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What makes risk acceptable? Revisiting the 1978 psychological dimensions of perceptions of technological risks

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ABSTRACT

The complex nature of perceived risk and the influence of perceived risks and benefits on risk acceptability or risk taking have been analyzed in multiple ways. R. Duncan Luce made important contributions to both normative and descriptive models of quantitative definitions of risk and risk acceptability, concentrating on the effects of possible outcomes and their probability. Fischhoff, Slovic, and Lichtenstein, in contrast, assessed a set of qualitative and affective dimensions of perceived technological and social risk and analyzed their effects on perceived risk and risk acceptability. The current research presents a minimally modified replication of their 1978 study, eliciting risk perceptions from a diverse group of US residents. After almost 40 years, we find a pattern of rank-ordered risk perceptions that remains practically unchanged, and is still explained by two factors: dread and uncertainty. We find, however, that today dread risk shows a greater influence than it did in the original study, and now reflects stronger contributions of the voluntary and uncontrollable risk characteristics. We end by reflecting on the mutual impact of different types of risk research and point out promising future research directions.

Throughout his career, R. Duncan Luce took a strong interest in risky decisions, from modeling risk taking early on (Luce & Raiffa, 1957) to later axiomatizing subjective perceptions of risk (Luce & Weber, 1986). Most recently he proposed a *p*-additive utility theory (Luce, 2010a,b) with three distinct representations that correspond to averse, neutral, or seeking risk attitude. Davis-Stober and Brown (2013) extended this work by allowing that decision makers may not have an invariant risk attitude across different situations.

The conjoint-expected-risk (CER) axiomatic model of perceived risk makes risk a more complex construct than variability of outcomes, allowing probabilities of gains or losses to affect perceived risk directly and allowing for a differential effect of upside and downside variability, with potential individual, group, or situational differences in the weight of these components on perceived risk (Luce & Weber, 1986). Weber, who developed the CER model with Luce, has modeled the subjective nature of risk in multiple other ways. A risk–return framework generalized from Markowitz (1952) – where people's willingness to pay (WTP) for risky option X is a tradeoff between the option's expected value (return) and variance risk – allows for return and risk estimates not necessarily equal to the moments of the outcome distribution or even measured on quantitative scales (Weber & Milliman, 1997). Here risk attitude determines the trade-off between risk and return:

$$\text{Risk Taking} = f(\text{Perceived Return, Perceived Risk, Risk Attitude}). \quad (1)$$

For example,

$$\text{WTP}(X) = V(X) - bR(X), \quad (2)$$

where b describes the tradeoff between the maximization of return and minimization of risk and measures a person's risk attitude. Factors such as familiarity which will vary between choice domains, often moderated by demographic factors such as gender or age, have been shown to influence perceptions of risk and of benefits (see Figner & Weber, 2011, for a recent summary).

In their domain-specific risk-taking (DOSPERT) framework, Weber, Blais, and Betz (2002) employed the same decomposition of risk taking (RT) as a tradeoff between perceived risks (PR) and perceived benefits (PB) of risky choice options:

$$\text{RT}(X) = \text{PB}(X) - b\text{PR}(X), \quad (3)$$

to account for domain-variant risk taking while still allowing for a domain-general individual difference risk-attitude parameter, b.

Domain-specific differences in risk taking, from recreational choices to financial, social, health/safety, and ethical decisions, can

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be explained by domain-specific differences in perceived risk (Weber et al., 2002) or perceived benefits (Hanoch, Johnson, Wilke, 2006). In addition, risky decisions also differ by the degree to which they involve "hot" affective processes or "cold" deliberative processes (Figner, Mackinlay, Wilkening, & Weber, 2009). "Risk as feelings" is a sufficiently widespread phenomenon to be the title of a widely-cited review paper (Loewenstein, Weber, Hsee, & Welch, 2001). Analytic consideration of risk has a long history and are captured in a normative fashion by the variance of outcomes in the risk–return models of finance and in a descriptive fashion by the CER model and the psychological risk–return framework. It is worth noting that emotional or affective considerations of risk were already examined and identified by Fischhoff, Slovic, Lichtenstein and colleagues in the 1970s, even if not explicitly presented in this light, and thus preceded the emotions revolution of the 1990s by a couple of decades.

Most if not all activities in everyday life carry some risk of harm. Driving a car could lead to a crash, taking a prescription antibiotic might cause unpleasant side effects, and living near a nuclear power plant increases the chances of radiation exposure. Different technologies vary both in their probability of causing death or injury and in the benefits they offer to society to make up for those costs—but they vary on many other dimensions as well, and these other dimensions may carry much more weight when it comes to our judgments about how risky different technologies seem or feel. For example, although many more people are killed or injured every year in car crashes than by nuclear power, the latter still often feels more unsafe.

In their 1978 paper "How Safe is Safe Enough?", Fischhoff, Slovic, Lichtenstein, Read, and Combs employed a psychometric analysis to model and help explain why different technologies and activities might inspire such different risk reactions. Taking the position that risk can vary across many characteristics—How immediately do the effects take place? How many people are affected at once? How controllable do the consequences feel?—Fischhoff et al. showed that perceptions of risk for everyday activities and technologies tend to load onto two orthogonal dimensions, which they called dread risk and unknown risk. Dread risk appeared to relate to consequences that are likely to be catastrophic, that are certain to be fatal, and that feel dreaded on a gut level. Unknown risks were those that are new, that are undertaken involuntarily, whose consequences are delayed, and which seem not fully known to science or to those exposed (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978). In later studies, similar sets of characteristics were found to load onto these factors: dread risk encompassing lack of control, catastrophic and fatal effects, a feeling of dread, and an imbalance in the distribution of risks and benefits; and unknown risk being associated with consequences that are unobservable, new, delayed, and unknown to science and the exposed (e.g., Slovic, 1987; Slovic, Fischhoff, & Lichtenstein, 1985, 1986).

Since the 1980s, hundreds of studies have cited the concepts of dread and unknown risk to illuminate risk perception on topics ranging from avian flu (Gstraunthaler & Day, 2008) to genetically modified foods (Gaskell et al., 2004), to financial decisions (Koonce, McAnally, & Mercer, 2005). Other studies have investigated risk perception cross-culturally using Fischhoff et al.'s (1978) framework in countries such as Norway (Teigen, Brun, & Slovic, 1988), Hungary (Englander, 1986), and Korea (Cha, 2000). However, little work has shown how perceptions of risks for everyday technologies and activities have changed (or not) over the past three decades, aside from studies looking at relatively specific domains (e.g., a study of food-related hazards by Sparks & Shepherd, 1994).

We therefore have little idea of how risk perceptions or attitudes may have shifted over time. Since the 1980s, the objective risks of many of the 30 items that Fischhoff et al. (1978) studied have in fact changed, as have the media culture and public knowledge about these risks. New technologies have emerged during the intervening decades, bringing new risks to public awareness and likely influencing public opinion about older technologies. Between the emergence of the 24-hour news cycle in the 1980s, the rise in awareness of global terrorism in the United States since 2001, and the information-sharing culture encouraged by social networking, it is reasonable to expect changes between 1978 and today in terms of the psychological availability of various social and technological risks, as well as the public's knowledge about and attitudes toward those technologies.

The goals for this study were to replicate Fischhoff et al.'s 1978 study, and to offer a descriptive look at how risk perceptions for a set of 30 activities and technologies have appear to have changed over the past several decades. While we did not expect that people today would show the same risk perceptions for those 30 items as people did in the 1970s, we did believe that the two-factor expressed preference framework that Fischhoff and colleagues developed would still be effective today to illustrate and partially quantify those perceptions of risk.

1. Method

We matched the design and content of this study as closely as possible to Fischhoff et al. (1978), referred to hereafter as FSLRC78. There are, however, two differences in method between the current version of the study and the original one: one in elicitation medium (now online vs. before on paper) and the other in participant population (now a diverse US sample vs. before Oregon League of Women Voters members and their husbands).

1.1. Design

Following FSLRC78, Ps evaluated 30 activities and technologies on multiple dimensions: (1) the technology/activity's perceived benefit (risk) to society; (2) the acceptability of the technology/activity's current level of risk; and (3) its placement on each of nine dimensions of risk. The first part of the study was varied between Ps: some judged only the perceived benefit of each activity or technology, while others judged only the perceived risk. All Ps then answered the same questions in Parts 2 and 3.

The list of 30 activities/technologies for Ps to judge was copied exactly from Fischhoff et al., and can be seen in Table 1. For each task in the study, the order in which the 30 activities/technologies appeared was counterbalanced in a blocked Latin square design: five blocks of six items each were shuffled so that each activity/technology appeared early in the list for some Ps, in the middle of the list for others, and at the end of the list for others. No order effects were detected, so order will not be discussed below.

