Author Manuscript

Author Manuscript

Author Manuscript

Published in final edited form as:

J Health Commun. 2008 September ; 13(6): 538–554. doi:10.1080/10810730802281627.

Applying the Common Sense Model to Understand Representations of Arsenic Contaminated Well Water

Dolores J. Severtson, RN, PhD[**], **Linda C. Baumann, RN, PhD**, and **Roger L. Brown, PhD**

School of Nursing, University of Wisconsin-Madison

Abstract

Theory-based research is needed to understand how people respond to environmental health risk information. The common sense model of self-regulation and the mental models approach propose that information shapes individual's personal understandings that influence their decisions and actions. We compare these frameworks and explain how the common sense model (CSM) was applied to describe and measure mental representations of arsenic contaminated well water. Educational information, key informant interviews, and environmental risk literature were used to develop survey items to measure dimensions of cognitive representations (identity, cause, timeline, consequences, control) and emotional representations. Surveys mailed to 1067 private well users with moderate and elevated arsenic levels yielded an 84% response rate (n=897). Exploratory and confirmatory factor analyses of data from the elevated arsenic group identified a factor structure that retained the CSM representational structure and was consistent across moderate and elevated arsenic groups. The CSM has utility for describing and measuring representations of environmental health risks thus supporting its application to environmental health risk communication research.

Keywords

Mental models; risk perception; risk communication; drinking water; health beliefs

A goal of environmental health risk communication is to provide information that supports informed decisions and actions. The common sense model (CSM) of self-regulation is well suited to explore how people respond to risk information because it includes concepts from risk communication, decision, and behavioral sciences. The CSM assumes that people are independent problem-solvers who actively process health threat information to create common sense understandings or representations that guide health-related decisions and behavior. Information from memory, external sources, and perceived experiences is processed via inter-related cognitive and emotional processes that shape representations and actions. An appraisal of these actions generates information that is fed back into the model (see Figure 1) (Leventhal, Brissette, & Leventhal, 2003). We provide an overview of the CSM, compare it to a risk communication framework, and report the results of our study that applied the CSM to measure representations of an environmental health risk.

[**]Corresponding author: National Library of Medicine Postdoctoral Fellow: UW-Madison Computation and Informatics in Biology and Medicine Training Program, djsevert@wisc.edu, H6/295 CSC, 600 Highland Ave., Madison, WI 53792-2455.

Representations play a key role because they mediate the relationship between information and behavior. Findings show that cognitive representations consist of five dimensions that describe 1) how people identify an illness using symptoms and a disease label (*identity*), 2) beliefs about *cause*, 3) duration (*timeline*), 4) personal *consequences*, and 5) *control* (Leventhal et al., 2003). A meta-analysis supports the content and discriminant validity of these dimensions (Hagger & Orbell, 2003). A sixth dimension measuring the *coherence* of one's understandings is a sometimes used recent addition (Moss-Morris et al., 2002). The emotional representation is typically comprised of negative emotions such as worry or fear.

Semi-structured interviews, close-ended survey items, and multivariate scales are used to understand and measure representations (Leventhal et al., 2003). Identity is typically measured by having participants check off symptoms that they believe are associated with an illness label. Factor analyzed has been used to understand the underlying structure of causal beliefs, for example Moss-Morris and colleagues (2002) found causal factors of psychological, risk factor, environmental/immunity, and chance. The Illness Perception Questionnaire-Revised is a standardized survey tool that uses scaled survey items to measure timeline, consequences, control, coherence, and emotions (Moss-Morris et al., 2002). Although a standardized tool allows for comparisons across populations and illnesses, it does not elicit specific lay understandings that are unique to a population, risk or context. For example some cultural groups view a sunken fontanel as a cause of illness in infants rather than a symptom that identifies dehydration (cite).

Representations are related to behavior. Perceptions of greater control were associated with seeking care more quickly after noting breast cancer symptoms (Baumann, Han, & Love, 1997) and with better outcomes among patients with lung disease, psoriasis, and arthritis (Scharloo et. al., 1998). Perceiving more symptoms, a long timeline, and severe consequences were associated with worse health outcomes in the Sharloo study. Beliefs of serious consequences predicted later disability for housework, recreational activities, and social interaction for first-time myocardial infarction patients (Petrie, Weinman, Sharpe, & Buckley, 1996).

Education can be designed to fit an individual's representation, fill in gaps in knowledge, or correct inaccurate beliefs (Baumann, Zimmermann, & Leventhal, 1989; Petrie, Broadbent, & Meechan, 2003). Patient education designed to alter beliefs about timeline and consequences resulted in improved self-reports of being prepared to leave the hospital, increased rates of returning to work, and decreased angina symptoms three months post intervention for myocardial infarction patients (Petrie, Cameron, Ellis, Buick, & Weinman, 2002).

Mental Models

Representations are akin to mental models – described as explanatory working models of reality. Decision and risk communication researchers developed a mental models approach to inform the production of risk information that connects with, corrects, and builds on lay mental models (Morgan, Fischoff, Bostrom, & Atman, 2002). Lay beliefs are compared with expert beliefs to locate knowledge gaps or inaccurate beliefs, especially those that may be crucial to effective decision-making. Expert mental models are developed using input from multiple authoritative sources and illustrated in influence diagrams that typically depict cause and effect processes that lead to risk consequences. Lay mental models are discerned using open-ended interviews that begin with unstructured questions and followed by prompts to elicit specific aspects of the risk. A rarely used step of this approach entails constructing a survey instrument based on interview data to measure the prevalence of specific beliefs among a sample population (Morgan et al., 2002).

The basic structure of influence diagrams varies across studies. A radon risk influence diagram depicted causes of household radon and lung cancer risk as consequence of personal exposure (Bostrom, Fischhoff, & Morgan, 1992). A wildfire risk model combined lay and expert beliefs to show causes and consequential risks and benefits of wildfires (Zaksek & Arvai, 2004). Cox and others (2003) developed a generic framework to depict expert beliefs about occupational risks showing five domains of workplace organization, processes and controls, transport, exposure pathways, and health effects. They used grounded theory to identify four lay model domains of concern, health effects, protective measures, and information.

CSM concepts are evident in mental model studies. Mental model interviews tapped beliefs about *causes* of radon exposure, effects (*consequences*), and risk management (*control*). An unstated assumption is that beliefs are based on recognizing the presence of a risk (*identity*). The mental models approach examines the *coherence* of lay mental models by comparing them to expert models. Concern, an affective attribute (*emotions*), was a key component of lay mental models for occupational exposures (Cox et al., 2003).

