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REVIEW

Logical Processing, Affect, and Delusional Thought in Schizophrenia

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Deficits of logical reasoning have long been considered a hallmark of schizophrenia and delusional disorders. We provide a more precise characterization of "logic" and, by extension, of "deficits in logical reasoning." A model is offered to categorize different forms of logical deficits. This model acknowledges not only problems with making inferences, which is how logic deficits are usually conceived, but also problems in the acquisition and evaluation of premises (i.e., filtering of "input"). Early (1940–1969) and modern (1970–present) literature on logical reasoning and schizophrenia is evaluated within the context of the presented model. We argue that, despite a substantial history of interest in the topic, research to date has been inconclusive on the fundamental question of whether patients with delusional ideation show abnormalities in logical reasoning. This may be due to heterogeneous definitions of "logic," variability in the composition of patient samples, and floor effects among the healthy controls. In spite of these difficulties, the available evidence suggests that deficits in logical reasoning are more likely to occur due to faulty assessment of premises than to a defect in the structure of inferences. Such deficits seem to be provoked (in healthy individuals) or exacerbated (in patients with schizophrenia) by emotional content. The hypothesis is offered that delusional ideation is primarily affect-driven, and that a mechanism present in healthy individuals when they are emotionally challenged may be inappropriately activated in patients who are delusional. (HARVARD REV PSYCHIATRY 2000;8:73–83.)

Although Kraepelin[1] identified cognitive abnormalities as one of the characteristics of schizophrenia when he first described the disorder, research specifically relating logic deficits to schizophrenia only gained prominence with the work of Von Domarus nearly half a century later. Von Domarus[2] argued that persons with schizophrenia reason in an organized fashion but by different rules of logic. In particular, he claimed that such persons show a flawed use of predicates, failing to distinguish between essential and nonessential properties. In practical terms this difference entails taking any two objects with a shared predicate (both green, for instance, or both scary, or both starting with the letter *p*) to be identical. The textbook case is of a patient who believes that she is the Virgin Mary because both she and the Virgin Mary are virgins. More colorfully, Von Domarus provided the example of a patient who associated Jesus with a cigar box. The connection was seemingly inexplicable until he realized that both Jesus and the cigar box had the property of being surrounded: Jesus by a halo, the cigar box by a state tax band.

Von Domarus's work evolved out of an interest already present in the field regarding the nature of inferences of identity among patients with schizophrenia. Goldstein[3,4] emphasized that the deficit was in identifying the essential qualities common to different objects. Hyman[5] later did research on patients' identity judgments based on partial con-

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ceptual similarities, echoing Vigotsky's earlier work[6] on patients' identity judgments based on concrete physical similarities between objects. After the publication of Von Domarus's paper,[2] the idea of a logical error relating to degenerative predicates became popular. Arieti[7] became one of the strongest proponents of the thesis, embracing the idea of the defective syllogism, although he qualified the theory by arguing that the inference from shared predicate to identical subject occurred only in cases in which a strong emotional factor was present.

This paper has three aims. First, we wish to provide a more precise characterization of "logic" and, by extension, of "deficits in logic." Second, because breakdowns in logic may occur at several different levels, we will model several different means by which one might arrive at false conclusions or maintain false beliefs despite contradictory evidence. These models, as we shall see, have particular relevance for understanding the subcategory of patients with schizophrenia who are delusional, and we will use these models as a context in which to evaluate modern research (1970–present) in this area. Finally, we will examine the implications of this research and suggest new directions for study. For easy reference, we provide definitions of relevant logic terms.

WHAT DO WE MEAN BY "LOGIC"?

A mathematical "function" provides a rule by which certain information ("input") is transformed into other information

RELEVANT LOGICAL TERMINOLOGY

Premise(s): the "input" from which later conclusions are drawn. Premises may be gathered through directly experienced sense data (for example, by seeing that there is a tree by the lake), or through data gained from other sources (for example, by hearing from a friend or reading in a newspaper that there is a tree by the lake). Premises may be true or false. They may be complete, in the sense that they provide enough data to derive a conclusion, or incomplete, in the sense that they could suggest more than one (mutually incompatible) conclusion.

Conclusion: the "output" that "follows" from the premises. Conclusions may be true or false.

Logical inference: the process by which one moves from premises to a conclusion. A *deductive* inference requires that the conclusion follow with certainty from the premises (for example, if Socrates is a man, and all men are mortal, then necessarily Socrates is mortal). *Inductive* inferences produce conclusions that are only suggested from the premises; they overgeneralize (for example, researchers make the inductive assumption that what is true for their sample is true for the population as a whole). In the literature, reference to inferences usually means "deductive inferences" unless otherwise specified.

