

# “A 30% Chance of Rain Tomorrow”: How Does the Public Understand Probabilistic Weather Forecasts?

Gerd Gigerenzer,<sup>1\*</sup> Ralph Hertwig,<sup>2</sup> Eva van den Broek,<sup>1</sup> Barbara Fasolo,<sup>1</sup> and Konstantinos V. Katsikopoulos<sup>1</sup>

---

The weather forecast says that there is a “30% chance of rain,” and we think we understand what it means. This quantitative statement is assumed to be unambiguous and to convey more information than does a qualitative statement like “It might rain tomorrow.” Because the forecast is expressed as a single-event probability, however, it does not specify the class of events it refers to. Therefore, even numerical probabilities can be interpreted by members of the public in multiple, mutually contradictory ways. To find out whether the same statement about rain probability evokes various interpretations, we randomly surveyed pedestrians in five metropolises located in countries that have had different degrees of exposure to probabilistic forecasts—Amsterdam, Athens, Berlin, Milan, and New York. They were asked what a “30% chance of rain tomorrow” means both in a multiple-choice and a free-response format. Only in New York did a majority of them supply the standard meteorological interpretation, namely, that when the weather conditions are like today, in 3 out of 10 cases there will be (at least a trace of) rain the next day. In each of the European cities, this alternative was judged as the least appropriate. The preferred interpretation in Europe was that it will rain tomorrow “30% of the time,” followed by “in 30% of the area.” To improve risk communication with the public, experts need to specify the reference class, that is, the class of events to which a single-event probability refers.

---

**KEY WORDS:** Cultural differences; risk communication; single-event probabilities; weather forecasts

## 1. INTRODUCTION

Predicting weather is an age-old problem of statistical inference. Harvesting, warfare, and outdoor sporting events depend on it. Before the Grand Prix, one of Ferrari's most-discussed decisions is which weather forecaster to hire, because reliable forecasts are key to choosing the right tires—and to winning the race. Over most of human history, forecasts of precipitation (rain or snow) were given in a deterministic form such as “It will rain tomorrow,” sometimes

modified by “it is likely.” In the mid-20th century, however, the advent of computers turned forecasting into a probabilistic science (Shuman, 1989) and later influenced the way forecasts were communicated to the public. In 1965, American laypeople became the first to be exposed to probabilities of precipitation in mass media weather forecasts (Monahan & Steadman, 1996).

But how does the public understand a quantitative probability of rain? In 1980, Murphy *et al.* reported that the majority of 79 residents of Eugene, Oregon, mostly college students, “misunderstood” what “a precipitation probability forecast of 30%” means. The authors concluded that the real cause of the students' confusion was not a misunderstanding of probabilities *per se*, but rather of “the event to which

<sup>1</sup> Max Planck Institute for Human Development, Berlin, Germany.

<sup>2</sup> University of Basel, Basel, Switzerland.

\* Address correspondence to Gerd Gigerenzer, Max Planck Institute for Human Development, Lentzeallee 94, 14195 Berlin, Germany; gigerenzer@mpib-berlin.mpg.de.

the probabilities refer” (p. 695). They recommended that the National Weather Service initiate a program to educate the general public in this regard and to study laypeople’s understanding of probabilistic forecasts.

Our investigation starts where Murphy *et al.* left off in 1980, extending their study in two respects. First, we examine how the general public in five countries—three of which have adopted probabilistic weather forecasts on a wide scale—understands probabilities of rain. Second, we argue that the confusion is largely due to the public’s not being informed about the *reference class* to which a probability of rain refers.

## 2. TO WHAT CLASS OF EVENTS DOES A PROBABILITY OF RAIN REFER?

A forecast such as “There is a 30% chance of rain tomorrow” conveys a *single-event probability*, which, by definition, does not specify the class of events to which it refers. In view of this ambiguity, the public will likely interpret the statement by attaching more than one reference class to probabilities of rain, and not necessarily the class intended by meteorologists. Consequently, laypeople may interpret a probability of rain very differently than intended by experts. This problem has been pointed out before (Gigerenzer, 2002; National Research Council, 1989); here, we provide an empirical test. Let us illustrate the problem of ambiguous reference classes by using another problem of risk communication: the side effects of drugs.