Representations also incorporate key concepts proposed by health behavior scientists. Weinstein maintains that attributes of risk comprehension include risk factors that modify susceptibility [*cause*], the nature and likelihood of potential ill effects [*consequences*], and the ease or difficulty of avoiding harm [*control*] (1999). Rothman and Kiviniemi (1999) propose that health risk perceptions are primarily shaped by beliefs about ‘antecedents’ and ‘consequences’. They assert that information designed to shape these beliefs is more influential than information about risk likelihood because it informs a *mental model of cause and effect processes* that provides a rationale for preventive behavior. Cognitive psychologists, decision scientists, and risk communication researchers propose that *affect* plays a powerful role in shaping how the public understands and responds to an *identified* risk (Slovic, Peters, Finucane, & MacGregor, 2005). The CSM elements of *identity*, *cause*, *consequences*, *control*, and *emotion* bring together these key concepts used in decision, risk communication, and health behavior research. Risk communication researchers tend to focus on factors that can be applied to producing more effective information. Health behavior researchers tend to focus on factors that explain human behavior. However, researchers in both fields are interested in promoting accurate understandings and effective risk decisions.

The value of applying the CSM to understand how people respond to risk information is four-fold: 1) it is congruent with the mental models approach for risk communication, but offers a structured theoretical framework to support building generalizable knowledge, 2) facilitates measuring representational constructs, 3) offers 28 years of accumulated CSM knowledge that provides insight into how people respond to risk information, and 4) it acknowledges the relationship between cognitive and affective processes, a current focus in risk communication research (McComas, 2006). We applied CSM concepts to characterize and measure representations of arsenic contaminated well water. This study aimed to: 1) develop and evaluate a method for measuring CSM risk representations, 2) assess the reliability and validity of these measures, and 3) describe the multivariate factor structure and the underlying meaning of measured representations.

Arsenic

The health effects of chronic arsenic exposure include skin lesions, neurological effects, hypertension, peripheral vascular disease, cardiovascular disease, respiratory disease, diabetes, and a variety of cancers (Yoshida, Yamauchi, & Sun, 2004). The arsenic drinking water standard in the USA was revised from 50 to 10 μg/L in January 2001 based on lung and bladder cancer risk (Environmental Protection Agency, 2001).

Arsenic contaminated groundwater water is widely prevalent in the United States and most commonly attributed to naturally occurring arsenic in the aquifer (Smedley & Kinniburgh, 2002). In the early 1990's, Wisconsin designated a 10 by 60 mile swath as an arsenic advisory area (AAA) due to mineralized arsenic deposits in the aquifer; approximately 23.5% of AAA private wells are at or over the revised standard. Two chemical processes are believed to release arsenic to the groundwater in the AAA: 1) an oxidation process initiated when the water table drops and exposes arsenic deposits to air, and 2) reduction processes from anaerobic conditions within wells (Gotkowitz, Schreiber, & Simo, 2004). Increasing arsenic in AAA groundwater has been partially attributed to groundwater drawdown at a rate of 2–3 feet per year due to residential and industrial development (Riewe, Weissbach, Heinen, & Stoll, 2001).

An arsenic well test program was offered in the AAA to encourage arsenic testing and promote informed decisions; private well owners are not required to comply with drinking water standards. The program, initiated in 2000, was sponsored by Wisconsin public health and natural resources agencies and offered in 19 of the 20 AAA towns at the time of the study. Well test results were dispensed at an arsenic town meeting where state and county agency staff presented an educational program to attendees. About a third of town residents tested through this program. We were interested in measuring representations of arsenic risk among program participants.

Methods

Proposed Measures

Representational constructs were developed by exploring the information provided in the well test program, interviewing program staff and participants, and reviewing risk communication, decision science, and health behavior literature. A CSM-based content analysis of oral presentations and printed literature provided at three arsenic town meetings showed that this information described arsenic in terms of how it could be identified, causes of arsenic in groundwater and of exposure, timeline, potential health consequences, and control strategies. Four program staff members, two from public health and two from natural resources, were asked about their perceptions of lay arsenic beliefs including beliefs that were not supported by program information. Seven AAA adult residents, suggested by program staff, were interviewed using 7 – 10 open-ended questions based on the CSM[1].

These expert and lay interviews showed that representations were composed of the same main elements in the educational component of the well test program. Additional lay beliefs included showering as a cause of exposure, quarry explosions as contributing to the release of arsenic, and concerns that about property value consequences. Uncertainty was a major theme from these interviews. Therefore, we conceptualized the CSM coherence dimension as *uncertainty,* a central concept in risk analysis and communication (Rowe, 1977).

Current Contents, a multidisciplinary OVID database, was searched using *'risk communication'*, or the combined terms of *'environmental health'*, with *'health behavior'*, *'perceived risk'*, or *'health education'* to locate research about perceptions of and responses to environmental health risks. Concepts from the literature were included in representational constructs if they fit with a CSM dimension. For example, beliefs about the likelihood and severity of health problems that are used by health behavior scientists to measure perceived risk (Weinstein, 2000), were included as measures of health consequences. Generalizable risk constructs and context-specific 'arsenic in the AAA' constructs were used to provide a richer measure of representations and more content validity than either single approach.

Results suggested the following conceptual descriptions for cognitive representational dimensions and the emotional representation. Environmental risks are *identified* by a label[2a], risk beliefs applied to a spatial[2b] or somatic level[2c], sensory cues[2d], factors related to the amount of risk one is exposed to[2e], and safety thresholds[2f] that identify the meaning of a risk measure[2g] Perceived *causal* mechanisms explain personal exposure to a risk and the presence of risk in the environment. Risk *timelines* are increasing, decreasing or cyclical over time and risks can be considered long or short-term. Environmental risks have potential health and financial *consequences. Health consequences* include perceived likelihood, severity, and problem seriousness (Weinstein, 2000). *Uncertainty* is conceptualized as uncertainty about each of the above dimensions of risk. *Emotion* was conceptualized as a range of emotions including concern, worry, fear and anger.