Valid and invalid inferences: a valid inference is one requiring that, if the premises are true, the conclusion is necessarily also true. If the premises are true but the conclusion is not necessarily true (even if the conclusion happens to be true in that instance), then the inference is invalid.

Syllogistic (or predicate) logic: also called "Aristotelian logic," this form of deductive logic makes reference to part-to-whole relationships defined by common attributes (for example, if all ravens are black, then necessarily some ravens are black, although the converse [if some ravens are black, then necessarily all ravens are black] does not hold).

Propositional logic: also known as "conditional logic," this form of deductive logic makes reference to a class of relationships that are vaguely conditional in nature (for example, if there is a storm then the power will go out; there is a storm; therefore, the power necessarily will go out).

Type A hypothesis: a hypothesis referring to one of the two ways in which a false conclusion can be reached: the choice of premises is inadequate (they are false or incomplete).

Type B hypothesis: a hypothesis referring to the second of two ways in which a false conclusion can be reached: the inferences used are invalid.

Mental models: a theory of cognition, advanced principally by Phillip Johnson-Laird, that treats the formation of conclusions as being akin to the scientific method. According to this theory, we create provisionary hypotheses (models), which are then either rejected or confirmed by future evidence. Most of our inferences would therefore be inductive rather than deductive.

("output") in a consistent manner. A familiar example of an algebraic function is $y = x^2$ (where, for instance, an input of $x = 2$ transforms into an output of $y = 4$). Logic is another example of such a function. An example of a logical rule is a disjunctive syllogism, by which an input of *either p or q* and *not p* transforms into an output of *q*. Logical rules of this kind are called "deductive rules of inference," or simply "inferences."

Most mathematical functions are arbitrary, in the sense that they are valid only with respect to their description of a specific system, physical or otherwise. Standard logical functions are unique in that they can be understood as modeling rationality itself. Thus, logical inferences are valid not only because they presume to say something about how the world works but also, at a more basic level, because they meet their own criteria for consistency. Reasoning "correctly," under these criteria, has a very precise meaning. Valid inferences are those that "preserve truth-value"—i.e., if the premises ("input information") are true and complete, the conclusion that follows from those premises will necessarily also be true. Inferences that cannot meet this stringent requirement are considered invalid or fallacious. Conclusions may thus be false for only two reasons: because the premises are false or incomplete, which we shall call type A errors, or because the inferences are invalid, which we shall call type B errors.

In conceiving of logic as a formalization of rationality, we rely upon two very strong assumptions: that people reason correctly at least most of the time, and that everyone reasons in more or less the same way. Of the two assumptions, the second is on firmer ground. Most people find other people's arguments coherent, and this observation presumably gives one good reason to suppose that they share a common logical structure. The problem in evaluating the first assumption is that the obvious manner of checking it, by determining whether the conclusions that people reach are in fact true, is effective only if we make the false assumption of perfect knowledge. That assumption requires both that people have access to all of the information they need in order to form their conclusions, and that the information they do have is reliable. Because premises are the result of sensory perception and inferences from other premises, and because sensory perception is imperfect and the quality of inferences is what we are attempting to evaluate in the first place, it follows that informal assessment of a subject's ability to reason logically is intrinsically difficult.

Even under formal assessment, in which the choice of premises is ostensibly controlled, it is important to consider subjects' potential both to assume information that is not present in the test and to dismiss information that is actually given. The aim in tests of logical inference-making is to require subjects to "shield" themselves from premises that they have previously accumulated and utilized during the rest of their thinking lives. For example, if subjects encounter a proof that depends upon a premise that they "know" to be false, their conclusions from those premises may differ, not necessarily because their reasoning differs; rather, some subjects may have been able to shield themselves better than others from information not contained in the proof. The situation becomes even more complicated when we factor in the possibility that the offending implicit premise may not appear to be equally "false" to all subjects because of different environments. It makes sense that the more a logic test approximates everyday thinking, the more we would expect to see the effects of such "rational noise." It would appear that symbolic representations are less likely to contradict or suggest information that the subject has encountered elsewhere. However, rather than treating "rational noise" as simply an annoyance of experimental design, we will argue below that the ability or inability to "shield" oneself is itself an independent cognitive function that serves a critical role in reasoning well. The choice and evaluation of premises, potentially leading to what we have called type A errors, is only beginning to be addressed by researchers of logical deficits.

LOGICAL REASONING IN HEALTHY INDIVIDUALS

Although the formalization of deductive inferences operates linearly, from premises to conclusions, there is some evidence to suggest that actual rational processing occurs instead by constructing generalizations from existing instances, searching for counterexamples to these belief models, then revising the models in light of discovered counterexamples.[8–10] This hypothesis is consistent with the prevalence of certain sorts of logical errors committed by healthy individuals, including errors discussed by Von Domarus and those that "affirm the consequent" (*if p then q; q; therefore, p*). It also explains the tendency for people to give weight to "believability" over logical necessity,[11] since domains that have already been "checked" and found to provide counterexamples will automatically invalidate the inferences that entail those domains.