A psychiatrist who prescribed Prozac to depressed patients used to inform them that they had a 30–50% chance of developing a sexual problem such as impotence or loss of sexual interest (Gigerenzer, 2002). On hearing this, many patients became concerned and anxious. Eventually, the psychiatrist changed his method of communicating risks, telling patients that out of every 10 people to whom he prescribes Prozac, three to five experience sexual problems. This way of communicating the risk of side effects seemed to put patients more at ease, and it occurred to the psychiatrist that he had never checked how his patients understood what “a 30–50% chance of developing a sexual problem” means. It turned out that many had thought that something would go awry in 30–50% of their sexual encounters. The psychiatrist’s original approach to risk communication left the reference class unclear: Does the percentage refer to a class of people (patients who take Prozac), to a class of events (a given person’s sexual encounters), or to some other class? Whereas the psychiatrist’s

reference class was the total number of his patients who take Prozac, his patients’ reference class was their own sexual encounters. When risks are solely communicated in terms of single-event probabilities, people have little choice but to fill in a class spontaneously, based on their own perspective on the situation. Thus, single-event probability statements invite a type of misunderstanding that is likely to go unnoticed.

The National Weather Service defines the probability of precipitation as “the likelihood of occurrence (expressed as a percentage) of a measurable amount of liquid precipitation . . . during a specified period of time at any given point in the forecast area” (National Weather Service Tulsa, 1998). In practice, the accuracy of “the rain forecast is the percentage correct of those days when rain was forecast” (Thornes, 1996, p. 69). Thus, a 30% chance of rain does not mean that it will rain tomorrow in 30% of the *area* or 30% of the *time*. Rather, it means that when the weather conditions are like today, at least a minimum amount of rain (such as .2 mm or .01 in.) will fall the next day in 3 out of 10 cases.<sup>3</sup> We refer to this as the “days” definition of rain probability. It implies only a possibility of rain tomorrow—it may or may not rain—whereas the “time” and “region” definitions mean that it will rain tomorrow for certain, the only question being where and for how long. If people want to know where, at what time, and how much it will rain, they might not naturally think of the “days” interpretation.

Given the ambiguity of single-event probabilities, the fact that weather forecasts rarely clarify the definition of rain probability led us to two hypotheses. According to the first hypothesis, the public has no common understanding of what a probability of rain means; rather, different people have different interpretations. The second hypothesis specifies where we can expect a higher or lower degree of confusion. It is reasonable to expect that various attempts to inform and educate the public—such as websites by meteorological institutes—will be more effective the longer they have been in place. Specifically, the confusion should be lower and the prevalence of the days interpretation should be higher (1) among people in countries that have been exposed to probabilistic weather

<sup>3</sup> Meteorologists do not always agree on a single definition of probabilities of rain. In this article we cite three definitions (National Weather Service Tulsa, 1998; Murphy & Winkler, 1971; Murphy *et al.*, 1980), which are all couched in different terms, such as single-event probabilities or betting quotients. No matter how these definitions are phrased, the accuracy of the forecast is measured in a more consistent way, as the percentage correct of days when rain was forecast (i.e., the *days* interpretation).

forecasts for a longer period (*national exposure*) and (2) among people who have been exposed to probabilistic weather forecasts for a larger proportion of their lives (*individual exposure*).

### 3. METHOD

To test these hypotheses, we surveyed citizens living in five cities of five countries that together reflect the full range of exposure to probabilistic weather forecasts. Probabilities of rain were introduced into mass media weather forecasts in New York in 1965, in Amsterdam in 1975, and in Berlin in the late 1980s; in Milan, they have been introduced only on the Internet; and in Athens, they are not reported in the mass media at all. Respondents were surveyed in public places and were paid for their participation. The Berlin sample was the only one that included both members of the general public and university students; the results for the two groups were pooled in the analysis because their responses did not differ. All respondents were asked to indicate their age. The survey was conducted in the fall of 2002.

Participants were told to imagine that the weather forecast, based on today's weather constellation, predicts "There is a 30% chance of rain tomorrow." They were asked to indicate which of the following alternatives is the most appropriate and which of the following alternatives is the least appropriate interpretation of the forecast:

1. It will rain tomorrow in 30% of the region.
2. It will rain tomorrow for 30% of the time.
3. It will rain on 30% of the days like tomorrow.

