Risk Analysis, Vol. 19, No. 4, 1999

"How Exposed Is Exposed Enough?" Lay Inferences About Chemical Exposure

Donald G. MacGregor,[1,3] Paul Slovic,[1] and Torbjörn Malmfors[2]

The concept of exposure is central to chemical risk assessment and plays an important role in communicating to the public about the potential health risks of chemicals. Research on chemical risk perception has found some indication that the model lay people use to judge chemical exposure differs from that of toxicologists, thereby leading to different conclusions about chemical safety. This paper presents the results of a series of studies directed toward developing a model for understanding how lay people interpret the concept of chemical exposure. The results indicate that people's beliefs about chemical exposure (and its risks) are based on two broad categories of inferences. One category of inferences relates to the nature in which contact with a chemical has taken place, including the amount of a chemical involved and its potential health consequences. A second category of inferences about chemical exposure relates to the pragmatics of language interpretation, leading to beliefs about the motives and purposes behind chemical risk communication. Risk communicators are encouraged to consider how alternative models of exposure and language interpretation can lead to conflicting conclusions on the part of the public about chemical safety.

KEY WORDS: Risk perception; risk communication; intuitive toxicology; mental models.

INTRODUCTION

To a toxicologist, the determination of whether or not (or to what degree) an individual (or population) has been exposed to a chemical involves a complex assessment of a chemical's presence in a human or animal. The conclusions of this assessment are highly conditioned on a number of factors, including measures of the chemical in the environment (e.g., air, water, or soil), assumptions about movement of the chemical through a particular medium (e.g., air), the pathways by which the chemical is taken into the body (e.g., inhalation, ingestion, skin contact), and the ability of the chemical to exert a biological effect. Potential interactions of the chemical with factors such as exercise, use of consumer products (e.g., pharmaceuticals), and diet are also taken into consideration.[1] Thus, exposure is a matter of degree, determined by the interaction of a number of variables that influence both the external contact with a chemical substance and the presence of the chemical in the body.

For those who wish to communicate the risks of chemical risk assessments (or to communicate chemical risks in general), it is virtually impossible to discuss the results of such analyses without invoking the concept of "exposure." Indeed, exposure is one of the

[1] Decision Research, 1201 Oak Street, Eugene, Oregon 97401.
[2] Malmfors Consulting AB, Vastmannagatan 48, S-113 25 Stockholm, Sweden.
[3] To whom all correspondence should be addressed.

0272-4332/99/0800-0649$16.00/1

most (if not the most) basic concepts in toxicology, as noted by Paracelsus centuries ago.[4] In principle, it is exposure to chemicals that results in danger to people and figures critically into the bottom-line conclusions that toxicologists, health officials or regulators draw about chemical risk and safety. Though risk communicators are cautioned to avoid messages couched in scientific language on the grounds that they may mean little to a lay audience,[2] some terms, such as exposure, are used by both scientists and lay people alike.

When terminologies have one meaning to the scientific community and another meaning in the general population, the difficulties of communicating between the two worlds are exacerbated.[3] The legacy of risk communication and its problems provides many examples, but probably none so pandemic as that created by the very different definition of "risk" held by scientific and technical experts versus that held by the public.[4,5] While technical models of risk are relatively narrow and quantitatively precise, the public's model of risk includes a broader set of qualitative factors relating to the potential seriousness of mishaps, the nature of exposure, and their beliefs about the level of knowledge and credibility of science, industry, and government.[5]

The prospects for effective communication with the public about chemical risks are improved to the degree that the model of risk and exposure used by the public is understood and utilized. However, there is some evidence to suggest that the model the public uses to judge chemical exposure is significantly different from that held by toxicologists. Kraus *et al.*[6] asked both members of the public and a group of toxicologists to express their attitudes and beliefs concerning chemicals and chemical risk assessment. Among the items studied were several concerning dose-response relationships. One item stated, "If you are exposed to a toxic chemical substance, then you are likely to suffer adverse health effects." While only 32.3% of toxicologists agreed with the statement, the public respondents expressed the opposite view, with 85.5% agreeing with the statement. A second item stated, "There is no safe level of exposure to a cancer-causing agent." Again, only 25.3% of the toxicologists agreed, while 53.9% of lay respondents expressed agreement.

These differences in agreement are of great importance, as they signal a potential disparity between how nonscientists view exposure to chemical risks (and its consequences) and how it is viewed by experts.

The objective of the studies reported here is to explore in greater depth the meaning to a lay audience of the concept of chemical exposure, and to show how the inferences people make about chemical exposure influence their interpretation of information about chemical risks when making judgments about how exposed is exposed enough to warrant concern.

METHOD

Overview of Research Design

The methodology used in this study was based on a questionnaire approach. Four questionnaires were designed to elicit the knowledge and beliefs people have about a broad range of concepts relating to chemical risks, including chemical exposure. The questionnaire modules relating specifically to chemical exposure were part of larger questionnaires that also asked about health effects, such as cancer.

Questionnaire Design and Administration

The four questionnaires were developed and administered over a period of 10 months, with the first questionnaire administered in August 1992, and the last questionnaire administered in May 1993. Respondents for the study were selected from the University of Oregon student population, through advertisements placed in the university newspaper. A total of 833 individuals responded to the advertisements and participated in the study. Each respondent answered only one of the four questionnaires.