Although model-checking can be expressed in terms of formal deductive inference and vice versa, they differ in several fundamental ways. A formal deductive inference exists as a computationally completed procedure from a fixed set of premises, while model-checking is a process of trial and error from a constantly expanding set of premises (because the domain of possible counterexamples is usually infinite, from a practical point of view). Because models make inductive generalizations (they extend conclusions beyond what is contained within the premises), they are stable in the face of contradiction and amendment by means of restriction. (In other words, if contradictory evidence is encountered, an overinclusive hypothesis may be made less inclusive rather than being completely invalidated. For example, upon sighting of a green raven, the model in which *all ravens are black* may be restricted to one in which *some ravens are black.*) Formal deductive inferences, on the other hand, cannot function if any of their premises are mutually contradictory.

Preliminary studies have shown that people who reason well (deductively, as well as inductively) are both willing to look for counterexamples and good at figuring out what a potential counterexample would look like (see Oakhill and Johnson-Laird[9]). For example, in evaluating the judgment *all x are y,* the better reasoner looks for examples of *not y* to see whether any is an *x* (disproving the model) rather than checking every instance of *x* to see whether any is *y.* According to the study by Oakhill and Johnson-Laird,[9] the majority of people reason inefficiently, by attempting to affirm rules rather than to disprove them. The likelihood of reasoning inefficiently was found to increase as the models became more complex.

The importance of the mental model view is that it reminds us that standard tests of formal logic measure only *half* the skills necessary for thinking rationally in the real world. Standard tests of logic measure one's ability to perform correct inferences from existing specified premises. In the real world, however, thinking rationally requires not only that we perform correct inferences but also that we be able to choose (and thus identify) relevant premises and counterexamples from among vast amounts of irrelevant information. It is therefore crucial to look at both processes in the evaluation of logical deficits.

MODELS FOR EVALUATING LOGICAL DEFICITS

From the above we can draw two major points: first, that most people reason in similar, if not necessarily truth-preserving, ways (i.e., in ways that they can justify to each other and be accepted as coherent), and second, that false conclusions may be the result of poor reasoning or of either false or incomplete premises. In fact, delusions seem consistent with false conclusions based on faulty a priori premises (i.e., those not arising from empirical observation), given their degree of internal consistency and imperviousness to correction by counterexample. Logic is thus an intriguing model by which to understand psychotic delusions.

The falsehood of the conclusions reached could also be due to a failure at the level of the inferences (moving from premises to conclusion). Internal consistency within a belief system would imply that "delusional" inferences, if nonstandard, are fallacious inferences that are different from those used by healthy individuals. These could indicate either a foundational difference in reasoning (i.e., one that is strictly formal, such as the "identity based on common attributes" inference postulated by Von Domarus), or a difference that

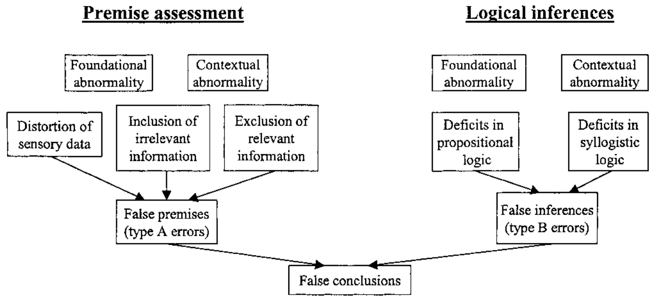

FIGURE 1. Summary of models for evaluation of deficits in logic.

is contextually dependent upon the content of the reasoning (patients reason poorly only with emotionally charged material, for instance, or with particularly complex material). Intuitively, we would not expect to see random use of fallacious inferences among persons who do not have formal thought disorder.

The premises may also be false in several different ways, each of which produces a different model for delusionality. Information about the world may be distorted at the level of sensory perception, as with partial deafness or hallucinations.[12] Alternatively, delusional patients may have access to the same information as healthy individuals yet have difficulties sorting appropriately through that information to determine what is relevant and what is irrelevant. They may be including irrelevant information (for example, in seeing connections between random events) or excluding relevant information (for example, in failing to appreciate counterexamples to their theories). As with the possibility of flawed inferences, these difficulties may be foundational—perhaps analogous to a sensory-gating problem in which sense data are not appropriately filtered—or contextually dependent upon content. A summary of these models is shown in Figure 1. Again, for simplicity, we shall refer to tasks that test premise assessment as utilizing type A models, and those that test logical inferences as utilizing type B models.

