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Increasing informativeness and reducing ambiguities: Adaptive strategies in human information processing

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Abstract

How do people deal with ambiguity and indeterminacy of incoming information? The results of the two reported experiments indicate that both young children and adults tend to reduce ambiguity, systematically 'converting' non-informative propositions into more informative ones. Although young children and older participants use different strategies, high rates of conversions were found in both groups. These conversions seem to represent an adaptive cognitive constraint — a tendency to reduce ambiguity and to increase the informativeness of incoming information.

Introduction

It is well known that people commit multiple errors when reasoning and making judgments (Evans & Over, 1996; for review). For example, when processing deductive arguments, they tend to deviate from the argument's logic, confusing familiar or believable conclusions with logically necessary ones; they also commit various logical fallacies in reasoning with conditionals (Evans, Newstead, & Byrne, 1993). Traditionally these errors have been explained as resulting from a variety of random factors (e.g., fluctuations of attention) and from reasoners' tendency to misconstrue some premises in accordance with conversational uses of connectives (e.g., reasoners may mistake a premise "If *P* then *Q*" for "If and only if *P* then *Q*") (Braine & O'Brien, 1991; Rips 1994). However, these deviations exhibit amazing regularity and systematicity for purely random fluctuations. In this paper we argue that some of these errors may stem from an adaptive strategy people use when dealing with uncertainty and ambiguity. This strategy may result in certain distortions of incoming information, but it allows reductions in the uncertainty and ambiguity of the environment.

This tendency to reduce ambiguity seems to be a general property of cognitive systems whose function is to process information from the environment, and to adequately navigate the organism using available environmental cues. There is ample evidence that both human and animal species tend to avoid *nondiagnostic* cues, those that do not allow the organism to discriminate among different objects or classes, and *highly variable* cues, those that may or may not be present in the same object or class (see Estes, 1988; 1994, for reviews). For example, the red color of the tomato does not allow one to distinguish the tomato from other red vegetables (nondiagnosticity), whereas the changing color of the chameleon does not help in identifying this animal (high variability). This tendency is especially apparent in human cognition that relies heavily on linguistic representations. A number of authors (Gibson, 1940, Shepard, Hovland, & Jenkings, 1961) have demonstrated that that the difficulty of learning a classification increases if the stimuli that are assigned to different classes are less discriminable (nondiagnosticity), or if stimuli that are assigned to the same class are more discriminable (highly variable). Similar difficulties have been demonstrated in concept attainment (Bruner, Goodnow, & Austin, 1956; Estes, 1994), reasoning and problem solving (Fay & Klahr 1996; Evans & Over, 1996), and early word learning (Markman, 1990). We hypothesize that these difficulties may represent an adaptive cognitive constraint. This constraint prohibits the organism from acquiring ambiguous, indeterminate information, which cannot be readily used to adapt to the environment, thus directing learning toward acquisition of more useful and less ambiguous information. In other words, the organism's spontaneous learning might be limited to those cues that better inform the organism about the environment. At the same time, human discourse is replete with ambiguities and indeterminacies — people use various propositional forms that do not unambiguously inform about states of the world. For example, the proposition "Either theory A or theory B is true" is ambiguous with respect to theory selection. Ambiguous propositions (e.g., "it is either blue or green") are less informative with respect to the environment than more determinate ones (e.g., "it is green").

The formal treatment of informativeness was proposed in semantics. Bar-Hillel and Carnap (1964) defined informativeness of a proposition to be a function of the number of states of the world that the proposition rules out.

Table 1: Informativeness of propositions varying in their logical form.