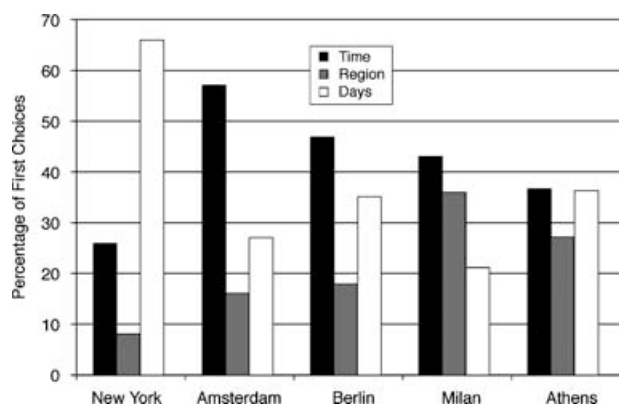
We refer to these as the "region," "time," and "days" interpretations, respectively. Each of these phrases is an abbreviation of the longer statement: if the weather conditions are like today, at least a minimum amount of rain will fall in 30% of the region, 30% of the time, or 30% of the days. In half of the Berlin sample, the order of these alternatives was counterbalanced, while in the other half the alternatives were listed in the order above. The order was found to have no effect on responses, and thus we used the above order for all other cities. Participants were then requested to provide their own interpretation of the statement in a free-response format. Finally, they were asked: "Assume that you have to run an errand and it will take you about an hour to walk to the store and to return. At what probability of rain will you take an umbrella with you?" The total number of participants was 750.

### 4. WHAT DO PEOPLE THINK A 30% CHANCE OF RAIN MEANS?

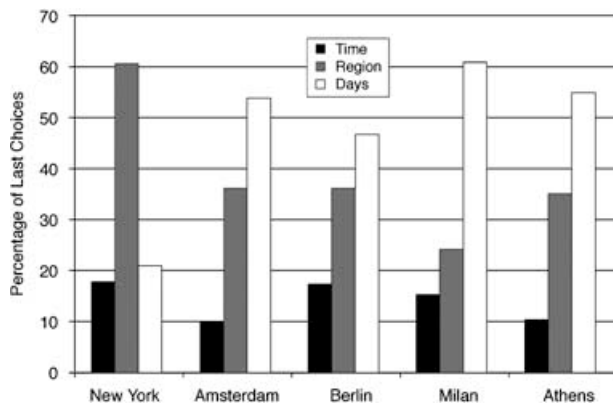
Fig. 1 shows that, as the correct interpretation, two-thirds of the respondents in New York chose days, about one-quarter chose time, and a few chose region. In none of the European cities, in contrast, did a majority of respondents select the days interpretation. The favored interpretation in Amsterdam, Berlin, Milan, and Athens was time.

As Fig. 2 reveals, the days interpretation is polarizing. It is often judged as the best (in New York) or the worst (in the European cities), but rarely as the second-best. For instance, consider the different distributions of first and last choices among the participants in Athens. Their first choices (Fig. 1) were fairly uniformly distributed, consistent with Greeks' lack of exposure to probabilities of rain in weather forecasts. However, it is the days interpretation (Fig. 2) that makes least sense to the participants in Athens, and the same holds for the other three European cities. As one Milanese expressed it, "A percentage of days is most absurd." Many people thought that the forecast refers to when, where, or how much it will rain tomorrow. Figs. 1 and 2 illustrate that lay interpretations of rain probability in the European cities diverge substantially from the meaning intended by meteorologists.

Does the prevalence of the days interpretation increase with a country's length of exposure to weather forecasts that include rain probability? Fig. 1, which orders the cities according to exposure, shows that



**Fig. 1.** First choice. People in New York ( $n = 103$ ), Amsterdam ( $n = 117$ ), Berlin ( $n = 219$ ), Milan ( $n = 203$ ), and Athens ( $n = 108$ ) were asked what the statement "There is a 30% chance of rain tomorrow" refers to. The three alternatives were "It will rain tomorrow for 30% of the time," "in 30% of the region," and "on 30% of the days like tomorrow."



**Fig. 2.** Last choice. For each alternative, the percentage of people is shown who chose it as the *least* appropriate one.

the prevalence of the days interpretation in the five countries is not positively correlated with length of national exposure. Only the high frequency in New York fits the national-exposure hypothesis.