An interesting question for future study is whether patients with bizarre delusions exhibit qualitatively different deficits in the reasoning process (e.g., the inferences that are corrupted are at a more fundamental level—say, inferences dealing with causation and randomness) or merely have a quantitatively more severe problem in that they make more errors overall.

Within the field of deductive logic, both propositional inferences and syllogistic inferences exist. Propositional inferences deal with causal implications and thus utilize conditional statements—for example, *if p then q; p; therefore, q.* (Note that although propositional logic also uses conjunctions and disjunctions, both may be formally reduced to conditional statements.) Syllogistic inferences, on the other hand, utilize part-to-whole/whole-to-part (subset/superset) relations. Examples of syllogistic reasoning are the inference from *all p are q* to *some p are q,* and the recognition that the converse, from *some p are q* to *all p are q,* is fallacious. The cognitive skills required for the two are presumably distinct. Both types of logical reasoning also differ from reasoning elicited in type/token tasks such as the Wisconsin Card Sorting Test and Raven's Progressive Matrices, in which a rule is inferred from instances and vice versa.

Tasks that aim to test logical reasoning, then, may be arranged in any number of ways. They may test type A deficits, both foundational and contextual, and according to whether information is either included or excluded inappropriately. They may test type B deficits, either propositional or syllogistic, and either foundational or contextual. In testing type B deficits, one can work under the hypothesis that patients' mechanism for thinking logically is defective (i.e., they think in a disordered fashion) or, alternatively, under the hypothesis that the structure of logic is different for patients with schizophrenia (i.e., patients think in an ordered yet non-truth-preserving fashion). Finally, both type A and type B tasks may be presented symbolically or using real-language substitutions (i.e., words may be substituted for the variables *p* and *q* in *if p then q*—as, for example, *if Paul rides a bicycle, then he will fall*).

MODERN RESEARCH ON LOGICAL DEFICITS

The optimism surrounding Von Domarus's theory receded as researchers gradually realized that healthy individuals were also prone to making identity judgments based on shared attributes (see, for instance, Chapman and Chapman,[14] Johnson-Laird et al.,[15] Byrne,[16] Maher,[17] and Evans et al.[18]). Even so, interest in Von Domarus's theory continues. Sinha and colleagues[19] conducted a study in which they found that patients with schizophrenia possess deficits in performing operations of transitivity (e.g., *if A is B, and B is C, then A is C*). Klee[20] systematized a "logic of schizophrenia," complete with theorems, based on a "deviant identity rule" involving shared properties. The majority of logical deficit studies since 1970, however, have been less concerned with discovering a "logic of schizophrenia" than with determining whether patients with schizophrenia and healthy individuals actually reason differently. The latter, the more basic question, is the one we will address here. A summary of these studies is presented in Table 1.

Ho[21] conducted one of the first studies to measure performance rigorously on tests of both syllogistic and propositional logic. The purpose of this investigation was to determine whether deficits in deductive reasoning were correlated with disorders of thought in schizophrenia. The subjects were 40 patients diagnosed with schizophrenia (undifferentiated for delusionality) and 40 normal controls,

TABLE 1. Summary of Studies on Logic Deficits in Schizophrenia

Study	Year	Hypothesis type	Parameters investigated	Methodological issues
Von Domarus[2]	1944	B	"Schizophrenic inferences"	Controls make the same fallacious inferences as patients; only syllogistic logic studied
Arieti[7]	1959	B	"Schizophrenic inferences" plus emotional content	Controls make the same fallacious inferences as patients; only syllogistic logic studied
Ho[21]	1974	B	Syllogistic and propositional logic	No discrimination between delusional and nondelusional patients
Watson et al.[22]	1976	B	Syllogistic logic and abstract reasoning	Only syllogistic logic studied; no discrimination between delusional and nondelusional patients
Watson & Wold[23]	1981	B	Syllogistic logic	Only syllogistic logic studied
Huq et al.[24]	1988	A	Probabilistic judgment	—
Phillips et al.[25]	1997	A, B	Sensory distortion; propositional and syllogistic logic	Sample too small (only two patients who were actively delusional)
Kemp et al.[26]	1997	A, B	Role of context; propositional and syllogistic logic	Floor effect (70% fallacious reasoning in healthy individuals); problem of power (only four contextual items)
Linney et al.[27]	1998	A	Hypothesis testing; determination of probability	Nonpatient population

matched for IQ (determined from vocabulary scores on the Wechsler Adult Intelligence Scale) and education. The task consisted of 41 multiple-choice problems, divided into 36 propositional logic problems (utilizing conditionals) and five syllogistic problems. Of the propositional logic problems, 12 were symbolic, 12 utilized affect-neutral real-language substitutions, and 12 utilized affect-laden real-language substitutions. Of the five syllogistic problems, one was symbolic, two were affect-neutral real-language substitutions, and two were affect-laden real-language substitutions. Subjects were given a premise and asked to choose from a set of five available options, which included the correct answer as well as fallacious inferences of several types. The patients performed significantly worse than did the controls on both propositional and syllogistic problems in the verbal section of the test, in particular with the affect-laden problems. Interestingly, no difference was noted on the symbolic section.

