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ABSTRACT

Implications of difficulties in using intuitive statistical reasoning are considered as they bear on the theoretic model viewing persons as intuitive scientists who make causal attributions in everyday life. Data sampling strategies and use of judgment rules to identify covariant events were investigated in two studies. Using a rule-analytic method, Study 1 probed the relationship between rules of causal and covariation judgment among junior high and college students. Findings indicated that the faulty rules of covariation judgment so common among the subjects resulted in incorrect assessments of many covariation relationships. Further analyses revealed that males and females produced notably different strategy distributions in response to the causal and covariation questions. Study 2 investigated information sampling strategy as a potential constraint on the adequacy of everyday causal reasoning among third grade, seventh grade, and college students. As in Study 1, subjects frequently failed to identify true event covariates as causes, often accepting noncovariates as causes of events. Although causal judgment accuracy increased with age, errors were common even among college subjects, especially when judging noncontingent relationships. Information sampling strategy was found to be one potential contributor to relative accuracy in causal judgment. Generally, individuals' statistical intuitions were too faulty to support accurate causal inference. (RH)

Judging Causes and Covariates:

Strategies of Older Children and Adults

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In the 1960's and 70's, theories of causal reasoning were dominated by an image of people as intuitive scientists. Prominent theories within this tradition included attribution theory in social psychology, and Piaget's model of formal operational reasoning. In these theories, people were said to draw conclusions about real world causal relationships by identifying several possible causes of the event to be explained, and collecting evidence relevant to those possible causes. Once the information was gathered, the intuitive scientist would evaluate the relative contributions of the alternative causes to determine the best account of the event.

However, the real world is a difficult context in which to test causal hypotheses, filled as it is with less-than-perfect relationships between events. Considering the many exceptions the intuitive scientist might find to any causal rule, how was he or she to identify reliable relationships? By the use of intuitive statistics, according to the model. In particular, people would sample data about the co-occurrence of an event and its possible causes in order to assess the extent to which the two events covary. Since causes and their effects do covary,

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this process would effectively define the set of possible causes of any event. If covariation judgment plays the central role in causal reasoning suggested by this model, then the quality of the intuitive scientist's causal judgments would depend on the adequacy of his or her statistical intuitions. Two aspects of statistical reasoning are likely to be of special importance: data sampling and judgment rule. In fact, existing research indicates that laypeoples' intuitions about both of these aspects are likely to be sources of error in causal judgment.

Studies of information sampling in hypothesis testing commonly show that people select only a subset of the potentially relevant information in testing hypotheses. In the case of causal judgment, a subject asked whether an outcome is caused by a particular event might prefer to sample information about the outcome when that possible cause is present, gathering less information about event frequencies when the possible cause is absent. A biased sample such as this may include too few cases of the minority event to provide a reliable index of the proportions in the population. The problem would be most severe in the case of the most extreme bias in sampling. That is, if an individual only gathers data under one event state and never samples information about the alternative state, judgment cannot be at better than a chance level of accuracy. Such an individual may reliably assess the likelihood of the outcome when the supposed cause is present, but would not know if that likelihood is any different when the cause is absent. In this way sampling strategies may contribute to relative causal judgment accuracy.

Once information has been sampled, the intuitive scientist must decide if the two events are, in fact, related. However, investigations in a variety of laboratories converge in identifying a panoply of problems that people have in judging such event covariations. Most relevant to the present concern are studies of the rules people use to identify event covariations. Developmental studies have shown that children begin to use systematic but overly simple rules of covariation judgment by the early elementary school years (Shaklee and Mims, 1981; Shaklee and Paszek, 1985). More complex rules become common with increasing age but, even in college populations, only a minority of subjects show a mathematically accurate understanding of covariation (Shaklee and Mims, 1981, 1982; Shaklee and Tucker, 1980; Shaklee and Hall, 1983). In fact about a third of adult subjects in these studies were classified as using the same simple and error-prone rule that is so prominent among second grade children.

In this presentation, I would like to consider the implications of people's problems with statistical reasoning for the model of people as intuitive scientists. In particular, we will report evidence about how older children and adults collect and evaluate data in order to reach a conclusion about cause-effect relationships. Two aspects of the process will be of central interest here: information sampling and judgment rule.

