Risk Analysis, Vol. 29, No. 2, 2009 DOI: 10.1111/j.1539-6924.2008.01137.x

Probability Information in Risk Communication: A Review of the Research Literature

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Communicating probability information about risks to the public is more difficult than might be expected. Many studies have examined this subject, so that their resulting recommendations are scattered over various publications, diverse research fields, and are about different presentation formats. An integration of empirical findings in one review would be useful therefore to describe the evidence base for communication about probability information and to present the recommendations that can be made so far. We categorized the studies in the following presentation formats: frequencies, percentages, base rates and proportions, absolute and relative risk reduction, cumulative probabilities, verbal probability information, numerical versus verbal probability information, graphs, and risk ladders. We suggest several recommendations for these formats. Based on the results of our review, we show that the effects of presentation format depend not only on the type of format, but also on the context in which the format is used. We therefore argue that the presentation format has the strongest effect when the receiver processes probability information heuristically instead of systematically. We conclude that future research and risk communication practitioners should not only concentrate on the presentation format of the probability information but also on the situation in which this message is presented, as this may predict how people process the information and how this may influence their interpretation of the risk.

KEY WORDS: Literature review; probability information; risk communication

1. INTRODUCTION

Communicating the results of risk analyses to people is important so that they are informed about risks.(1–3) The risk's probability may be one of the outcomes of a risk analysis, in addition to, for example, details about the people at risk and the exposure level.(4,5) Numerous studies have been conducted about how (i.e., in which format) to present the probability of a risk to the general public. These are reported in many publications, are from different research fields, and examine various presentation formats. As a result, there is no overall picture of the way these various presentation formats affect risk perception and other factors, such as understanding, attitude, and behavior. Hence, it seems worthwhile to review the research literature about the communication of probability information. The purpose of this review is to come to general recommendations about the presentation of probability information in risk communication, which should be particularly useful

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0272-4332/09/0100-0267$22.00/1

for practitioners involved in risk communication. However, this article is not only targeted at practitioners, but also at researchers, as it also tries to find a theoretical explanation for the findings and indicate areas for future research.

Probability information can be communicated in different formats, such as frequencies, percentages, rates, and verbal expressions. Several studies have tried to determine which of these presentation formats can best facilitate comprehension and interpretation (e.g., References 1, 2, 6–8). Also, some reviews have already been published about probability information in risk communication. However, these were either in the medical field, focusing on doctor-patient communication;[9–14] covered only a limited number of presentation formats;[15–17] or were not based on empirical evidence but on conceptual analysis.[18–20] In this review, we not only include medical and health risks, but also technological and accident risks that may damage people's health. The review covers studies about what kind of probability information people prefer and about the effects of different presentation formats on comprehension, risk perception, and related measures (e.g., willingness to pay).

The present review is restricted in three ways. First, it does not focus on recommendations that are based on practical cases that caused public outrage, as these recommendations have been summarized elsewhere.[21–24] Instead of such a practice-based approach, we choose an evidence-based approach by reviewing mainly quantitative research and, sometimes, qualitative research. Second, we use a narrow definition of *risk communication*; we only examine risk messages and the way people perceive them. As a result, we do not discuss broader issues that may be involved in risk communication, such as context, policy issues, and two-way risk communication. Third, we focus on one main element in risk messages in this review, that is, probability information, although we acknowledge that many other factors may influence the way people perceive a risk, such as the framing of risk information, trust, risk comparisons, and the qualitative content of messages.

We start this review by explaining the method of our literature search. We then discuss studies that concerned probability information in risk perception and risk communication. These are arranged in the following categories: (1) frequencies, percentages, base rates, and proportions, (2) cumulative risk information, (3) absolute and relative risk information, (4) verbal probability information, (5) numerical versus verbal probability information, (6) graphs, and (7) risk ladders. We further organize the review by presenting recommendations. The review ends with a discussion of the findings and research gaps, and a possible theoretical explanation for them, based on the heuristic-systematic information processing model (HSM).[25,26]

2. METHOD

2.1. Literature Search

The literature search was done by the first author. This took place in March 2006 and was replenished in April 2007. The topics that we looked for in the PsycINFO, Medline, Eric, and the International Bibliography of Social Sciences literature databases are mentioned in Table I. The topics in the first column of Table I were the main topics of the literature search. Risk communication and risk perception are the main topics of this review, and the other two items are synonyms to these topics. These four main topics were first combined with the general terms probability and chance. This, together with brainstorming with the co-authors, resulted in more specific items (Column 2), which were then combined with the main items of the first column. In certain cases, the combination of the four topics in Column 1 with a specific item of Column 2 resulted in so many irrelevant hits, that specific items (see Column 3) were added to this specific combination to reduce the number of irrelevant hits. All items were combined in conjunctive searches and resulted in 1,058 hits.

In addition, we used the snowball method; that is, "new" articles were found by looking up interesting references, based on their description in "old" articles. The articles selected by means of the snowball method were also characterized by the items mentioned in Table I. We probably did not find these articles in the databases because they were not listed there.

We applied five criteria to the selection of the articles, based on the title and abstract. The article should (1) be a research article in a scientific journal, a book, or a presentation at a conference, (2) be about probability in risk communication, (3) be about a medical or health risk, or a technological or accident risk that could damage people's health, (4) be studied among laypeople (i.e., the general public), and (5) include a description of method, procedure, sample size, dependent variables, and independent variables. If the title and abstract indicated that the article did not meet one of these criteria, the article was excluded. After removing double entries and applying these five criteria, 91 articles remained:

Table I. Items of the Literature Search

Main Items	In Combination with	In Combination with
Risk communication	Probability*	
Risk information	Chance*	
Risk message	Percentage	
Risk perception	Frequency	
	Natural frequency	
	Mortality rate	
	Survival rate	
	Numerical and/or verbal	Risk estimate, probability, chance, risk, format, description, or frequency
	Relative and/or absolute	Presentation, risk, or risk reduction
	Number needed to treat	
	Number needed to screen	
	Odds ratio	
	Cumulative risk	
	Conjunctive and/ or disjunctive	Estimate, risk, or probability
	Graph	Line, bar, chart, histogram, stick figure, or pie chart
	Graphical display	
	Risk ladder	Paling Perspective Scale
	Risk scale	
	Visual tool	
	Survival and/or mortality	Curve, display, chart

*At first, we combined the main items of Column 1 only with probability and chance.

71 from the databases search and 19 from the snowball method. The full articles were then evaluated thoroughly on the same criteria, so that 45 were finally selected for this review. We omitted, for example, articles that did not investigate laypeople, although they discussed a probability format for risk communication about health risks (e.g., References 27 and 28); papers that reported studies about a probability format but did not include one of the risks mentioned before (e.g., References 29 and 30); or articles that included one of the relevant risks, probability format, and laypeople sample, but did not compare the effect of this format with that of another format or control condition.[31]

The details of the studies discussed in the next sections are summarized in tables about each of the topics, as referred to in the text. The tables present the design of the study, sample size, type of respondents (e.g., students, general public), dependent and independent variables, and subject of the risk communications ("risk").

2.2. Formulation of Recommendations

A recommendation is formulated when at least *several* studies about *several* types of risks support it, although not all studies may back the recommendation. We first state a recommendation and then explain the studies on which it is based, including studies that do not back the recommendation. These studies are discussed in more detail than the studies that do not lead to a recommendation, for example, because only one study addresses the issue. We indicate the strength of the evidence by means of stars in Table II. The reader can thus easily evaluate the empirical basis of a certain recommendation and see whether empirical evidence is still lacking. The recommendations may differ on the level of details and conditions under which they may apply.