RESULTS AND DISCUSSION

Unspecified Chemical Exposures

Risk communication often involves general statements concerning exposure or the relationship

[4] Though Paracelsus is often attributed with noting that "the dose makes the poison," his exact words were a bit more extensive, in accordance with his general nature. Depending upon translation, Paracelsus actually said, "In all things there is a poison, and there is nothing without a poison. It depends only upon the dose whether a poison is a poison or not."[12] Paracelsus made many observations concerning the curative and beneficial powers of potential poisons, distinguishing "That which redounds to the benefit of man is not poison; only that which is not of service to him, but which injures him, is poison."[12]

Table I. General vs. Specific Exposures

	Strongly disagree	Disagree	Agree	Strongly agree	Don't know/no opinion
a. If a person is exposed to a chemical that can cause cancer in humans, then that person will probably get cancer some day.	4.0%	40.3%	36.9%	6.0%	12.8%
b. Cigarette smoke contains chemicals known to cause cancer in humans. If a person smokes only one cigarette then that person will probably get cancer some day.	38.0	50.0	6.0	—	6.0
c. Gasoline and gasoline vapors contain benzene, a chemical which is known to cause cancer in humans. If a person pumps their own gasoline only once, then that person will probably get cancer some day.	38.0	56.0	2.0	—	4.0
d. Peanut butter contains aflatoxin, a natural chemical which is known to cause cancer in humans. If a person eats only one peanut butter sandwich, then that person will probably get cancer some day.	46.9	51.0	2.0	—	3.4
e. If a person is exposed to an extremely small amount of a chemical that can cause cancer, then that person will probably get cancer some day.	8.7	71.1	4.7	1.3	14.1
f. There is an exposure level below which a cancer-causing chemical does not cause cancer.	2.7	24.8	43.6	6.7	22.2

between exposure and possible health effects. A series of statements probed respondents' beliefs about exposure, both generally and with regard to specific exposures. Each statement was rated on a response scale ranging from 1 = *Strongly disagree* to 4 = *Strongly agree.* Intermediate values were 2 = *Disagree* and 3 = *Agree.* Table I summarizes these responses.

Respondents were first asked to indicate their degree of agreement (or disagreement) with a general statement about exposure, worded as follows: "a. If a person is exposed to a chemical that can cause cancer in humans, then that person will probably get cancer some day."

The statement did not qualify the meaning or time frame of exposure, nor did it mention a specific chemical or manner of exposure. Respondents were divided in their endorsement of this general proposition about exposure, with almost half agreeing with the statement (42.9%) and half almost disagreeing (44.3%).[5] Slightly more than 12% of the respondents answered *Don't know/no opinion.*[6]

The general exposure statement (a) was followed by one of three statements about exposure to a specific, known carcinogen (statements b, c, and d). Each respondent received only one of the specific exposure statements. The specific exposures concerned very brief exposure to carcinogens in cigarette smoke (b), gasoline and gasoline vapors (c), and peanut butter (d). Each statement described a single instance of exposure, along with the proposition that the person exposed will probably get cancer some day. If respondents' attitudes about the unqualified, general exposure were consistent with their attitudes when given a specific instance of exposure, they should express similar patterns of agreement and disagreement.

As can be seen from Table I, however, respondents expressed strong disagreement with the specific exposure statements for all three carcinogens. Clearly, respondents did not equate exposure as presented in the general statement with that of a specific instance of brief exposure.

Later in the questionnaire, respondents read a second statement (e) about general exposure. This statement was similar to the first except that the statement referred to ". . . an extremely small amount of a chemical . . .". The majority of respondents (79.8%) now disagreed with the second general exposure statement, though a number of them (14.1%) expressed no opinion. Of the respondents who expressed an opinion, 58.6% were consistent in expressing disagreement with both the first and second gen-

[5] Percentages calculated by summing the percentages for the two *disagree* and *agree* categories.

[6] *Don't know* or *No opinion.*

eral exposure statements (i.e., both *a* and *e*). Thus, the attitudinal change seen in the revised statement was largely due to respondents who *agreed* with the original statement, but *disagreed* with the statement when exposure was specified as a very small amount.

A final statement in this set (f) probed for a general threshold effect of exposure by asking directly if "there is an exposure level below which a cancer-causing chemical does not cause cancer." Slightly more than half (50.3%) of the respondents agreed with the statement, and more than a quarter (27.5%) disagreed. A high percentage (22.2%) indicated no opinion.

Comparing the responses to the second general exposure statement (e) with the threshold exposure statement (f) provides an indication of consistency in respondents' beliefs about the relationship between exposure and health effects. Disagreement that a person exposed to an extremely small amount of a carcinogenic chemical will get cancer some day implies that there is a level of exposure below which a carcinogenic chemical does not cause cancer. Thus, to have been consistent, respondents would have disagreed with the second general exposure statement (e) and agreed with the threshold statement (f). Conversely, agreement with the statement that an extremely small amount of a chemical will probably result in a health effect implies that there is *not* a threshold for exposure. Of the respondents who expressed an opinion about the general exposure statement (f), 62.1% disagreed with the general exposure statement and agreed with the threshold statement, while 3.9% agreed with the statement and disagreed with the idea of a threshold.