To test the individual-exposure hypothesis, we measured the proportion of each participant's life during which he or she had been exposed to weather forecasts expressed in probabilistic terms. This continuous measure ranged from 0 for all respondents in Greece and Italy (where probabilistic forecasts have not been introduced into the mass media) to 1 for people who both resided in the United States, the Netherlands, or Germany (where probabilities are routinely reported in mass media weather forecasts) and who were born after probabilities of rain were introduced (e.g., for New Yorkers, after 1965). Consistent with the individual-exposure hypothesis, the proportion of individual exposure was positively related to choosing the days interpretation ( $r = 0.2, p = 0.0001$ ), negatively related to choosing the region interpretation ( $r = -0.2, p = 0.0001$ ), and unrelated to choosing the time interpretation ( $r = -0.02$ ). Although these correlations are statistically significant, they are small in magnitude, indicating that exposure to probabilities of rain *per se* affords little opportunity to learn what they really mean.

When people answered the open question, they often simply restated the probability (e.g., "a 3 in 10 chance of raining tomorrow"). If they referred to a reference class, they mostly referred to time, region, and days, but a few referred to other classes of events. Several people in New York and Berlin, for instance, thought that the rain probability statement means "3 out of 10 meteorologists believe it will rain." A woman in Berlin said, "Thirty percent means that

if you look up to the sky and see 100 clouds, then 30 of them are black." Participants in Amsterdam seemed the most inclined to interpret the probability in terms of the amount of rain. "It's not about time, it indicates the amount of rain that will fall," explained a young woman in Amsterdam. Some people seemed to intuitively grasp the essence of the "days" interpretation, albeit in imaginative ways. For instance, a young woman in Athens in hippie attire responded, "If we had 100 lives, it would rain in 30 of these tomorrow." One of the few participants who pointed out the conflict between various interpretations observed, "A probability is only about whether or not there is rain, but does not say anything about the time and region." Another said, "It's only the probability that it rains at all, but not about how much." Many participants acknowledged that, despite a feeling of knowing, they were incapable of explaining what a probability of rain means. Borrowing Judge Potter Stewart's remark in a landmark court case, a 74-year-old New York man explained, "It's like with pornography; you can't define it, but you know it when you see it."

Do people who interpret probabilities of rain differently have different thresholds for taking an umbrella? Across all cities, the average threshold among respondents who chose the days interpretation was 55.9%; the time interpretation, 53.5%; and the region interpretation, 50.6%. In terms of effect sizes, the differences between the thresholds for days as opposed to region and time are small ( $d = 0.25, p = 0.05$ ;  $d = 0.11$ ; see Cohen, 1988). This result is consistent with the fact that the days interpretation implies only a possibility of rain; it may not rain at all. To someone who makes the region or time interpretation, in contrast, the only uncertainty is where and for how long it will rain.

## 5. WHY DOES THE GENERAL PUBLIC STILL NOT UNDERSTAND?

Twenty-three years after Murphy *et al.*'s (1980) study, some two-thirds of the New Yorkers we surveyed interpreted a probability of rain as intended by meteorologists, but only one-third to one-fifth of respondents in Amsterdam, Berlin, Milan, and Athens did so. The inclusion of quantitative probabilities in weather forecasts has been advocated because probabilities can "express the uncertainty inherent in forecasts in a precise, unambiguous manner, whereas the crude measure of uncertainty represented by traditional forecast terminology is subject to a wide range of misinterpretations" (Murphy *et al.*, 1980,

p. 695). If probabilities are really unambiguous, one may ask why probabilistic forecasts are still so widely misunderstood. Our data point to some potential explanations.

**6. MISSING AND CONFLICTING INFORMATION FROM METEOROLOGICAL AUTHORITIES AND MASS MEDIA**

In each of the European countries represented in this study, we consulted representatives of local meteorological authorities and perused weather forecasts in daily newspapers. Consider the Dutch case first.