The greatest conceptual difference is between illness and risk *identity*. While illness risks are primarily identified by perceived symptoms linked to an illness label, we propose environmental risks are identified by perceived environmental symptoms (aspects of the environment that can be sensed), a safety threshold, and beliefs related to recognizing personal and community risk. The safety threshold is specified as a single-item measure of identity thus excluded from this study of multivariate representational measures.

[1]For example, 'How do people know if they have too much arsenic in their well water?' was used to tap beliefs about identifying an arsenic problem.

[2]For example, a) 'we have arsenic', b) risk advisory area, community, home, c) skin rash, d) odors, e) amount of water consumed over number of years, f) a drinking water standard, g) a laboratory value

Survey items were constructed or adapted from the literature to measure cognitive and emotional representations. Successive survey drafts were developed based on reviews by colleagues and program professionals, cognitive testing by six program participants, and a mailed pilot survey (n = 97). This process resulted in 36 variables. Most items were answered using a 6-point scale (1 = strongly disagree; 6 = strongly agree). Uncertainty was scaled to measure certainty (1 = very unsure; 6 = very sure).

Participants and Study Design

The study sample consisted of all people who tested through the well test program and had an arsenic level ≥ 5 μg/L (n = 1067). The sample was split into two groups. The *elevated* arsenic group (n = 545) had levels at or over the revised arsenic standard (≥ 10 μg/L). The *moderate* arsenic group (n = 352) had levels below the standard but of potential concern (5 – 9 μg/L). This was a cross-sectional study. Surveys were mailed over February and March of 2003; about 6 months to 3 years after the well test program was offered to community residents. A modified Dillman (2000) method was used that entailed up to five contacts by mail: 1) pre-notice letter, 2) survey, stamped return envelope and $2 incentive, 3) postcard reminder, 4) replacement survey, and 5) final postcard reminder. The study was determined to be exempt from requiring a full review by the University of Wisconsin-Madison Health Sciences IRB.

Analysis

Surveys with more than 50% missing data (n = 25 or 2.7%) were removed from analysis[3]. Data judged as missing completely at random were imputed using an iterative expectation-maximization procedure (Schafer, 2004).

Two steps were used to develop multivariate measures of representational dimensions for the elevated arsenic group (Kroonenburg & Lewis, 1982). First, exploratory factor analysis (EFA) indicated the initial factor structure. Second, the EFA solution was used as a starting point for a confirmatory factor analysis (CFA) to improve measurement model fit.

Maximum-likelihood (ML) EFA with SPSS and PRELIS (Joreskog & Sorbom, 2001) used an oblique rotation (promax) since factors characterize integrated representational dimensions. Variables with less than 10% of their variance explained by the factor solution were removed from analysis. Explained variance (Eigenvalues > 1 and scree plot) and a goal of having theoretically justifiable factors guided the number of factors to retain.

The EFA output informed the starting values for ML CFA. Each variable was assigned to load on one factor based on its highest loading, variables' loadings on remaining factors were set to zero resulting in an oblique rotation of the promax solution (Kroonenburg & Lewis, 1982). The model was scaled by setting the covariance of each factor with itself to a value of one. Modification indices[4] were judiciously applied to guide adjustments to the CFA model. Variables were allowed to load on more than one factor if the smallest loading

[3]Eight of 36 variables had more than 3% missing data; two of these had more that 10% missing data (14.1% for bleach and 13.0% for quarries as causes of arsenic).

[4]These indices provide estimates of model coefficients for relationships that are currently not in the model.

was greater than 50% of the larger loading. Correlated error variances were specified if two variables loaded on the same factor, there was reason to believe the errors were correlated[5], and they were substantial (defined as a standardized coefficient of ~ .30). Fit indices of RMSEA < .08 (Browne & Cudeck, 1993) and SRMR < .10 (Kline, 1998) were deemed sufficient for this exploratory analysis. A simple measurement model (each variable loading on one factor) was generated by removing the path with the smallest standardized loading in a sequential order from the pair with the largest to the smallest difference between loadings.

We examined whether the measurement model was invariant across the elevated and moderate arsenic groups using multiple group CFA. Three successively more restrictive models were explored: 1) structure held constant across groups *(congeneric model)*, 2) structure and factor loadings held constant across groups *(tau-equivalent model)*, and 3) structure and all coefficients held constant across groups *(parallel model)*. Factor means were explored by estimating factor mean differences for the moderate group relative to the elevated group[6].

Results

Descriptives

The response rate was 86.4%; 922 of 1067 delivered surveys were returned with 897 suitable for analysis. Participants' demographic characteristics were: 58.6% male, 45.8% with children in the home, mean age 52.3 years (*SD* = 13.1), median education category of 'high school', median income of $40,000 – $79,000, and 99% homeowners. The moderate arsenic group lived more years in their homes than the elevated group; 17.6 (*SD* = 14.2) versus 15.7 (*SD* = 12.02), $p < .05$.

Means and standard deviations for imputed study variables among the elevated and moderate arsenic groups are in Table 1. Across groups, participants had the highest mean level of agreement with the following variables: arsenic is a long-term problem, town wells are at risk for having arsenic, and feeling certain about how to identify an arsenic problem (see Table 1). Participants had the most disagreement with: concerned about bathing or showering, frightened by one's arsenic level, and angry about one's arsenic level.

Multivariate Measures of Risk Representations

Initial factor solution—The initial EFA solution for the elevated arsenic group had 7 factors with an Eigenvalue > 1. Three variables were removed because less than 10% of their variance was explained by the factor solution (1d, 1e, 7f, see Table 2). The second EFA solution from this reduced set of 33 variables had 6 factors with an Eigenvalue > 1: *identity, environmental cause, health consequences, control barriers, certainty, and emotions*. These factors explained 56.1% of the variance among the 33 variables. The scree plot showed a

[5]For example, errors might be correlated for adjacent survey variables if the answer for one influenced the other's answer (Rubio & Gillespie, 1995).

[6]Although factor means are not estimated, the difference in the factor mean of one group relative to that of a reference group can be estimated if the latent variables are on the same scale in both groups (Sorbom, 1974).

departure of a linear trend at 6 factors. A number of variables had significant loadings on more than one factor.

Confirmed factor solution—Factor assignments, loadings, correlated errors, and Cronbach's alpha for the simple measurement model for the elevated arsenic group are in Table 1. The confirmed model had improved fit over the starting model ($\Delta\chi^2 = 421.4$, $\Delta df = 3$, $p < .001$). Improved fit resulted from reassigning two variables and adding 3 correlated errors. 'Exposed to arsenic' (4d) was moved from *health consequences* to *identity* and 'change over time' (3b) was moved from *identity* to *cause*. Fit indices for the elevated arsenic group simple model are in Table 2. Given the exploratory nature of this study these fit indices, some less than adequate, are tolerated.