The relatively high percentages of *don't know/no opinion* ("DKNA") responses in Table I suggests that some respondents may have had difficulty expressing their attitudes to these statements. However, looking more closely at the DKNA responses reveals little consistency in the use of this response. For the two general exposure statements (*a* and *e*), 40 respondents answered DKNA to either or both of the statements; however, of that number, only six (15%) gave DKNA to both. Likewise, looking at the second general exposure and threshold statements (*e* and *f*), of the 54 respondents who gave DKNA to either or both, only eight (14.8%) gave DKNA to both.

Taken together, responses to the entire set of exposure statements suggest that people have a labile and somewhat inconsistent model of chemical exposure and its relationship to health effects. Though respondents initially were split in their belief about the meaning of exposure in a general context, they were much more polarized when the level of exposure was qualified as "an extremely small amount." This suggests that without appropriate qualification, the term "exposure" presented in a singular context (e.g., newspaper article) may evoke a wide range of beliefs about magnitude. Indeed, when presented with specific instances of relatively small exposures of known carcinogens, the majority of respondents disagreed that cancer was a likely result. However, when later asked directly about a threshold effect of exposure, a wide range of beliefs surfaced again. Though there was some consistency between the general exposure statements and the threshold effect statement, many respondents were either inconsistent or unable to express an opinion. Apparently, somewhat subtle changes in how the concept of exposure is conceptualized and communicated evokes very different inferences about its meaning.

Specified Chemical Exposures

The previous analysis suggests that our respondents believed that particularly small exposures to specific carcinogens (e.g., a single cigarette) would not lead to cancer. Is this because the exposure is seen to be negligible? Or is the very fact of exposure unclear for these brief contacts with carcinogens? At what level of exposure has a person been "exposed," and what behavior with regard to chemicals or other carcinogens constitutes exposure? As a start toward answering these questions, respondents were told that:

> A substance that has the capability to cause cancer in human beings is called a carcinogen. Cigarette smoke is a carcinogen. So is radiation, sunlight, benzene (a chemical in gasoline), and aflatoxin (a mold that grows on peanuts).

They were then presented with a number of behaviors, each involving one of five different carcinogens. Three of the carcinogens were chemical: cigarette smoke, gasoline (liquid and vapors), and aflatoxin in peanut butter. Two of the carcinogens involved radiation: medical X-rays and ultraviolet light. For each carcinogen, a high and a low level of exposure was given (e.g., smoked a pack of cigarettes daily vs. smoked one cigarette). Respondents rated each behavior according to "whether or not you believe a person has been exposed to a carcinogen if he or she has done each of the following things." Ratings ranged from 1 = *Definitely has not been ex-*

posed to a carcinogen to 4 = *Definitely has been exposed to a carcinogen.* Intermediate values were 2 = *Possibly has been exposed* and 3 = *Probably has been exposed.* A *Don't know/unsure* response category was provided. Table II shows the mean rating for each behavior. Figure 1 shows the distribution of responses for *definitely* and *probably.*

The behavior receiving the highest rating for likelihood of exposure was "smoked one pack of cigarettes daily." Over 90% of the respondents indicated that a person who smoked this heavily was definitely exposed to a carcinogen. However, the behavior "spent 10 min in a smoke filled room" also received a fairly high rating, with slightly over 40% of the respondents indicating that this definitely constituted exposure. "Smoked one cigarette" was rated somewhat lower than the other two cigarette behaviors, though over a third (34.2%) of the respondents believed a single cigarette definitely meant exposure.

Several of the behaviors tended to form clusters in terms of having similar "exposure frequencies." For example, breathing gasoline fumes, pumping own gas at filling stations, a single X-ray, two sessions in a tanning parlor, and a single cigarette received statistically indistinguishable mean ratings. As can be seen in Fig. 1, these behaviors were also similar in their response distributions. The two lower ratings were for exposure to aflatoxin in peanut butter.

Across a very broad range of behaviors, from single instances of an activity (e.g., smoking a single cigarette) to a lifetime of exposures (e.g., yearly chest X-ray), respondents made significant distinctions between levels of exposure. Only for the two behaviors involving aflatoxin did exposure (based on consuming a single peanut butter sandwich or one sandwich per week) seem unlikely. These results suggest that, when presented with specific instances of behaviors involving carcinogens, people may make distinctions between exposures that an expert toxicologist would not. Indeed, from a toxicological perspective all of the behaviors in Table II constitute exposure, though lay respondents were variable in the degree to which they believe exposure had occurred.