In the Netherlands, chances of rainfall have been communicated to the public since 1975, when an automated prediction model began to be used by meteorological experts. On television and to some extent in newspapers, however, forecasts are mostly presented in terms of the amount of rain expected (e.g., “1 mm rain expected tomorrow”) rather than in terms of a probability. Often, the expected time of day when the rain will start is also presented, as in the following newspaper report: “In the morning it will remain dry, but during the afternoon, there is a fair chance that some showers will occur locally.” This statement appeared next to a table with expected chances (60%) and expected amount of rain (2 mm). When quantitative probabilities are used, they are sometimes accompanied by a verbal explanation. Consider how the official weather forecast website of the Dutch Meteorological Institute (KNMI, 2002) explains what a probability of rain means:

If the chance exceeds 90%, then one can count on rain in every region in Holland. The higher the percentage, the more certain the meteorologist is that it will rain. Some examples:

|        |                       |                           |
|--------|-----------------------|---------------------------|
| 10–30% | Almost none           | Almost nowhere            |
| 30–70% | Possible              | In some places            |
| 70–90% | There’s a fair chance | In almost all the regions |

Note that the introductory text refers to meteorologists’ degree of certainty while the descriptive labels refer to the number of regions in which it will rain, thus misleadingly suggesting that probabilities of rain pertain to meteorologists’ degree of certainty and to the size of the affected region. As Dr. Robert Mureau of the Royal Dutch Meteorological Institute explained: “We are aware of the fact that probabilities are not very well understood by the general public. We ourselves have not been very clear about

the terminology definitions either, which might have caused even more confusion. We do sometimes ask people, including meteorologists, about their understanding of the forecasts, and the confusion about probabilities is striking—people mention the portion of time, region, or one out of ten” (personal communication, 2002; see also Floor, 1992). These observations illustrate that the Dutch public is exposed to various aspects of rain forecasts—including amount and meteorologists’ confidence—but that efforts to clarify which aspects a probability of rain refers to have been confusing.

Although television, radio, and newspaper weather forecasts in Italy are largely devoid of probabilities, we found Italian websites that aim to explain what probabilities of rain mean and explicitly warn of the potential for reference class confusion. The website of Sirmione, a town on Lake Garda, for example, says: “The probability of precipitation does not specify the duration and quantity of the precipitation, nor its exact location. A probability of 70% does not mean that it will rain for 70% of the time, or that there will be rain in 70% of the region, but rather that somewhere in this region there are 7 out of 10 chances of rain.” Another site cautions: “A probability of rain specified for the entire day and for the whole region does not coincide with the probability that it will rain only in the morning in a smaller part of the region” (Comune di Prato, n.d.). Although these authorities make an effort to spell out what probability of rain is not, the responses of our Italian participants indicate that they had only limited impact. Why are mass media weather forecasts in Italy probability-free? An Italian meteorologist explained that the media abhor uncertain predictions. When a meteorologist provides percentages, Italian journalists dichotomize the percentages into “it will rain or it will not rain.”

In Germany, the use of probability in mass media weather forecasts is only somewhat more advanced. We found that a few of the major German newspapers report probabilities of precipitation; the same holds for radio and television stations. And when probabilities of rain are reported, their meaning is rarely explained. For instance, the *Berliner Morgenpost* reports the probability of precipitation every day using a pictorial representation of a dial, but there is never an explanation of it or any reference to this probability in the weather section in which it appears. Similarly, *infoRadio*, the major Berlin news station, broadcasts probabilities of rain without explanation. In the words of Kirk and Fraedrich from the Meteorological

Institute of the University of Hamburg: “Today, probabilities of precipitation have become entrenched in the daily forecasts in the press and radio. However, they are not unproblematic, because we are lacking a unique definition of probabilities of precipitation, and in most cases, it is only a subjective estimate of the consulting meteorologist. Furthermore, the probability is often confused with a spatial or temporal frequency distribution” (Kirk & Fraedrich, n.d.).

According to two experts of the General Secretary for Civil Protection of the Greek Ministry of Internal Affairs, Greek meteorologists rarely use numerical probabilities: “There is considerable disagreement among meteorologists about what numerical probabilities of rain might mean or how they could be derived. . . . It is not uncommon that, just before the time the forecast has to be broadcasted on T.V., a number of meteorologists meet to discuss and debate their opinions, and finally reach a consensus about the forecast.”