Table 1 shows supported CSM factors and the variables assigned to each. *Timeline* variables were reassigned to identity and cause. *Cause*, *consequences*, and c*ontrol* lost variables to become more specific - *environmental cause*, *health consequences*, and *control barriers*. *Identity* became more global by acquiring variables related to exposure and property value. The last column of Table 1 indicates variables' pre-analysis factor assignment.

Estimated factor correlations for the elevated arsenic group simple model are in Table 3. Strongest correlations were between *health consequences* and *emotions* (.86), *health consequences* and *identity* (.81), and *identity* and *emotions* (.80). *Certainty* was most strongly correlated with *identity* (.46). *Barriers to control* had the weakest relationships to other variables ranging from .38 with *emotion* to .10 with *certainty*. The weakest correlation was marginally significant ($p = .05$), all others were highly significant ($p < .001$).

The elevated arsenic group fitted model that allowed four dual loading variables and an additional correlated error resulted in improved model fit over the confirmed model ($\Delta\chi^2 = 302.1$, $\Delta df = 5$, $p < .001$). Coefficients for dual loading variables are in Table 4.

Applying confirmed solution to moderate arsenic group—Fit indices for the elevated and moderate arsenic groups and the two-group analysis are in Table 2. The moderate arsenic group (n = 372) likely had better χ^2-related fit indices than the elevated arsenic group (n = 545) because χ^2 is dependent on sample size. Reasonable fit indices for the two-group model suggest that the congeneric, tau-equivalent, and parallel models were equivalent across these groups.

Estimated factor mean differences show that moderate arsenic group factor means were significantly smaller compared to the means for the elevated arsenic group for: *identity* (−0.53), *health consequences* (−0.55), and *emotions* (−0.50); all at $p < 0.001$. Factor mean differences were not significant for *environmental cause* (−0.07), *barriers to control* (−0.11), and *certainty* (−0.12).

Reliability and Validity

The reliability of each multivariate measure in the simple model was assessed using Cronbach's alpha (reported in Table 2). Factor reliabilities are in the range of adequate (> .70) to excellent (> .90) (Kline, 1998). Content validity is supported by using multiple authoritative sources (program information, experts, well owners, and risk literature) to inform the development of study measures (Kline, 1998).

Discriminant validity indicates that most factors are measuring distinct concepts. Factors with correlations > .85 are excessively high (Kline, 1998). The estimated correlation between health consequences and emotions (.86) shows a minor violation of discriminant validity. The emotion factor was retained because it is a key feature of the CSM. Also, when these factors were merged, model fit declined from RMSEA =.075 to .086 further supporting the decision to keep emotion as a separate variable.

Convergent validity, demonstrated when indicators for a factor have relatively high loadings, means that variables work together to measure a factor (Kline, 1998). While most indicators had fairly high loadings, lower loadings were noted for some elements of arsenic cause; namely quarries, natural causes, and bleach. Quarries reflect a lay belief about *cause*. Whether a risk is caused by man or nature is an important element in perceived risk (Slovic, 1996). At the time of the study, well test program information stated that using too much bleach or chloride in wells was related to increasing arsenic levels. These elements were left in because they were theoretically important and contributed to the content validity of the *cause* factor. Some convergent validity was sacrificed for content validity.

Factor mean differences suggest that participants with moderate levels had less strong beliefs about identifying arsenic risk and health consequences and less strong emotions than participants with elevated levels. These expected findings contribute to known group validity.

Discussion

The method we described produced reasonably valid and reliable multivariate measures of risk representations. The measurement model was composed of arsenic risk factors that retained the basic meaning of previously established CSM dimensions. Environmental health risk cognitions were composed of *identifying* risk at a community or personal level, *causal* factors at an environmental level, health *consequences*, barriers to *control*, and *uncertainty*. *Emotions* were strongly and positively related to *identity* and *consequences*. Measurement model structure and loadings were equivalent across the elevated and moderate arsenic groups suggesting that the measurement properties were the same across these groups. This supports the generalizability of the measurement model among study participants with different arsenic levels. Collectively, findings suggest that CSM representational constructs have utility for understanding representations of environmental health threats.

The content and meaning of arsenic risk representations can be understood by examining the loadings, variable means, and standard deviations for individual items contributing to factors. We proposed that *identifying* arsenic risk included risk recognition (town and household at risk) and risk modifiers (amount and duration of use). The supported *identity* dimension brought in variables that measured beliefs about exposure (sources of exposure, exposure processes, personal exposure, and benefits of reducing exposure). This is conceptually valid because risk is a function of exposure. Beliefs about property values also belonged to the identity factor. People may link identifying community or household risk with potential loss of home value.

Participants with elevated and moderate arsenic levels had similarly strong beliefs about identifying community level risk; appropriate since they all lived in an advisory area and expected since they all tested for arsenic. Participants with higher arsenic levels had stronger beliefs about identifying personal risk - consistent with a dose/risk relationship and encouraging because recognizing personal risk is needed to prompt protective behavior (Weinstein, 1988).

The *health consequences* factor is similar to the CSM illness consequence dimension (perceived likelihood, severity, and problem seriousness). Health consequence beliefs were the weakest among the cognitive dimensions; people identified being at risk without having strong beliefs about potential health consequences. The idea that one can be exposed to arsenic without having consequences is evident in the remark made by a participant with 71 μg/L arsenic: “How much water do I really need to drink to have arsenic cause health problems?” Participants with lower arsenic levels had less strong beliefs about health consequences than those with higher levels. This trend is also consistent with a dose-response model of risk.

Emotional representations were not strong among either group and expectedly less strong among participants with moderate arsenic levels. Recognizing the presence of arsenic risk in their community did not appear to engender strong emotions, perhaps because participants did not have strong beliefs about health consequences. We expected stronger emotions because, in general, people are concerned about the effects of environmental contaminants on their health and especially concerned about contaminated drinking water (Petrie et al., 2001). People tend to have optimistic biases about their personal susceptibility to health risks (Weinstein, 1987) that are resistant to modification by information designed to alter these beliefs (Weinstein & Klein, 1995). Emotional responses to environmental risks are heightened when people perceive that a risk is manmade (Slovic, 1996) or that those in authority can’t be trusted (Slovic, 1993). Beliefs that arsenic is naturally occurring, optimistic bias, and minimal distrust may partially explain why arsenic risk did not engender strong emotions among participants with elevated arsenic levels.