Proposition	Form	Example	Proportion of states of the world ruled out by the proposition	N of states of the world where the proposition is true (ΣT_j)	Logical Probability ($\Sigma T_j/2^n$)	Informativeness ($-\log_2 P(i)$)
Affirmation	A	*I drank tea this morning*	.5	1	.5	1
Negation	Not-A	*I did not drink tea this morning*	.5	1	.5	1
Conjunction	A AND B	*I drank tea AND coffee this morning*	.75	1	.25	2
Disjunction (inclusive)	A OR B	*I drank tea OR coffee this morning*	.25	3	.75	0.42
Disjunction (exclusive)	A OR B (but not both)	*I drank EITHER tea OR coffee this morning*	.5	2	.5	1
Conditional	IF A THEN B	*IF I drank tea THEN I drank coffee*	.25	3	.75	0.42
Bi-Conditional	IFF A THEN B	*I drank coffee IF AND ONLY IF I drank tea*	.5	2	.5	1
Tautology	A OR not-A	*I drank tea this morning OR I did not drink tea this morning*	0	4	1	0
Contradiction	A AND not-A	*I drank tea this morning AND I did not drink tea this morning*	1	0	0	Undefined

More precisely, the informativeness of a statement is inversely related to the logical probability of the statement (see, Bar-Hillel & Carnap, 1964; Johnson-Laird 1993), for discussions). According to Bar-Hillel (1964), the relations are specified by the following equation.

$$\inf(i) = -\log_2 P(i) \qquad \text{Equation 1}$$

The logical probability of a statement is the number of states of the world where the proposition is true divided by the total number of all possible states of the world covered by the proposition. Thus, logical probability could be calculated using equation 2.

$$P(i) = \Sigma T_j/2^n \qquad \text{Equation 2}$$

T_j is a state of the world where the proposition is true and n is the number of atomic statements in the proposition. The informativeness of the most common forms of propositions is provided in Table 1. According to the table, a conjunction of two statements is more informative than an atomic assertion, a biconditional, and an exclusive disjunction, and these are more informative than a disjunction and a conditional. At the same time, a tautology is a totally non-informative statement, and informativeness of a contradiction is not defined.

It seems plausible that if the tendency to reduce ambiguity stems from a cognitive constraint, then people would try to reduce ambiguity of non-informative propositions by increasing their informativeness, and this tendency will be present early in their lives. In particular, they may change the propositional form of less informative propositions to increase informativeness. This tendency could be defined as conversion of less informative propositions into more informative ones. Therefore, we predicted that contradictions and tautologies would be converted more frequently than disjunctions, which, in turn would be converted more frequently than conjunctions. To test this hypothesis we designed tasks where young children and adults had to determine the truth status of more and less informative predictions (Experiment 1), and where adolescents and adults had to memorize and recall more and less informative propositions (Experiment 2). The goal of the two reported experiments was to test the hypothesis and to provide descriptive accounts of human conversion strategies.

Experiment 1

Method

Participants Two groups of participants were included in the design. The first group consisted of 34 four- and five-year old children currently enrolled in two child care centers in a large Midwestern city. These participants were selected on the basis of returning a parental consent form. The second group of participants included 31 undergraduate students currently enrolled in a large Midwestern university. These participants were recruited from introductory courses in a department of human development and family science.

Materials The experimental tasks consisted of a series of predictions by an imaginary character, ZZ (references to ZZ were omitted for the university students), as to the outcome of a ball dropped in the Tautology Machine. The Tautology Machine is a 36" x 24" board with a chute at the top in which a ball dropped will fall through several nails which direct the ball to one of two terminating points (the two chutes were marked with red and green colors). ZZ made predictions regarding the outcomes of the game. These predictions had syntactic forms of logical constants (tautologies and contradictions), and contingent statements (affirmations and negations). The following predictions were presented to subjects in four random orders:

Tautology 1: The ball will NOT land on Red OR will land on Red.
Tautology 2: The ball will land on Red OR will NOT land on Red.
Contradiction 1: The ball will NOT land on Red AND will land on Red.
Contradiction 2: The ball will land on Red AND will NOT land on Red.
Negation: The ball will NOT land on Red.
Affirmation: The ball will land on Red.

