural personal care products, because they perceive such products to be free of hazardous substances (Hartmann & Klaschka, 2017). Hence, it might prove useful to address chemophobia in risk communications to limit its consequences and ensure informed consumer decisionmaking regarding chemicals.

2.4. Study Aims

Previous studies have assessed laypeople's attitudes via knowledge questions related to their perceptions of toxicology principles (Kraus et al., 1992; Neil et al., 1994; Slovic et al., 1995). The present mixed-methods study aimed to extend upon prior research by investigating consumer knowledge of chemicals in relation to basic toxicology principles and chemophobia. Thus, the first objective of the study was to develop a scale that measures people's knowledge of basic toxicological principles. The second objective was to explore people's associations and affect evoked by natural and synthetic chemicals. The third objective was to determine how chemophobia is associated with knowledge, affect toward chemicals, risk-benefit perceptions of synthetic chemicals, trust in the regulation of consumer products, and general health concerns.

3. METHODS

3.1. The Mental Models Approach

The mental models approach (MMA) offers a method to investigate laypeople's mental models regarding a certain risk, aimed at including their views in the development of risk communications (Morgan, Fischhoff, & Bostrom, 2002). It is composed of five consecutive steps. In this study, only the first three steps in the MMA were followed to gather insights into laypeople's perceptions and knowledge of the risks of chemicals and experts' risk assessments. Furthermore, the first two steps of this method are qualitative, whereas the third step is quantitative.

First, in-depth, qualitative, semi-structured interviews were conducted with experts. This step was intended to gather information regarding the current practices of chemical risk assessment, the regulation process, and the principles of toxicology. In total, six experts were recruited and interviewed individually; three of whom were from governmental regulatory offices, one was a toxicologist working for an advisory and educational organization, another one was a toxicologist working in the chemical industry, and one was an expert from a poison prevention and emergency center.

Second, 10 consumers with different educational and vocational backgrounds were recruited (24–63 years old, 40% male) from Switzerland via convenience and snowball sampling. The aim of this step was to explore laypeople's perceptions and knowledge concerning toxicology principles and steps for the risk assessment and regulation of chemicals. This revealed potential misconceptions and gaps in the knowledge of laypeople in comparison to the experts. The interviews began with general, open-ended questions and shifted to more focused questions regarding chemicals to limit bias in the responses of the interviewees. At the beginning of the interview, interviewees were asked about their first thoughts upon hearing the word "chemical substances." Then, they were shown pictures of different consumer products that are commonly found in households (e.g., cleaning products, medicine) and asked about their experiences, attitudes, and risk-benefit perceptions of these products (e.g., how beneficial these products are, which products they believe are the most and least harmful ones, etc.). The interviews continued with questions about how the interviewees assume the risk assessment and risk management processes for these products are performed. Moreover, the interviewees' trust in the regulation authorities, preferences, and safe handling practices of chemical-containing products were also discussed. Interviewees indicated factors (e.g., purpose of the consumer products, packaging of the products) that shape their judgments concerning the dangerousness of the products. Whether the product contains natural or synthetic chemicals was one of the most prominent factors interviewees discussed. They expressed more favorable perceptions of products with natural chemicals than for those with synthetic ones. Additionally, they had little to no knowledge regarding chemical risk assessment and regulation processes. The interviews lasted 60 minutes on average and were recorded to ensure accuracy during the transcription process.

Third, the interview findings served as the basis for the design and development of the questionnaire used in the quantitative study, which was intended to provide information regarding the representativeness of the insights gained from the qualitative interviews (Morgan et al., 2002).

3.2. Quantitative Study: Sample

For the quantitative step, an online survey was conducted via a consumer panel provided by a market research company in June 2018 in the German-speaking part of Switzerland. Respondents were not informed of the survey topic in the participation invitation and were compensated with a small financial incentive. Quota sampling was applied to ensure a balanced ratio of male to female respondents and age distributions. There were a total of 663 respondents to the survey. Note that 74 respondents with missing values were excluded from the analyses. An additional 43 respondents were excluded due to their participation duration being too short (half the median), which could have increased their likelihood of potentially giving biased responses. The final sample was composed of 546 respondents (52.7% females, $M_{\text{age}} = 45$ years, $SD_{\text{age}} = 14$, range: 18–70 years old). Furthermore, the sample was comparable to the general Swiss population in terms of both gender and age (50.4% females, $M_{\text{age}} = 42$ years) (Swiss Federal Statistical Office, 2017b). The respondents' self-reported education levels ranged between mandatory school, basic apprenticeship, prevocational school, or apprenticeship (45.6%), to high school or technical and vocational training (29.9%), and university (24.5%). The reported education levels were slightly higher than that of the general Swiss population (Swiss Federal Statistical Office, 2017a). Moreover, a total of 15 (2.7%) respondents worked in a chemical-related field (e.g., toxicology, chemical regulation).