Meanings of Exposures

The above experiments suggest that people reserve the term "exposure" for substantial contact or contact sufficient to cause cancer. We investigated this hypothesis by asking respondents to rate a number of possible meanings for the term exposure by imagining they had read in a newspaper article that

Table II. Beliefs About Specific Exposure to a Carcinogen

	Mean rating	1. Definitely *has not* been exposed to a carcinogen	2. Possibly has been exposed to a carcinogen	3. Probably has been exposed to a carcinogen	4. Definitely has been exposed to a carcinogen	Don't know/unsure
Smoked one pack of cigarettes daily	3.89	1.3%	2.1%	3.0%	92.4%	1.3%
Developed a deep suntan	3.27[a]	1.3	16.9	32.9	46.0	3.0
Spent 10 min in a room filled with other people's cigarette smoke	3.15[a]	3.0	21.9	30.4	42.2	2.5
Smoked one cigarette	2.73[c]	12.7	35.0	15.2	34.2	3.0
Had a chest x-ray every year	3.01[a,b]	3.0	24.9	37.6	32.1	2.5
Breathed gasoline fumes at a filling station	2.81[b,c]	6.3	31.6	32.1	26.2	3.8
Did two sessions in a tanning parlor	2.56[c]	10.5	44.3	19.8	22.8	2.5
Had a single chest X-ray	2.62[c]	7.2	44.7	23.6	22.4	2.1
Had a dental X-ray	2.57[c]	12.2	38.8	24.9	21.1	3.0
Always pumped own gas at filling stations	2.62[c]	5.9	45.6	25.3	20.7	2.5
Walked briefly in sunlight	2.20	25.7	41.8	14.8	15.2	2.5
Eats peanut butter sandwiches once a week	1.78[d]	42.2	37.1	10.5	5.5	4.6
Eaten a peanut butter sandwich	1.68[d]	47.7	35.0	8.0	4.6	4.6

Note. The mean rating was calculated by assigning values of 1, 2, 3, or 4 to the responses (e.g., 1 = *definitely has not been exposed*).
[a,b,c,d] Means with a common superscript do not differ significantly (Tukey HSD, $p > .05$).

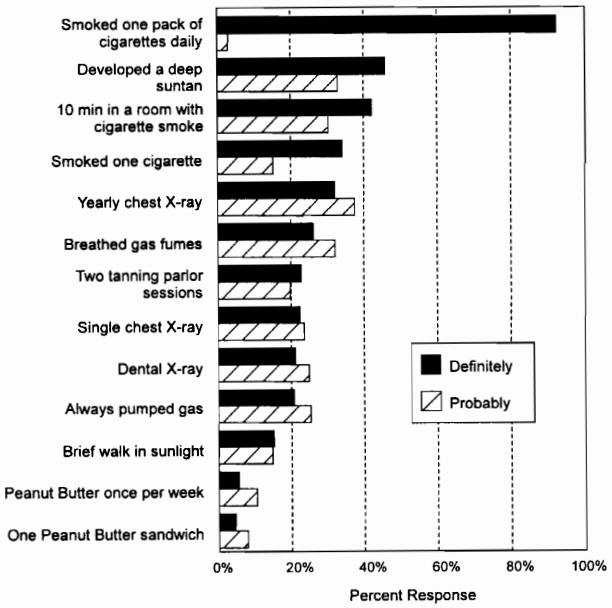

Fig. 1. Beliefs about specific exposure to a carcinogen.

"exposure to a certain chemical can cause cancer." The chemical was unstated. Ratings of each of seven meanings of the term exposure in this context were made on the same *agree/disagree* scale as used previously. Figure 2 shows the response distributions.

All of the definitions were agreed to by at least 30% of the respondents. "Coming in contact" was the meaning of exposure endorsed by the highest percentage of respondents (84%), while "minuscule, tiny amount of contact" received the lowest endorsement (31%). Three other meanings of exposure were agreed to by half or more of the respondents: "Any contact, no matter how small" (61%), "contact large enough to cause cancer" (55%), and "massive contact" (52%).

From these responses, it appears that a key component of lay definitions of exposure involves some contact with a chemical, though a minuscule amount of contact is perhaps insufficient. Indeed, these results suggest that the nature of the chemical contact itself may be what defines exposure.

Inferences about "Cancer Causing"

An important factor in how people reason about chemical exposure is the meaning they give to carcinogenicity. What does it mean to people for a chemical to be portrayed as "cancer causing"?

Respondents were again asked to imagine that they had read a short newspaper article about an unnamed chemical, and that the article stated that the "chemical can cause cancer." They were then asked to express their agreement or disagreement with a number of inferences about the cancer-causing chemical based on the passage. These responses are summarized in Fig. 3.

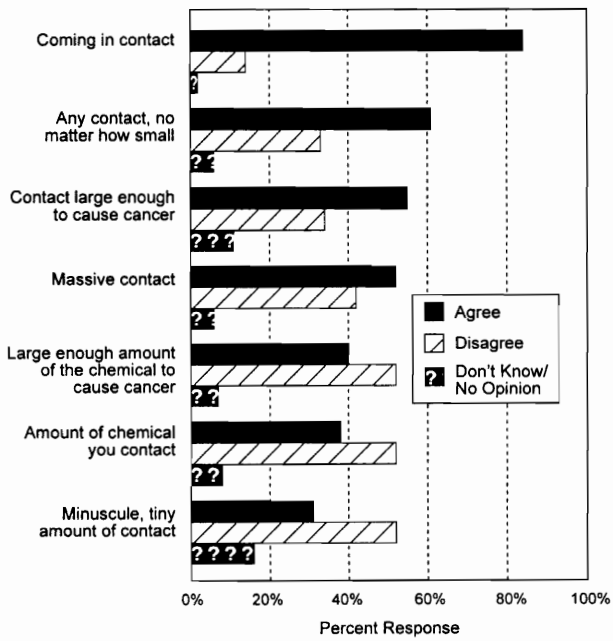

Fig. 2. Beliefs about the meanings of chemical exposure.