Matching the instructions used by FSLRC78, our Ps were told before they began their evaluations that "This is a difficult, if not impossible, task. Nevertheless, it is not unlike the task you face when you vote on legislation pertaining to nuclear power, handguns, or highway safety. One never has all the relevant information; ambiguities and uncertainties abound, yet some judgment must be made. The present task should be approached in the same spirit".

1.2. Tasks

1a. **Perceived benefit**. Participants in the *benefits* condition were asked to judge the benefits to society of each of the 30 activities or technologies. For each, Ps were asked to "consider all types of benefits: how many jobs are created, how much money is generated directly or indirectly (e.g., for swimming, consider the manufacture and sale of swimsuits), how much enjoyment is

Table 1
Mean judgments of risk and benefit from 30 activities and technologies.

	Activity or technology	Perceived benefit (geometric mean)	Perceived risk	Risk adjustment factor (geometric mean)		Acceptable level of risk	
				Risk Ps	Bene. Ps	Risk Ps	Bene. Ps
1	Alcoholic beverages	20	39	1.0	1.0	39.1	39.3
2	Bicycles	36	20	1.6	1.1	12.8	17.7
3	Commercial aviation	51	34	0.7	0.8	46.4	41.9
4	Contraceptives	50	17	1.8	1.5	9.5	11.9
5	Electric power	86	33	1.1	1.2	30.6	28.8
6	Fire fighting	59	56	1.4	1.6	40.4	35.4
7	Food coloring	17	17	3.0	2.8	5.5	6.0
8	Food preservatives	41	17	1.1	1.4	15.1	12.2
9	General aviation	41	37	2.5	2.2	14.5	16.4
10	Handguns	26	77	1.1	1.0	67.7	73.6
11	HS & college football	22	25	0.9	1.0	27.7	26.1
12	Home appliances	42	19	0.9	1.2	22.6	16.3
13	Hunting	26	41	1.1	0.9	36.0	43.0
14	Large construction	55	38	2.7	1.5	13.9	25.0
15	Motorcycles	27	48	1.9	2.0	25.0	23.4
16	Motor vehicles	60	50	7.9	4.7	6.3	10.5
17	Mountain climbing	21	42	2.3	3.6	18.1	11.8
18	Nuclear power	58	64	2.5	2.7	25.5	24.1
19	Pesticides	32	31	0.7	1.1	44.5	29.5
20	Power mowers	27	30	0.9	1.5	32.1	19.3
21	Police work	61	54	12.4	14.7	4.4	3.7
22	Prescription antibiotics	62	20	2.3	1.5	8.5	13.0
23	Railroads	61	35	0.9	1.1	37.8	33.1
24	Skiing	21	29	12.1	7.1	2.4	4.0
25	Smoking	13	56	1.0	1.3	59.0	44.6
26	Spray cans	18	23	1.8	1.8	12.9	12.7
27	Surgery	75	45	3.4	2.6	13.4	17.2
28	Swimming	27	22	0.7	0.9	28.9	24.9
29	Vaccinations	70	20	1.6	1.9	12.2	10.6
30	X-rays	44	20	0.8	1.1	24.1	18.8
	Mean of all activities/technologies:	42.4	30.3	1.6	2.7		
	Coefficient of Concordance	0.50	0.37	0.28	0.21		

brought to people, how much of a contribution is made to the people's health and welfare, and so on''. Ps in this condition were instructed to ignore risks:

> Do not consider the costs of the risks associated with these activities or technologies. It is true, for example, that swimmers sometimes drown. But evaluating such risks and costs is not your present job. Your job is to assess the gross benefits, not the net benefits, which remain after the costs and risks are subtracted out. Remember that a beneficial activity affecting few people will have less gross benefit than a beneficial activity affecting many people. If you need to think of a time period during which the benefits accrue, think of a whole year—the total value to society from each activity or technology during one year.

The wording used for these instructions matched, as closely as possible, the language used by FSLRC78. Some changes were made to better fit the online nature of the task, e.g., asking Ps to click on the name of an activity/technology to place it into a ranked list, rather than moving index card into place to determine the rankings of the 30 items.

Ps were instructed to first "study each activity or technology individually, thinking of all the benefits of each''. Then Ps were asked to place the 30 activities/technologies in order of increasing benefit by clicking on each of the 30 items to move it into their ranked list. Ps could adjust the list until they felt it accurately reflected their judgments of the rankings of benefit. Once this had been done, Ps were asked to assign a numerical value for the perceived benefits of each item, with the least beneficial (the first item on their list) assigned the value of 10, and other items judged relative to that. Ps were encouraged to take their time on this portion of the task, and given detailed instructions about how to assign values:

> If you feel that an item is twice as beneficial as the least beneficial item, assign it a 20. This means that a rating of 12 indicates that the item is 1.2 times as beneficial as the least beneficial item (this means it is 20% more beneficial). A rating of 200 means that the item is 20 times as beneficial as the least beneficial item, to which you assigned a 10. Please take some time on this question, and double-check your ratings to make sure that they are consistent. For example, if one activity is rated a 50 and a second is rated 100, the second item should seem twice as beneficial as the first. Adjust the numbers until you feel that they are right for you.

1b. **Perceived risk**. Participants in the *risks* condition were given very similar instructions to those of the *benefits* Ps, except that they were asked to consider the "the risks of the activities and technologies listed below. Consider the risk of dying as a consequence of this activity or technology. For example, use of electricity carries the risk of electrocution. It also entails risk for miners who produce the coal that generates electricity. Motor vehicles entail risk for drivers, passengers, bicyclists, and pedestrians, etc.''. Just as the *benefits* Ps were instructed not to consider risks, the *risks* Ps were instructed that "Your job is to assess the gross risks, not the net risks which remain after the benefits are subtracted out''. As before, the language used in this section was modeled on the task used by FSLRC78.

2. **Risk adjustment factor**. After judging *either* the risks or benefits of the 30 activities and technologies, all Ps were asked to decide for each activity/technology "whether the associated risks are either too high, at an acceptable level, or too low''. As in FSLRC78, Ps were told:

> Almost any activity or technology carries some amount of risk, but this is not the ideal risk. Ideally, the risks should be zero. The acceptable level is a level that is "good enough'', where "good

enough" means you think that the advantages of increased safety are not worth the costs of reducing risk by restricting or otherwise altering the activity. For example, we can make drugs "safer" by restricting their potency; or lower speed limits to make cars safer, but all of these improvements come at a price. We may, or may not, feel restrictions are necessary. If an activity's present level of risk is acceptable, no special action need be taken to increase its safety. If its riskiness is unacceptably high, serious action, such as legislation to restrict its practice, should be taken. On the other hand, there may be some activities or technologies that you believe are currently safer than the acceptable level of risk. For those activities, the risk of death could be higher than it is now before society would have to take serious action.

For each activity or technology, Ps could choose among "(a) Could be riskier", or "(b) It is presently acceptable", or "(c) Too risky". If (a) was selected, an additional question appeared on the screen, asking the *P* to fill in the blank in the statement "It would be acceptable if it were _____ times riskier". If (c) was selected, the *P* instead saw the question "To be acceptable, it would have to be ____ times safer". If (b) was selected, no additional questions appeared, and the *P* would move on to judging the risks of the next activity or technology. As piloting revealed this task to be taxing, the 30 items in this section appeared in blocks of 6 items on 5 separate pages, allowing Ps to take a short break between blocks if they wished.

3. **Characteristics of risk**. In the final section, Ps were asked to judge each technology or activity on each of nine scales representing different characteristics of risk. Each characteristic, measured on a seven-point scale, was assessed for all 30 activities/technologies before moving on to the next characteristic. The order and wording of the nine scales closely matched those used in the original 1978 study:

1. How Voluntary is the Risk? For the activities and technologies listed below, please indicate whether you think people take on the potential risks voluntarily. If for a particular activity some of the risks are voluntarily undertaken and some are not, choose an appropriate rating toward the center of the scale. (1 = voluntary, 7 = involuntary).
2. How Immediate is the Risk? For the activities and technologies listed below, to what extent is the risk of death or injury immediate—or is death or injury likely to occur at some later time? (1 = immediate, 7 = delayed).
3. Knowledge About Risk: For the activities and technologies listed below, to what extent are the risks known precisely by the persons who are exposed to those risks? (1 = known precisely, 7 = not known).
4. Scientific Knowledge About Risk: For the activities and technologies listed below, to what extent are the risks known to science? (1 = known precisely, 7 = not known).
5. Control Over Risk: If you are exposed to the risk of each activity or technology listed below, to what extent can you, by personal skill or diligence, avoid death or serious injury while engaging in the activity? (1 = uncontrollable, 7 = controllable).
6. Newness of Risk: For the activities and technologies listed below, are the risks new and novel ones, or old and familiar ones? (1 = new, 7 = old).
7. Chronic vs. Catastrophic Risk: For the activities and technologies listed below, is it a risk that kills people one at a time (a chronic risk, meaning the risk is continual over time) or a risk that kills large numbers of people at once (a catastrophic risk)? (1 = chronic, 7 = catastrophic).
8. Common Risk vs. Dread Risk: Is each of the activities and technologies listed below a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for—on the level of a gut reaction? (1 = common, 7 = dread).
9. Severity of Consequences: And finally, when the risk of each activity is realized in the form of a mishap or illness, how likely is it that the consequences will be fatal? (1 = certain not to be fatal, 7 = certain to be fatal).