3.3. Quantitative Study: Materials

The survey questionnaire was divided into two sections. The first section was composed of items intended to address the respondents' associations with the term "chemical substances," their affective responses, their knowledge of basic toxicology principles of, and their trust in, the regulation of chemical-containing products. Furthermore, in the first section, respondents also answered questions about their risk perceptions, general health concerns, and chemophobia. Tables I and II and Fig. 1 present all items included in the first section. In the second section of the survey, the respondents answered more specific questions regarding their preferences in terms of chemicals used in consumer products. The results of the second part of the survey are not discussed in this article. Finally, at the end of the survey, respondents answered sociodemographic questions (i.e., age, gender, level of education, profession), and were provided with information regarding the principles of toxicology and the regulation of chemicals to ensure their perceptions

Table I. Trust in the Regulation of Consumer Products and Synthetic Chemicals' Risk-Benefit Perceptions: Items-Total Correlations, Items Means (M), Standard Deviations (SD), and Scales' Cronbach's Alpha (α)

		Item-Total Correlation	M (SD)
	Trust in the regulation of consumer products[a]		
	How much trust do you have in the current regulation that monitors the safety of consumer products with chemical substances in Switzerland?		3.81(1.15)
	Synthetic chemicals' risk-benefit perceptions[b] ($\alpha = 0.74$)		3.11 (0.97)
1	I believe that the benefits of synthetic chemical substances in consumer products outweigh the potential risks they pose for the environment.	0.47	2.82 (1.29)
2	I believe that the use of synthetic chemical substances in consumer products is associated with greater benefits than health risks.	0.56	3.00 (1.29)
3	I believe that the environmental risks associated with synthetic chemical substances in consumer products are more significant than the benefits for the consumers. (r)	0.54	3.22 (1.31)
4	I believe that the health risks of synthetic chemical substances in consumer products outweigh their benefits. (r)	0.54	3.39 (1.31)

[a]Item response was within the range from 1 (extremely low) to 6 (extremely high).
[b]All scale items responses were within the range from 1 (strongly disagree) to 6 (strongly agree).
(r) = a reverse coded item.

Table II. General Health Concern and Chemophobia: Items-Total Correlations, Items Means (M), Standard Deviations (SD), and Scales' Cronbach's Alpha (α)

		Item-Total Correlation	M (SD)
	General health concern[a] ($\alpha = 0.74$)		3.60 (0.97)
1	Developing a chronic disease concerns me a lot.	0.66	2.88 (1.42)
2	I worry a lot about getting a serious disease (e.g., cancer).	0.64	3.12 (1.48)
3	I am very concerned about my health.	0.65	3.58 (1.41)
4	I protect myself as much as possible from getting even slightly sick.	0.29	3.83 (1.30)
5	I never worry about my health. (r)	0.29	4.59 (1.32)
	Chemophobia[a] ($\alpha = 0.88$)		3.15 (1.19)
1	I believe that chemical substances are the main reason why people suffer from cancer.	0.72	2.90 (1.44)
2	I do everything I can to avoid in my daily life contact with chemical substances.	0.71	3.08 (1.48)
3	I would like to live in a world where chemical substances do not exist.	0.73	3.13 (1.58)
4	Chemical substances scare me.	0.73	3.27 (1.39)
5	I believe that chemical substances are the reason for most environmental problems.	0.65	3.39 (1.41)

[a]All scale items responses were within the range from 1 (strongly disagree) to 6 (strongly agree).
(r) = a reverse coded item.

were not negatively affected by the content of the survey.

3.3.1. *Free Associations and Affect*

The free associations technique allows for the assessment of spontaneous subjective meanings that are associated with a given stimulus (Peters & Slovic, 1996; Slovic, Flynn, & Layman, 1991). First, respondents were asked to indicate the first two words, terms, or thoughts that came to mind when they heard the term "chemical substances." They were then instructed to evaluate the feelings evoked by each association using a slider scale ranging between "extremely negative" (0), "neutral" (50), and "extremely positive" (100). Next, respondents were asked to read the following definitions of synthetic and natural chemical substances:

Natural chemical substances occur in nature, or are produced by plants and animals, without any human involvement, such as "vitamin C" (ascorbic acid), which is found in oranges.