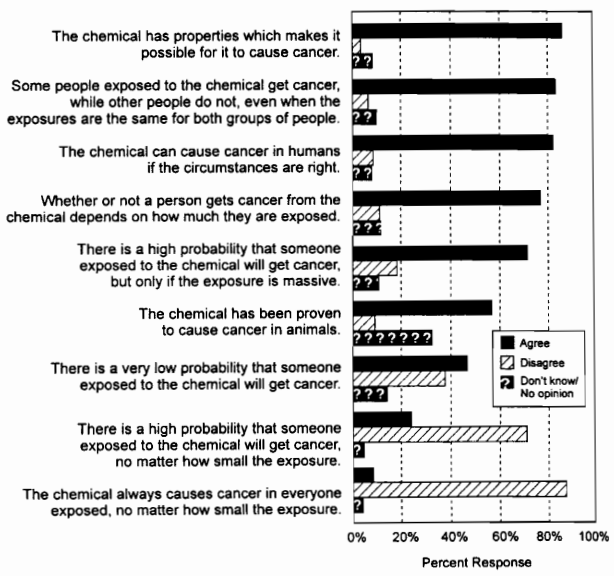

Fig. 3. Interpretations of "cancer-causing" in a newspaper context.

There were a number of very strong inferences from this limited passage about chemical exposure. The strongest, and perhaps the most direct, was that "the chemical has properties which makes it possible for it to cause cancer" (86.4%). Equally strong were "some people exposed to the chemical get cancer, while other people do not, even when the exposures are the same for both groups of people" (83.4%) and "the chemical can cause cancer in humans if the circumstances are right" (82.4%). The weakest inference was "the chemical always causes cancer in everyone exposed no matter how small the exposure" (8.5%). Though a majority of respondents (56.8%) agreed with the inference that "the chemical has been proven to cause cancer in animals," a very high percentage (32.2%) indicated that they did not know.[7]

In this set of inferences there was some evidence that judgments about cancer-causing incorporate the concept of a dose-response relationship. However, the probabilistic relationship between exposure and cancer was unclear. Respondents generally rejected the concept of a threshold effect of exposure by endorsing inferences that the probability of cancer is related to the amount of exposure. However, the inference receiving the most equivocal reaction was "there is a very low probability that someone exposed to the chemical will get cancer." Less than half of the respondents (46.7%) agreed with this inference while over a third did not (37.7%); almost 15%, however, did not know. Respondents apparently did not all interpret "very low probability" in the same way. This high variability suggests that this relatively common message contained in many risk communications about chemical exposure may lead more often to confusion or heightened concerns, when it is actually intended to reduce concerns.

Inferences About Chemical Exposure

One important objective of the media is to alert people to potential health and safety risks. In doing so, media reports often express their risk messages in broad, general terms. Lay people who read or hear such messages are left to draw whatever implications and inferences seem appropriate. However, a risk communicator implicitly hopes that only those facts and judgments directly stated in the message will be the ones received. If other messages are implied, then misunderstanding and conflict may result.

To better understand what people infer from brief passages about the risks of chemical exposure, a group of subjects was given the following passage as might appear in a news article: "People in Oregon are exposed to chemicals that can cause cancer."

For half of the respondents, the passage mentioned *cancer* as the consequence of exposure; for the other half, the passage mentioned *hair loss* as the consequence. The respondents were then given a number of statements and asked to indicate for each statement whether it was *directly stated in the passage, strongly implied by the passage, weakly implied by the passage,* or *neither stated nor implied by the passage.* Their responses are summarized in Fig. 4.

The statements in Fig. 4 are ordered according to the percentage of respondents who indicated that the statement was either directly stated or implied at some level (strongly or weakly), aggregated across both the cancer and hair loss conditions. Looking across each of the entries in Fig. 4, at least some percentage of respondents indicated that the statement was *directly stated* in the passage. Only the statement "a large number of chemicals are involved" was judged to be neither stated nor implied by more than 50% of the respondents. All of the other statements were judged to be either directly stated or implied, including that the chemical is potent; exposure to any one person is large, frequent,

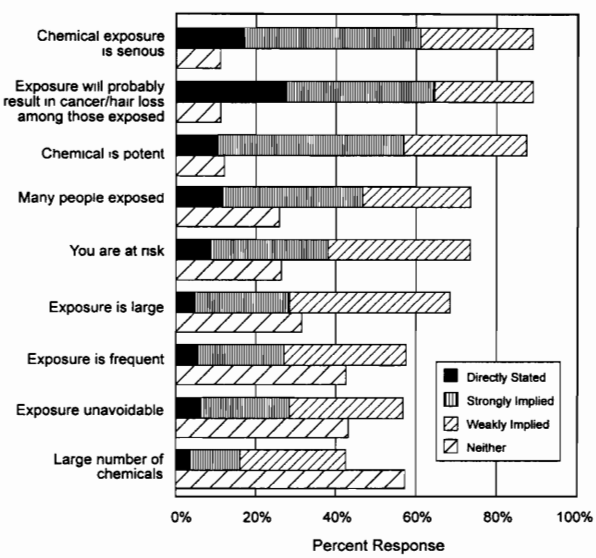

Fig. 4. Inferences about chemical exposure.