After completing these three parts of the study, Ps answered basic demographic questions and received debriefing information. Ps were paid $3 for participation in the study.

1.3. Participants

The 83 participants (Ps) were recruited through Amazon's Mechanical Turk online labor market in August of 2013. Mean completion time for the study was about 90 min. We omitted data from any Ps whose answers to attention-check questions indicated that they were clearly not reading instructions: eight Ps were removed from analysis in this way. This relatively low rate is consistent with recent research indicating that MTurk participants may be more attentive to instructions than undergraduates completing studies in person (Ramsey, Thompson, McKenzie, & Rosenbaum, 2016).

Of the remaining 75 Ps (36 female, 37 male, 2 unspecified), 42 were randomly assigned to the "benefits" condition, and 33 Ps to the "risks" condition. Ps' mean age was 36.1 ($sd = 12.5$), with 57.5% having earned a bachelor's or associate's degree, 27.4% having earned a high-school diploma, and 15.1% having earned a master's degree or higher. These demographics make our sample reasonably representative of the United States population overall,[1] which is consistent with general findings that participants recruited on MTurk are much more diverse than the typical sample of college students and are slightly more diverse than other online samples (see, e.g., Buhrmester, Kwang, & Gosling, 2011). The political beliefs of our Ps, on the other hand, skew more liberal than the US population: 52.1% identify as Democrats, 30.1% identify as Independents, and 16.4% identify as Republicans, compared to a nationwide average of 31% Democrats, 43% Independents, and 24% Republicans in August of 2013 (Gallup, 2015).

FSLRC78 do not provide a specific breakdown of demographic information on their sample population, so we cannot directly compare our sample to theirs. We must therefore be cautious when comparing the results of the two studies. But based on the fact that the 1978 participants were members of the League of Women Voters and their spouses, we make two assumptions about the comparability of the two samples. One assumption is that the Oregon League of Women Voters shared our participants' leftward lean in politics (at least in direction of skew, if not in strength), in line with FSLRC78's description of the League as "a generally liberal, environmentally minded group". Such a skew would lead us to expect similar priorities in attitudes across the two groups, and therefore a similar rank-ordering of items in terms of perceived risk. The second assumption is that the population of the League of Women Voters in Oregon is likely more homogeneous, and less nationally representative, than our sample of MTurk workers from across the US. We would therefore expect our relatively more diverse sample to show more heterogeneity in their risk perceptions and attitudes.

2. Results and discussion

2.1. Perceived risk and benefit

Geometric means of perceived risk and perceived benefit for each of the 30 activities/technologies are shown in Table 1.

[1] As of 2013, 29.5% of US adults over 18 had a high-school diploma, 28% had a bachelor's or associates degree, and 10.2% had a master's degree or higher, per: https://www.census.gov/hhes/socdemo/education/data/cps/2013/tables.html.

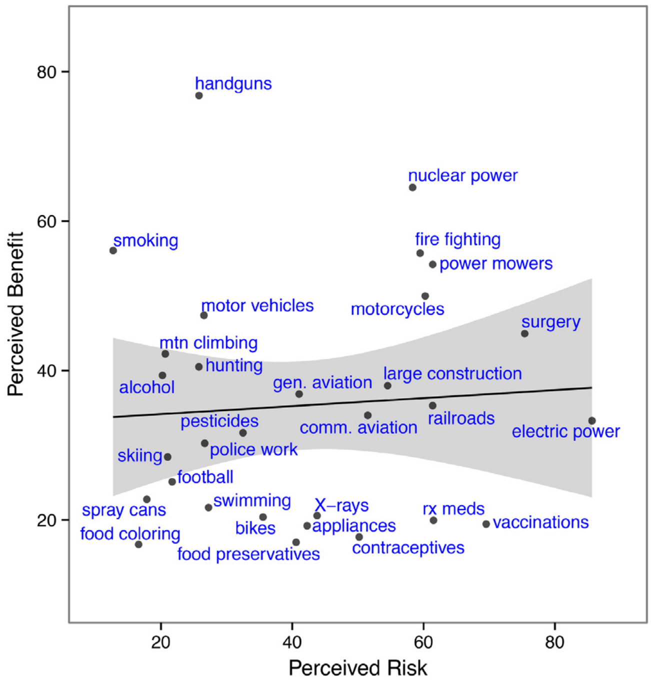

Fig. 1. Relationship between perceived risk and perceived benefit. Linear model shows no significant correlation: $y = 33.1 + 0.054x$, $r^2 = 0.005$, $p > 0.10$.

The range of judgments of perceived benefit and perceived risk in our study is much smaller than in Fischhoff et al. (1978) (FSLRC78): maximum benefits and risks in FSLRC78 were 274 and 250, respectively; here they were 86 and 77 (see supplementary material for a table comparing Table 1 between 1978 and the current study). Neither study constricted the range for perceived risk and benefit values, except to specify that the lowest-ranked item for risk (or benefit) should be assigned a value of 10, and that other judgments should be made based on that value. Participants could, therefore, assign to risks and benefits any value between 10 and infinity.

Although our Ps used a more limited range of values, the activities/technologies' rank order for the 1978 results and the current data correlate strongly with each other (for benefits: $\rho = 0.91$, $p < 0.001$; for risks: $\rho = 0.83$, $p < 0.001$). That is, across both studies the same activities/technologies in both studies fall in roughly the same order. As a result, we see similar items appearing at both extremes of the perceived benefit scale (lowest benefit: smoking, food coloring, spray cans; highest benefit: electric power, vaccinations, antibiotics) just as the same activities/technologies tend to cluster at each end of the perceived risk ratings (lowest risk: food coloring & preservatives, appliances, vaccinations; highest risk: handguns, nuclear power, smoking).

Consistent with FSLRC78, there is no significant relationship in this study between perceived risk and benefit, as shown in Fig. 1. (For a comparison of risk and benefit ratings between 1978 and now, see supplementary material.)

2.2. Risk-adjustment factor

Judgments of whether the risks associated with each activity/technology "could be higher", "must be lower", or were "presently acceptable" were used to calculate a risk-adjustment factor (RAF) for each activity/technology for each *P*. For risks that a *P* considered too high, the RAF was calculated as the value they entered to finish the statement "must be __ _ times safer to be acceptable". For risks that a *P* believed could be higher, RAF was calculated as the multiplicative reciprocal of the value that finished the statement "would be acceptable if it were ___ times higher". For activities/technologies that Ps judged as "presently acceptable", RAF was set to 1.0. Thus, RAF values greater than 1.0 indicate that current risk of the activity or technology is too high and must be lowered, and RAF values less than 1.0 mean that the risk could be higher. Table 1 shows the geometric mean RAF for those Ps who had previously judged risks, versus those who had previously judged benefits (geometric means were used, as in FSRLC78, because they are more resistant to skewing by large outliers than arithmetic means are). The risk-adjustment task was identical for these two groups, and a paired *t*-test shows that RAF does not differ between the groups ($t(29) = 0.82$, $p > 0.05$).

Of the 2250 total risk judgments, 7.7% were "could be riskier", while 66.4% of judgments were "appropriately risky" and 25.8% were "should be safer". While the proportion of "could be riskier" activities/technologies does not appear to be substantially different from that same proportion in 1978 (Fischhoff et al. found it to be 10%), the values for the other two judgment categories represent a trend toward activities and technologies being judged as less risky since 1978: FSRLC78 found that only 40% of their Ps' judgments were "appropriately risky", while 50% were "should be safer".