Procedure One within-subject variable, the form of the prediction, and age and gender as across-subject factors were included in the design. The experiment was conducted in a single 10-15 minute session that included two phases: warm-up/instruction phase and the experimental phase. Each participant was tested individually in a quiet room. Children were videotaped in order to ensure accurate coding of responses. In the warm-up phase, the participants were familiarized with the device. To ensure that the participants could distinguish between statements that were true and not true, they were also asked to evaluate two statements (one explicitly true and another explicitly false). In the experimental phase, the instructions and predictions were read to each participant and repeated if requested. The participants were asked three questions. First, they were asked to evaluate the *a priori* truth status of the prediction as "Not True", "True", or "Can't Tell" (*a priori* evaluation). Then participants were asked if it was necessary to drop the ball to check the truth status of the *a priori* prediction, constituting the request for empirical verification (request for verification). If empirical verification was requested, then the ball was actually dropped through the machine. Finally, after the ball was dropped, the participants were asked to again evaluate the initial predictions as "Right", "Wrong" or "Can't Tell" (*a posteriori* evaluation).

Results and Discussion

Table 2 contains data on how the participants handled propositions of different logical form. These data indicate that children did not distinguish between logically true, logically false, and contingent statements. At the same time, university students consistently distinguished between propositions of different logical form. Note that for all six propositions, all 34 children requested to drop the ball in order to test the truth status of the proposition, but only 3 university students requested to drop the ball in order to test Tautology1. As a result of these uniform responses, university students were excluded from further analyses. After the ball was actually dropped, children's responses presented in Table 2 changed dramatically. These new responses are presented in Table 3. Data in the table indicate that the truth status of the predictions is a function of the ball's landings rather than the logical form of the predictions. Correlations between where the ball actually landed and what truth status children attributed to the propositions appeared to be very high (see the note at the bottom of Table 3). In addition, there were almost perfect correlations between the first part of compound statements and affirmations and negations (see Table 4). Data in Tables 3 and 4 clearly indicate that (a) the determiner of the truth status of tautologies and contradictions (non-informative logical constants) was not their logical form, but empirical outcomes (i.e., where the ball actually landed) and (b) children systematically ignored the second part of tautologies and contradictions. These findings suggest that children have considered the first part of compound statements by cutting the second part, and converting non-informative tautologies and contradictions into more informative affirmations or negations. The described "cuts" appeared to be the only conversion strategy used by young children.

The results partially support our hypothesis and provide descriptive accounts of the conversion strategy children use to increase the informativeness of non-informative propositions. However, a number of important points are missing from the results. First, only younger participants exhibited conversions. Second, the design included only non-informative and informative forms and did not include forms that differ in degree of informativeness (e.g., conjunctions and disjunctions). Finally, the results do not allow to rule out the possibility that "cuts" merely reflect young children's memory limitations (i.e., young children simply forget the second part of a lengthy statement). These problems were addressed in the second experiment. Experiment 2 focused on older participants, it had a whole range of logical forms differing in informativeness, and the procedure allowed us to distinguish conversions from memory limitations.

Table 2: Percent of participants' responses evaluating *a priori* predictions by response type, form of the proposition, and participants' age.

	Response type					
	Not true		True		Can not tell	
Form of the proposition	Children	Students	Children	Students	Children	Students
Tautology1	17.7	0.00	35.3	90.32	47.00	9.68
Tautology2	8.8	0.00	26.47	100	64.71	100
Contradiction1	17.65	83.87	32.35	3.22	50.00	9.67
Contradiction2	17.65	100	38.24	0.00	44.12	0.00
Affirmation	14.71	0.00	50.00	0.00	35.29	100
Negation	23.53	0.00	44.12	0.00	32.35	100

Table 3: Numbers of participants' a posteriori evaluations of the initial predictions as true or false by different landings of the ball.

	Ball's actual landing and *a posteriori* evaluations			
	Lands on Red		Lands on Green	
Initial predictions	True	False	True	False
The ball will land on Red or will NOT land on Red[1]	20	1	0	10
The ball will NOT land on Red or will land on Red[2]	0	13	14	1
The ball will land on Red and will NOT land on Red[3]	16	0	0	16
The ball will NOT land on Red and will land on Red[4]	1	15	17	0
The ball will land on Red[5]	13	0	2	19
The ball will NOT land on Red[6]	0	11	20	2

Note: [1]$\phi = .93$, ($\chi^2(1) = 26.8, p<.0001$); [2]$\phi = -.93$, ($\chi^2(1) = 24.3, p<.0001$); [3]$\phi = 1$, ($\chi^2(1) = 32, p<.0001$); [4]$\phi = -.94$, ($\chi^2(1) = 29.2, p<.0001$); [5]$\phi = .89$, ($\chi^2(1) = 26.7, p<.0001$); [6]$\phi = -.88$, ($\chi^2(1) = 25.4, p<.0001$).