Our first study investigates the implications of peoples' rules of covariation judgment for their inferences about causal relationships. Four rules have been commonly proposed as bases of covariation judgment. Two of the least sophisticated of the proposed judgment rules would draw a conclusion about event covariations without using all of the information in a two-by-two contingency table. By the cell-a rule, judgment is made according to the frequency with which the target events co-occur. For example, such a rule would identify a positive relationship between plant food and plant health if there are more healthy plants with plant food than any of the other event-state combinations. A second simple approach would compare the frequency of target event states with and without the supposed covariate (e.g. healthy plants with plant food vs. healthy plants without plant food, comparison of contingency table cells a and b, strategy a-versus-b). By a much improved approach, an individual would compare the number of event-state combinations confirming a positive relationship between plant food and plant health, i.e. healthy plants with plant food and unhealthy plants without plant food, with the number of event-state combinations disconfirming the relationship, i.e. healthy plants without plant food and unhealthy plants with plant food. Since this strategy compares the sums of diagonal contingency table cells a+d and b+c, this rule is referred to as the sum of diagonals rule. Finally, an individual might determine the relationship by an optimal rule: comparing the likelihood of the target event-state under each of the two conditions (e.g. P(healthy plants/plant food) vs. P(healthy plant/no plant food)), conditional probability rule. This is the only one of the four rules which would accurately judge all interevent contingencies.

This analysis of possible rules has allowed us to discriminate among strategies actually employed by subjects of various ages in making covariation judgments. That is, different rules should produce different judgments on carefully selected covariation problems. A set of such problems is illustrated in Table 1. Solution accuracy is indexed by the direction of the judged relationship. Problems are structured hierarchically such that cell-a problems are correctly solved by all strategies, a-versus-b problems are accurately solved by all strategies except cell-a, sum of diagonals problems are accurately judged by sum-of- diagonals and conditional probability strategies, and conditional probability problems are accurately judged by the conditional probability rule alone (see Table 1b).

Past arguments of a covariation-causal judgment link would predict that subjects should prefer as causes those events which they identify as event covariates. The strategies subjects use to judge covariations between events should be the same as those employed to define cause-effect relationships. The present investigation uses our rule analytic method to identify the relationship between rules of causal and covariation judgment.

Junior high (grades 6, 7, 8) and college subjects were asked to make either causal or covariation judgments of a set of 12 different problems, specially structured to yield a distinctive pattern of solution accuracy by each of the four proposed judgment rules. Each problem was set in a concrete context of two everyday events which may or may not be related. Subjects were shown instances of event-state combinations organized in a

2X2 table and were asked to make either a causal or covariation judgment about the relationship shown. In the case of the covariation condition subjects were asked:

The picture shows that plants were more likely to be healthy if

a) it was foggy.

b) it was not foggy.

c) no difference.

The causal question for the same problem was:

The picture shows that plant food:

a) makes plants healthy.

b) keeps plants from being healthy.

c) has no effect on plants' health.

Subjects' judgments in this experiment inform us in two ways about the link between event covariation and causal judgment. First, did subjects consistently select true event covariates as causes? As we might have expected from our prior research in covariation judgment, the answer to this question is no. In the present set of problems, junior high subjects identified covariates as causes only 49% of the time, college subjects on 65% of the problems. The data in Table 2 indicate the percentage of problems of each type in which subjects judged the causal relationship to be in the same direction as the depicted covariation. As the table shows, subjects did consistently judge covariates as causes for the cell-a and a-versus-b problems. The strong influence of problem type points to the strategic basis of these judgment patterns. That is, the faulty rules of covariation judgment so common among these subjects result in incorrect assessments of many covariation relationships.

However, we can use the data to ask a second question about the supposed cause-covariate link. That is, are subjects' causal judgments based on their intuitive notions about covariation? By this interpretation, subjects' rules of covariation judgment (however faulty) should match their rules of causal reasoning. Table 3 shows the rule classifications of junior high and college males and females for causal and covariation judgments.