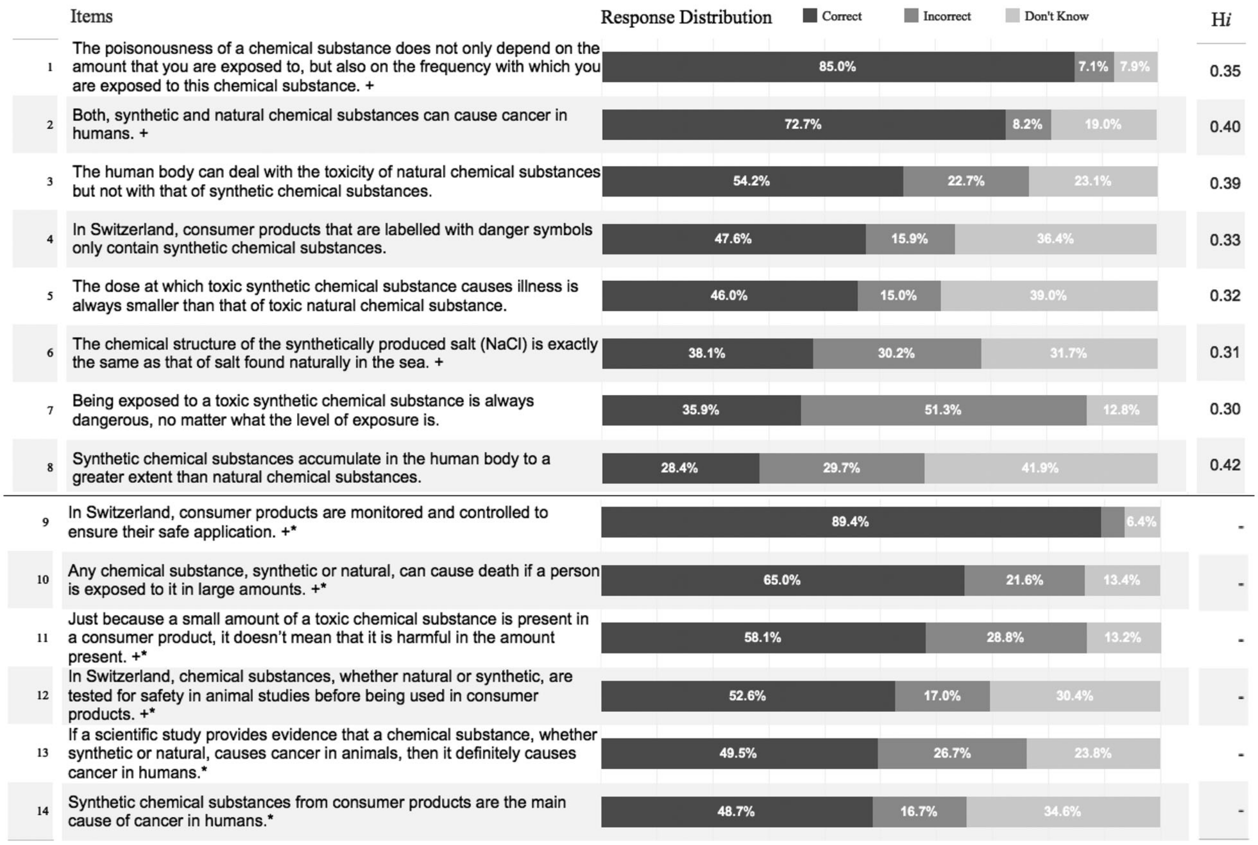

Fig. 1. Knowledge of basic toxicological principles and regulation of chemicals: response distribution and Mokken scale scalability coefficients for each item (*Hi*).
Note: $N = 546$; scalability coefficient of the whole scale $H = 0.35$ ($SE = 0.02$); reliability of the Mokken scale $\rho = 0.72$. (+) = Items with a true statement. (*) = Items that are not part of the Mokken scale. This figure was prepared using Tableau Desktop (Tableau Software Inc., 2003).

Synthetic chemical substances are made by humans to serve particular purposes. These chemical structures may or may not be found in nature, too. For example, “vitamin C” (ascorbic acid) can also be manufactured from glucose, while “Teflon,” which is used in nonstick pans, is man-made and cannot be found in nature.

Both synthetic and natural chemical substances are used in a wide range of consumer products, including cleaning products, medicine, clothes, and cosmetics, to give these products certain desired features (e.g., colors, smell) and functions (e.g., waterproofing, disinfectant).

The respondents were then asked to separately indicate their affective responses to synthetic and natural chemical substances on a slider scale ranging between “extremely negative” (0), “neutral” (50), and “extremely positive” (100).

3.3.2. Knowledge of Basic Toxicological Principles and Regulation of Chemicals

The respondents’ knowledge of basic toxicological principles and regulation was measured using 14 statements (cf. Fig. 1). Statements 4 and 9 measured regulation-related knowledge, while the remaining statements were related to aspects of toxicology and its principles. The latter included comparisons between natural and synthetic chemicals in terms of specific toxicological principles (e.g., doseresponse, exposure scenarios, etc.) that act as the basis for the chemical risk assessment process. The items consisted of seven correct and seven incorrect statements and were based on a literature review and the interviews with both experts and laypeople. Only item 13 was adapted from the work of Kraus et al. (1992). All items varied according to their level of difficulty and were presented in a randomized order.

The respondents were able to respond to each item with “correct,” “false,” or “do not know.”