There may be several reasons for this shift of activities/technologies from "should be safer" to "appropriately risky". It may be that the standard for acceptable risk levels has changed. Participants in the original 1978 study were "a generally liberal, environmentally minded group" drawn from a socially aware population (the Oregon League of Women Voters), and it is possible that such a population would set a lower threshold for what risk level constitutes "appropriately risky" vs. "should be safer". It is perhaps more likely, though, that the decrease in "should be safer" judgments is due to the fact that the risks for many of the 30 activities and technologies have indeed decreased over time, due to increased regulation or advances in technology. Smoking rates, for example, have nearly halved since the 1970s, dropping from 34% in 1978 to 19% in 2011 (CDC, 2011b), and although the risk of death among smokers rose precipitously between 1959 and 2010, the death rate attributed to smoking has dropped overall in that time period (USDHHS, 2014). Similarly, although handgun death rates remain higher in the United States than in many other Western nations, the per-capita risk of firearms death has dropped from a peak of 16 per 100,000 in 1975 to 10.4 per 100,000 in 2011 (CDC, 2011a; FICAP, 2011).

FSLRC78 found that the mean perceived risk ratings from the group that judged risk correlated significantly with mean RAF both among Ps who had originally rated benefits and those who had rated risks ($r = 0.75$ and $r = 0.66$, respectively). The greater the mean perceived risk of an activity, the more people would want that risk reduced (higher RAF scores indicate a greater desired reduction in risk), both for participants who had previously considered only the benefits and those who had only considered the risks of that activity. In the current study, in contrast, we did not see a significant correlation between RAF and perceived risk for either group: $r = 0.25$ for benefit Ps, $r = 0.19$ for risk Ps, both p's > 0.05. In other words, our participants did not feel that the higher-risk activities/technologies needed to be reduced proportionally more than the lower-risk activities/technologies. For example, although handguns were ranked as the technology with the highest perceived risk (77), the RAFs for handguns are 1.1 and 1.0, indicating that this high risk level is currently acceptable. Other activities/technologies with RAFs very close to 1 are smoking (perceived risk = 56), hunting (perceived risk = 41), alcohol (perceived risk = 39), and x-rays (perceived risk = 20). This range of risks that are all considered presently acceptable clearly illustrates the lack of correlation between perceived risk and RAF, even if it does not explain the disappearance of this effect since the 1978 study.

Following FSLRC78, a value for "level of acceptable risk" was calculated for each activity/technology by dividing its perceived risk (averaged across the Ps who judged risk) by the risk-adjustment factor (see the final two columns in Table 1). In this way, activities/technologies that were judged as currently too risky have a lower acceptable risk level than the current perceived risk, and activities/technologies that were judged as safer than necessary end up with an acceptable risk that is higher than the current risk. For example, motor vehicles received a risk score of 50 and a RAF of 7.9 from the Ps who judged risks, indicating that the risk would need to be nearly 8 times lower in order to be acceptable. This results in an acceptable risk score of 6.3, or ($50 \div 7.9$). On the other hand, pesticides, with their perceived risk of 31 and "could be riskier" RAF of 0.7, indicate an acceptable risk of 44.5, which is higher than the currently judged risk.

Fischhoff et al. (1978) found this mean acceptable risk level to correlate positively, if not strongly, with mean perceived benefit ($r = 0.42$ for Ps who had previously rated risks, and $r = 0.31$ for Ps who had previously rated benefits), i.e., that higher perceived benefits allowed for higher acceptable risk levels. Given that the current study found no relationship between perceived risk and RAF, it is not surprising that we fail to replicate these correlations with acceptable risk level, given our difference in RAF scores. The acceptable risks did not correlate with perceived benefit among Ps who had previously judged benefits ($r = -0.12$, $p = 0.39$), nor did they among Ps who judged risks ($r = -0.19$, $p = 0.22$). It is slightly surprising that both of these correlations would be negative when the original relationships were found to be positive (although weak), but given that neither relationship is statistically significant, we cannot read much into the apparent direction of the effects.

2.3. Inter-participant agreement

We find moderate inter-participant agreement for both perceived benefit and perceived risk across all 30 activities/technologies: Kendall's coefficient of concordance is 0.50 for perceived benefit and 0.37 for perceived risk. The agreement among our participants is not as substantial as in FSLRC78 (1978 values: $W_{\text{benefit}} = 0.77$, $W_{\text{risk}} = 0.50$), but both values are significantly different from zero, $p < 0.001$. This pattern of lower inter-participant agreement is not surprising, considering the relative diversity of our population compared to the fairly homogeneous group that Fischhoff and colleagues sampled.

The inter-participant agreement for the risk-adjustment factor (RAF) is weaker than for perceived risk and benefit, but still significant: $W = 0.28$ among benefit Ps, and $W = 0.21$ among risk Ps, $p < 0.001$. As with perceived risk and perceived benefit, these coefficients of concordance in our nationally representative sample show relatively less agreement than among Fischhoff and colleagues' more homogeneous participant group (their values: $W_{\text{RAFb}} = 0.50$, $W_{\text{RAFr}} = 0.50$).

2.4. Nine characteristics of risk

Participants in both conditions judged the 30 activities/technologies on the same nine scales (see Table 2). As in FSLRC78, the scores from the risk and benefit participants for this task do not differ substantially from each other (only one difference, out of the 270, is greater than 1.0; the mean absolute difference across all judgments is 0.31), and so we pooled the data from the two groups for the remaining analyses.

Inter-participant agreement. As with the risk and benefit judgments and risk-adjustment factors, the agreement on the nine risk scales is generally lower than it was among Fischhoff and colleagues' participants, although in each case it is still significantly different from zero. Where the 1978 data show coefficients of concordance mostly between 0.4 and 0.6, here eight out of the nine characteristics see a concordance of $W = 0.24$ to $W = 0.42$. The notable exception is for the "known to science" characteristic: here the concordance is a very high $W = 0.76$, compared to only $W = 0.30$ or $W = 0.35$ (for benefit and risk Ps, respectively) in Fischhoff and colleagues' data. This may be a reflection of the (perceived or actual) advances in technology in the past three decades, which has led both to a significantly lower mean score and lower variance on "known to science" (this characteristic may be more readily understood as degree of being *unknown* to science, where 1 = "known precisely" and 7 = "not at all known", but here we follow the nomenclature of the original FSLRC78 study), and greater interparticipant agreement abut which items are better known than others. Interestingly, mean scores on the characteristic of "known to those exposed" have also shifted significantly toward "known precisely" since 1978, but the concordance ($W = 0.31$) is substantially lower than that for "known to science", reflecting a perception that on average the public knows more now about these 30 technologies and activities than they did in the 1970s, yet indicating a lack in unanimity over the relative ranking of the 30 items in terms of which are now most precisely known.

This shift in the concordance for this single risk characteristic is striking, and may in fact help to explain the finding that perceived risk is no longer correlated with risk-adjustment factor. Although both knowledge characteristics (known to the exposed, known to science) have significantly lower mean scores today than in 1978 (see Table 2), the ratings for "known to science" are nearly all approaching the "known precisely" end. Thus, the consensus today appears to be that, as we would expect, the risks of every one of these 30 activities/technologies are all very well understood by the scientific community.

Our Ps' judgments also indicate a significant shift toward more knowledge of the risks among those exposed to them, and toward risks being assumed more voluntarily than in the past—though there is more variation between activities/technologies for these variables than there is within the "known to science" characteristic. These shifts are consistent with our expectations: over the past three decades, science does indeed know more about the risks of these activities and technologies, as does the general public, and thus those people who are at risk are more likely to have placed themselves knowingly and voluntarily in that situation.

It is also logical that overall, the 30 activities/technologies are seen as both more controllable and less new today than they were several decades ago. The shift that may seem somewhat counterintuitive is the one toward more catastrophic as opposed to chronic risk. Overall, this trend suggests that the risks of these 30 activities/technologies are more likely to affect large numbers of people at once, as opposed to one at a time. It is tempting to guess that increasing population and population density may contribute to this increase in catastrophic risk potential, but to fully understand this shift, it may be necessary to look at differences between the studies for specific activities/technologies. Only five out of the 30 activities/technologies appear to have shifted toward the chronic (lower) end of the 1–7 scale, and only three of those shifts are greater than 1/3 of a point: spray cans (−1.26), pesticides (−0.94), and nuclear power (−0.46). Given increased regulation of aerosol cans and pesticides, and a temporal remove from large-scale nuclear disasters like Chernobyl, a move away from the catastrophic end of the scale seems to make sense. (Note that nuclear power, despite the nearly half-point drop in catastrophic risk, is still considered extremely catastrophic at 5.97 on the 7-point scale.) By contrast, the activities and technologies that have increased the most toward the catastrophic end of the scale are general aviation (+2.0), handguns (+1.94) and mountain climbing and skiing (+1.56 and +1.44, respectively). As of the fall of 2013,

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Table 2
Mean ratings for nine characteristics of risk.