3. FREQUENCIES, PERCENTAGES, BASE RATES, AND PROPORTIONS

First, we discuss three papers that presented quantitative studies about frequencies versus percentages, base rates, and proportions. In addition, two quantitative papers about natural frequencies are reviewed. Last, we present a paper about a qualitative study concerning the effects of frequency and percentage information on risk perception and understanding.

The probability of a risk is often expressed in frequencies[1] or percentages. Risks expressed in

[1] Frequency can be defined as "the number of times an event or character occurs in a given sample."[90] In case of the risks discussed in this review, the sample mostly consists of a certain group of people, e.g., all women in the age of 40 to 50 years living in the Netherlands.

Table II. Recommendations About Probability Information in Risk Communication, Including the Quality of the Evidence

Recommendation	Number of Stars#
Frequencies, Percentages, Base Rates, and Proportions	
1. Use the same denominator in probability information throughout the risk message, so that people who neglect the denominator can still compare the probability information.	**
2. A step-by-step description of a probability calculation is recommended to present risky situations that include false positives, such as screening test results, because step-by-step probability descriptions are relatively easy to understand and are likely to result in adequate risk estimates.	**
Relative Risk Reduction, Absolute Risk Reduction, and Related Formats	
3. Be careful about presenting RRR, as this may be mistaken for ARR.	***
4. Information about the number needed to treat (NNT) should be used with care because people do not like this format and have difficulty in understanding it.	**
Verbal Probability Information	
5. Take the context of the risk communication into account when selecting appropriate verbal probability expressions for a risk message.	*
Numerical Versus Verbal Probability Information	
6. Present both numerical and verbal probability information in a risk message. People prefer numerical information for its accuracy but use a verbal statement to express a probability to others. Presenting both makes sure that people have the right information no matter the purpose for which it is used.	**
Graphs	
7. Graphs are useful means to present probability of harm as they are more likely to draw people's attention to a probability of harm and than numerical information (except for pie charts).	***

#Number of stars:
*Several studies about several types of risks in which the effects are not always clear (e.g., trends).
**Several studies about several types of risks that have contradicting effects between (some of) them, or several studies about one type of risk with similar, clear effects.
***Several studies about several types of risks with similar, clear effects.

frequencies may be differently understood or interpreted than risks expressed in percentages. In addition, the layout of these two formats may determine the understanding and perception of risks.

Recommendation 1: Use the same denominator in probability information throughout the risk message, so that people who neglect the denominator can still compare the probability information.

Yamagishi(32) investigated the effects of several frequency formats on risk perception. In his study, respondents estimated the risk of 11 causes of death, which varied on two probability dimensions: small versus large divisors (12.86 and 24.14 vs. 1,286 and 2,414) combined with small versus large denominators (100 vs. 10,000). This resulted in four frequency formats (see Table III). For 9 of the 11 causes of death, respondents appeared to rely on the divisor (number of deaths) as an anchor to estimate the risk and neglected the denominator (sample size) of the risk in the population. The higher the first number of the probability estimate, the more risky the hazard was perceived to be. Consequently, respondents thought that a mortality of "1,286 out of 10,000" represented a higher risk than a mortality of "24.14 out of 100." Thus, it is recommended to apply the same denominator in a frequency format throughout a risk message that includes several probabilities, so that people can still compare the frequency information if they ignore the denominator.

Recommendation 1 is also supported by a study that compared rates and proportions.(33) In rates, the number of people affected by the risk (divisor) changes while the denominator is a round, constant number (e.g., 3 per 1,000 people). In proportions, the divisor is kept constant and the denominator changes (e.g., 1 per 333 people). Both formats were examined among women, using the probability of contracting a bladder infection (see Table III). The participants received two proportions simultaneously (a

Table III. Characteristics of Studies About Frequencies, Percentages, Base Rates, and Proportions.

Authors	Study	Design	Respondents	N	Dependent Variables	Independent Variables	Risk
Yamagishi[32]	1	Experiment	Students	52	Risk perception	4 (proportions: 2,414 per 10,000; 1,286 per 10,000; 24.14 per 100; 12.86 per 100) × 11 (risks)	Well-known causes of death (e.g., heart disease, cancer)
	2	Experiment	Students	41	Risk perception	2 (proportions: 1,286 per 10,000 vs. 24.14 per 100) × 11 (risks)	Well-known causes of death
Grimes & Snively[33]		Experiment	Women	633	Probability estimate	2 (proportions: 1 in 384 vs. 1 in 112) × 2 (rates: 2.6 per 1,000 vs. 8.9 per 1,000)	Bladder infection
Greening *et al.*[34]	1	Experiment	Students and mothers	262	Probability estimate, concern, behavior response	2 (type of base rate: general vs. high and low conditional) × 5 (risks)	5 medical and traffic risks
	2	Experiment	Students	225	Probability, concern, behavior response	2 (type of base rate: general vs. high and low conditional) × 5 (risks)	5 medical and traffic risks
Gigerenzer & Hoffrage[35]	1	Experiment	Students	60	Adequate statistical reasoning (Bayesian algorithms)	2 (frequency vs. percentage) × 2 (shortened vs. standard description)	15 risks, e.g., breast cancer, AIDS
Girotto & Gonzalez[36]	1	Experiment	Students	160	Probability estimate	2 (frequency vs. percentage) × 2 (question format: two-steps vs. single-step)	Infection with a disease
	2	Experiment	Students	32	Probability estimate	2 (question format: single-step vs. single-step with explicit question about the expected frequency) × 1 (risk)	Infection with a disease
	3	Experiment	Students	40	Probability estimate (of a true positive)	2 (frequency vs. percentage) × 2 (standard description vs. reversed description)	Infection with a disease
	4	Experiment	Students	80	Probability estimate	2 (frequency vs. percentage) × 2 (question format: distributive percentage vs. distributed frequency)	Infection with a disease
	5	Experiment	Students	40	Probability estimate	2 (frequency problems: standard vs. defective version) × 2 (risks)	Disease infection and college admission
Shapira *et al.*[7]		Focus groups	Women	41	Presentation format preference	Frequency versus percentage, icons array with pictograms, bar graphs, time frame	Breast cancer

high and a low) and were asked to indicate which chance of bladder infection was higher (e.g., 1 in 112 or 1 in 384). A similar procedure was used for rates. The high and low proportions corresponded to the high and low rates, respectively. As expected, it was easier to indicate which rate was higher than which proportion, although many women did not understand either format.

Another way to express probability information is by means of base rates: the number or proportion of people that experiences certain negative consequences in the population at hand. Base rates are frequently misunderstood or neglected.[2] Greening *et al.*[34] investigated whether people understand tailored base rates (e.g., specific base rates for a low- or high-risk group) better than general base rates. People who were confronted with tailored base rates of low-risk groups seemed to take this

[2] Studies about base rates in nonrisk situations suggested that additional information in the message may facilitate understanding of base rates. For example, information about a random sampling method, a realistic description of the uncertain event, and notification of a reference class.[29,91]

information into account better than those presented with tailored base rates of high-risk groups or general base rates. This was the only study we found about the effects of base rates in risk communication on understanding and risk perception. This therefore did not result in a recommendation.

Recommendation 2: A step-by-step description of a probability calculation is recommended to present risky situations that include false positives, such as screening test results, because step-by-step probability descriptions are relatively easy to understand and are likely to result in adequate risk estimates.