3.3.3. Chemophobia, General Health Concerns, Risk-Benefit Perceptions of Synthetic Chemicals, and Trust in the Regulation of Consumer Products

The respondents’ chemophobia, general health concerns (cf. Table II), and risk-benefit perceptions of synthetic chemicals (cf. Table I) were assessed via a six-point Likert scale (1 = strongly disagree, 6 = strongly agree). Furthermore, items 2 and 3 were adapted from the studies of Kraus et al. (1992) and Dickson-Spillman et al. (2011), respectively, to measure respondent chemophobia. The remaining items were formulated based on both a literature review and the findings of the qualitative interviews. For each of the investigated constructs, a scale was built by taking the mean value over the values of all items included in that construct. The chemophobia scale (five items) had a good Cronbach’s $\alpha = 0.88$, while the general health concerns scale (five items) and the risk-benefit perceptions scale (four items) each had a moderate Cronbach’s $\alpha = 0.74$. Respondents’ trust in the regulation of consumer products in Switzerland was assessed with one item (cf. Table I) using a six-point Likert scale (1 = extremely low, 6 = extremely high). The item-total correlation, mean, and standard deviation for all items included in the above-mentioned scales are presented in Tables I and II.

3.4. Quantitative Study: Data Analysis

To explore the associations evoked by and the affect associated with the term “chemical substances,” a correspondence analysis (CA) was conducted (Weller & Romney, 1990). Before being submitted to a CA, data were prepared in a two-way contingency table, which then the CA analyzed and reduced its complexity (Greenacre, 2010; Sourial et al., 2010). Next, CA provided factor scores for each category in the rows and columns of the contingency table. These scores were used as coordinates to visualize the rows and columns categories as points in a low-dimensional graphical map. The more similar the scores of the categories, the closer the points were to each other. Correspondingly, categories with different scores were represented by more distanced points (Clausen, 1998). Hence, the distance between points reflected the associations between the row and column variables.

A Mokken scale analysis (MSA) was used to scale respondent knowledge of basic toxicological principles. This scaling procedure considers item difficulty and is more suited to analyze knowledge items than the classical test theory. The latter assumes that all items of a given scale will have similar distributions, thereby disregarding the different levels of knowledge individuals possess, which renders it unsuited to scaling knowledge items (van Schuur, 2003). MSA is a nonparametric, probabilistic version of the Guttman scaling process (van Schuur, 2003). It assumes that if an individual responds correctly to a difficult item, then that individual is more likely to respond correctly to the easier items of the scale (van Schuur, 2003). The scale is based on the assumption that each respondent’s probability of answering items correctly depends on both the item’s difficulty and the respondent’s knowledge (Molenaar & Sijtsma, 2000). The respondents are ranked according to their abilities, while the items are ordered according to their difficulty levels (Mokken & Lewis, 1982; Molenaar & Sijtsma, 2000). The degree of accuracy in terms of ordering respondents by the scales can be assessed using Loevinger’s coefficient H (Molenaar & Sijtsma, 2000). Hence, the coefficient H is an important indicator of the goodness of the formed Mokken scale, with $H = 0.3$–0.4 suggesting a weak scale, and $H = 0.5$–1 suggesting a strong scale. The reliability of the Mokken scale is assessed with the ρ, which should be above 0.70. Additionally, the scalability coefficients for each individual item should be $Hi > 0.3$. The knowledge items were recoded as 1 for correct responses and 0 for incorrect and “do not know” responses. The analysis was run on R version 1.1.456 using the Mokken package (van der Ark, 2007). Finally, to produce a knowledge score for each respondent, the correct responses to the Mokken scale items were summed. A high score indicated more knowledge, while a low score indicated less knowledge.

A regression analysis was conducted with chemophobia as the dependent variable. The following variables were used as independent variables: sociodemographic variables, respondent scores regarding their knowledge of basic toxicological principles, overall affect toward “chemical substances,” trust in the regulation of consumer products, risk-benefit perceptions of synthetic chemicals, and general health concerns. The regression analysis and CA were conducted using SPSS version 25.0 (IBM Corp., 2017).

Table III. Frequencies and Examples of the Main Categories of Respondents' Associations with the Term "Chemical Substances"

Main Categories (Examples of Respondents' Associations)	Frequency of the First Associations	Percentage	Frequency of the Second Associations	Percentage
Science (e.g., chemistry, laboratory, experiments)	151	27.7	127	23.3
Toxic (e.g., poison, dangerous, death)	122	22.3	118	21.6
Specific chemicals (e.g., chlorine, oxygen, sulfur)	69	12.6	39	7.1
Medications (e.g., tablets, medications, pills)	44	8.1	42	7.7
Synthetic (e.g., synthetic)	24	4.4	20	3.7
Unnatural (e.g., unnatural)	17	3.1	13	2.4
Health danger (e.g., unhealthy, impairment to health)	16	2.9	32	5.9
Cleaning products (e.g., detergent, to clean)	15	2.7	4	0.7
Food (e.g., unwanted additives in food, eat, sweetener)	14	2.6	24	4.4
Illegal drugs (e.g., doping, ecstasy)	13	2.4	7	1.3
Chemical disasters (e.g., spillage, weapon, explosion)	6	1.1	14	2.6
Environment danger (e.g., pollution, ecological damage)	4	0.7	22	4.0
Personal care products (e.g., cosmetics, perfume)	4	0.7	3	0.5
Industry (e.g., chemical production, industry waste)	3	0.5	10	1.8
Natural (e.g., nature, natural)	3	0.5	1	0.2
Agriculture (e.g., fertilizers, pesticides, insect repellents)	1	0.2	12	2.2
Benefits (e.g., huge potential, endless opportunities)	1	0.2	4	0.7
Nonapplicable[a]	39	7.2	54	9.9
Total	507	100.0	492	100.0

[a]These associations were not included in the analysis for their nonapplicability or nonsensical meanings.