Classifications of subjects in the two grades show parallel age trends for covariation and causal judgment, in support of this interpretation. The present data indicate that improvements in covariation judgment during these years are matched by progress in causal reasoning as well. These data fit well with the interpretation that subjects look for covariates as causes throughout these years. However, improved rules of covariation judgment enable older subjects to more accurately find true covariates when explaining events.

However, the interpretation further requires that subjects use the same rules to make causal and covariation judgments. Male subjects' judgments fit well with this prediction: distributions of strategies for covariation and causal judgments are quite comparable for male subjects in both the junior high and college samples. Females, on the other hand, produce notably different strategy distributions in response to the causal and covariation questions. As shown in the table, in the junior high sample, females' classifications indicate that they rely heavily on the very simple cell-a strategy for covariation judgment. However, when making causal judgments they were more likely to use the a-versus-b and sum of diagonals strategies. The increase in unclassifiable strategies among both males and females among these younger subjects indicates that several of the subjects failed to use any of our proposed strategies, perhaps using some other strategy or no consistent strategy at all. Inspection of these unclassified judgment records failed to reveal any systematic bases of these judgment patterns.

College females also show use of different strategies for the causal and covariation judgments, using more complex judgment strategies when asked about causes than when asked about covariations. These subjects were most likely to use the more accurate sum of diagonals and conditional probability rules in response to the causal question. In contrast, responses to the covariation question show a strong consensus toward use of the a-versus-b rule. This is ironic in view of the fact that the covariation question directly asks for a comparison of conditional probabilities, i.e. is a given outcome more likely given condition B1, or condition B2. Rule classifications indicate that, overwhelmingly, college women respond to this question by comparing frequencies, not probabilities.

Thus, the outcome of this study offers qualified support for the much-suggested link between covariation and causal judgment. People in the junior high to college age span are not particularly good at identifying true covariates as causes of events. However, parallel rule use when judging causes and covariates suggests that males, at least, may define causes and covariates in the same terms. Females, in contrast, seem to define the two concepts by different rules.

However, our model of the intuitive scientist suggests yet another major aspect of causal judgment in which intuitive statistics may play a role: i.e. information sampling. Our next study investigates information sampling strategy as a potential constraint on the adequacy of everyday causal reasoning.

In this study, subjects in third grade, seventh grade and college were asked to test hypotheses about causal relationships between the state of a plant (e.g. flowers open or closed) and the lighting conditions under which it grew. For each problem, subjects were given two envelopes, one containing observations of plants growing in the sun, the other containing observations of plants growing in the shade. They were to select from these envelopes a total of 24 observations of the plant growing in the sun and/or in the shade. Subjects recorded their observations, then judged whether the stated hypothesis was true. Hypotheses were stated either in terms of the effects of the sun (e.g. Sun makes spots on leaves) or the effects of the shade (e.g. Shade makes spots on leaves). Subjects judged three such problems, including one noncontingent relationship in which the plant was in a given state in 75% of the observations in both the sun and the shade, and two contingent relationships (plant in a given state in 75% of the sun observations, 25% of the shade observations). In one contingent problem, the direction of the contingency matched the causal hypothesis so that the correct answer to the causal question would be yes (contingent-yes). In the other problem, the contingency was opposite in direction to the stated hypothesis, so that an accurate judge would reject the causal hypothesis (contingent-no).

First we can ask how accurate subjects were at judging these causal relationships. A judgment was scored as accurate if the subject judged the causal relationship as being in the same direction as the covariation relationship. Accuracy could be evaluated either in comparison to the proportions of event-states represented in the envelopes from which the subjects sampled (population-based accuracy), or in relation to the samples they actually drew (sample-based accuracy). These two different definitions of accuracy produced essentially the same results, so we will restrict our discussion to the results of the population-based measure.

These analyses show that accuracy of causal judgments improved with age, with means represented in Table 4, and that the noncontingent problem was harder than the two contingent problems in all age groups. Thus, as in our previous experiment, subjects frequently failed to identify true event covariates as causes, often accepting noncovariates as causes of events. Although causal judgment accuracy increases with age, errors were common even among college subjects, especially when judging noncontingent relationships.