Table 4: Correlations between evaluation of the truth status of empirical statements and logical constants after dropping the ball.

	Affirmation	Negation
Contradiction1 (Negation first)[1]	-.99	.89
Contradiction 2 (Affirmation first)[2]	.99	-.86
Tautology1 (Negation first)[3]	-.81	.84
Tautology 2 (Affirmation first)[4]	.81	-.82

Note: $\phi_{1,2} = -.9$; $\phi_{3,4} = -.76$.

Experiment 2

Method

Participants Participants included 31 college students (11 males and 21 females) from a large Midwestern university who were enrolled in introductory psychology classes (mean age = 19.3 years) and 34 sixth graders (19 males and 15 females) selected from a local middle school (mean age = 11.8 years).

Materials Materials for the experiment consisted of 12 pictures and 12 short descriptions referring to the people in the pictures as "college professors" (e.g. "This professor walks to school or goes fishing") or " school teachers." The appearances of the people in the pictures were all quite distinct from one another. These 12 descriptions were evenly divided, in form, among tautologies, contradictions, disjunctions, and conjunctions. The first atomic proposition in each of the descriptions was affirmative. Each description was paired with one of the pictures.

Procedure The only experimental factor, form of description (Tautology, Contradiction, Disjunction, and Conjunction) varied within subjects. Each participant was tested individually in a session lasting from 20-40 minutes, depending on how many repetitions the participant required to reach the criterion (to be described below). Participants were informed that the experimenter would show them a series of pictures of professors (or teachers, in the case of the sixth graders) along with short descriptions of them, one at a time. The participants were required to remember at least 7 of these descriptions correctly; once they reached this criterion, the experiment would move onto another task. The first part of the experiment, the learning phase, consisted of several training trials (the number ranged from 1 to 4, depending on how many trials each participant required to reach the criterion of 7 correct recalls). In each trial, the experimenter placed one picture and its corresponding description on the table in front of the participant. The experimenter read the description aloud, and then the participant repeated the description. As soon as the participant finished repeating the description, the experimenter went on to the next picture-description pair. The 12 pairs were presented in a single random order meant to minimize the confounding of order of presentation with the logical form of the description. After all 12 descriptions had been presented, the experimenter shuffled the pictures randomly, then placed them, one at a time, in front of the participant and asked for recall of the corresponding description. This entire process was repeated until the participant recalled 7 descriptions correctly, at which time the experiment proceeded to a 5-minute distracter task (consisting of math word problems). After the distracter task came the recall phase. The experimenter again presented the participant with the pictures, one at a time, and asked the participant to recall the description going with each. All participants received the pictures in a single random order (different from that used during the learning phase). This recall phase concluded the experiment. All participants were videotaped (all gave consent to do so in advance) for subsequent analyses of errors in recall.

Results and Discussion

Because there were no gender or age differences found, all the participants were analyzed as a single group. The percent of correctly recalled items aggregated within the same logical form is presented in Figure 1. While in the first trial, the recall rate did not differ significantly for propositions of different logical form, in the delayed recall trial, recall rates differed markedly for different forms of propositions. With 82% recall rate, conjunctions were most likely to be recalled ($F(1,65)=106.3$, $p<.0001$), while contradictions with 41% recall rate were least likely to be recalled ($F(1,65) = 11.5$, $p<001$). Recall rates of disjunctions and tautologies were in-between these two extremes (49% and 52% respective recall rates).