	Voluntariness 1 = voluntary	Immediacy 1 = immediate	Known to exposed 1 = known precisely	Known to science 1 = known precisely	Controllability 1 = uncontrollable	Newness 1 = new	Chronic–catastrophic 1 = chronic	Common-dread 1 = common	Severity of consequences 1 = certain not to be fatal
Alcoholic beverages	1.59	4.89	2.32	2.03	5.62	6.16	2.15	2.06	4.03
Bicycles	1.82	3.14	2.22	2.29	5.42	6.42	2.33	1.61	3.42
Comm. aviation	2.88	2.36	2.63	2.10	2.68	5.47	6.00	4.49	5.57
Contraceptives	1.92	5.27	4.04	2.73	4.90	4.44	2.28	2.28	2.75
Electric power	4.24	3.62	3.23	2.26	4.08	5.37	3.65	2.56	3.97
Firefighting	2.73	2.11	1.79	2.03	4.10	5.97	3.82	3.56	5.15
Food coloring	3.47	5.65	5.04	3.23	4.18	4.07	2.56	2.06	2.60
Food preservatives	3.99	5.51	4.73	3.19	4.00	4.34	2.86	2.44	3.04
Gen. aviation	2.53	2.35	2.59	2.21	3.41	5.51	5.40	4.19	5.42
Handguns	2.76	1.80	1.78	1.97	4.92	5.74	4.04	4.36	5.53
HS & college football	1.78	4.07	3.16	2.86	4.95	4.90	2.39	2.49	3.07
Home appliances	2.99	3.84	3.85	2.84	5.03	5.26	2.44	1.78	2.88
Hunting	1.73	2.34	1.86	2.27	5.08	6.38	2.60	2.74	4.71
Large construction	3.38	3.09	3.03	2.58	4.15	5.42	4.06	2.53	4.49
Motorcycles	1.76	2.11	1.85	1.97	4.86	5.67	2.74	2.83	5.14
Motor vehicles	3.04	2.23	2.14	2.15	4.41	5.70	4.10	2.56	4.68
Mountain climbing	1.61	1.91	1.74	2.19	5.15	6.22	2.88	3.25	5.08
Nuclear power	5.08	4.39	3.59	2.47	2.19	3.73	5.97	5.28	5.71
Pesticides	4.57	5.23	4.41	2.81	3.30	4.07	3.81	3.67	4.19
Power mowers	2.38	2.86	2.92	2.48	5.47	5.23	2.44	2.10	3.43
Police work	2.84	2.65	2.32	2.47	3.77	5.89	3.15	3.22	4.74
rx antibiotics	3.78	4.72	4.23	2.44	4.04	4.38	2.44	2.29	3.33
Railroads	3.36	2.82	3.10	2.58	3.52	6.12	5.08	2.47	4.81
Skiing	1.57	2.12	1.90	2.15	5.08	6.10	2.50	2.24	3.83
Smoking	1.66	5.54	1.79	1.86	5.03	5.84	2.36	2.69	5.08
Spray cans	2.70	4.65	4.04	2.53	4.68	4.75	2.56	2.01	3.03
Surgery	3.99	2.96	2.78	2.30	2.71	4.90	2.28	4.58	4.65
Swimming	1.65	2.66	2.32	2.16	5.56	6.48	2.38	1.88	4.06
Vaccinations	3.80	5.18	4.27	2.68	3.71	4.34	2.56	2.57	3.28
x-rays	3.86	5.74	3.89	2.32	3.52	4.90	2.01	2.49	3.19
Mean	2.85	3.59	2.99	2.40	4.32	5.33	3.19	2.84	4.16
σ	1.00	1.32	0.99	0.34	0.90	0.78	1.13	0.92	0.94
Coeff of concordance	0.31	0.42	0.31	0.76	0.24	0.26	0.32	0.28	0.37
Mean (1978)	3.24	3.49	3.78	2.98	3.73	4.41	2.50	2.85	4.37
Difference in means[a] (2013–1978)	−0.39**	0.10	−0.80**	−0.58**	0.59**	0.92**	0.69**	−0.01	−0.21

[a] Stars indicate significant paired-t-tests at the $\alpha = 0.01$ level (*) and the $\alpha = 0.001$ level (**).

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Table 3
Pairwise correlations among the 9 risk characteristics. Variable pairs that were correlated (at $\alpha = 0.001$) in Fischhoff et al.'s 1978 data are underlined here.

	Immediate	Known (exposed)	Known (science)	Controllable	New	Chronic	Common	Severe
Voluntary	0.37	0.64**	0.43	−0.80**	−0.71**	0.39	0.39	−0.02
Immediate		0.77**	0.55*	−0.13	−0.69**	−0.34	−0.28	−0.62**
Known (exposed)			0.85**	−0.36	−0.86**	−0.09	−0.19	−0.67**
Known (science)				−0.18	−0.67**	−0.13	−0.27	−0.67**
Controllable					0.53*	−0.63**	−0.70**	−0.33
New						−0.06	−0.19	0.39
Chronic							0.68**	0.68**
Common								0.75**

* $p < 0.005$.
** $p < 0.001$.

when this study was run, airplane crashes and mass shootings were concepts with high psychological availability, which would contribute to higher perceptions of catastrophic risk (Johnson & Tversky, 1984; Tversky & Kahneman, 1973). The United States saw vivid examples of these risks in an Asiana Airlines flight crashing short of the runway at San Francisco International airport on July 6, 2013 (Onishi, Drew, Wald, & Nir, 2013), and a mass shooting on July 26, 2013 in Florida that left 7 people dead (Madigan, 2013). Similarly, the perceptions of catastrophic risk for both skiing and mountain climbing may have increased partly due to the availability of vivid stories from, among other incidents, the April, 2013 Sheep Creek avalanche, which killed 5 people; and the February, 2012 Tunnel Creek avalanche, which killed 3 skiers and was profiled in an extensive and interactive multimedia piece on NYTimes.com in December of 2012.

Correlations among the risk characteristics. As expected, the nine characteristics of risk are highly inter-correlated (see Table 3), in a way similar to FSLRC78: 14 of the 17 pairs that show significant correlations in our current study were also significantly correlated, in the same direction, in the 1978 study. Of the five additional pairs of characteristics that were correlated in 1978 but are not in this current study, all show moderate, though non-significant, correlations in the same direction as in 1978. Even though the correlations in both studies were evaluated at a conservative alpha level of 0.001 to correct for multiple comparisons, we are hesitant to make specific comparisons between the two studies on the basis of such a large number of individual tests. Instead, we will focus on the ability of the current risk dimension data to predict perceived risk, benefit, and acceptable risk.

Relationship of the nine risk characteristics with perceived risk and benefit. Perceived risk and perceived benefit correlate with many of the nine risk characteristic scores individually, but given the multicollinearity among the nine characteristics, we will not attempt to interpret the individual correlations.[2] Using a multiple linear regression model, perceived benefit is predicted only by scores on the voluntary scale: for every one-point increase on that seven-point scale, the perceived benefit increases by 15.6 points. In other words, the more involuntary the activity, the greater the perceived benefit. This is a substantial effect, given that the maximum mean benefit score was 86 (for electric power), on a scale where 10 represents the benefit of the lowest-ranked technology or activity (the lowest mean benefit was smoking, coming in at 13). It may seem counterintuitive that involuntary activities carry higher benefits, but this relationship may make more sense when viewed in the opposite direction: the higher the benefit of a risky technology or activity, the more likely may it be imposed upon members of society. While this relationship between voluntariness and perceived benefit was not significant in FSLRC78, it was in the same direction ($r = 0.24$).

Several of the risk characteristics predict scores on perceived risk. As with benefits, (in)voluntariness has a positive relationship with perceived risk: for every one-point shift toward involuntary, perceived risk increases by 10.2 points. We also see an effect of newness: for every one-point shift toward an activity or technology being newer, there is a 14.4-point increase in perceived risk. There is a similarly strong effect of controllability, in which a one-point move toward an activity/technology being more controllable is associated with a 14.7-point jump in perceived risk. Although knowledge to science does not predict risk perception, knowledge to the exposed does: a one-point shift toward precise knowledge of an activity/technology's risks predicts a 17.3-point increase in perceived risk. Taken together, these relationships suggest that riskier activities and technologies tend to be more involuntarily undertaken, newer, more controllable, and more precisely known to those exposed to the risk. This profile is consistent with the highest perceived risk scores going to activities and technologies that are typically taken on knowingly: handguns, nuclear power, smoking, fire fighting, police work, and motor vehicles top the rank list of perceived risk.