Like Ho, Watson and colleagues[22] aimed to determine whether patients with schizophrenia suffer from a logical reasoning deficit, but they went further in asking whether such a deficit (if it exists) is separate from a generalized deficit in abstract thinking. The sample comprised 21 patients diagnosed with schizophrenia and 21 psychiatric patients with diagnoses other than schizophrenia, matched for age and intelligence (determined from verbal and nonverbal scores on the Wechsler Adult Intelligence Scale). Subjects were given four tests of abstraction: a rule-inference verbal task, a rule-inference symbolic task, a verbal analogy task, and a logical syllogism task (with real-language substitution). These scores were compared with the subjects' earlier performance in a previous study on two measures of nonabstract intellectual ability: vocabulary and arithmetic. Patients with schizophrenia were found to perform equivalently to the comparison psychiatric group on all measures of abstract ability except for syllogistic logic, on which they performed significantly more poorly. Furthermore, in contrast to Von Domarus, Watson and colleagues[22] did not find that the patients made any single kind of error consistently.

In a subsequent study Watson and Wold[23] tested the logical deficit hypothesis again, with different results. This time they used 100 patients with schizophrenia, 50 patients with neurological damage, and 50 psychiatric comparison subjects. The patients with schizophrenia were characterized additionally by five subdistinctions: process/reactive, paranoid/nonparanoid, anhedonic/nonanhedonic, length of illness, and length of hospitalization. The participants took a test of syllogistic reasoning in which they chose between two options (one correct, one incorrect), given the available information. Of the 50 problems, 25 offered an overexpansive answer (an answer that infers more than is contained in the premise) and 25 a Von Domarus error of identity as the incorrect option. No significant differences were found between subjects and controls, or among patients when they were divided according to the various subdistinctions.

The three previous studies examined type B hypotheses regarding the possibility that inferences might be distorted. Huq and colleagues[24] examined the type A hypothesis that the choice of relevant input might be problematic. This study was also unusual in that it specifically used subjects who were delusional rather than merely diagnosed with schizophrenia. The purpose of the investigation was to compare probabilistic judgment-making of delusional patients with that of both nondelusional patients and healthy individuals. The sample included 15 patients diagnosed with schizophrenia and suffering from delusional ideation, a psychiatric comparison group (ten psychiatric patients diagnosed with depression, bipolar disorder, phobia, anxiety, or an eating disorder but without delusions), and 15 healthy control subjects. The task utilized four pairs of jars. Each jar contained 100 colored beads of two colors in the proportion of 85% to 15%. The second jar of each pair contained beads of the same colors as the first, but with the proportions reversed (for example, 85% blue/15% green in one jar and 85% green/15% blue in the other). On the basis of being shown individual beads, subjects were instructed to choose the jar from which the beads had most likely been picked (i.e., the 85/15 or the 15/85). The examiner recorded: (a) how many draws were necessary before a decision could be made; (b) the initial certainty level following the first draw; (c) the subject's probability estimate of the outcome of the previous draw, and (d) errors in decision-making. All the groups were quite accurate in determining the correct jar. However, patients with delusions consistently reported decisions after fewer draws and indicated greater initial certainty regarding that decision than did persons in either of the other groups. The psychiatric patients without delusions took longer and reported less certainty than did the healthy controls or the patients with delusions.

Phillips and colleagues[25] measured both the type A and type B hypotheses. They examined whether sensory distortion (at the level of premises) or faulty reasoning (at the level of inferences) was responsible for delusional ideation. The sample consisted of only 11 persons: three patients with late-onset schizophrenia and eight healthy controls matched for age. Two of the three patients had delusional ideation (two with persecutory delusions, one with additional misidentification); the other patient was in remission at the time of the study. The reasoning portion of the task involved two sections: propositional ("conditional") logic and syllogistic logic. Both portions were presented with ordinary language substitutions. Both included problems judged to be strongly affect-laden. The first section contained 40 conditional statements of the form "*if p then q*." Each statement had four questions; two utilized truth-functional inferences (*modus* *ponens* [*given that if p then q, and p; therefore, q*] and *modus tollens* [*given that if p then q, and not q; therefore, not p*]) and two utilized fallacious inferences. Additional and alternative premises were introduced for each problem to determine their effect on the inference made.