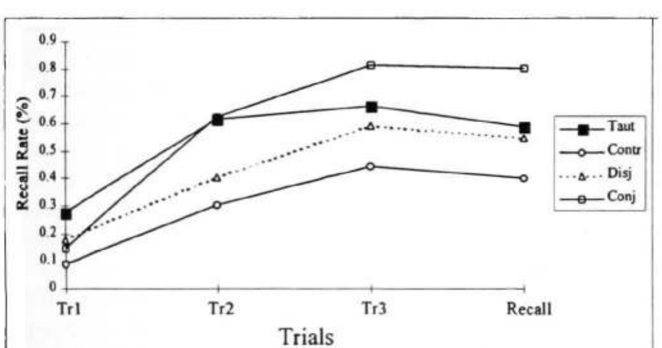

Figure 1: Recall rates of propositions of different logical form across training and delayed recall trials.

While recalling the descriptions, the participants exhibited a variety of memory errors. The most systematic errors were those of substitution, "and" for "or"; and "or" for "and." These substitutions indicated conversions of some types of propositions into propositions of different types. The percentage of these substitution conversions, as a function of total responses, across trials is presented on Figure 2.

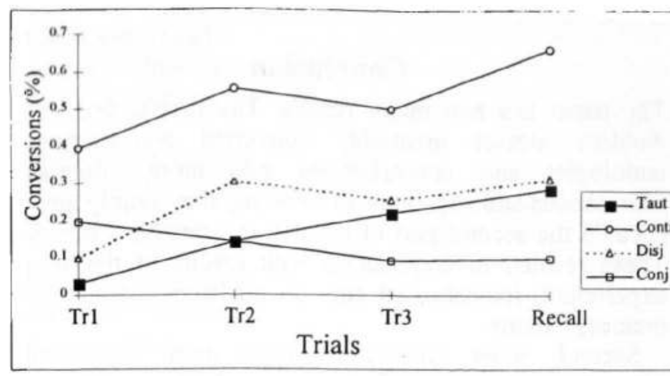

Figure 2: Conversion rates by proposition type and by trial

The results indicate that across training trials (Tr1-Tr3), contradictions were more likely to be converted than the other forms ($F(1,65) = 12.3$, $p<.01$), whereas recall rates of the other forms were approximately the same. However, in the recall trial not only contradictions were most likely to be converted ($F(1, 65) = 24.9$, $p<.001$), but also conjunctions were least likely to elicit conversions ($F(1, 65) = 117.6$, $p<.0001$). These data also suggest that participants try to convert less informative propositions into more informative ones when trying to memorize them. As predicted, the participants exhibited (1) higher conversion rates for less informative propositions (tautologies, contradictions, and disjunctions), and (2) higher recall rates for more informative propositions (conjunctions).

One could have expected that recall rates for disjunctions would be higher than those for tautologies. However, both recall rates and conversion rates of disjunctions and tautologies were approximately the same. One possible explanation is that the informativeness of disjunctions is low enough to be frequently confused with the informativeness of tautologies.

General discussion

Results of both experiments indicate that people have a tendency to increase the informativeness of propositions. However, in so doing they may use different strategies. Young children tended to completely ignore (or cut) the second part of non-informative propositions, e.g., converting a statement $A \vee {\sim}A$ into A. Older participants exhibited different strategies. The most prevalent strategy was to substitute *or* for *and* and *and* for *or* to increase informativeness. The rate of substitutions, however, differed dramatically across logical forms. For example, in conjunctions and disjunctions the likelihood of substituting *and* for *or* (substitution that lead to an increase in informativeness) was three times higher than the likelihood of substituting *or* for *and* (substitution that lead to an decrease in informativeness). This pattern of substitutions along with markedly higher recall rates for more informative propositions suggests the tendency to increase informativeness of propositions is present in both children and adults. However, additional studies are needed in order to determine specific quantitative relations between the informativeness of a form and the likelihood of this form being converted into a more informative one.

Conclusion

The paper has two major results. The first is that young children almost invariably converted non-informative tautologies and contradictions into more informative affirmations and negations. In so doing, they simply ignored ("cut") the second part of the non-informative statements. These results, in conjunction with results of the second experiment, indicate that cuts do not stem solely from a memory failure.

Second, older participants used more sophisticated conversion strategies than young children. The most prevalent strategy among older participants was to remember less informative forms as more informative ones. This strategy resulted in the tendency to substitute *or* for *and*, thus converting less informative disjunctions into more informative conjunctions. As a result, more informative forms were more likely to be correctly recalled than less informative forms.

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