[7] Kraus *et al.*[6] asked four questions about the value of animal studies in determining the harmfulness of chemicals. The percentages of their lay respondents indicating DKNA were generally in the range of 5% to 10%.

serious, and unavoidable; many people are exposed, and the respondent is personally at risk.

Collapsing the categories *directly stated* and *strongly implied* gives an indication of the strong inferences respondents made from the relatively little information given in the passage. Respondents strongly inferred from the passage that the chemical mentioned is potent (56.9%), that the exposure is serious (61.0%), and that the exposure will probably result in either cancer or hair loss among those people exposed (64.5%).

Though respondents generally inferred a great deal from the brief passage, the strength of their inferences varied according to the consequence of the chemical exposure. Table III summarizes the response distributions separately for the two consequences *cancer* and *hair loss.*

In general, respondents who were told that the chemical can cause cancer drew stronger inferences from the passage than did those who were told it can cause hair loss. For those told the chemical was cancer-causing, the strong inferences (i.e., directly stated or strongly implied) were that the chemical is potent (60.8%), exposure is frequent (70.1%) and serious (70.1%), many people are exposed (50.6%), and exposure probably results in cancer (57.8%). Interestingly, a higher percentage of respondents inferred that exposure to a chemical that can cause hair loss probably would cause hair loss (71.0%) than a chemical that can cause cancer probably would cause cancer (57.8%).

The passage respondents were given was extremely brief, and probably not representative of larger newspaper articles, media reports, or other types of communications about chemical risks. Arguably, longer or more complete messages about chemical risks could qualify the meaning of "exposure" and give pertinent information about a chemical's potency, the frequency of exposure, or the amount of exposure an individual might receive. However, more information is not necessarily better understood information. What the results discussed above suggest is that lay people draw a wide range of inferences from a relatively small amount of information, even to the extent of judging things to be directly stated that in fact were not. Indeed, it may be inferred from the inferences respondents made that the passage they were given about chemical exposure was brief only in the sense that it contained few words. From a psychological perspective, the passage was very rich, evoking concepts and ideas about chemical exposure that went well beyond those given.

Avoiding Chemical Exposures

The more strongly people perceive something to be risky, the more likely they are to take some

Table III. Response Distributions for the Consequences of Cancer and Hair Loss

	Consequence	Directly stated	Strongly implied	Weakly implied	Neither
The chemical is potent	Cancer	9.3%	51.5%	26.8%	12.4%
	Hair Loss	11.0	42.0	34.0	12.0
The exposure to any one person is large	Cancer	7.2	20.6	42.3	29.9
	Hair Loss	2.0	27.0	38.0	33.0
The exposure to any one person is frequent	Cancer	8.2	22.7	29.9	39.2
	Hair Loss	2.0	21.0	31.0	46.0
The chemical exposure is serious	Cancer	22.7	47.4	23.7	6.2
	Hair Loss	11.0	41.0	32.0	16.0
The exposure was unavoidable	Cancer	9.3	22.7	29.9	38.1
	Hair Loss	3.0	22.0	27.0	48.0
Many people are exposed	Cancer	15.5	35.1	25.8	33.0
	Hair Loss	8.0	35.0	28.0	28.0
A large number of chemicals are involved	Cancer	4.1	12.4	27.8	55.7
	Hair Loss	3.0	13.0	25.0	59.0
You, personally, are at risk	Cancer	10.3	34.0	33.0	22.7
	Hair Loss	7.0	25.0	38.0	30.0
The exposure will probably result in cancer/hair loss among those people who were exposed to the chemical	Cancer	18.6	39.2	28.9	13.4
	Hair Loss	36.0	35.0	20.0	9.0

action to avoid exposure in order to reduce their risk. While we can't directly test what people actually do with regard to chemical risks, we can elicit from them their behavioral intentions or what they believe they would do in situations where avoidance of chemicals is a possibility. People could, for example, choose to sit in a nonsmoking section of a restaurant, not purchase foods with preservatives, or not use an OTC drug as a way of avoiding the risks of chemical exposure.

As a measure of behavioral intention with regard to chemicals, we asked respondents to indicate whether they agreed or disagreed with the statement, "I try hard to avoid contact with chemicals and chemical products in my daily life." Slightly more than half of the respondents agreed that they did try to avoid chemical contact (50.6%), while less than half (41.8%) did not agree. The remainder (7.8%) responded that they didn't know.

After asking about general avoidance of chemicals, respondents were asked to indicate which of eight specific actions they take to avoid chemical contact. Again, they gave their responses using an *agree/disagree* scale. Figure 5 summarizes these responses for each of the eight chemical-avoidance actions, both for respondents who agreed that they try hard to avoid chemical contact and for those who disagreed.