The syllogistic portion of the test included 40 problems that allowed for a choice between four responses: valid and believable, valid but unbelievable, fallacious but believable, or fallacious and unbelievable. Presumably, "believability" makes reference to other premises that the subject has developed from everyday experience and thus tests for type A errors.

With the conditional problems, the addition of a premise to the problem was found to be significantly disruptive for the patient group but not for the controls. Emotive content was found to have an effect only in compounding the disruption introduced by the additional premise for the patients. The inclusion of an alternative premise was disruptive for both patients and controls, but more so for the patients. With the syllogistic problems, both patients and controls were most likely to answer with the valid and believable response and least likely to respond with the fallacious and unbelievable one. Interestingly, however, patients were significantly more likely than controls to choose valid yet unbelievable responses. This tendency in patients was somewhat diminished on affect-laden problems.

Kemp and colleagues[26] also tested both type A and type B hypotheses, observing whether delusional patients were cognitively impaired on measures of conditional and syllogistic reasoning and whether they were abnormally immune to context. The sample consisted of 16 high-functioning patients with well-developed delusions and a control group of 16 healthy individuals. The task was a multiple-choice test consisting of three sections. The first section, adapted from Evans and coworkers' real-language multiple-choice test,[18] comprised 40 propositional logic problems. Two truth-functional inferences (*modus ponens, modus tollens*) were tested, as well as two fallacies (denying antecedent, affirming consequent). The second section had 40 syllogism problems. Each of these sections contained some affect-laden problems. In the last section four problems tested sensitivity to context. Subjects were instructed to choose the "best" conclusion from the available information. The information given, however, was designed to be incomplete, sufficing only to suggest rather than to logically imply one of the given solutions. The participants, therefore, were expected to rely upon "implied premises" relating to common correlations (for instance, between a woman who is sexually attractive and has many partners and the contraction of a sexually transmitted disease).

The results were largely negative, except when emotion was introduced as an additional variable. The authors[26] noted that "all subjects displayed considerable irrationality and a propensity to go with prior beliefs rather than reasoning through a problem . . . however, higher rates [$p = 0.004$] of endorsement of fallacies in conditional reasoning were found in the subjects with delusions." Emotional content significantly ($p = 0.024$) affected both groups, but particularly ($p = 0.004$) the patient sample. With the syllogisms, the authors noted a tendency ($p = 0.059$) for emotional content to cause patients to "endorse more unbelievable responses regardless of validity." The results of the context problems were found to be suggestive yet inconclusive. On the first problem, all of the healthy controls picked the context-driven response, while only a quarter of the patients did (a significant difference; $p = 0.02$). On the other three problems, the majority of both patients and controls picked the context-driven response, with patients performing slightly worse (a nonsignificant difference; $p = 0.08$).

Linney and colleagues[27] again tested the type A hypothesis, aiming to determine whether "individuals high in delusional ideation exhibit a reasoning bias on tasks involving hypothesis testing and probability judgments." Forty healthy students were tested using the Peters et al. Delusions Inventory.[28] They were divided into two groups (high and low delusional ideation) of 20 each, based on whether they scored above or below the median. The degree of delusional ideation was confirmed with additional testing on the Magical Ideation Scale.[29] Approximate IQ was determined with a slightly modified version of the Quick Test.[30,31]

The subjects were given four tasks to complete; two involved hypothesis testing and two involved determinations of probability. The first hypothesis-testing task was a revised version of Wason's 2-4-6 task,[32] and the second was a revised version of Wason's selection task.[33] These involved identifying a rule and its parameters governing successive choices of, in the first case, three digits (three different digits or two or more digits the same, for instance) and in the second case, combinations of letters (consonants and vowels) and numbers (even and odd).

The first probability-determination task involved coin-tossing. Subjects were asked to determine the bias of a coin (either 50% or 75%, in actuality) based on the results of various numbers of tries (4,12, 20, or 60). The aim was to determine how much information was required before subjects were certain of their answers and to see the role that they accorded to randomness. The second probability test, the "book/suicide problem," measures a person's ability to discern probabilities within probabilities (for example, high probability that *x* will occur within a population *y* that itself occurs with low probability). Focusing on one statistic without taking into account its larger context is called "base rate neglect"; in healthy individuals it occurs most often when the wording of the problem does not explicitly mention the entire population. In the suicide problem the entire population was not explicitly mentioned ("specific-type problem"), while in the book problem it was mentioned ("population-type problem").