These interviews and media analyses reveal three practices that fuel the public’s confusion about what probabilities of rain mean. First, in countries such as Greece, probabilities of rain are simply not provided to the public. Note that this also holds to some degree in other countries, where only some mass media use probabilities. Second, when probabilistic weather forecasts are provided, they are typically presented without explaining what class of events they refer to. Third, in the rare cases where an explanation is presented, it sometimes specifies the wrong reference class. The way to resolve these confusing and contradictory signals is straightforward: always communicate the reference class to which probabilities of precipitation pertain.

## 7. A COMPARISON WITH MURPHY *ET AL.*’S (1980) ANALYSIS

In response to the question of whether the public is “confused about the meaning of probabilities or about the definition of the event to which the probabilities refer” (p. 695), Murphy *et al.* concluded that the event, not the probabilities, is misunderstood. Consistent with this conclusion, a majority of participants in our study correctly rephrased the probability portion of the statement as a relative frequency (“it will rain in 3 out of 10 days”), a single-event probability (“a 3 in 10 chance of raining tomorrow”), or odds (“odds are 7 to 3 that it won’t rain”). Only a few of them confused probabilities with odds (“the

odds are 3 to 10”; on odds see Thornes & Stephenson, 2001).

Although we agree with Murphy *et al.* on what is not the problem, our results and interpretation of what is the problem differ from theirs. Murphy *et al.* asked students what a “precipitation probability forecast of 30% means” and gave four choices. One of them corresponded to the time interpretation and another to the area interpretation. The other two were:

At any one particular point in the forecast area (for example, at your house) there is a 30% chance that there will be measurable precipitation and a 70% chance that there will be no measurable precipitation during the forecast period,

and

There is a 30% chance that measurable precipitation will occur *somewhere* (i.e., in at least one place) in the forecast area during the forecast period, and a 70% chance that it will not occur anywhere in the area during the period. (p. 700, italics in the original)

Based on their finding that 39% and 56% of the students, respectively, thought that the alternatives quoted verbatim above were correct, Murphy *et al.* concluded that the problem was the lack of distinction between “precipitation at a particular point in the forecast area” and “precipitation somewhere in the forecast area.” Whereas they identified the first one as correct, the majority of students opted for the second one. The “time” and “area” interpretations were each chosen by only 3% of their college students.

Why were these results so different from ours? It may have to do with the difference between college students and the general public, or with the simple fact that the two options endorsed most frequently in Murphy *et al.*’s study were longer and more elaborately phrased (they added clarifications in parentheses) than the “time” and “area” alternatives. Also, if we compare our New York sample with Murphy *et al.*’s data, the difference is smaller than in the international comparison.

For Murphy *et al.*, the problem lies in the definition of the event. In their interpretation, “a probability of 3/10 means that the forecaster is indifferent between receiving three dollars for sure and receiving ten dollars if measurable precipitation occurs. This forecast is for the *unique* situation . . . not for a large collection of similar situations” (Murphy & Winkler, 1971, p. 241). Yet the accuracy of a weather forecaster is measured on a

class of events, such as all days where a minimal amount of rain was predicted (Thornes, 1996). Thus, the problem may not only be in the definition of the event, but also with the specification of the class of events, as we propose. In the two interpretations cited above, the events are singular (“at any one particular point . . .”) and it is not immediately clear to John Q. Public what reference class, if any, this definition refers to.

## 8. REFERENCE CLASSES IN RISK COMMUNICATION

In 1995, the World Meteorological Organization (WMO) estimated the global budget for weather services at approximately \$4 billion (Sherden, 1998). We have shown that, despite impressive technologies that allow meteorologists to produce these probabilities, the public understands probabilities of rain in multiple ways, such as referring to “days,” “regions,” “time,” or “meteorologists.” The present analysis suggests a simple solution to the problem. Misunderstandings can be easily reduced if a statement specifying the intended reference class is added. For instance, the rain forecast might say “There is a 30% probability of rain tomorrow. This percentage does not refer to how long, in what area, or how much it rains. It means that in 3 out of 10 times when meteorologists make this prediction, there will be at least a trace of rain the next day.”

The ambiguity of a single-event probability and the resulting possibility of miscommunication about risks is not limited to weather forecasts (Budescu & Wallsten, 1995; Gigerenzer *et al.*, 1991). Far-reaching consequences arise, for instance, when single-event probabilities are used by expert witnesses to explain DNA evidence in court (Koehler, 1996), by clinical psychologists and psychiatrists to predict the possibility that a mental patient will commit violent acts (Slovic *et al.*, 2000), and by medical organizations to communicate the benefits and risks of treatments (Gigerenzer, 2002).