Variables with the strongest contribution to *environmental cause*, groundwater drawdown and an increasing number of wells, reflect information that was a component of the well test program. Speakers at two of the three arsenic town meetings and several interviewees used the phrase ‘like Swiss cheese’ to describe the well-riddled aquifer. Evoking Swiss cheese, a vivid and concrete mental image, may have powerfully conveyed a causal model relating increasing well construction to increasing amounts of arsenic thus explaining why timeline beliefs belonged to this factor. Other beliefs about *environmental cause* contributed weakly to this factor, and logically so because quarries as a cause was not a widely held lay belief, bleach as a cause was not widely publicized, and whether arsenic was a manmade or a naturally occurring risk was arguable as it had elements of both.

Variables measuring various aspects of certainty all loaded on the same factor. Participants were least certain about which control methods to use, suggesting they need information to support decisions about control methods. A global c*ertainty* factor may not be useful for understanding how *certainty* is related to information needs, outcomes, or other representational dimensions. It may be more appropriate to explore how each specific element of *certainty* (certainty about *cause, control*, *consequences,* and so forth) is related to other variables.

Identity, *health consequences*, and *emotions*, strongly correlated in our study, are conceptually related. *Health consequences* are a result of exposure. Beliefs about risk exposure and health consequences likely generate negative *emotions*. Similar correlation patterns are noted for illness threats (Hagger & Orbell, 2003). In our study, these strong correlations were, in part, driven by the fact that each of these factors shared a variable (concerned and exposed) with one of the other two factors in the dual loading model.

Dual loading variables provide insight into the meaning of the factors they belong to and how factors are integrated. Concern contributed to both *identity* and *emotions*. Concern may be a more 'rational' emotion than worry, fear, or anger and thus more related to cognition. The belief of being exposed to arsenic contributed to *identity* and *health consequences*, an appropriate duality given that consequences result from exposure to a risk. Beliefs of exposure brings an environmental risk that is 'out there' to the level of one's body, perhaps a crucial belief for promoting protective behavior. Researchers exploring exposure beliefs found that about 80% of participants agreed that exposure means 'coming in contact' with a risk (MacGregor, Slovic, & Malmfors, 1999). Exposure confers risk but does not necessarily imply the nature or likelihood of consequences which may explain its stronger contribution to *identity* than *health consequences*. People may use protective behavior to reduce exposure and potential risk, even in the absence of beliefs about the nature or likelihood of health consequences. An interviewee with 3.1 μg/L arsenic who used a costly filter to reduce that level said that she knew her level was considered safe, but didn't want to take any chances with her children's health. While factor analysis convention discourages variables with an ambiguous factor assignment, their absence would decrease the content validity of representational measures. People had more 'concern' about arsenic than 'worry' or 'fear'. The belief of being exposed is a central concept of environmental risk.

Limitations

Variability in time between participants' receipt of their arsenic well test results and measuring risk representations is a source of error. Beliefs about risk consequences may be less strong if control measures have been taken (Weinstein & Nicolich, 1993). We asked people to respond to the survey items based on using their untreated water at its highest arsenic level, but they may have had difficulty answering retrospectively. Patterns of shared variance were likely influenced by the use of different response scales for the variables measuring certainty and for the variable measuring change over time.

Implications for Practice and Research

CSM dimensions offer a framework for constructing information that fits with and builds on people's beliefs about health threats. People need information about each of the five cognitive dimensions to develop a working 'mental model' of cause and effect that informs decisions about controlling a risk. For example, exposure beliefs were an important component of identifying arsenic risk suggesting that people need information about likely and unlikely routes of exposure to inform decisions about controlling personal exposure to arsenic. Descriptive findings that were not provided here, such as frequencies of responses for each survey item, could provide a granular understanding of people's beliefs. Examining how patterns of beliefs vary based on demographics such as gender, age or education could be used to assess specific information needs among subgroups.

This research offers a method for measuring structured risk representations that produced reasonably valid and reliable measures. Further work is needed to refine these methods so they can be consistently applied to other environmental health risks. We envision a standard set of survey items, worded to apply to a particular risk, mingled with a set of risk or context specific items. For example, beliefs about whether a risk is natural or manmade can be broadly applied, however, the lay belief that arsenic risk was exacerbated by quarry explosions was peculiar to our study population. Exploratory followed by confirmatory factor analyses allows researchers to develop multivariate measures that fit the risk rather than apply a one size fits all approach to measurement and facilitates understanding differences and similarities in factor structure among different risks. As research accrues, it may be possible to identify variables that have a consistent factor assignment and those that vary based on specific risk attributes. Allowing variables to load on more than one factor provides insight into those particular beliefs that may integrate factors into coherent representations. Locating key generalizable elements of environmental risk representations would support the construction of a standardized tool that would be useful for research and practice.

Quantitative representational measures facilitate building a cohesive body of research to explore 1) how representations vary across risks, contexts, and populations and 2) how people understand and respond to risk information by quantifying relationships between information, representations, and outcomes. We applied the measures reported here to explore the dimensions through which information exerted an effect on arsenic safety judgments and protective actions (Severtson, Baumann, & Brown, 2006). Quantifying risk representations facilitates measuring correlational and cause and effect relationships that can advance our understanding of how information works. This research can determine those representational elements that are more stable, those that are more easily modified, and explore informational features that promote representational modifications. Measuring risk representations is an important first step toward building a line of CSM-based research to support the development of risk information that promotes informed decisions about environmental health risks.

Acknowledgments

This research was partially supported by a grant from the Agency for Toxic Substances and Disease Registry (U50\ATU500005) through an agreement with the Wisconsin Department of Health and Family Services and also by National Institute of Nursing Research pre-doctoral fellowship F31NR07409. The first author is currently supported by a National Library of Medicine post-doctoral fellowship (5T15LM007359). We also thank state and local well test program professionals who provided advice and assistance with this research.

Reference List

Baumann LC, Han Y, Love RR. Beliefs about breast cancer and care seeking in Vietnam. Clinical Excellence for Nurse Practitioners: The International Journal of NPACE. 1997; 5:301–311.