Gigerenzer and Hoffrage[35] studied whether frequency and percentage formats could stimulate adequate statistical reasoning using probability information (see Table III). These authors use the term "natural frequency," which is a step-by-step description of a risk's probability in the way people would learn its probability in real life.[3] In this study, respondents were presented with either natural frequencies or percentages of the occurrence of 15 events (of which seven were health and accident risks). The respondents had to estimate the probability that one person would experience the specific event. In addition, they had to explain their estimation by "writing aloud." More respondents in the natural frequency conditions than in the percentage conditions appeared to apply adequate statistical reasoning. Gigerenzer and Hoffrage suggested several explanations for the favorable effects of these step-by-step probability descriptions. First, this format requires fewer cognitive operations than percentages, as the probability information is presented in the same way as it is encountered in daily life. Second, frequencies are easier to use than percentages because the base rate can be neglected in the former, which is not possible in the latter.

Girotto and Gonzalez[36] refuted the special status of "natural frequencies" compared to percentages in relation to statistical reasoning. They argued and showed in five studies that percentage information can also activate adequate statistical reasoning as long as the question format and structure of the problem facilitate this (see Table III). Probability information is easily understood when it is asked in two steps (e.g., first the chance estimate of a positive test result and then the chance estimate of being infected) and when it is explicitly represented as a conjunctive event (i.e., the base rate and the positive test results) Hoffrage *et al.*[37] responded that Girotto and Gonzalez actually used natural frequencies disguised as percentages.

According to a focus group study by Shapira *et al.*,[7] women appeared to think that frequency information is easy to interpret and that it provides a human context. Respondents considered risks expressed in percentages to be personally relevant and associated them with mathematics. Further, they were doubtful about frequencies with small denominators: respondents thought that the sample size was too small. In addition, risks expressed in frequencies were positively interpreted, i.e., an optimistic bias. For example, some respondents seemed to associate themselves with one of the nine people not affected by a risk that was presented as "1 out of 10 people will be affected."

In short, frequency information and proportions often seem to be misinterpreted. Rates are more easily understood than proportions. Probabilities expressed step-by-step are more adequately understood. People may not regard frequencies as personally relevant information, although they consider them as easy to understand.

4. ABSOLUTE RISK REDUCTION, RELATIVE RISK REDUCTION, AND RELATED FORMATS

4.1. Absolute Versus Relative Risk Reduction

The probability of a risk prevention method is often presented as an absolute risk reduction (ARR) or a relative risk reduction (RRR). ARR is the absolute difference between the percentage of victims when this preventive measure would succeed and the percentage of victims in the current situation. An example is: "If all car drivers and passengers would wear seat belts in the Netherlands, the probability of dying from a car accident would decrease by 8%."[38] RRR describes the absolute risk reduction divided by the percentage of victims in the current situation: "If all car drivers and passengers would wear seat belts in the Netherlands, the relative probability of dying from a car accident would decrease by 17%."

Recommendation 3: Be careful about presenting RRR, as this may be mistaken for ARR.

[3] For example, 10 of every 1,000 women who are tested for breast cancer actually have breast cancer. Eight of those 10 women with breast cancer also get a positive mammogram result. Ninety-five of every 1,000 women who get tested, get a positive mammogram result, but do not have breast cancer. Thus, the probability that a women who received a positive mammogram result actually had breast cancer is 8/(8 + 95), which is 7.8%.

The majority of the 11 studies we found (see Table IV) reported that RRR increased people's willingness to get treatment, their willingness to advise treatment, and their willingness to pay to prevent the risk, compared to ARR or other presentation formats.[8,39–44] For example, the study by Malenka *et al.*[42] showed that when patients received RRR information, such as the relative probability that medicine X prevented disease Y, this led to greater compliance with the recommendations of the risk information than when they received this in an absolute format. Thus, respondents who read the RRR information were more inclined to avoid the risk than those who received ARR information.

RRR is presented as a larger figure than ARR of the same probability. Respondents may thus think that the RRR is larger than the ARR because the wordings of RRR and ARR are almost identical.

Two studies that measured the effects of RRR and ARR on laypeople's *comprehension* did not find any differences between RRR and ARR on this dependent variable, although the people's understanding was low for both formats (Table IV).[45,46] Studts *et al.*[44] interviewed students about their interpretation of RRR, ARR, number needed to treat (NNT), and absolute survival benefits. The respondents often misunderstood RRR. Moreover, RRR had more influence on respondents' willingness to get treatment than the other formats. On the other hand, respondents thought that ARR was clear and concise but considered the treatment expressed in this format to be inefficient, and they did not like the negative outcome of this format. Another qualitative study revealed that respondents preferred receiving ARR rather than RRR to understand the risk.[47] According to these interviewees, RRR was "too alarming because the risk appeared bigger" (Reference 47, p. 10). In a study by Gyrd-Hansen *et al.*,[40] respondents explicitly received RRR or had to compute the RRR themselves based on the ARR, which both groups received. ARR and RRR had two levels: low or high. Based on the information they received or computed, the respondents had to choose one of two treatment options. Respondents who had explicitly received RRR preferred the treatment option with high RRR and low ARR, whereas respondents in the other conditions chose the treatment option with low RRR and high ARR. Respondents with less than 10 years of education appeared to neglect ARR, which might indicate that they did not understand ARR.

Based on two studies, Stone *et al.*[8] concluded that RRR might be more persuasive than ARR for a small risk that is otherwise neglected because people may transform a small risk's ARR to nil and thus ignore it, whereas people do not transform the larger number of the RRR.

In conclusion, we suggest not presenting RRR as it may lead to confusion. In the case of a small risk with large consequences, however, this format may be considered, so that people will not ignore the small risk.

Apart from describing the reduction of a risk, a probability can also express the relative probability difference compared to another group of people or to another risky situation. Emmons *et al.*[48] applied computer-tailored risk communication to compare the effects of absolute personal risk information to both absolute and relative personal risk information, and to no risk information about colorectal cancer (Table IV). The authors investigated these three formats with respect to the respondents' risk perception. They found some evidence that personal risk information led to more accurate risk perception than general risk information, independent of whether this personal risk information was in a relative or in an absolute format. As we only found one study on this topic, this did not result in a recommendation.

4.2. Number Needed to Treat and Benefit Information

Five of the studies described in the previous section also examined the effects of the number needed to treat (NNT) and of benefit information, in addition to RRR and ARR (Table IV).[39,43,44,46,47] The NNT describes the average number of people that should be treated to cure one person. Benefit information was presented, for example, as the absolute survival benefit (ASB)[39,44] or the personal probability of benefit (PPB).[43] These studies have already been discussed in the previous section; we therefore only mention the results related to NNT and benefit information.

Recommendation 4: Information about the number needed to treat (NNT) should be used with care because people do not like this format and have difficulty in understanding it.