Information sampling strategy is one potential contributor to relative accuracy in causal judgment. Subjects did frequently draw biased samples, with the extent of that bias increasing somewhat with age (mean absolute difference of sun and shade observations = 8.7, 6.2, 5.9 for grades 3, 7 and college students respectively). Sampling bias showed its greatest effect on causal judgment accuracy in interaction with the form of the causal question. In each of the three problems, subjects who drew biased samples of the sun and shade observations were substantially different in accuracy depending on whether they were asked whether sun or shade caused a given outcome. As shown in Table 5, subjects showed near-chance accuracy when asked about the effect of the event about which they had sampled few cases. However, when asked about the majority event, subjects' responses were consistent with the proportions represented within that event.

These accuracy patterns may be interpreted in terms of the subjects' rules for combining the frequency information into a causal judgment. The appropriate approach to the causal question would be to compare rates of the target outcome (e.g. open flowers) in the two growing conditions (sun and shade). Someone who uses this rule should be similarly accurate whether the question is phrased in terms of the effect of the sun or the shade. The differential accuracy observed here indicates that subjects used some other rule for causal judgment.

We suggest that subjects judged the causal relationship by looking at the proportions of event states in the condition about which they were asked (e.g. Does sun make?...), ignoring the equally relevant cases in the alternative condition. This would be a variant of the tendency to ignore base rates seen in a variety of contexts in judgment research (Arkes and Rothbart, 1985; Bar-Hillel, 1980; Beyth-Marom & Fischhoff, 1983). That is, subjects consider the ratio of event-s .tes in the presence of the supposed cause, without regard for the event-state base rates when the cause is absent.

For the two contingent problems, this strategy could yield the correct answer. For example, in one problem, the ratio of open to closed flowers was 3:1 in the sun and 1:3 in the shade. Half of the subjects were asked if sun caused the flowers to open. Subjects who sampled heavily from the sun envelope were very accurate in judging this relationship (89%); subjects who primarily sampled observations in the shade were at chance level accuracy (54%). Other subjects saw the same ratios of open and closed flowers and were asked about the effects of shade (contingent-no, shade). These subjects were more accurate if they had sampled primarily shade observations (82% vs 61% correct). We would suggest that, in all cases, subjects answered the question in terms of the outcome frequencies in the condition about which they were asked. In these problems, the direction of differen: in target-state outcomes within that condition (e.g. more open than closed flowers within the sun) matched the true contingency in the problem. Those who had sampled dominantly in that condition had a reliable sample of event state outcomes within that condition, hence were accurate in judgment. Subjects who had sampled dominantly from the other condition had a poor sample on which to base their judgment, thus were less accurate. The contribution of sampling bias to this differential accuracy is further indicated by looking at subjects who sampled equally from the two conditions. For each problem, accuracy levels were more similar for the sun and shade question forms for these unbiased subjects than for the two biased sample groups.

This proposed strategy receives its clearest support in the noncontingent problem where it will lead the subject to the wrong conclusion about the causal relationship no matter which sampling bias is used. Both lighting conditions in this problem show the same 3:1 ratio of open to closed flowers. Subjects who sampled primarily from the sun envelope erroneously concluded that the sun caused the flowers to open (71%); subjects who sampled dominantly from the shade decided that the shade made the flowers open (77%). Note that these two groups reached opposite conclusions about the same relationship, and that both of those conclusions are wrong. We would suggest that subjects in each case were impressed with the predominance of open flowers in the condition sampled and failed to consider the possibility that open flowers might occur at the same rate in the alternative condition.

In overview, the combined results of these experiments show the later childhood and adolescent years to be periods of active development in these more complex aspects of causal reasoning. Causal judgment accuracy improves over these years, but judgment errors continue to be common even at adulthood. The evidence further suggests that faulty strategies of information sampling and rules of covariation judgment undermine the abilities of subjects in these age ranges to make accurate causal inferences.

In light of these findings, let's reconsider the model of people as intuitive scientists in everyday causal reasoning. If the model is interpreted to mean that people make accurate statistically-based causal inferences, the present evidence raises serious questions about the model. People's statistical intuitions are just too faulty to support accurate causal inference.