4. RESULTS

4.1. Associations and Affect

4.1.1. *Free Associations' Content and Affective Ratings*

The respondents were asked to provide two associations related to the term "chemical substances," which resulted in a total of 1,092 associations. Approximately 507 first associations and 492 second associations were considered meaningful and were assigned to one of the 18 categories listed in Table III. The associations given by the respondents were originally in German and then translated into English. The English and German versions of the associations were coded via two independent coders. Moreover, the interrater reliability was (Cohen's kappa) $\kappa = 0.82$. Disparities in the coding between the two raters generally occurred in relation to infrequent and nonmeaningful associations and were all resolved by the first author. In terms of the first associations, the most prevalent categories were "science," "toxic," and "specific chemicals." Only the affective evaluations of the most prevalent associations (i.e., mentioned at least 60 times) are presented. The affective rating for "science" was approximately the midpoint ($M = 54.39$ [$SD = 19.72$]), whereas the affective rating for "toxic" was much more negative ($M = 19.10$ [$SD = 15.56$]), and the affective rating for "specific chemicals" was negative ($M = 41.97$ [$SD = 26.54$]). These three associations were also found to be dominant among the second associations (cf. Table III). Additionally, "synthetic," "unnatural," "health danger," and "environmental danger" were relatively prevalent associations. It should be noted that only a minority of respondents associated chemical substances with benefits or a positive affective rating. The respondents also associated chemical substances with specific consumer products (i.e., medication, food, personal care products, cleaning products, and illegal drugs).

The respondents' affective ratings of the first associations with the term "chemical substances" were negative ($M = 38.43$ [$SD = 25.02$]). Moreover, respondents also reported negative affect in relation to the second associations ($M = 36.75$ [$SD = 26.27$]). The overall affect reported for all associations (i.e., both the first and second associations) was negative ($M = 37.85$ [$SD = 22.26$]) and had an acceptable Cronbach's $\alpha = 0.64$. The respondents' affective rating of the two sets of associations differed significantly from the scale's midpoint (50) based on a one-sample t-test, t (522) = –12.46, $p < 0.001$. Moreover, their affective reactions to "synthetic chemical substances" were negative, with $M = 42.79$ ($SD = 17.41$), whereas their affective reactions to "natural chemical substances" were positive, with $M = 67.30$ ($SD = 19.40$).

4.1.2. *Correspondence Analysis*

The CA was only applied to the first set of associations to emphasize the first associations and minimize bias stemming from potential random fillings for the second associations. Only associations with $n > 10$ were included. Gender was also taken into account in this analysis, since women were found to be more concerned about chemicals than were men (Kraus et al., 1992; Mertz et al., 1998). Hence, a two-way contingency table consisting of the first association as the column category (10 columns) and gender (female, male) combined with affective reaction to the association (1 = [0–45] as negative, 2 = [46–54] as neutral, 3 = [55–100] as positive) as the row category (six rows) was submitted for a CA. The overall chi-squared value was $\chi^2(45) = 217.66$, $p < 0.001$, while the total inertia was $\lambda G = 0.45$. The results of the CA showed that the first dimension explained 80% of variance, while the second dimension explained 9%. Moreover, the third dimension explained less than 5% of the variance and, therefore, a two-dimensional solution was used for the interpretation. Fig. 2 presents a graphical display of the CA output.