Baumann L, Zimmerman RS, Leventhal H. An experiment in common sense: Education at blood pressure screening. Patient Education and Counseling. 1989; 14:53–67. [PubMed: 10294790]

Bostrom A, Fischhoff B, Morgan MG. Characterizing mental models of hazardous processes: A methodology and an application to radon. Journal of Social Issues. 1992; 48(4):85–100.

Browne, MW.; Cudeck, R. Alternative ways of assessing model fit. In: Bollen, KA.; Long, JS., editors. Testing structural equation models. Newbury Park, CA: Sage; 1993. p. 136-162.

Cox P, Niewohner J, Pidgeon Nick, Gerrard Simon, Fischhoff B, Riley D. The use of mental models in chemical risk protection: Developing a generic workplace methodology. Risk Analysis. 2003a; 23(2):311–324. [PubMed: 12731816]

Dillman, DA. Mail and internet surveys: The tailored design method. New York: Wiley; 2000.

Environmental Protection Agency. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Final Rule. Vol. Federal Register/66, 14. 40 CFR Parts 9, 141, and 142. 2001

Gotkowitz MB, Schreiber ME, Simo JA. Effects of water use on arsenic release to well water in a confined aquifer. Ground Water. 2004; 42(4):568–575. [PubMed: 15318779]

Hagger MS, Orbell S. A meta-analytic review of the common-sense model of illness representations. Psychology and Health. 2003; 18(2):141–184.

Joreskog, KG.; Sorbom, D. LISREL 8.50 and PRELIS 2.50 [Statistical Program]. Chicago, IL: Scientific Software International; 2001.

Kline, RB. Principles and practice of structural equation modeling. Montreal: Guilford Press; 1998.

Kroonenburg PM, Lewis C. Methodological issues in the search for a factor model: Exploration through confirmation. Journal of Educational Statistics. 1982; 7(2):69–89.

Leventhal, H.; Brissette, I.; Leventhal, E. The common-sense model of self-regulation of health and illness. In: Cameron, LD.; Leventhal, H., editors. The self-regulation of health and illness behavior. London: Routledge; 2003. p. 42-65.

MacGregor DG, Slovic P, Malmfors T. "How exposed is exposed enough?" Lay inferences about chemical exposure. Risk Analysis. 1999; 19(4):649–659. [PubMed: 10765428]

McComas KA. Defining Moments in Risk Communication Research: 1996 – 2005. Journal of Health Communication. 2006; 11(1):75–96. [PubMed: 16546920]

Morgan, MG.; Fischoff, B.; Bostrom, A.; Atman, C. Risk communication: A mental models approach. New York: Cambridge University Press; 2002.

Morgan MG, Fischoff B, Bostrom A, Lave L, Altman CJ. Communicating risk to the public. Environmental Science Technology. 1992; 26(11):2048–2056.

Moss-Morris R, Weinman J, Petrie KJ, Horne R, Cameron LD, Buick D. The revised illness perception questionnaire (IPQ-R). Psychology and Health. 2002; 17(1):1–16.

Petrie, KJ.; Broadbent, E.; Meechan, G. Self-regulatory interventions for improving the management of chronic illness. In: Cameron, LD.; Leventhal, H., editors. The self-regulation of health and illness behavior. New York: Routledge; 2003.

Petrie KJ, Cameron LD, Ellis CJ, Buick D, Weinman J. Changing illness perceptions after myocardial infarction: An early intervention randomized controlled trial. Psychosomatic Medicine. 2002; 64:580–586. [PubMed: 12140347]

Petrie KJ, Sivertsen B, Hysing M, Broadbent E, Moss-Morris R, Eriksen HR, et al. Thoroughly modern worries: The relationship of worries about modernity to reported symptoms, health and medical care utilization. Journal of Psychosomatic Research. 2001; 51(1):395–401. [PubMed: 11448708]

Petrie KJ, Weinman J, Sharpe N, Buckely J. Role of patients' view of their illness in predicting return to work and functioning after myocardial infarction: Longitudinal study. British Medical Journal. 1996; 312:1191–1194. [PubMed: 8634561]

Riewe T, Weissbach A, Heinen L, Stoll R. Naturally occurring arsenic in well water in Wisconsin. Well Water Journal. 2001:24–29.

Rothman AJ, Kiviniemi MT. Treating people with information: An analysis and review of approaches to communicating health risk information. Journal of the National Cancer Institute Monographs. 1999; (No. 5):44–51. [PubMed: 10854457]

Rowe, WD. An anatomy of risk. New York: John Wiley & Sons; 1977.

Rubio DM, Gillespie DF. Problems with error in structural equation models. Structural Equation Modeling. 1995; 2(4):367–378.

Schafer JL. NORM: Multiple imputation of incomplete multivariate data under a normal model. 2004 (Version 2.03, software for Windows 1995/1998 ed.).

Severtson DJ, Baumann LC, Brown RL. Applying a health behavior theory to explore the influence of information and experience on arsenic risk representations, policy beliefs, and protective behavior. Risk Analysis. 2006; 26(2):356–372.

Scharloo M, Kaptein AA, Weinman J, Hazes JM, Willems LNA, Bergman W, et al. Illness perceptions, coping and functioning in patients with rheumatoid arthritis, chronic obstructive pulmonary disease and psoriasis. Journal of Psychosomatic Research. 1998; 44(5):573–585. [PubMed: 9623878]

Slovic P. Perceived risk, trust and democracy. Risk Analysis. 1993; 13(6):675–682.

Slovic P. Perceptions of risk from radiation. Radiation Protection Dosimetry. 1996; 68:165–180.

Slovic P, Peters E, Finucane ML, MacGregor DG. Affect, risk, and decision-making. Health Psychology. 2005; 24 Supplement(4):S35–S40. [PubMed: 16045417]

Smedley PL, Kinniburgh DG. Arsenic in ground water of the United States: Occurrence and geochemistry. Applied Geochemistry. 2002; 17:517–568.

Sorbom D. A general method for studying the difference in factor means and factor structures between groups. British Journal of Mathematical and Statistical Psychology. 1974; 27:229–239.