In FSLRC78, only the risk characteristics of dread and severity were found to be significantly correlated with perceived risk ($r = 0.64$ and $r = -0.67$, respectively); although we did not find significant contributions of either of these characteristics in our linear model (see Table 4), we do see effects in the same direction. Of the characteristics that do significantly predict perceived risk scores in our model, only one (known to exposed) showed a moderate, though not significant, correlation in the same direction ($r = -0.20$) with perceived risk in FSLRC78. All of the other characteristics that significantly contribute to the linear model of perceived risk were close to zero in FSLRC78, including voluntariness ($r = 0.08$), controllability ($r = -0.04$), and newness ($r = 0.05$).

This linear model of perceived risk does not, therefore, replicate FSLRC78's finding that perceived risk correlates directly with (only) dread and severity. Although we do see strong individual correlations between these two risk characteristics and perceived risk in the current dataset in the same direction as seen in the 1978 data (see supplementary material), these relationships disappear when the other risk characteristics are controlled for. Additionally, the nine risk characteristics do a markedly better job at predicting perceived risk (adjusted $r^2 = 0.82$) than perceived benefit (adjusted $r^2 = 0.44$). This effect is consistent with the finding that in this study, perceptions of risk and benefit are unrelated to each other, and the fact that the nine characteristics were designed to be measures of risk, not of benefit.

Factor analysis of the 9 risk characteristics. We ran a principal components factor analysis to see whether our participants' responses on the nine scales loaded onto the same two factors that

[2] Correlation tables are presented in the supplementary material to this paper. The differences in the apparent relationships among the four outcome variables and the nine risk characteristics as indicated by the individual correlations, compared to the relationships indicated by the linear models, shows the importance of controlling for the effects of other, correlated predictor variables in situations like this one—relationships that appear to be substantial and significant in the correlation tables are negligible when controlling for the other risk characteristics, and vice versa.

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Table 4
Linear models predicting perceived risk and benefit by scores on the nine risk characteristics. The minimum score for perceived risk and perceived benefit is 10; the maximum mean scores for benefit and risk are 86 and 77, respectively. Note that, for this analysis, scores on the 9 characteristics were mean-centered, so the intercepts represent the perceived risk and benefit score for a technology or activity that is "average" on all nine characteristics.

		Perceived benefit (β)	Perceived risk (β)
Intercept		41.6	35.3
Voluntariness	1 = *voluntary*	15.6*	10.2**
Immediacy	1 = *immediate*	−6.53	1.36
Known to exposed	1 = *known precisely*	−11.7	−17.3*
Known to science	1 = *known precisely*	−24.9	1.81
Controllability	1 = *uncontrollable*	−8.81	14.7***
Newness	1 = *new*	−8.75	−14.4**
Chronic–catastrophic	1 = *chronic*	4.32	2.26
Common-dread	1 = *common*	−8.17	3.07
Severity of consequences	1 = *certain not fatal*	−16.2	7.43
	Adjusted R^2	0.44	0.82

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 5
Factor loadings for the nine risk characteristics for the current study.

	Voluntary	Immediate	Known (exposed)	Known (science)	Controllable	New	Chronic	Common	Severe	λ (loadings)	Proportion of variance
Factor 1	0.64	0.83	0.98	0.85	−0.34	−0.88	−0.18	−0.20	−0.70	4.23	0.47
Factor 2	0.65	−0.18	0.03	−0.10	−0.88	−0.31	0.85	0.90	0.67	3.31	0.37
Commonality	0.83	0.71	0.96	0.74	0.90	0.87	0.75	0.85	0.94		

Table 6
Factor loadings for the nine risk characteristics from Fischhoff et al. (1978).

	Voluntary	Immediate	Known (exposed)	Known (science)	Controllable	New	Chronic	Common	Severe	λ (loadings)	Proportion of variance
Factor 1	0.89	0.70	0.88	0.88	−0.83	−0.87	0.62	0.67	0.11	5.30	0.59
Factor 2	0.03	−0.45	−0.39	−0.28	−0.24	0.14	0.55	0.6	0.91	1.91	0.21
Commonality	0.79	0.69	0.93	0.86	0.75	0.78	0.69	0.81	0.84		

Table 7
Differences in factor loadings between the current study and those from Fischhoff et al. (1978). Positive values indicate a loading that is higher (or has shifted from negative to positive) in the present study compared to in 1978; negative values indicate a loading that is lower (or has shifted from positive to negative).

	Voluntary	Immediate	Known (exposed)	Known (science)	Controllable	New	Chronic	Common	Severe
Factor 1	−0.25	0.13	0.10	−0.03	0.49	−0.01	−0.80	−0.87	−0.81
Factor 2	0.62	0.27	0.42	0.18	−0.64	−0.45	0.30	0.30	−0.24

Fischhoff and colleagues called "Technological Risk" and "Severity" (1978), and that in subsequent studies have also at times been called "Unknown Risk" and "Dread Risk", respectively (Slovic, 1987). Following Fischhoff et al., we computed the factor analysis on the pooled data (risk and benefits groups, combined), and did not find any improvements in interpretability by applying a varimax rotation. As Tables 5 and 6 show, the unrotated factor loadings and communality scores for the nine characteristics are similar to the 1978 results.

In the current study, the two orthogonal factors together account for 84% of the variance, and the two-factor solution appears sufficient to explain the correlations among the variables (a third factor explains only an additional 6% of the variance). Although a direct comparison of the two factor analyses would require sample sizes much larger than used in either the 1978 study or the current study, it does look qualitatively as if the current study has captured the same or very similar factors. One notable difference between the two factor analyses is the relative strength of loadings of the two factors: whereas in the original study Factor 1 (technological/unknown risk) accounted for nearly three times as much of the variance as Factor 2 (severity/dread risk), here the division is more even: Factor 1 explains 47%, while Factor 2 explains 37%. This greater balance of the explanatory power of the two factors makes sense: as technology has advanced in the past three decades, perhaps an increase (actual or perceived) in scientific and public knowledge about the risks has led to decreased impact of the unknown factor, while the 24-hour news cycle may have contributed to an increased influence in the dread factor.

Here, Factor 1 appears to capture delayed consequences, lack of knowledge (of the exposed and of science), newness, nonfatal consequences, and to a lesser extent, involuntariness. As the differences between the factor loadings in Table 7 illustrate, this unknown risk factor is therefore missing the components of chronic (as opposed to catastrophic) risk and dread risk that loaded onto it in FSLRC78, though it now captures the characteristic of severity, which did not load substantially onto unknown risk in 1978. In contrast with the trimming of the loadings on Factor 1, Factor 2 captures more variables in our current study than it did in 1978: catastrophic, dread, and uncontrollable, and to a slightly lesser extent involuntary and fatal. This shift toward substantial loadings for more of the variables on Factor 2 leads to the increase in the proportion of the overall variance that it explains.

By using the loadings on each of the two factors of each of the 30 activities and technologies, we can create a risk factor space that allows for visual depiction of the activities/technologies along the axes of Factor 1 (unknown risk) and Factor 2 (dread risk or

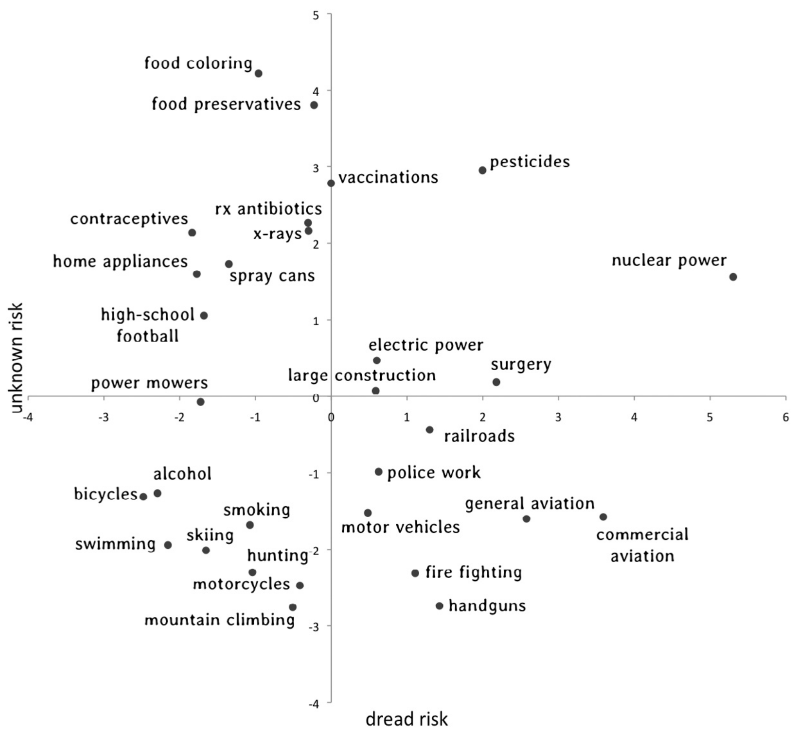

Fig. 2. Factor space for the 30 activities and technologies.

severity). The placement of the 30 activities/technologies in Fig. 2 is somewhat similar to the corresponding figure from Fischhoff and colleagues' paper (1978, Figure 7). Although the sample sizes of this study and the original do not give us enough power to compare the two factor analyses quantitatively, there do appear to be a few noticeable differences between the two.