The respondents who agreed that they try hard to avoid chemicals also indicated that they did a larger number of the eight specific actions than did respondents who did not try to avoid chemicals ($\bar{x}$ = 3.25 vs. 1.59; $t = 7.86$, $p < .001$). Only one (<1%) of the respondents who generally avoided chemicals did not take any of the specific avoidance actions, while 16% of those who said they did not try to avoid chemical contact took none of the specific actions.

For both those who did and those who did not try to avoid chemicals, the specific action most often taken was to sit in the nonsmoking section of restaurants (94.2%). Of those who said they try to avoid chemical contact in general, more than half (64.2%) indicated that they don't use artificial sweeteners. However, the remaining specific avoidance actions were taken by well less than half the respondents who said they generally avoid chemical contact. These included eating foods with preservatives (39.2%), use of cosmetics (37.5%), over-the-counter (29.2%) and prescription drugs (25.0%), vitamins (21.7%), and household cleaning products (14.2%).

Respondents who *disagreed* that they generally try to avoid contact with chemicals also tended to disagree that they take specific actions to avoid contact. However, well over half (68.7%) still agreed that they sit in the nonsmoking section of restaurants. Less than half (36.4%) indicated that they don't use artificial sweeteners.[8] The actions that most discriminated the avoiders and nonavoiders (based upon endorsement ratios) were avoiding preservatives, cosmetics, over-the-counter drugs, and prescription drugs.

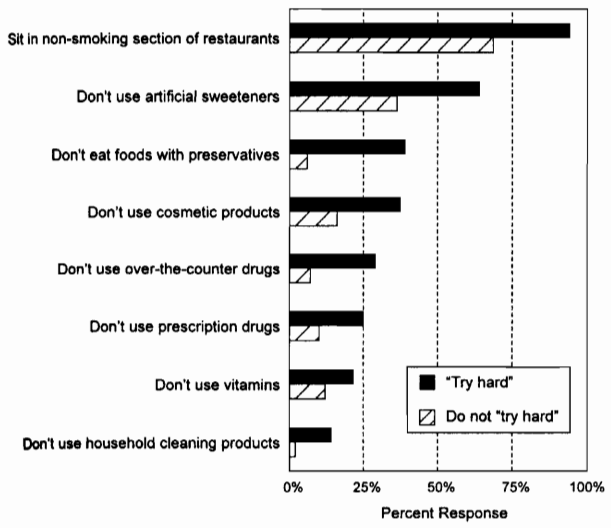

Fig. 5. Percentage of respondents who *try hard* and *do not try hard* to avoid contact with chemicals, for each of eight specific behaviors regarding chemical exposure.

GENERAL DISCUSSION

What we have attempted to develop in this paper is a better characterization of how lay people interpret and perceive the concept of chemical exposure. What we have found is that people's beliefs about chemical exposure (and its risks) are based on two broad categories of inferences. One set of inferences relates to the nature in which contact with a chemical has taken place, including the specific amount of the chemical involved and the perceived link between the exposure and a health consequence. Indeed, the overall pattern of results suggests that knowledge or beliefs about the consequences of chemical exposure serve to anchor the concept of exposure and give it

[8] In a separate study, respondents were asked if they "avoid" rather than "don't use." As might be expected, the percentages of people who "avoid" were higher than those who "don't use," though the general ordering of the eight actions was the same in either case.

meaning by suggesting a causal relationship between exposure (an event) and an outcome. Viewed this way, it appears that lay perceptions of chemical exposure have deterministic properties that lead to inferences about consequences. Likewise, knowledge or beliefs about consequences lead to inferences about the meaning and significance of chemical exposure, including whether exposure has taken place. The circular quality of these beliefs suggest that at least for some categories of chemicals, particularly those associated with carcinogenicity, a process of narrowing and sharpening occurs in which the concept of exposure gains its meaning from both the nature of exposure and the perceived seriousness of its consequences.

A second category of inferences about chemical exposure appears to be derived from beliefs about the motives and purposes behind chemical risk communication. Though the science of risk assessment is strongly quantitative in nature, communicating the results of risk assessment to the public relies heavily on language rather than numbers. Risk-related concepts such as exposure, carcinogen, cancer, health effects, and the like are the fundamental elements or primitives that the risk communicator must use as part of risk messages and risk dialogues with the public. However, as complex as some aspects of technical risk assessment can be, language is even more so. While scientists and technical experts strive for a common understanding and definition of terms within their respective fields of study (indeed, it has been argued that a significant role of science is the creation and definition of language), the public is not constrained by a scientific imperative to be precise in its use and interpretation of language, nor is it required to be so to utilize language effectively in daily life.

It is tempting to write off the public in risk debates as not "understanding" what risk assessment is all about. Indeed, that conclusion could be drawn, albeit unfairly, from the empirical results presented here. An approach that we believe, and experience appears to show is more fruitful, takes the course of developing a deeper awareness of how the public comes to understand and reason about risks. Likewise, if we seek to make the process of risk management more amenable to public involvement, we must develop better models of how the language of risk assessment is understood by the public as compared to the technical community.