SPSS Inc. SPSS for Windows (Version 11.5) [Statistical Program]. 2002

Weinstein ND, Klein WM. Resistance of personal risk perceptions to debiasing interventions. Health Psychology. 1995; 14(2):132–140. [PubMed: 7789348]

Weinstein ND, Nicolich M. Correct and incorrect interpretations of correlations between risk perceptions and risk behaviors. Health Psychology. 1993; 12(3):235–245. [PubMed: 8500454]

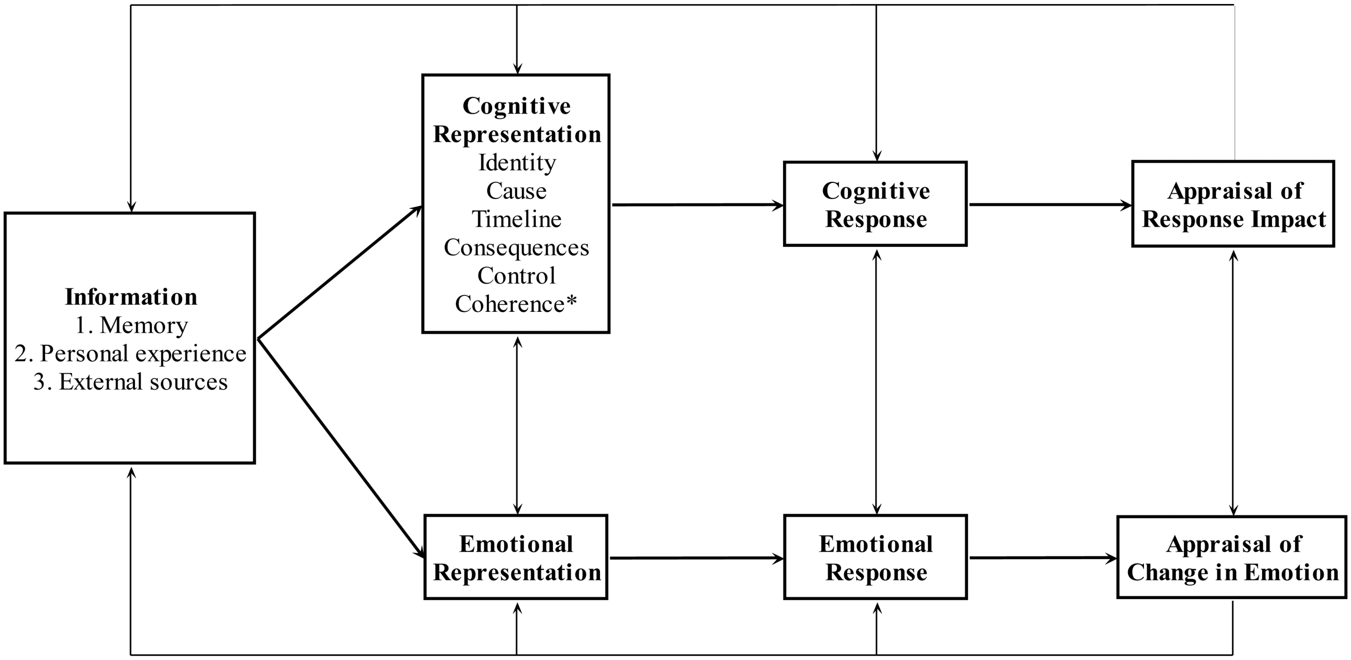
Weinstein ND. Unrealistic optimism about susceptibility to health problems: Conclusions from a community-wide sample. Journal of Behavioral Medicine. 1987; 10(5):481–500. [PubMed: 3430590]

Weinstein ND. The precaution adoption process. Health Psychology. 1988; 7:355–386. [PubMed: 3049068]

Weinstein ND. Perceived probability, perceived severity, and health-protective behavior. Health Psychology. 2000; 19(1):65–74. [PubMed: 10711589]

Yoshida T, Yamauchi H, Sun GF. Chronic health effects in people exposed to arsenic via the drinking water: dose-response relationships in review. Toxicology and Applied Pharmacology. 2004; 198:243–252. [PubMed: 15276403]

Zaksek M, Arvai J. Toward improved communication about wildland fire: Mental models research to identify information needs for natural resource management. Risk Analysis. 2004; 24(6):1503–1514. [PubMed: 15660607]



*Some researchers include this dimension

Figure 1.
The Common Sense Model

Table 1

Supported Factors & Variable Loadings for Elevated Arsenic Group & Variable Means for Both Arsenic Groups

Factors and variables	$^{a}\lambda$ *SE*	$^{b}R^2$	^{c}Elvt. Mean *SD*	^{d}Mod. Mean *SD*	**Original factor assignment**
Identity Cronbach's alpha = .91					
Our household is at risk for contaminated well water.	1.11 *.05*	.67	4.35 *1.35*	3.70 *1.46*	Identity
[e]our arsenic well level decreases our property value.	1.07 *.06*	.48	4.13 *1.54*	3.38 *1.64*	Consequence
[e]we are exposed to arsenic from our well water.	1.04 *.05*	.56	4.14 *1.40*	3.53 *1.55*	Consequence
[e]years of use increases our arsenic-related health risks.	1.03 *.05*	.60	4.23 *1.32*	3.82 *1.42*	Identity
[e, f]drinking less of our water would decrease our health risks.	0.96 *.05*	.51	4.31 *1.34*	3.67 *1.50*	Control
[e]our main source of arsenic exposure is from our well water.	0.95 *.05*	.52	4.71 *1.32*	4.19 *1.51*	Cause exp.
[e, f]reducing arsenic would increase the value of our home.	0.92 *.05*	.44	4.43 *1.38*	3.65 *1.61*	Control
Arsenic is likely to be a long-term problem for area wells.	0.75 *.04*	.49	4.93 *1.07*	4.73 *0.99*	Timeline
Town households are at risk for contaminated well water.	0.75 *.04*	.45	4.63 *1.12*	4.41 *1.16*	Identity
Environmental Cause Cronbach's α = .71					
Increased well drilling is causing arsenic levels to increase.	1.19 *.06*	.68	4.09 *1.45*	3.94 *1.47*	Env. Cause
Decreasing groundwater levels cause levels to increase.	1.02 *.05*	.64	4.29 *1.28*	4.23 *1.26*	Env. Cause
Quarries are increasing arsenic levels in the groundwater.	.57 *.06*	.19	3.59 *1.32*	3.57 *1.23*	Env. Cause
Arsenic in groundwater is from natural processes not affected by water use.	−.49 *.06*	.13	3.44 *1.37*	3.38 *1.37*	Env. Cause
[i]In the next ten years the arsenic level in our well is likely to	0.48 *.04*	.25	3.66 *0.96*	3.61 *0.82*	Timeline
Chlorine well treatments/bleach increase levels of arsenic.	0.45 *.05*	.14	3.16 *1.21*	3.26 *1.22*	Env. Cause