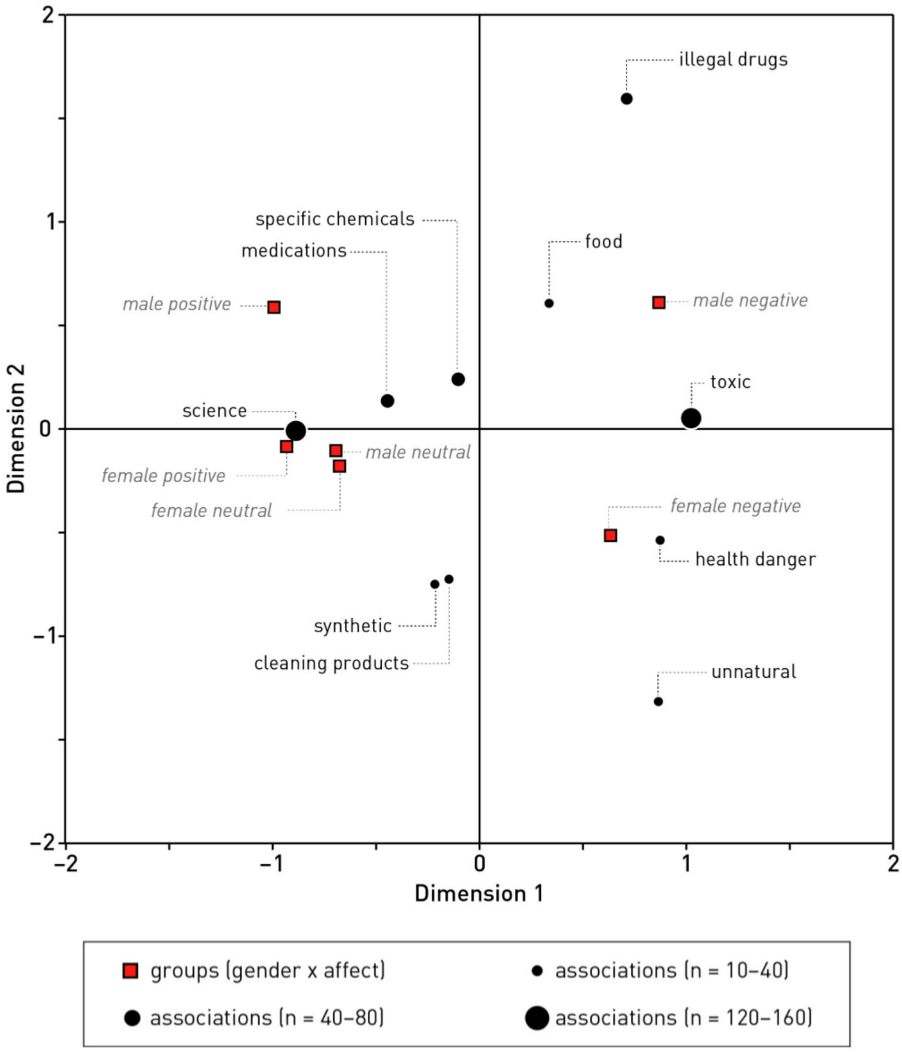

Fig. 2. Content of the first free associations given by respondents ($N = 485$) to the term "chemical substances," in relation to gender and affect analyzed by correspondence analysis.

The first dimension illustrates the differences between the content of the associations in relation to the respondents' affective responses. The respondents with positive affect mentioned associations similar to those of the respondents with neutral affect. These associations were often related to "science," "specific chemicals," and "medication." In contrast, the respondents with negative affect mainly expressed associations related to "toxic," "health danger," "food," "unnatural," and "illegal drugs." The second dimension illustrates the differences between the female and male respondents. Both females and males mentioned "science," "medication," "specific chemicals," and "toxic"; however, female respondents associated "health danger," "unnatural," "cleaning products," and "synthetic" with "chemical substances," whereas male respondents more often associated "illegal drugs" and "food."

4.2. Knowledge of Basic Toxicological Principles and Regulation of Chemicals

The response distributions of the 14 knowledge items are presented in Fig. 1, differ according to difficulty, and differentiate between those with high and low levels of knowledge. The easiest items were related to the regulation of the use of chemicals in consumer products, with the harmfulness of chemicals depending on amount and frequent exposure levels. These items had the highest correct response rates (≥85%). The item regarding the deadliness of exposure to large doses of any chemical substance also had a relatively high correct response rate. However, the correct response rates of the items related to the dangerousness of small doses of chemicals in consumer products and the labeling of potentially dangerous products were relatively low (<60%). Similarly, the correct response rate for the item regarding the role of animal testing in assessing the safety of chemicals was low. Items concerned with the chemical structure and toxicity of synthetic and natural chemicals (considering doses, exposure levels, and the ability of the human body to protect itself) had lower correct response rates (between 35% and 55%). The most difficult item referred to the accumulation of synthetic and natural chemicals in the human body and had the lowest correct response rate (<30%).

One item (item 9) (cf. Fig. 1) concerned people's trust in Swiss regulatory bodies. To ensure the knowledge scale would only contain objective and knowledge-centric items, item 9 was excluded from the MSA. Hence, the MSA was run only with the remaining 13 items. Overall, it revealed that five of the items were unscalable and, therefore, were not included in the Mokken scale. So, the final Mokken scale included eight items regarding natural and synthetic chemicals and basic toxicological principles (cf. Fig. 1) while exhibiting an adequate scalability coefficient of $H = 0.35$ and a reliability of $\rho = 0.72$, which indicates a reliable, one-dimensional scale. The scalability coefficients for the individual items of the Mokken scale are shown in Fig. 1. Furthermore, the mean knowledge score for all respondents was $M = 4.08$ ($SD = 2.13$) (range: 0–8, with 8 being the highest score, indicating high knowledge).