The studies that included NNT showed that this format did not result in more patients being willing to get the necessary treatment than ARR, RRR, or benefit information (see Table IV).[43] Also, respondents had mixed opinions about the influence and helpfulness of NNT on people's decision making because it has a negative frame.[44] Respondents considered NNT to be confusing,[39,47] and they appeared to

Table IV. Characteristics of Studies About Absolute (ARR) and Relative Risk Reduction (RRR), Number Needed to Treat (NNT), and Benefit Information

Authors	Study	Design	Respondents	*N*	Dependent Variables	Independent Variables	Risk
Stone *et al.*[8]	1	Experiment	Students	108	Willingness to pay	2 (format: RRR vs. ARR) × 2 (product: improved vs. standard)	Tire blowout injury, gum disease
	2	Experiment	Students	227	Willingness to pay	2 (format: RRR vs. ARR) × 2 (actual risk level: high vs. low) × 2 (media exposure: high vs. low)	Chainsaw accident, airplane accident, amusement park ride accident, burglary in rental houses
Chao *et al.*[39]		Experiment	Students	203	Willingness to recommend treatment, confidence, confusion	4 (format: RRR, ARR, NNT, and absolute survival benefit) × 1 (risk)	Breast cancer
Gyrd-Hansen *et al.*[40]		Experiment	General public	3,201	Choice of health intervention	9 (scenarios: different base-line risks and ARRs) × 2 (framing: social vs. individual) × 2 (RRR wording: explicit vs. implicit)	Hypothetical disease
Hembroff *et al.*[41]		Experiment	General public	952	Willingness to recommend treatment	baseline information + probability of breast cancer + 2 (probability of heart disease: RRR vs. ARR), within subjects	Bone disease, breast cancer, heart disease
Malenka *et al.*[42]		Quasi-experiment	Students	470	Choice of medication	2 (format: RRR vs. ARR) × 1 (risk)	Effectiveness of two medicines to prevent a hypothetical disease
Misselbrook & Arm-strong[43]		Experiment	Patients	277	Willingness to get treatment	4 (format: RRR, ARR, NNT, and personal probability of benefit) × 1 (risk)	Hypertension
Studts *et al.*[44]		Experiment	Medical students	203	Confusion, confidence, helpfulness, influence on decision making, qualitative description	4 (format: RRR, ARR, absolute survival benefit, and NNT) × 1 (risk)	Breast cancer
Marteau *et al.*[45]	2	Experiment	Women	722	Understanding	2 (format: ARR vs. RRR) × 2 (additional information: present vs. not present)	Cervical cancer
Sheridan *et al.*[46]		Experiment	Patients	357	Understanding	4 (format: NNT, RRR, ARR or combination of all three) × 1 (risk)	Hypothetical disease
Fortin *et al.*[47]		Focus group and in-depth interviews	Women	25	Probability format preferences	bar -, line -, thermometer graph, pictograms vs. survival curve; 10-year, 20-year vs. lifetime time horizons; 1 disease in 3 time horizons vs. 3 diseases in multiple clinical outcomes; ARR, RRR; and NNT	Coronary heart disease, hip fracture, breast cancer, with and without hormone replacement therapy
Emmons *et al.*[48]		Experiment	Students	353	Risk perception	3 (format: ARR, ARR with RRR, or no risk information) × 2 (type of information: personalized vs. general)	Colorectal cancer

have even more difficulties in understanding this than ARR or RRR.[46] Last, Fortin *et al.*[47] asked interviewees which NNT format they preferred: a standard format (1 in X), an alternative format (X in 100) or neither. The majority of the respondents chose the alternative format.

Absolute survival benefit (ASB) information provides a positive presentation of the risk reduction, as it presents the absolute number of people in a certain sample that avoids a risky event or is cured due to treatment. Two studies suggested that ASB is comprehended relatively well.[39,44] The personal probability of benefit (PPB) is the probability for one person that the treatment succeeds, compared to the probability that it fails. Patients who were shown this format were more likely to refuse treatment than patients who were presented RRR, ARR, or NNT.[43] Due to the small number of studies about benefit information, we do not feel permitted to make a recommendation about using benefit information. Hence, we described the studies only briefly.

5. CUMULATIVE PROBABILITIES

People rarely consider that when they are exposed to the same risk factors over a longer time period or that when they are simultaneously exposed to several risk factors (e.g., both smoking and radon), these result in so-called cumulative probabilities. Instead, people perceive each hazard or exposure moment as a single, independent exposure.[49] Consequently, when they have to calculate the cumulative probability themselves, this may result in an overestimation[49] or an underestimation of the risk.[31] Although several researchers gave recommendations about how cumulative risk can be communicated, they did not provide any empirical evidence proving the effectiveness of these recommendations on understanding.[31,49] Two experiments by Keller *et al.*[50] showed that probability information in a cumulative format (i.e., the cumulative probability is directly provided) increased perceived riskiness compared to probability presented as a single event (a percentage; see Table V). Doyle[51] found some evidence that people better understand formats that present the probability that an event will at least happen one time (disjunctive probability), than formats that present the probability that an event will never happen (conjunctive probability). The findings of these two studies are insufficient to form a recommendation about cumulative probabilities.

6. VERBAL INFORMATION

People tend to focus on the qualitative aspects of risks instead of, and in addition to, the quantitative aspects.[52–54] They may therefore better understand a risk that is communicated in verbal expressions, for example, "Risk event X is very unlikely to happen," than when the likelihood of this event is presented in numbers. Table VI presents five papers about the effects of verbal expressions on people's understanding and numerical ratings of verbal expressions. We additionally review three papers that examined the effect of the context in which the verbal expression is used on its interpretation.

Several studies investigated people's understanding of verbal probability expressions, which numerical probability they associated with each verbal expression, and people's risk perception following a verbal expression.[55–57] For example, Brun and Teigen[55] let their respondents judge verbal probability expressions (e.g., "possibly") either in the context of an influenza vaccine or without a context (Study 2, see Table VI). Their study and others[55,56] revealed large differences between individuals in the numerical probabilities that were associated with the same verbal expressions.[4] In the case of the study by Brun and Teigen, the individual differences could not be explained by the context. These studies also indicated that the numerical ratings of verbal expressions differed between experts (e.g., physicians) and the general public.[55,56]

Recommendation 5: Take the context of the risk communication into account when selecting appropriate verbal probability expressions for a risk message.

The context in which a verbal expression is reported was found to affect its interpretation.[55,57,58] The study by Brun and Teigen,[55] which we just described, showed that a medical treatment context triggered lower numerical probability estimates of the verbal expressions compared to a no-context condition.[5]

[4] In addition, a meta-analysis about what numerical estimate people assign to verbal probability expressions without mentioning a specific risk also showed that individuals differ in their interpretation of verbal expressions. Moreover, there appeared to be large differences between studies that use the same verbal expressions.[28] Other studies that examined verbal expressions in isolation indicated that individuals can consistently give the same numerical estimates for different verbal expressions.[30,55]

[5] In their third study, respondents had to estimate the numerical probability of identical verbal expressions in various TV news

Table V. Characteristics of Studies About Cumulative Probabilities

Authors	Study	Design	Respondents	*N*	Dependent Variables	Independent Variables	Risk
Keller *et al.*[50]	1	Experiment	Students	170	Risk perception	4 (format: frequency, percentage 1 year, percentage 40 years, percentage 80 years) × 1 (risk)	Flooding of house
	2	Experiment	General public	1,598	Risk perception	2 (time period: 1 year vs. 30 years) × 2 (format: pie chart vs. percentage) × 1 (past experience)	Flooding of house
Doyle[51]	1	Experiment	Students	128	Probability estimate, estimation strategy	6 (single-year probabilities: 0.005, 0.01, 0.03, 0.05, 0.08, vs. 0.13) × 6 (time period: 1 month, 1, 5, 10, 15, 25 years) × 2 (type of probability: conjunctive vs. disjunctive) × 2 (order)	Using contraceptives and natural hazards
	2	Experiment	Students	87	Probability estimate, estimation strategy	3 (time period: 10, 25, 50 years) × 2 (single-year probabilities: 0.005 vs. 0.05), using all disjunctive probabilities	Natural hazards
	4	Think aloud	Students	12	Probability estimation strategy	6 (single-year probabilities: 0.005, 0.01, 0.03, 0.05, 0.08, vs. 0.13) × 6 (time period: 1 month, 1, 5, 10, 15, 25 years) × 2 (type of probability: conjunctive vs. disjunctive)	Using contraceptives and natural hazards

Weber and Hilton[57] showed in three studies that the context effects of verbal probability expressions may partly be explained by variations in respondents' perceived severity and their perceived personal base rate in the hazardous context (Table VI). For example, the numerical rating of the risk of life-threatening side effects of a medicine (low perceived personal base rate and high perceived severity) in combination with the verbal expression "possible" was similar to the risk of sprained ankle (high perceived personal base rate and moderate perceived severity) in combination with the expression "slight chance."