We propose that the results found in the present study do not reflect *mis*understanding about the concept of chemical exposure, but rather are an example of how psychological processes influence language interpretation. Noam Chomsky[7] theorized that language possesses a "surface structure" that is experienced as words and sounds (i.e., phonologically), but that understanding occurs through the "deep structure" of language that is interpreted semantically.[8]

If the psychological processing of language were nothing more than the referencing of words, such as "exposure," to a mental lexicon, then perhaps we could say that the public does misunderstand the meaning of the term "exposure" either because there is an error in their mental dictionary or because they make an error in "looking it up." This model supposes that there is one *right* dictionary and that the processes by which language is understood are relatively simple and linear. We know, however, that semantic interpretation is complex and involves fundamental and imprecise cognitive processes of categorization and association,[9] and that these processes operate simultaneously and inform each other.[10] Indeed, modern theories of understanding view language processing as occurring at multiple levels. In addition to understanding language at a syntactical level (how it is structured), and at a semantic level (what it means), people also understand language by inferring the intent of the speaker or communicator.[11] The *pragmatics* of language interpretation are particularly important in the context of risk communication because it is this level of processing that potentially signals the importance to people of a risk message from the (inferred) intent of the risk communicator. It is the level of language processing that evokes significant psychological questions such as "What is this person trying to tell me?" or "Why do they want me to know this?" Thus, when a newspaper report about a chemical includes the phrase "has been found to cause cancer," the reader may infer that since only an important and serious finding would warrant publication, typical exposures to the chemical must be widespread, pose a significant risk, and should be a matter of some concern.

With this framework in hand, it can (perhaps) be more readily seen that what lay people infer about the concept of exposure from its use in a risk-communication context is based less on *mis*understanding than on the results of powerful psychological processes that are a fundamental part of how both lay people and experts interpret language. As a result of these processes, language terms that are used as part of technical risk assessments and that have a surface structure common to both technical experts and the

public, may also have a very different deep structure and resulting semantic interpretation. Indeed, it is perhaps true that technical experts have a comparatively less complex interpretation of the concept of exposure than the public, since the technical expert is, arguably, less concerned with the pragmatics of risk communication.

How, then, can we utilize the results of the present study to improve the ability of risk managers to effectively communicate with the public about risk? As a first step, risk communication needs to take greater recognition of the psychological processes that are invoked in interpreting the language used in discussions about risk. Our results suggest that these processes occur at several levels and go well beyond a simple definitional interpretation of the language used in risk communication.

Communicating about risk virtually always entails communicating about exposure, either directly or by implication: if there were no exposure, there would be no risk. But technical experts in risk assessment should not assume that their understanding of exposure is the same as that of the public. Nor should they assume that the public's interpretation of exposure represents a misunderstanding or is deficient. The process the public uses to assess chemical exposure and the process risk assessors use to assess exposure appears to be quite different. The latter is based primarily on quantitative models of chemistry and biology, the former is based on qualitative psychological models of inference, linguistics, semantics, and pragmatics. For communication of technical risk assessments to "raise the level of understanding of relevant issues or actions and satisfy those involved that they are adequately informed within the limits of available knowledge" Ref. (2, p. 26), will require mutual regard for the fundamental, and sometimes differing, processes that lead both experts and the public to their respective conclusions.

ACKNOWLEDGMENTS

This research was supported by the U.S. National Science Foundation under Grants SES-9122178 and SBR-9422754 to the Decision Science Research Institute. We thank C. K. Mertz for carrying out the statistical analysis of the data. We also thank Janet Douglas for her careful assistance in the preparation of the manuscript.

REFERENCES

1. B. D. Beck, E. J. Calabrese, and P. D. Anderson, "The Use of Toxicology in the Regulatory Process," in Hayes, A. W. (ed.), *Principles and Methods of Toxicology* (2nd Ed.), (Raven, New York, 1989), pp. 1–28.
2. National Research Council (NRC), *Improving Risk Communication* (National Academy Press, Washington, DC, 1989).
3. D. MacGregor, "Inferences About Product Risks: A Mental Modeling Approach to Evaluating Warnings," *J. Products Liabil.* **12,** 75–91 (1989).
4. B. Fischhoff, S. Watson, and C. Hope, 'Defining Risk,' *Policy Sciences* **17,** 123–139 (1984).
5. P. Slovic, "Perception of Risk," *Science* **236,** 280–285 (1987).
6. N. Kraus, T. Malmfors, and P. Slovic, "Intuitive Toxicology: Expert and Lay Judgments of Chemical Risks," *Risk Anal.* **12,** 215–232 (1992).
7. N. Chomsky, *Aspects of the Theory of Syntax* (MIT, Cambridge, MA, 1965).
8. J. J. Katz and J. Fodor, "The Structure of a Semantic Theory," *Language* **39,** 170–210 (1963).
9. A. M. Collins and E. F. Loftus, "A Spreading-Activation Theory of Semantic Processing," *Psychological Rev.* **82,** 407–428 (1975).
10. D. E. Rumelhart and J. L. McClelland, *Parallel Distributed Processing* (The MIT Press, Cambridge, MA, 1986).
11. G. A. Miller and P. N. Johnson-Laird, *Language and Perception* (Harvard, Cambridge, MA, 1976).
12. J. Jacobi, (ed.) *Paracelsus—Selected Writings* (Translated by Norbert Guterman), (Princeton University Press, Princeton, NJ, 1951), pp. 95–96.