Factors and variables	[a]λ *SE*	[b] R^2	[c]Elvt. Mean *SD*	[d]Mod. Mean *SD*	Original factor assignment
Health Consequences Cronbach's α = .91					
[e]arsenic-related health effects are likely to be serious.	1.35 *.05*	.83	3.28 *1.48*	2.63 *1.34*	Consequence
[e]arsenic is a serious problem for our household.	1.30 *.05*	.72	3.82 *1.53*	3.03 *1.50*	Consequence
[e]we are at risk for having arsenic-related health effects.	1.29 *.05*	.79	3.48 *1.45*	2.78 *1.37*	Consequence
Control Barriers Cronbach's α = .74					
It takes a lot of effort to decrease arsenic exposure.	1.22 *.06*	.82	4.14 *1.35*	4.08 *1.32*	Control barriers
It costs a lot of money to decrease arsenic exposure.	0.99 *.05*	.61	4.51 *1.26*	4.30 *1.30*	Control barriers
It is hard to compare the pros and cons of control methods.	0.57 *.05*	.21	4.30 *1.24*	4.12 *1.23*	Control barriers
[j]**Certainty** Cronbach's α = .85					
Certain about whether to control for arsenic	1.09 *.05*	.67	3.94 *1.34*	3.76 *1.35*	Certainty
Certain about causes of arsenic exposure	0.95 *.05*	.54	3.53 *1.30*	3.41 *1.30*	Certainty
Certain about which control methods to use	0.90 *.06*	.40	3.28 *1.43*	3.26 *1.38*	Certainty
Certain about how arsenic will change over time	0.87 *.06*	.40	3.31 *1.36*	3.29 *1.29*	Certainty
[g]Certain about effect on property values	0.85 *.06*	.39	4.12 *1.37*	3.73 *1.32*	Certainty
[g]Certain about arsenic health effects	0.80 *.05*	.37	3.63 *1.31*	3.56 *1.24*	Certainty
Certain about how to identify an arsenic problem	0.72 *.05*	.34	4.63 *1.24*	4.74 *1.15*	Certainty
Emotional Representation Cronbach's α = .91					
[e]I feel worried about our arsenic well level.	1.44 *.05*	.89	3.61 *1.53*	2.91 *1.41*	Emotion

Factors and variables	[a] λ *SE*	[b] R^2	[c] Elvt. Mean *SD*	[d] Mod. Mean *SD*	Original factor assignment
[e] I feel concerned about our arsenic well level.	1.31 *.05*	.77	4.13 *1.49*	3.43 *1.54*	Emotion
[e, h] I feel frightened about our arsenic well level.	1.28 *.05*	.69	2.83 *1.54*	2.29 *1.27*	Emotion
[e, h] I feel angry about our arsenic well level.	1.17 *.06*	.52	2.91 *1.63*	2.38 *1.36*	Emotion
[e] I am concerned about using our well water for showering.	0.87 *.05*	.39	2.30 *1.39*	1.92 *1.10*	Emotion & Cause exp.
Deleted Variables					
[e] *I feel skeptical about the health risks of arsenic.*			3.29 *1.41*	3.16 *1.38*	Consequences
[e] *We can sense when our water has too much arsenic.*			*1.81* *0.71*	1.68 *0.85*	Identity
[e] *amount consumed decreases our arsenic-related health risks.*			*3.04* *1.57*	2.97 *1.56*	Identity

All variables measured on 6-point scale from strongly disagree - strongly agree unless otherwise noted.

[a] λ= unstandardized factor loading

[b] Explained variance

[c] Elevated arsenic group

[d] Moderate arsenic group

[e] Using our well water at its highest arsenic level…

[f,g,h] Indicates 3 pairs of variables that had correlated errors.

[i] This item answered on a 5-point scale from decrease – increase.

[j] These items answered in a 6-point scale from very unsure – very sure.

Table 2

Fit Indices for Single-sample and Multiple Group Confirmatory Factor Analysis

Model	χ^2	*df*	χ^2/df < 3.0[a]	RMSEA < .08[a]	CFI > .90[a]	*NNFI* > .90[a]	SRMR < .10[b]
Single-sample analysis							
Elevated arsenic group	[c]1926	477	4.0	.075	.87	.86	.078
Moderate arsenic group	[c]1256	477	2.6	.068	.88	.87	.077
Two-group analysis							
Structure invariant *Congeneric model*	[c]3183	954	3.3	.072	.88	.86	.077
Factor loadings invariant *Tau-equivalent model*	[c]3294	987	3.3	.072	.87	.86	.083
All parameters invariant *Parallel model*	[c]3499	1038	3.4	.073	.86	.86	.100

[a] value indicates adequate fit (Kline, 1998)

[b] value indicates adequate fit (Brown & Cudeck, 1993)

[c] all values significant at $p = 0.00000$

Table 3

Estimated Correlations* Among Representational Factors in the Simple Model: Elevated Arsenic Group

	1	2	3	4	5	6
1. Identity	1.00					
2. Environmental Cause	0.60	1.00				
3. Health Consequences	0.81	0.43	1.00			
4. Barriers to Control	0.33	0.26	0.34	1.00		
5. Certainty	0.46	0.34	0.40	0.10	1.00	
6. Emotions	0.80	0.50	0.86	0.38	0.31	1.00

*correlations estimated by standardized phi values, all are significant at $p < .001$ except the correlation between certainty and barriers which was marginally significant at $p = .05$

Table 4

Unstandardized Coefficients* and Standard Errors for Dual Loading Variables: Elevated Arsenic Group

Variable	**Environmental Cause**	**Identity**	**Health Consequences**	**Emotion**
	λ ***SE***	λ ***SE***	λ ***SE***	λ ***SE***
Exposed to arsenic		0.62 *.07*	0.46 *.08*	
Concerned about showering/bathing			0.49 *.10*	0.42 *.10*
Concerned about our arsenic level		0.61 *.06*		0.82 *.06*
Levels are….(increasing-decreasing)	0.28 *.05*	0.29 *.05*		

*all significant at $p < .001$