Wogalter *et al.*[58] studied another definition of context, namely, the severity of the hazard's consequences. They combined verbal probability expressions and severity of the consequences (i.e., context) in a study about warnings that are presented on hazardous products. They examined the effects of verbal probability expressions, severity, and no information (control condition) on the risk perception of 10 products (Study 3) and on precautionary behavior (Study 4, Table VI). The context of the risk (i.e., the severity) had more effect on the respondents' risk perception and behavior compliance than the verbal probability expressions or no risk information.

To sum up, the studies that examined verbal expressions of probability information showed that people have various interpretations of the same expressions. It might thus be difficult to develop verbal probability expressions for risk communication that all people interpret in the same way. It is unclear which contexts (e.g., setting, frame, and severity) can influence the interpretation of verbal expressions due to a limited number of studies. Nonetheless, the context should be taken into account when choosing the verbal probability expression to communicate a risk. Hence, verbal expressions of probability information should be pretested in the specific context and target group.

fragments.[55] The respondents' numerical estimates of the verbal expressions differed to a greater extent between different contexts, and when a context was added compared to when no context was included. The authors did not mention which contexts in combination with which verbal expressions caused more variability than others.

7. NUMERICAL VERSUS VERBAL INFORMATION

Probability information can be expressed both numerically (e.g., frequencies or percentages) and

Table VI. Characteristics of Studies About Verbal Probability Information

Authors	Study	Design	Respondents	*N*	Dependent Variables	Independent Variables	Risk
Brun & Teigen[55]	2	Experiment	Medical experts, parents, students	66 + 64 + 24*	Numerical probability estimate (7-point scale)	3 (respondents: medical experts, parents, or students) × 1 (14 verbal probability expressions) × 2 (context: medical scenario or no context)	New influenza vaccine
Shaw & Dear[56]	1	Quasi-experiment	Mothers, medical experts	100 + 50*	Numerical probability estimate	1 (8 verbal probability expressions) × 2 (respondents: medical experts or mothers)	Health issues of baby
Weber & Hilton[57]	1	Experiment	Students	85	Numerical probability estimate, perceived personal probability, perceived severity	4 (verbal probability expressions) × 4 (health problems)	Health problems, e.g., leukemia, gastric disturbance
	2	Experiment	Students	71	Numerical probability estimate, perceived personal probability, perceived severity, perceived probability for others	4 (verbal probability expressions) × 4 (health problems)	Health problems, e.g., leukemia, gastric disturbance
	3	Experiment	Students	41	Numerical probability estimate	2 (base rate expressions: rare vs. common) × 2 (severity expressions: mild vs. severe) × 2 (verbal probability expressions: likely vs. chance) × 3 (health problems)	Health problems, e.g., leukemia, gastric disturbance
Wogalter *et al.*[58]	3	Experiment	Students	46	Risk perception	2 (severity expressions: high vs. low) × 2 (verbal probability expressions: high vs. low) + control cond.	Accidents with consumer products
	4	Experiment	Students	79	Safety-related behavior	2 (severity expressions: high vs. low) × 2 (verbal probability expressions: high vs. low) + control cond.	Chemical substances in lab

*The different sample sizes correspond with the different types of respondents.

verbally (a qualitative description). First, we report 10 studies about what type of information most people prefer. Second, we review six papers that empirically compared the effects of verbal and numerical information on risk perception.

Recommendation 6: Present both numerical and verbal probability information in a risk message. People prefer numerical information for its accuracy but use a verbal statement to express a probability to others. Presenting both makes sure that people have the right information no matter the purpose for which it is used.

First, do people prefer to receive verbal or numerical information? In most studies, respondents were given both types of information and asked which type they preferred to receive (see Table VII).[6,56,59–65] Respondents most often

Table VII. Characteristics of Studies About Numerical Versus Verbal Probability Information

Authors	Study	Design	Respondents	N	Dependent variables	Independent variables	Risk
Shaw & Dear [56]	2	Interviews	Mothers	81	Preference for numerical vs. verbal information	2 (format: numerical vs. verbal expression) × 1 (risk)	Health issues among babies
Lion & Meertens[62]		Experiment	Students	75	Preference for and use of percentages vs. verbal information	Accountability of the choice, risk-taking tendency	Effectiveness of a medicine
Mazur *et al.*[64]		Quasi-experiment	Patients	226	Choice of treatment, preference for numerical vs. verbal information	2 (format: verbal vs. numerical expression) × 1 (risk)	Prostate cancer
Teigen *et al.*[65]	4	Experiment	Students	64	Sentence completion including numbers or without numbers, preference for receiving verbal vs. numerical statements	2 (statement: general vs. specific) × 2 (format: numerical vs. verbal) × 2 (probability: low vs. high)	Hazardous activities (e.g., car accident) or health issues (e.g., an appendix operation)
Gurmankin *et al.* [61]		Experiment	General public	115	Numerical probability estimate, trust, feeling of comfort with information	3 (format: verbal expression, frequency or percentage information) × 4 (risks)	Prostate, lung, colon and breast cancer
Berry *et al.*[59]		Experiment	General public	188	Information satisfaction, severity estimate, verbal probability estimate, numerical probability estimate, risk perception, behavior intention	2 (format: verbal vs. numerical expression) × 2 (action label: immediately vs. a.s.a.p.)	Side effects of Ibuprofen (an over-the-counter drug)
Marteau *et al.*[63]		Experiment	Pregnant women	220	Understanding, fear	2 (format: numerical vs. verbal expression) × 1 (risk)	Screening for Down syndrome
Knapp *et al.*[66]		Experiment	Patients	120	Probability estimate, risk perception, severity estimate, decision to take medicine, information satisfaction	2 (format: verbal vs. numerical expression) × 2 (side effect: constipation vs. pancreatitis) × 2 (severity: high vs. low)	Medication to treat cardiac problems
Hendrickx *et al.*[6]		Experiment	Students	128	Behavior intention, probability estimate (rank order of 16 risky activities), preference for numerical expression vs. verbal description	2 (scenario format: present vs. absent) × 2 (frequency format: present vs. absent)	16 small-scale risks, e.g., a parachute-jumping course
Gurmankin *et al.*[60]		Experiment	General public	217	Numerical probability estimate	3 (format: verbal, verbal + percentage, or verbal + frequency) × 4 (risks)	Prostate, lung, colon and breast cancer
Teigen & Brun[67]	1	Experiment	Students	154	Treatment advice, probability estimate	3 (format: positive verbal expression, negative verbal expression, numerical percentage expression) + 2 (control groups to check numerical estimates of verbal expressions)	Acupuncture treatment for migraine

preferred to receive risk information in a numerical format when they had to interpret a hazard.(56,62,64,65) Other studies showed that numerical information was trusted more,(61) gave more satisfaction about the information,(59) and was better understood than verbal information.(63) Two studies found that people significantly overestimated the hazards' probabilities when these were presented in some of the verbal expressions suggested by the European Union (e.g., "common" and "rare") to communicate in medicine leaflets, compared to numerical information (Table VII).(59,66)

Second, it is interesting to know what type of information has more effect on risk perception: verbal information or numerical information. A study by Hendrickx *et al.*(6) indicated that verbal information had more effect on probability estimates of risks than numerical information, if both types of information were presented. These authors examined the effects of no risk information, numerical information (frequency), a verbal description (scenario of the risky event), and a combination of these last two types on the perception of various risks (see Table VII). Variations both within the numerical information and within the verbal description (e.g., number of scenarios or probability size) influenced the respondents' probability estimate of the risk. However, when both the numerical information and verbal description were presented, the variations in the verbal description had more influence on the probability estimate than variations in the numerical information. Thus, the verbal description appeared to suppress the numerical information when both formats were presented.