Linney and colleagues[27] found that individuals high in delusional ideation performed significantly more poorly and were more likely to jump to conclusions. However, there were no significant differences in the time required to make a decision or in the certainty expressed. The possibility of a floor effect was suggested, since approximately 50% of both groups made incorrect responses. Individuals high in delusional ideation also performed significantly more poorly at the coin-tossing task. Finally, the base-rate neglect of the "high delusional ideation" subjects was found to be more or less equivalent to that of the low delusional ideation subjects.

CRITIQUE OF MODERN RESEARCH ON LOGICAL DEFICITS

Although the studies presented above provide some preliminary information on both type A and type B hypotheses, each raises some important issues of experimental design. The earliest studies, as well as those of Watson and colleagues,[22,23] utilized only syllogistic logic in testing for logical deficits and did not include a symbolic test of the concepts (without real-language substitutions). Ho[21] avoided both of these limitations, but his use of only five syllogism problems introduced a problem of power. Like Watson and coworkers,[22] Ho[21] employed a heterogeneous patient sample.

Watson and Wold[23] did not discriminate within the patient sample on the basis of delusional ideation but did use descriptive subsets of patients (paranoid versus nonparanoid, for instance) that could be equivalent. As mentioned above, they utilized only syllogistic logic, and only two types of errors in syllogistic logic. The availability of just two options for each item, one correct and one incorrect, meant that a subject had a 50% chance of being correct just by guessing, which may have constrained the results.

Phillips and colleagues[25] had a well-designed task, yet with a sample of only two subjects who were actively delusional, drawing any conclusions from the data is impossible. Likewise, interpreting the results of Kemp and coworkers[26] is difficult; one would suspect a floor effect, given the high rate (70%) of fallacious reasoning by the healthy individuals. Because there were only four contextual problems, a problem of power exists here as well.

Finally, the study by Linney and colleagues,[27] although highly suggestive, used a nonpatient population. Obviously, the advantages of this choice were that the participants were higher functioning and their performance was more likely to reflect delusional ideation rather than globally impaired functions of intelligence and attention. The disadvantage, on the other hand, was the assumption that delusional ideation in a nonpatient and delusional ideation in an individual diagnosed with psychosis occur along a continuum.

Despite nearly 30 years of research on the subject, the basic question of whether patients with delusions reason differently than controls ("controls" defined to include not only healthy individuals, but also nondelusional patients diagnosed with schizophrenia or other psychiatric disorders) has not yet been definitively answered. The challenge in evaluating the research done thus far in "logical reasoning" is in synthesizing information that includes both variability of tasks (which aspect of "logical reasoning" is being studied) and heterogeneity of patient samples.

The heterogeneity of samples follows from the fact that most of the research has been performed with schizophrenic patients, with no distinctions made between different disorders of thought. The earlier investigations mentioned above are representative of the literature as a whole: often within a single study, patients who were delusional were grouped together with patients who were nondelusional but hallucinatory and those who displayed disorganized thought processes. Although all of these patients may have shared the diagnosis of schizophrenia, lumping them together failed to discriminate with regard to the very characteristic that logic would have been likely to elucidate—namely, patterns of reasoning. Ideally, studies of logic should reduce heterogeneity by discriminating not only between delusional and nondelusional patients but also among the different types of delusions.

The variability of tasks is largely a product of the vagueness of the term "logic." As we have noted, formal deductive logic encompasses both propositional and syllogistic reasoning; scores for tasks that included both types of problems failed to distinguish between the different cognitive skills required for the two. More-recent studies, particularly those by Phillips and colleagues[25] and Linney and coworkers,[27] have been more successful in reducing heterogeneity of both subjects and tasks. Unfortunately, Phillips and colleagues tested only three patients, while Linney and coworkers examined normal individuals with delusional ideation. The study by Kemp and coworkers[26] suffered from neither of these problems but contained a surprisingly high rate of fallacious reasoning by healthy controls. Whether this fact indicates a problem with their task or a problem with our assumption that healthy individuals reason rationally most of the time is yet to be determined.

The premise-assessment tasks have been more homogeneous, combining judgments of probability with certainty about those judgments. Studies involving such tasks have been successful in documenting tendencies to "jump to conclusions" and to ignore the role of random variation and the existence of counterexamples on the part of delusional patients. We hope that future tests will be able to examine specific aspects of that mechanism. In particular, it would be useful to determine whether there is a consistency in the pieces of information that patients find relevant and irrelevant in making judgments, with respect both to different judgments made by the same patient and to the same judgments made by different patients.