Some items, such as surgery and contraceptives, appear not to have moved much at all compared to their positions four decades ago. The most dramatic difference between 1978 and today is nuclear power's drop on the unknown axis: it has gone from being a notable outlier on both factors to ranking only 10th out of the 30 items on unknown risk. Fig. 3 highlights this movement in the factor space for nuclear power, as well as some other notable shifts for some of the other activities and technologies. Pesticides and spray cans have also moved down in unknown risk since 1978, which may illustrate the public's growing comfort with both technologies; regulation of pesticide use and labeling for food products was tightened dramatically by Congress in 1996 (The Food Quality Protection Act, 1996), and the 1987 Montreal Protocol led to international regulation of chlorofluorocarbons (CFCs), causing spray cans to become much less environmentally harmful and in fact leading to a drop in the atmospheric chlorine levels starting in 1998 (Nangle, 1989; UN, 2010).

In contrast to pesticides and spray cans, vaccinations and high-school and college football have each increased markedly in both dread and unknown risk, and it is not hard to imagine why. With the recent increase in public attention to the prevalence of concussions in football, the public likely does now know much more clearly just how much is currently *unknown* about the long-term health risks associated with head trauma (Delaney, Lacroix, Leclerc, & Johnston, 2002). Vaccines, on the other hand, have certainly increased in both safety and effectiveness since 1978—but although science has come to an overwhelming consensus, the public conversation remains dominated by many loud (if uninformed) voices questioning the wisdom of vaccination. A look at the two risk characteristics related to knowledge nicely illustrates this gap, with the rating of vaccinations as "known to science" leaning toward "known precisely" at 2.68, but the rating for "known to those exposed" a much more ambivalent 4.27. In general, items tend to be rated as more precisely known to science than to the exposed, indicating (likely accurate) belief that the public has a less comprehensive understanding of the risks of these technologies than does the scientific community. For vaccines, however, this gap between the ratings on "known to science" and on "known to the exposed" is larger than for any other technology—there is a substantial difference of 1.59 between "science" and "the exposed" for vaccines, while the mean difference between these two characteristics across all technologies is only 0.80.

Other items appear to have dropped considerably on the dread axis: although all of the transportation-related technologies have come down on both dread and unknown, commercial aviation has shifted the farthest. Again, this difference is consistent with actual trends over the past decades. Despite several memorable crashes in recent years, the number of aviation accidents and deaths have both steadily declined since the 1970s, even while passenger load has grown dramatically (Tolan, Patterson, & Johnson, 2014). So while commercial aviation still ranks second highest on the dread factor, it is no longer quite the outlier it was in 1978.

Fig. 4 shows the mean scores on each of the nine risk characteristics for vaccinations, compared with three other technologies: nuclear power (which is more dread/severe but slightly less unknown), food preservatives (which, like vaccinations, fall at the mean of the dread/severe axis, but rate as somewhat more unknown than vaccinations), and pesticides (which are about even with vaccinations on the unknown axis, but considered substantially more dread/severe). While vaccinations and food preservatives share a very similar profile across the nine characteristics, the difference between the two technologies on the unknown factor can be seen in the higher scores for vaccinations on immediate-delayed, uncontrollable–controllable, and both known–unknown characteristics. Similarly, we can see the components of the dread/severe factor in the differences between vaccinations and pesticides: the latter is more involuntary, catastrophic, dread, and certain to be fatal.

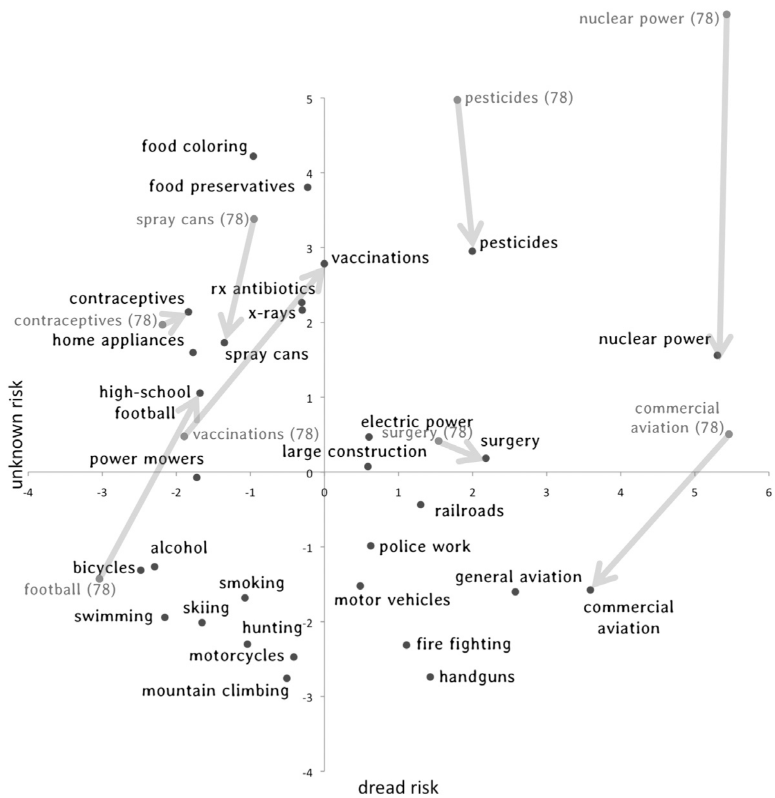

Fig. 3. Movements of selected items in the dread–unknown factor space between FSLRC78 (grey dots) and the current study (black dots). As we do not have sufficient power in this study to analyze these shifts quantitatively, they should be considered as rough qualitative estimates.

Table 8
Linear models predicting acceptable risk and perceived risk as a function of the two risk factors.

	Acceptable risk (β)	Perceived risk (β)	Acceptable risk (β)	Perceived risk (β)
Intercept	24.2	35.3	28.4	39.6
Factor 1 (unknown)	-3.15^{*}	-4.48^{***}	-2.97^{*}	-4.30^{***}
Factor 2 (dread)	2.56	4.36^{***}	3.11	4.92^{***}
Perceived benefit	–	–	−0.10	−0.10
Adjusted R^2	0.21	0.60	0.19	0.59

* $p < 0.05$. ** $p < 0.01$.
*** $p < 0.001$.

2.5. *Multivariate determination of acceptable risk levels*

Following Fischhoff and colleagues' successful attempt to predict acceptable risk levels using perceived benefit along with Factor 1 and Factor 2, we tested a model that predicts scores of acceptable risk on the 30 activities and technologies as a function of our factors of unknown risk and dread risk. We find that the two factors together do a moderately good job of predicting acceptable risk level ($F(27) = 4.81, p = 0.017, R^2 = 0.21$), though adding perceived benefit to the model does not add any additional predictive power (see Table 8). The two factors do a better job at predicting perceived risk ($F(27) = 22.8, p < 0.001, R^2 = 0.60$), but again, adding perceived benefit as a predictor does not improve the model.

Perceived benefit does not add to these models' predictive power, but the model of perceived risk quite nicely shows the relationship between the two factors in terms of their influence on risk perception. While increases on Factor 1 (toward more unknown) lead to *lower* perception of risk, equivalent increases on Factor 2 (toward higher dread) are associated with the same magnitude of change in perceived risk, but toward *higher* risk. In other words, the more known and the more dread a risk is, the higher the perceived risk. This relationship allows us to consider the risk space in Fig. 2 as having perceived risk increase roughly from the upper left quadrant to the lower right, as in Fig. 5.