Gurmankin *et al.*(60) found that verbal information caused more variability in risk perception than numerical information, both between and within the respondents (see Table VII). Teigen and Brun(67) showed that positive verbal information had more effect on treatment advice than numerical information. Respondents who received positive verbal information about a treatment's success rate (e.g., "some possibility") were more likely to advise the necessary treatment to others than respondents who received negative verbal information about a treatment (e.g., "quite uncertain"). Further, respondents who received numerical information were in between these two verbal groups and indecisive. Additionally, two studies showed that verbal information is more likely to be overestimated or to lead to unnecessary treatment than numerical information.(59,64)

Only the study by Hendrickx *et al.*(6) showed an indirect, larger influence of verbal information on risk perception than numerical information, although there was no difference between these two types of information on behavior intention. This overruling effect of verbal information may be because Hendrickx *et al.* presented risky leisure activities and external safety risks, whereas the other studies mainly tested medical risks.(59,60,64,67) One should therefore be careful in generalizing the effects of verbal and numerical information on perception of a certain risk to other types of risks.

Overall, the results of these studies seem to be in agreement with the communication mode preference (CMP) paradox, for which evidence has been found in gambling studies.(68) The CMP paradox states that people prefer to receive numerical information to evaluate a risk, whereas people use verbal information when they have to express a risk to others. The task thus determines whether people prefer verbal or numerical probability information. The articles reviewed here showed that numerical information is better understood and trusted than verbal information. Verbal information can also be helpful; for example, it may help people when they have to report a probability to others and may guide them in giving advice about a risk's probability.

8. GRAPHS

Graphs can depict probability information, such as the number of people affected by the risk (e.g., in pictograms), a cumulative risk over a certain time period (e.g., in mortality and survival curves), a comparison of the mortality rate of people affected versus the mortality rate of those unaffected by the risk (e.g., in histograms, bar charts, and pie charts), and a comparison of the probabilities of different risks (e.g., in histograms and bar charts). First, six papers are discussed that compared the effects of graphs to the effects of numerical information on understanding, accuracy, and the willingness to pay for a safer or healthier product. Second, we review a number of studies about the effects of differences between graphs. Third, we examine several studies about the layout and content of graphs.

Recommendation 7: Graphs are useful means to present probability of harm, as they are more likely to draw people's attention to a probability of harm than numerical information (except for pie charts).

In the studies that compared graphs to numerical information, respondents received either a graph (pictograms or bar graphs) or numerical

Table VIII. Characteristics of Studies About Graphs

Authors	Study	Design	Respondents	*N*	Dependent Variables	Independent Variables	Risk
Schirillo & Stone[69]	1	Experiment	General public	157	Willingness to pay for improved product	2 (format: numerical information vs. asterisks) × 7 (injury rate: 1, 5, 10, 15, 20, 25, and 29 out of 5 million drivers)	Tire blowout injury
	2	Experiment	General public	492	Willingness to pay for improved product	2 (format: numerical information vs. asterisks) × 7 (injury rate: 1, 5, 10, 15, 20, 25, and 29 out of 50,000 drivers)	Tire blowout injury
Stone *et al.*[70]	1	Experiment	Students	108	Willingness to pay for improved product	2 (format: pictograms vs. numerical information) × 2 (risks)	Tire blowout injury, gum disease
	2	Experiment	Students	532	Willingness to pay for improved product	4 (format: pictograms, asterisks, bar graphs vs. numerical information) × 2 (risks)	Tire blowout injury, gum disease
	3	Experiment	Students	135	Willingness to pay for improved product	2 (pictograms: with or without faces of people) × 2 (risks)	Tire blowout injury, gum disease
Waters *et al.*[71]		Experiment	General public	2,601	Understanding, risk perception, preferred probability format	3 (cognitive effort: difficult, moderate, or easy) × 2 (text: only vs. + bar graph) × 2 (format: percentage vs. frequency) × 2 (risk: large vs. small)	Cancer
Chua *et al.*[72]	1	Experiment	Students	138	Willingness to pay for improved product, initial risk perception, percentage of risk reduction, significance of risk reduction	2 (format: horizontal bar graph vs. numerical information) × 2 (frame: negative vs. positive)	Gum disease
	2	Experiment	Students	155	Willingness to pay for improved product, affective associations with format, recall of provided information	2 (format: horizontal bar graph vs. numerical information) × 1 (risk)	Tire blowout injury
Armstrong *et al.*[73]		Experiment	General public	451	Understanding, treatment preference	3 (graph: survival curve, mortality curve, or survival and mortality curves) × 1 (risk)	Colon cancer
Zikmund-Fisher *et al.*[74]		Experiment	General public	864	Severity of disease, treatment effectiveness	2 (visual difference between lines: large vs. small) × 2 (time period: 5 vs. 15 years)	Fictitious disease: Crawford disease
Armstrong *et al.*[75]		Experiment	General public	246	Understanding at a specific time point, and after time period	2 (practice: survival curves with practice vs. without practice) × 1 (risk)	Fictitious disease: soap-oparititis

information about a risk and were then asked to evaluate the risk and its information on understanding, accuracy, or the willingness to pay for a safer or healthier product, which is a risk aversion measure (see Table VIII).[69–72] Contradicting results have been found with respect to whether graphs increase or decrease people's accurateness of probability estimates compared to numerical information.[71,72] A more clear-cut finding was that graphs resulted in more risk aversion, as people were more willing to pay for a safer or healthier product, than numerical information.[69,70,72] This appeared to be irrespective of the risk's actual base rate.[69,72] However, probability information expressed in pie charts appeared to decrease the perceived risk compared to the same information presented as percentages (see Table V).[50] The authors suggested that the respondents may have considered the probabilities in the pie charts as too small and were therefore not impressed by them. Only large probabilities presented in graphs may be noticeable and increase perceived risk.

The attention-grabbing effect of graphs can explain these findings. According to the attention priority model,[72] graphs draw people's attention to the visual contrast in the display, for example, the contrast between the number of people affected versus the number of unaffected people. This leads to increased perceived probability of the risk if the graph only presents the probability of harm (i.e., the number of people affected in a bar graph), so that people's attention is only drawn to this, although the actual probability of harm may be low. However, in a pie chart both the probability of harm and the probability of no harm are presented, so that a small harm probability seems negligible and people's attention is drawn to the substantial no-harm probability. Thus, most graphs seem to increase risk aversion, except for pie charts representing small probabilities of harm, as these do not draw people's attention to this.