Many risk experts and meteorologists promote quantitative probabilities because they believe that numbers are more precise and convey more information to the public than qualitative risk statements (Monahan & Steadman, 1996; Murphy & Winkler, 1971). This is only partly true. Quantitative probabilities will continue to confuse the public as long as experts do not spell out the reference class when they communicate with the public.

## ACKNOWLEDGMENT

We thank Valerie M. Chase for her comments on the article.

## REFERENCES

- Budescu, D. V., & Wallsten, T. S. (1995). Processing linguistic probabilities: General principles and empirical evidence. In J. R. Busemeyer, R. Hastie, & D. Medin (Eds.), *Decision Making from the Perspective of Cognitive Psychology: The Psychology of Learning and Motivation* (pp. 275–318). New York: Academic Press.
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. Hillsdale, NJ: Erlbaum.
- Comune di Prato. (n.d.). Retrieved December 4, 2003, from <http://www.comune.prato.it/associa/cai/htm/bolmeteo.htm>.
- Floor, C. (1992). Kans op regen. *Zenit*. Retrieved December 1, 2003, from <http://www.knmi.nl/~floor/artikelen/kans&eps.htm>.
- Gigerenzer, G. (2002). *Calculated Risks: How to Know When Numbers Deceive You*. New York: Simon & Schuster (UK edition: *Reckoning with Risk: Learning to Live with Uncertainty*. London: Penguin 2002).
- Gigerenzer, G., Hoffrage, U., & Kleinbölting, H. (1991). Probabilistic mental models: A Brunswikian theory of confidence. *Psychological Review*, 98, 506–528.
- Kirk, E., & Fraedrich, K. (n.d.). *Prognose der Niederschlagswahrscheinlichkeit: Modelle und Verifikation [Precipitation Probability Forecasting: Models and Verification]*. Retrieved December 9, 2003 from Meteorological Institute, University of Hamburg, Germany: <http://puma.dkrz.de/theomet/prognosen/paper.html>.
- KNMI. (2002). *Het weer nader verklaard: Neerslagkans [The Weather Explained: Precipitation Chances]*. Retrieved May 5, 2003 from <http://www.knmi.nl/voor/nader/neerslagkans.htm>.
- Koehler, J. J. (1996). On conveying the probative value of DNA evidence: Frequencies, likelihood ratios, and error rates. *University of Colorado Law Review*, 67, 859–886.
- Monahan, J., & Steadman, H. J. (1996). Violent storms and violent people. *American Psychologist*, 51, 931–938.
- Murphy, A. H., Lichtenstein, S., Fischhoff, B., & Winkler, R. L. (1980). Misinterpretations of precipitation probability forecasts. *Bulletin of the American Meteorological Society*, 61, 695–701.
- Murphy, A. H., & Winkler, R. L. (1971). Forecasters and probability forecasts: Some current problems. *Bulletin American Meteorological Society*, 52, 239–247.
- National Research Council. (1989). *Improving Risk Communication*. Washington, DC: National Academy Press.
- National Weather Service Tulsa. (1998). *General Forecast Terminology and Tables*. Retrieved May 5, 2003, from [http://www.srh.noaa.gov/tulsa/forecast\\_terms.html#pop](http://www.srh.noaa.gov/tulsa/forecast_terms.html#pop)
- Sherden, W. A. (1998). *The Fortune Sellers: The Big Business of Buying and Selling Predictions*. New York: Wiley.
- Shuman, F. G. (1989). History of numerical weather prediction at the National Meteorological Center. *Weather and Forecasting*, 4, 286–296.
- Slovic, P., Monahan, J., & MacGregor, D. G. (2000). Violence risk assessment and risk communication: The effects of using actual cases, providing instructions, and employing probability versus frequency formats. *Law and Human Behavior*, 24, 271–296.
- Thornes, J. E. (1996). The quality and accuracy of a sample of public and commercial weather forecasts in the UK. *Meteorological Applications*, 3, 63–74.
- Thornes, J. E., & Stephenson, D. B. (2001). How to judge the quality and value of weather forecast products. *Meteorological Applications*, 8, 307–314.