However, if the model simply implies that causal judgments are based on people's impressions about event covariations (faulty though they may be), the present evidence offers some support for the notion. In fact, these studies find a central role for statistical reasoning in processes of causal inference.

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Table 1

A) Sample covariation problems

Cell *a* Problem

	B_1	B_2
A_1	2	11
A_2	7	4

a versus *b* Problem

	B_1	B_2
A_1	4	11
A_2	8	1

Sum of Diagonal Problem

	B_1	B_2
A_1	8	8
A_2	8	0

Conditional Probability Problem

	B_1	B_2
A_1	12	2
A_2	10	0

B) Strategy use and resultant patterns of problem accuracy
(+ = accurate, 0 = inaccurate)

		Problem Strategy Type			
		Cell *a*	*a* versus *b*	Sum of Diagonals	Conditional Probability
Subject Strategy Type	Conditional Probability	+	+	+	+
	Sum of Diagonals	+	+	+	0
	a versus *b*	+	+	0	0
	Cell *a*	+	0	0	0

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Table 2

Percent Correct per Problem Type

		Problem Types				
		Cell _a_	_a_ versus _b_	Sum of Diagonals	Conditional Probability	All
Covariation	Junior High	96.3	92.7	16.0	8.0	53.0
	College	95.7	98.7	43.0	33.7	67.7
Cause	Junior High	75.7	60.0	31.0	28.7	48.7
	College	88.0	80.0	53.0	38.3	64.7

Table 3

Strategy Classifications by Question and Gender at Each Age (Percentages)

	Strategy Classifications					
Gender	Unclas-sified	Cell-a	a-vs-b	Sum of Diagonals	Conditional Probability	N
			Junior High			
			Covariate			
Male	0.0	10.0	70.0	20.0	0.0	10
Female	14.3	78.6	7.1	0.0	0.0	14
All	8.3	50.0	33.3	8.3	0.0	24
			Cause			
Male	33.3	0.0	44.4	11.1	11.1	9
Female	38.5	23.1	23.1	15.4	0.0	13
All	36.4	13.6	31.8	13.6	4.5	22
			College			
			Covariate			
Male	4.0	0.0	32.0	20.0	40.0	25
Female	0.0	0.0	86.2	0.0	13.8	29
All	1.8	0.0	61.1	9.3	27.8	54
			Cause			
Male	0.0	13.0	30.4	26.1	30.4	23
Female	7.1	3.6	42.9	25.0	21.4	28
All	4.0	7.8	37.2	25.5	25.5	51

Table 4

Accuracy of Causal Judgment:
Percent Correct by Problem and Subjects' Grade

Problem	Grade 3	Grade 7	Grade College	Grade All
Population-based Accuracy				
Noncontingent	44.0	27.3	60.0	45.0
Contingent-yes	68.0	81.8	78.2	75.8
Contingent-no	60.0	79.5	98.2	79.9
All	57.3	62.8	78.8	66.9
Sample-based Accuracy				
Noncontingent	55.8	54.0	66.7	59.2
Contingent-yes	61.9	78.9	78.2	73.0
Contingent-no	57.1	75.7	100.0	78.6
All	58.3	69.5	81.6	70.3

Table 5

Population-Based Accuracy of Causal Judgment by Direction of Information Sampling Bias for Each Problem Contingency

(Percent correct, N's in parentheses)

Problem Contingency	Question	Direction of Sampling Bias		
		Shade = Sun	Shade > Sun	Sun > Shade
Noncontingent	Sun	55.9 (34)	58.3 (13)	29.0 (31)
	Shade	42.9 (35)	23.5 (17)	68.4 (19)
Contingent-yes	Sun	69.0 (29)	53.8 (13)	88.9 (36)
	Shade	80.0 (40)	86.7 (15)	56.2 (16)
Contingent-no	Sun	83.8 (37)	57.1 (14)	92.6 (27)
	Shade	83.3 (36)	82.3 (17)	61.1 (18)

Question: Form of the causal question: Does the sun (or shade) make flowers open? (or other target state)