Different types of graphs may affect risk perception, understanding, willingness to pay, and preference for graphs differently. Studies 2 and 3 by Stone *et al*.[70] indicated that type of graph (e.g., pictograms and bar graphs) did not affect respondents' willingness to pay for a safer or healthier product.

The effects of mortality and survival curves were compared with respect to their impacts on understanding and treatment preference (see Table VIII).[73] Mortality curves represent the probability of dying caused by a risk over time, whereas survival curves demonstrate the probability of surviving over time. Respondents either received survival curves, mortality curves, or both about the risk of colon cancer. Respondents who received the survival curves or survival and mortality curves had a more accurate understanding of the probability of death and of survival than the respondents given the mortality curves only. Furthermore, the survival curves increased the preference for preventive surgery compared to the mortality and survival curves, which again resulted in a higher preference for this than the mortality curves.

In addition, the research literature provides suggestions about what kind of graph can be used best under which circumstances. One interview study indicated that women rated pictograms as easier to understand than bar graphs. However, pictograms were more likely to lead to biased interpretations of the probability (i.e., overestimation) compared to bar graphs by younger, low-educated women (see Table III).[7] Respondents preferred bar graphs to represent the probabilities of multiple risks, for example, to compare these probabilities. In another interview study, the respondents preferred bar graphs instead of line graphs, thermometer graphs, pictograms, and survival curves to present the probabilities of coronary heart disease, hip fracture, and breast cancer, both with and without hormone replacement therapy (see Table V).[47]

Furthermore, the content and layout of graphs can be varied in diverse ways. Studies have led to suggestions about the way to present a specific type of graph, for example, with respect to highlighting, legend, visual differences between slopes, and the probability's time frame.[6] One of the interview studies reported above[7] demonstrated that respondents preferred consecutive highlighting of pictograms (i.e., in rows) to random highlighting of pictograms because it was easier to grasp the frequency information at once in the first format. Also, respondents preferred absolute risk information to relative risk information in graphs.[47]

Zikmund-Fisher *et al.*[74] tested several variations within survival curves; that is, various slopes for different treatments, which result in large versus small visual differences in the graph, combined with 5- versus 15-year time periods (Table VIII). Respondents rated a disease the probability of which was depicted in a graph with a large visual difference and 15-year time period to be more serious and its treatment more effective than when the same disease's probability was presented in a graph with a small visual difference and a five-year time period. Because the annual risks were similar in both graphs, respondents seemed to have been misguided by the visual characteristics. The authors suggested

[6] Studies in nonrisk fields indicated that the suitability of graphs may depend on the type of task that people should do with the probability information. Line graphs are suggested to facilitate reading a trend over time and understanding cumulative risks; bar graphs and icon arrays may be useful to compare risks or treatments; and pie charts may be suitable for evaluating risk proportions.[79,92]

Table IX. Characteristics of Studies About Risk Ladders

Authors	Study	Design	Respondents	*N*	Dependent Variables	Independent Variables	Risk
Sandman *et al.*[77]	1	Experiment	General public	449	Probability estimate, danger, threat, concern, fear, behavior intention	2 (exposure scale: 3.5–1,500 vs. 0.15–75) × 2 (probability level: 3/1,000 vs. 30/1,000) × 2 (test magnitude: fibers/liter vs. fibers/cubic ft)	Radon in houses
	2	Experiment	General public	534	Probability estimate, danger, threat, concern, fear, behavior intention	2 (exposure scale: 1.5–400, 4–1,000, or 1.5–300) × 2 (probability level: 5/1,000 vs. 125/1,0000) × 2 (risk)	Radon and asbestos in houses
Connelly & Knuth[76]		Experiment	General public	4,016	Presentation preference, understanding, behavior intention, information satisfaction	2 (tone: commanding vs. cajoling) × 2 (reading level: 5th grade vs. 11th grade) × 2 (format: graphics vs. text) × 2 (risk ladder format: numerical vs. verbal)	Fish consumption
Lee & Mehta[81]		Experiment	General public	200	Knowledge, risk perception, qualitative characteristics	2 (format: numerical vs. Paling Perspective Scale) × 2 (quiz in pretest: yes vs. no) × 2 (measurement: pre- vs. posttest)	Blood transfusion

mentioning the time period explicitly in the title or legend and being consistent in the units of time within different graphs in one risk communication. Moreover, another interview study revealed that people prefer longer, life time risks in graphs to 10- or 20-year cumulative probabilities or to single time points.[47]

Armstrong *et al.*[75] found that people can learn to interpret complex survival curves about a disease (Table VIII). Presenting people first with a simple survival curve facilitated respondents' ability to identify the number of survivors at a single point in a complex survival curve that showed the outcomes of two different treatments in one graph. Even so, the results of this study also pointed out that people have difficulty in calculating changes in survival rates between two points in both simple and complex survival curves.

In sum, probability information presented in graphs appears mostly to lead to higher probability estimates and more risk aversion than numerical probability information only. The task at hand may determine which graph is most appropriate to present probability information. Last, the layout of graphs influences people's interpretation of a graph. Our short review about graphs and probability information indicates that many studies have been published concerning the effect of different types of graphs and of layout variations on people's risk perception and other factors. These studies tested many different graphical materials. It is therefore not possible to formulate a recommendation about graph types and layout issues.

9. RISK LADDERS

A risk ladder is a tool commonly used to present a risk in comparison to other risks.[76,77] It includes several risks that are ordered from low to high probability, with or without reporting the numerical probabilities. The risk to be evaluated is presented in between the other risks. Risk ladders can take different forms, such as the Paling Perspective Scale, the Community Risk Scale, or the Lottery Scale (see Reference 78). Lipkus and Hollands[79] already reviewed several studies about risk ladders (e.g., References 76 and 77). We only repeat their main findings and add the Paling Perspective Scale.

The target risk's probability and its location on the ladder appears to determine people's risk perception (see Table IX).[77] Respondents rated risks that were presented with high probability levels (10 times higher probability) and those located high on the ladder as more risky than risks with low probability levels and those located low on the ladder. The type of hazard and the test magnitude (15 fibers per liter vs.

450 fibers per cubic foot) used in the ladders did not influence perceived risk. According to another study, respondents evaluated a risk ladder that included numerical information as more understandable than a risk ladder with verbal probability labels (see Table IX).[76]

A specific example of a risk ladder is the Paling Perspective Scale (PPS).[27,80] It presents the probability of several risks on a horizontal logarithmic scale, that is, it shows relative probability levels of risks, for example, the relative probability increase of the risk of cancer due to exposure to radon to that of x-rays. The PPS was tested by Lee and Mehta.[81] The study consisted of a pre- and posttest in which risk perception and knowledge were measured (Table IX). In between these two tests, respondents received either numerical information about the risk of blood transfusion or the PPS. The perceived risk decreased and knowledge increased between pre- and posttests in both the numerical information condition and the PPS condition. The authors concluded that it is not the type of risk communication that is important but the content: as long as its content is clear, numerical information and PPS result in similar levels of perceived riskiness and of knowledge about the risk. The numerical information was quite similar to a risk ladder, as the target risk was presented between several risks that ranged vertically from small to high probability of occurring. The participants may therefore have compared this simple risk ladder to the PPS.

In sum, risk ladders may be a useful format to compare risks with various probabilities. The location of the new risk on the ladder and the probability of the target risk seem to affect risk perception. These two properties should thus be presented with care. Nevertheless, we only identified two studies that investigated risk ladders and these studies used different paradigms. Hence, it is not possible to provide a recommendation about this topic. More research is needed to examine the roles of the different elements in a risk ladder in people's risk perception and understanding of probability information. Furthermore, we suggest more research that compares the effects of risk ladders to those of numerical or verbal information, with respect to understanding and risk perception.