3. Conclusions

Our results are consistent with the view that perceived risk is influenced by far more than the dispersion of possible outcomes around the expected value of a risky option. We were able to successfully replicate many of Fischhoff et al.'s 1978 results, starting with the fact that the rank ordering of the 30 activities and technologies in their perceived risks and benefits has not changed since 1978. Additionally, the nine characteristics of risk investigated by Fischhoff et al. continue to reduce to two dimensions, dread risk and unknown risk, that together explain a great deal of the variance in perceived risk across the 30 activities. Perceived benefit is not related to these factors, but perceived risk is predicted by both factors, such that technologies or activities that are higher on dread and are better known tend to receive the higher risk scores. As in the psychological risk–return framework developed by Weber (Weber & Milliman, 1997; Weber et al., 2002), risk acceptability is jointly determined by perceived risks and

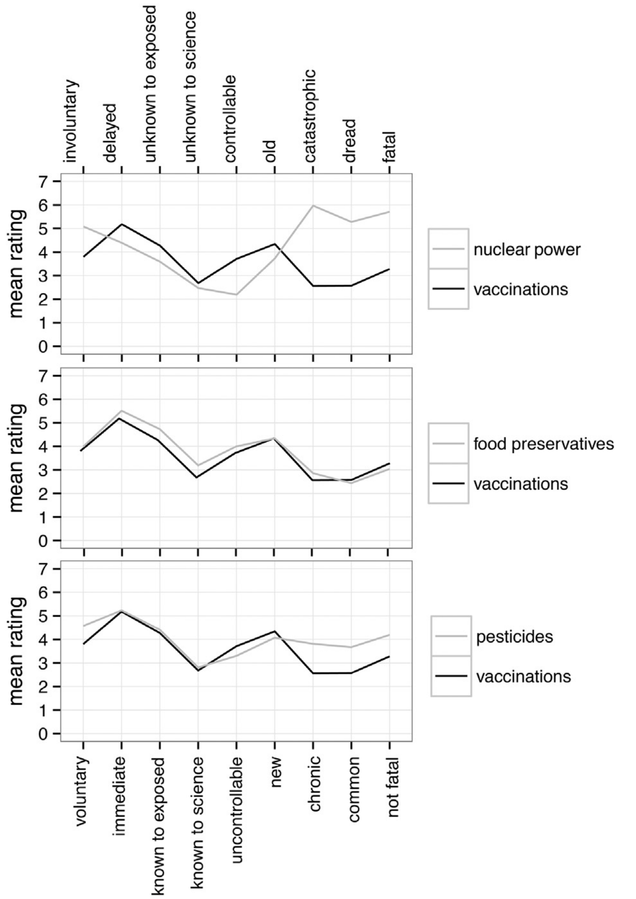

Fig. 4. Mean ratings across all nine characteristics for vaccinations, compared with nuclear power (top), food preservatives (middle), and pesticides (bottom). The distances between vaccinations and nuclear power in the dread-risk factor space is underscored by the two items' very different profiles across the nine risk characteristics. Although vaccinations fall a similar distance from food preservatives and pesticides in the dread–unknown factor space, these risk profiles show them to be more closely similar to preservatives.

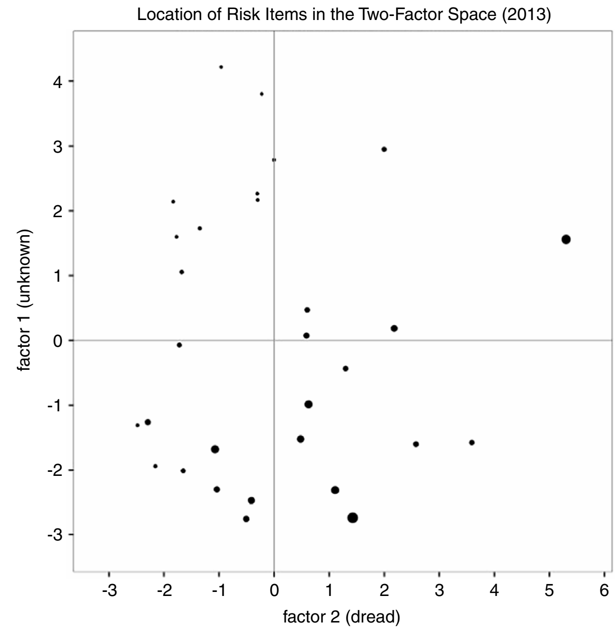

Fig. 5. Factor space from Fig. 2 with point size determined by mean perceived risk for each of the 30 activities/technologies. Though the activity/technology labels have been removed to make the point size gradient more visible, the activities/technologies locations are the same as in Fig. 2.

benefits, where perceived risk is influenced by the two factors that summarize psychological risk dimensions.

Notable differences compared to the 1978 study include the fact that risks for these 30 activities and technologies appear to have become more acceptable overall. Although some amount of variation might be expected across two non-identical populations, a substantial portion of these differences likely represent real changes in risk attitudes over time due to two factors: the fact that the actual risks of many of these items have decreased over the past three decades, and the fact that these activities have become more familiar to people. The application of the nine studied risk characteristics has also changed slightly over time: the dread risk dimension appears to capture the characteristics of voluntariness and controllability, which it did not before. This dimension also now explains more of the variance than it did in the original study, while the unknown risk dimension explains slightly less of the variance. In these respects, the current study's risk dimensions look more similar to those found in later studies by the same researchers (Slovic et al., 1985), where the dread risk factor did include the characteristics "uncontrollable" and "involuntary".

While this study meets its goal of investigating the current state of risk perception for 30 activities and technologies, one of its limitations is that comparisons made between the current results and those from the original 1978 paper must in most cases be limited to qualitative statements. Neither the current nor the original study have large enough samples to allow for a quantitative comparison.

As for the qualitative shifts described above – for example, the dramatic drop of nuclear power on the dimension of unknown risk – this study alone cannot definitively explain *why* the current data appear to show a change from the risk attitudes measured in 1978. For many of these shifts we can identify matching trends in external factors such as regulation or death rates, but to show causal connections between these trends is beyond the reach of this study. The speculations made throughout this paper call for dedicated study of the process behind many of these apparent changes. In this sense, this study's results raise at least as many questions as they answer. For example, *why* have vaccines and football shifted upward on the dread and unknown risk dimensions? And how much of the drop in nuclear power on the unknown dimension can be explained by extrinsic factors such as regulation and improvements in technologies, versus cognitive effects such as changes in perception due to factors like availability and the relative nature of risk?

It should also be noted that all of the trends and conclusions reported here are based on aggregate data. This approach to the analysis of risk perception has its drawbacks, among them the loss of variation and detail that an individual-level analysis could provide, and likely a falsely elevated assumption of consistency of risk judgments within the same individual (Marris, Langford, Saunderson, & O'Riordan, 1997). Since Fischhoff et al.'s study in 1978, other researchers have tested models of risk perception that allow for different patterns among individuals (e.g., Arabie & Maschmeyer, 1988), and explored similar dimensions of risk in populations large enough to examine individual-level data on perception of salient local hazards (Vlek & Stallen, 1981), both directions that have added much-needed nuance to the field's understanding of how people perceive risk. But keeping in mind the limitations on the conclusions we can draw from the current study, there is also a benefit from getting a broad look at many activities and technologies across a range of risk characteristics—not to mention the advantages of matching Fischhoff et al.'s 1978 methods as closely as possible for the purposes of replicating and updating their findings.

Our study demonstrates the persistent influence and importance of qualitative and to a large extent affective dimensions in people's perceptions of and reactions to risk. To best predict the risky choices of decision makers, it may be advisable to supplement models like Luce and Weber's (1986) CER model that capture the influence of quantitative consequentialist dimensions such as probabilities and outcomes on risk taking with qualitative experiential predictors like the FSLRC1978 psychological risk dimensions. Holtgrave and Weber (1993) did this to explain risk taking in both financial and health-and-safety decisions made by University of Chicago MBA students and found that both CER model components and psychological risk dimensions were independent and significant predictors.

This study also serves as a jumping-off point for a broader investigation into risk perceptions for some of the most pressing environmental hazards facing society today. After establishing the continued usefulness of the psychometric approach to risk perception in this preliminary study, we can extend the current line of research to include modern risks such as terrorism and cell phones, and – more importantly – to understand how people think differently about risks across various domains, including natural disasters and global climate change. It has been suggested that the lack of an inherent dread quality to climate change may contribute to the public's hesitance to acknowledge the dangers it poses (Weber, 2006); however, it remains to be shown that climate change really inspires less of a dread reaction than other environmental and technological hazards. The current study marks the first step toward a larger body of research that will allow us to assess climate change as a dread risk, as well as to better understand other aspects of the ways that people perceive the risks of environmental and technological hazards in relation to one another.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.jmp.2016.05.003.

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