4.3. Regression Analysis on Chemophobia

Table IV shows the correlation between respondents' chemophobia and their knowledge of basic toxicological principles, their overall affect toward "chemical substances," their trust in the regulation of consumer products, their risk-benefit perceptions of synthetic chemicals, and their general health

Table IV. Pearson's Correlations Between Chemophobia, Overall Affect Toward "Chemical Substances," Knowledge of Toxicological Principles, Trust in Consumer Products' Regulation, Risk-Benefit Perceptions of Synthetic Chemicals, and General Health Concern

Variables	1	2	3	4	5
1. Chemophobia	–				
2. Overall affect toward "chemical substances" ($N = 523$)	-0.35^{***}	–			
3. Knowledge of toxicological principles	-0.36^{***}	0.14^{**}	–		
4. Trust in consumer products' regulation	-0.29^{***}	0.20^{***}	0.19^{***}	–	
5. Synthetic chemicals' risk-benefit perceptions	-0.38^{***}	0.27^{***}	0.11^{**}	0.42^{***}	–
6. General health concern	0.44^{***}	-0.17^{***}	-0.13^{**}	-0.09^{*}	-0.19^{***}

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
$N = 546$ (unless indicated otherwise).

Table V. Regression Analysis on Respondents' Chemophobia ($N = 523$)

Independent Variables	B (SE)	t	β
Constant	3.16 (0.32)	10.04	
Gender (b)	0.18 (0.08)	2.10	0.07*
Age	0.01 (0.00)	2.34	0.08*
Low education (b)	0.08 (0.11)	0.73	0.03
Medium education (b)	0.09 (0.11)	0.77	0.03
Overall affect toward "chemical substances"	−0.01 (0.00)	−5.25	−0.19***
Knowledge of toxicological principles	−0.13 (0.02)	−6.03	−0.22***
Trust in consumer products' regulation	−0.10 (0.04)	−2.47	−0.09*
Risk-benefit perceptions of synthetic chemicals	−0.22 (0.05)	−4.59	−0.18***
General health concern	0.41 (0.04)	9.53	0.33***

Note: Gender (1 = female, 0 = male), low education (1 = low level, 0 = high level), medium education (1 = medium level, 0 = high level). $R^2 = 0.41$, adjusted-$R^2 = 0.40$.
*$p < 0.05$; ***$p < 0.001$.
(b) = a binary variable.

concerns. All variables were found to be significantly correlated, although the strongest correlations were found in regard to chemophobia. Furthermore, there was a negative correlation between chemophobia and overall respondent affect toward "chemical substances" ($r = -0.35$, $p < 0.001$, $N = 523$) and their risk-benefit perceptions of synthetic chemicals ($r = -0.38$, $p < 0.001$, $N = 546$). Respondent knowledge of basic toxicological principles also exhibited a negative correlation with chemophobia ($r = -0.36$, $p < 0.001$, $N = 546$). Moreover, knowledge exhibited a positive correlation with overall affect toward "chemical substances" ($r = 0.14$, $p < 0.01$, $N = 523$). However, this correlation was weak and similar to most of the correlations occurring between the independent variables.

Table V presents the results of the multiple regression analysis for respondent chemophobia. The model was found to be significant with $F(9,513) = 39.80$, $p < 0.001$ and explained 40% of the variance, with respondent knowledge of basic toxicological principles being negatively related to chemophobia. Respondent risk-benefit perceptions of synthetic chemicals, overall affect toward "chemical substances," and trust in the regulation of consumer products all displayed statistically significant negative relationships with chemophobia, whereas their general health concerns displayed a positive relationship with chemophobia. Furthermore, both gender and age had a significantly positive relationship with chemophobia, albeit a less important one compared to the above-mentioned factors. The respondents' education level was not significant.

5. DISCUSSION AND IMPLICATIONS

One of the key goals of the present study was to develop a scale for measuring people's knowledge of basic toxicological principles. Applying the MMA (Morgan et al., 2002) allowed for considering both expert knowledge and a broad range of laypeople's perceptions of the topic. Eight items measuring laypeople's knowledge of natural and synthetic chemicals in terms of basic toxicological principles formed a reliable Mokken scale. This provided a strong indication that the proposed scale is one-dimensional and reliable. The knowledge items were formulated based on qualitative interviews conducted in Switzerland; however, the items were not specific to Switzerland. Therefore, the scale may also be used to explore cultural differences.

A number of prevalent misconceptions among laypeople regarding both natural and synthetic chemicals were identified, including dose–response insensitivity and the underestimation of the toxicity of chemicals of natural origin. The insensitivity to dose–response relationships and exposure scenarios was also identified in previous research (Bearth et al., 2016; Dickson-Spillmann et al., 2011; Kraus et al., 1992; Slovic et al., 1997). Rather than a dose–response function, laypeople tend to perceive a causal relationship between exposure to a chemical and inevitable consequences, especially in the case of chemicals associated with carcinogenicity (MacGregor, Slovic, & Malmfors, 1999). Furthermore, laypeople seem to consider the origin of a chemical (natural vs. synthetic) to be an indicator of its toxicity. Chemicals of a natural origin are considered to be healthier and safer than synthetic ones, since the latter involve human intervention and processing, which in turn negatively influences laypeople's perceptions of synthetic entities (Rozin, 2005; Rozin et al., 2004).