Last, we would like to remark that various risks can be compared in risk ladders. However, previous research has indicated that risk comparisons do not often have the desired effect on acceptance and on risk perception because the risks that are compared differ in important characteristics.[82–85] Hence it is important to choose the other risks in the ladder with care and to base this selection on similar characteristics.

10. DISCUSSION AND RECOMMENDATIONS

This article presents an overview of studies about probability information in risk communication. The studies reviewed covered a wide range of risks: from very specific diseases to hazardous consumer products. Also, the settings in which the studies were conducted varied, e.g., a hospital versus laboratory setting. Moreover, various types of samples were used in these studies, such as students, patients with a specific disease, and adolescents. Despite these differences, the general theme of all studies was risk communication of probability information related to medical, health, technological, and accident risks.

We now first discuss the recommendations and indicate several research gaps. Then, based on current theories of information processing, we will argue that the effect of probability formats depends on specific context factors that determine the depth of information processing. Last, we give some empirical examples of how information processing depth and probability format are interlinked.

10.1. Recommendations and Research Gaps

We organized this review around several recommendations to provide some structure to the studies reviewed and to their findings. In Table II, we present the quality of the support for each recommendation based on the number of studies, the number of different risks, and the strength of the findings obtained.

These are the best recommendations we can give on basis of the empirical evidence available. However, they are not "magic bullets." Uncertainties remain because the majority of studies reviewed here considered medical risks, although we searched for various types of risks in the literature databases. Consequently, a format that improved the understanding of the probability of a medical risk may not have the same effect when it is applied on environmental-health, technological, or accident risks.

Another limitation of the review is that 37 of the 63 studies reported in this review were conducted on student samples. Although students' affective association with a risk may be similar to that of the general public, students may have a different perception and understanding of a risk's *probability* since they may have higher numeracy skills than the general public (cf., Reference 86).

We also identified several research gaps concerning the specific presentation formats. First, few studies explored the presentation of cumulative risk information, although people often misunderstand this type of probability information. It may be interesting to examine whether presenting both the probability rate after a single exposure and the probability rate after multiple exposures increases understanding, as has been suggested. Second, little research has focused on using tailored probability information and reference information in risk communication. Promising presentation formats seem, for example, a tailored lexicon to express probabilities verbally,[87] and base rates that are tailored to the actual exposure level of the respondents.[34] There are also some preliminary suggestions from the literature that tailored information is helpful to increase people's understanding of base rates,[29] and of risk ladders.[77] Third, we discovered few scientific papers about graphs and risk communication; for example, what kind of graph works best in what situation. We obtained contradictory findings about whether graphs can increase people's accuracy of a risk estimate.[71,72] Fourth, little has been investigated in the field of risk ladders. It is unclear, for example, what the layout should look like and which comparison risks can be presented.

10.2. Explaining the Effect of Presentation Formats

Despite these limitations and research gaps, this review gives useful insights into what determines the effectiveness of these probability formats in risk communication. However, we do not suggest trying to find the ideal presentation format to communicate probability information, as two factors seem to determine how this information is understood and how it influences risk perception. These are the *content* of the format and the *situation* or context in which the format is used.

First, the exact content of the presentation format may determine its effect, i.e., the way the format is filled in. The discussion about natural frequencies illustrates this rather nicely. Although natural frequencies may lead to more accurate risk estimates, other studies showed that percentages can also have this effect as long as they are presented in the same way as natural frequencies.[36] Similarly, we believe that other presentation formats that are not recommended here could be rearranged in a risk message so that it is more understandable, such as NNT.

Second, and more important, we suggest that the situation or context in which the probability is communicated may explain the format's effect. Current views about the way people process risk information point out that people do this either heuristically or systematically (see heuristic-systematic information processing model).[25,26] Heuristic information processing entails people using schemata or simple inferential rules to come to an evaluation of a risk. Systematic information processing represents in-depth processing of the information, and is more deliberate and time consuming.

The person's situation determines which type of processing prevails, that is, someone's cognitive capacities, motivation, and available time.[88] If people have sufficient resources of one or several of these factors, they will probably process the information systematically. However, when they do not have enough resources available, people will process the information heuristically. It seems likely that the presentation format plays a larger role in the latter type of processing than in the former. For example, an unmotivated person under time pressure may conclude that a mortality of 1,286 out of 10,000 represents a higher risk than a mortality of 24.14 out of 100, based on, for example, the anchoring and adjustment heuristic.[89] Whereas someone who is not under time pressure, is highly motivated, and capable of processing probability information elaborately may spontaneously reorganize the different formats of probability information and conclude that 24.14 out of 100 is the higher probability (see Reference 32). Thus, this implies that the presentation format hardly has an impact on people in situations where they have time, motivation, and cognitive capacity to process information systematically.

The results of various studies reported here seemed to support the assumption that probability information can be processed heuristically or systematically. These examples also illustrate that certain formats stimulate systematic processing, whereas others promote heuristic processing. Two studies showed, for example, that when the risk was made more personally relevant for people by presenting tailored probability information, this resulted in more accurate risk estimates,[34,48] perhaps because tailored information motivated them to use systematic processing. Other studies reviewed here indicated that highly-educated people were more likely to process probability information systematically than less-educated people, as the former were able to manipulate the probability information they received to their own preferences.[7,40] Further, presenting probability information as "natural frequencies" appeared to result in more adequate statistical reasoning.[35]

Nevertheless, in many situations, people are not motivated or do not have the ability to process information systematically, so they rely on heuristic processing. Then the presentation format of the probability information is crucial for the way it is interpreted. Information that is highlighted in a risk message influences the way the risk and its information are interpreted. This can be explained by three heuristics. First, many studies reviewed here indicated that respondents estimated a risk's probability based on the *first number* that was presented to them and neglected numbers that were presented later in the message or that should be computed; that is, the anchoring and adjustment heuristic. This was demonstrated in studies about frequency information, RRR, and survival and mortality graphs (e.g., References 33, 39 and 74). Second, when risk information was made more *available* in memory, people appeared to perceive the risk as more likely than when risk information was less easily available, which the availability heuristic can explain. This was illustrated by the location effect in risk ladders.[77] Third, information that was concrete and easy to *simulate* in memory was preferred to more abstract information, which the simulation heuristic predicts. An example is scenario information versus frequency information.[6]

In conclusion, probability information can be processed either systematically or heuristically. Risk communicators usually prefer people to process information systematically because this is more likely to lead to informed decision making. The recommendations that are presented in this review may especially help practitioners in situations where the message's receivers are expected to process the probability or risk information heuristically. In situations where people are assumed to use systematic processing, these recommendations may not matter that much, because people will manipulate the presentation format to their own wishes. However, even in such situations it is advisable that practitioners follow the recommendations, as they assure that the risk information is processed more easily.

We suggest that future studies about the effects of probability information in risk communication on risk perception and understanding should not solely concentrate on finding the perfect probability format but also on the specific content of the format. Moreover, it may be useful to take the situation in which the probability information is presented into account in the development of a risk message, as this may predict which type of processing people use and in what way probability information may influence them.

ACKNOWLEDGMENTS

The work presented in this article was part of the first author's doctoral thesis at the Department of Health Education and Promotion, Nutrition and Toxicology Research Institute Maastricht (NUTRIM), Maastricht University, Maastricht, The Netherlands.

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