An inspection of the response distributions for the knowledge items and the revealed misconceptions suggests that the respondents were not familiar with the similarities between natural and synthetic chemicals in terms of basic toxicological principles. They might have been relying on their affect and associative imagery rather than referring to factual information to weigh the risks and benefits of synthetic and natural chemicals. Moreover, the experts do not differentiate between chemical substances of natural or synthetic origin. The laypeople, however, reported similar levels of negative affect regarding the terms "chemical substances" and "synthetic chemical substances," while the term "natural chemical substances" was associated with a more positive affect. Respondents frequently mentioned risky associations (e.g., poison, death, dangerous), whereas only a small minority of them associated "chemical substances" with benefits. Hence, it appears that the advancements brought about by the synthesis of chemical substances might not be salient in laypeople's minds. This could largely be explained by the different use of the terms "chemical substances" and "natural versus synthetic" in everyday speech and in scientific language.

The negative relationship identified between knowledge and chemophobia indicates that a better understanding of (natural and synthetic) chemicals and the basic toxicological principles tends to mean laypeople are less afraid of chemicals. Previous research has shown that knowledge provision can influence people's opinions and attitudes (Bearth et al., 2016; Gaskell, 1998; Shim et al., 2011). However, as is the case in other areas of risk research, the "knowledge deficit model" falls short when attempting to tackle chemophobia (Hansen, Holm, Frewer, Robinson, & Sandoe, 2003). Communication efforts have been undertaken, for example, the European Chemicals Agency's (ECHA) website about chemicals in everyday life (e.g., chemicals in clothes and textiles, in personal care products), with the aim of improving people's understanding and knowledge. However, laypeople's resources are limited and, therefore, a lack of time or motivational or other resource conflicts might prevent them from seeking and processing complex information. It might prove more important to reduce the stigma associated with the terminology, as well as to clarify the differences between laypeople's and experts' use of the terms "chemical substance," "natural," and "synthetic." Furthermore, the advancements brought about by the inclusion of "chemical substances" in consumer products, medicine, or other beneficial applications should be rendered more salient to improve acceptance and informed decisionmaking. Prior studies have shown that communicating the benefits associated with a given technology or product may improve people's level of acceptance or promote more positive perceptions toward that technology or product (Bearth & Siegrist, 2016; Ueland et al., 2012). Mitigating chemophobia and its negative consequences on consumers could ensure people's informed decisionmaking. One possible approach to reduce chemophobia could be to stress the implications of the substitution of certain chemical substances with their counterparts of natural origin (e.g., a reduced range of products, higher costs, unknown risks due to impurities, medicine shortages). Moreover, people's trust in the communication agent represents a vital factor in relation to their acceptance of the communicated message (Breakwell, 2000; Siegrist, 2008). Thus, it is not only relevant to consider from whom the information originates, but also to understand what builds and destroys trust and then to implement measures accordingly.

A major limitation of this study is the fact that, due to its cross-sectional design, caution is warranted when stating the causal relationships. Future research should therefore attempt to test the directionality and strength of the relationships using longitudinal designs. For instance, changes in knowledge, perception, and chemophobia could be measured using the developed scale both pre- and postinformation provision. Furthermore, there might be additional factors related to chemophobia that were not included in this study. There is evidence concerning the importance of worldviews (e.g., technological enthusiasm, economic growth, egalitarianism) in determining individuals' risk perceptions (Mertz et al., 1998; Slovic et al., 1995). Additionally, situational factors (e.g., labels, advertisements) (Basso et al., 2014) might also influence people's risk perceptions of chemicals and their chemophobia. Future studies should investigate the relationships between these factors and chemophobia to develop a better understanding of the factors that shape chemophobia and inhibit informed decisionmaking. Finally, the study was conducted in the German-speaking part of Switzerland and, therefore, the findings may not be generalizable to other cultural contexts. For instance, the public's views on chemicals in the French-speaking part of Switzerland might differ from the German-speaking part, since there is divergence in the sociopolitical orientations between the two parts of Switzerland (Eugster, Lalive, Steinhauer, & Zweimuller, 2011). This study should also be conducted in other countries to compare the findings regarding people's misconceptions and chemophobia.

6. CONCLUSION

In summary, this mixed-methods study contributes in several ways to the understanding of laypeople's perceptions of natural and synthetic chemicals in terms of basic toxicological principles. First, the Mokken scale helps reveal and quantify common misconceptions and knowledge gaps on the part of laypeople regarding chemicals. Second, the results suggest that chemophobia (i.e., people's irrational fear of chemicals) is largely fueled by negative associations and affect stemming from the stigmatized term "chemical substances." Finally, while greater knowledge is associated with lower levels of chemophobia, it might prove difficult to overcome the negative stigma associated with the term, particularly for synthetic chemicals.

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