TOWARD AN AFFECT-DRIVEN MODEL OF TYPE A LOGICAL DEFICITS

Three common patterns can be discerned from the research thus far. First, when inferences are presented in a purely symbolic format, patients perform well, and equivalently to healthy controls, in drawing logical conclusions. In contrast, the patients' performance diminishes, both overall and with respect to controls, when these inferences are presented in a real-language format. Second, the introduction of affect-laden material distorts the reasoning of both patients and healthy controls, but particularly patients. Third, tests that measure the influence of context and believability on patients' reasoning, as well as patients' lack of attention to the possibility of counterexample (see Huq et al.,[24] Phillips et al.,[25] Kemp et al.[26]), seem to indicate a tendency for delusional patients to block out relevant information in drawing inferences.

The contrast between symbolic logical problems and real-language substitutions of those problems on patient performance suggests that the inference structure per se is not impaired in a fundamental manner (thus, to use the language of our models above, the deficit is "contextual" rather than "foundational"). Because a "processor," once broken, is unlikely to repair itself in a consistent manner, it seems far more plausible to hypothesize that the pathways leading to that logical processor are sometimes blocked.

The remaining two pieces of information indicate both a possible trigger and a possible mechanism for such a blockage. The mechanism might be the suppression of contextual information ("implicit premises") necessary to construct and amend mental models accurately. In particular, background context indicating the presence of likely counterexamples would be crucial in appropriately limiting the range of possible explanations for phenomena, and the absence of this context would permit "unbelievable" hypotheses to go unchallenged internally. Examples of background context might include an appreciation for the likelihood of randomness and common causes in evaluating correlations between two events, basic inductive generalizations regarding the resemblance of future behavior to past behavior, the role of confirmation from other sources in judging the reliability of information, and so forth. From a physiological point of view, we might expect the hippocampus to play a mediating role in evaluating context, serving as a link with the prefrontal cortex, which would then govern the purely formal aspects of logical operations. We may speculate upon the evolutionary utility, from the point of view of neurological efficiency, for an organism under imminent threat to focus mentally on (or mostly on) what is directly in front of it, conceptually speaking.

It is not hard to imagine that strong emotional states might serve as a trigger for disrupting access to contextual information. On a purely anecdotal level, everyday examples abound of these sorts of considerations (i.e., randomness, common causation, past behavior, degree of confirmation) being disregarded by ostensibly normal individuals in the presence of stress or euphoria. The role of emotion in distorting logic may explain the poorer performance of patients on all real-language tasks, if they are inclined to attach emotional import inappropriately to material normally considered to be emotionally neutral.

The association of delusions with strong emotion is also compelling because it provides a needed explanation for the fact that certain patterns of delusionality appear so consistently among patients. It may be the case that delusions of paranoia evolve from an attempt by the patient to explain spontaneously generated feelings of threat, while delusions of grandeur evolve from an attempt by the patient to explain spontaneously generated feelings of euphoria. This hypothesis may provide some insight into the correlation between emotional stress and relapse in schizophrenia.

According to this view, the difference between the healthy individual who forms false beliefs temporarily and then dismisses them as implausible and the delusional patient who holds false beliefs over long periods of time is not in the mechanism by which the false beliefs are formed, but rather in their ultimate origin. In both cases inappropriately unrestricted models may arise as a consequence of the suppression of contextuality that occurs during periods of strong emotion. The difference would lie in the formation and maintenance of that emotional state. A person whose perception of threat is based on the presence of a real source of danger will take action to avoid that danger and will presumably return to a nonaroused state when it is no longer present. At that time the contextual reality of counterexamples would intrude on one's mental models, and false beliefs would quickly be discarded. If, however, the perception of threat is unfounded (i.e., it is either spontaneously generated or exaggerated), then it might remain indefinitely, since avoidance of that feeling is not something that the perceiver can control. Under these conditions of sustained perceptions of threat, false beliefs could remain immune to counterexample long enough to become entrenched.

We wish to emphasize that the story we have told above, although pretty, is only a hypothesis consistent with the limited amount of data that we have thus far. We have argued that these data are both incomplete and unreliable for various methodological reasons. Our purpose in telling this story, therefore, is simply to advance the claim that applications of mathematical logic can provide a valuable tool for exploring the phenomenology and neurology of rationality and, by extension, irrationality. The connection between emotion and reason, and the possibility that the etiology of delusions places inappropriate emotional response as the cause, rather than the result, of faulty reasoning, raises some fertile areas for research.

The first step for future research on these questions will probably be to perform logical reasoning studies similar to those that have already been done, preserving the best of their innovations while eliminating the flaws that have confounded their results. In particular, we would strongly suggest testing a sample that explicitly discriminates for delusionality (either, say, patients with delusions, patients without delusions, and healthy controls, or these categories plus healthy controls with a high degree of magical ideation). The study should include items that independently test for type A and type B errors. The type A section should include items that determine a subject's ability both to include relevant information and to exclude irrelevant information (by giving a hypothesis, for example, and asking the subject to indicate which of the various pieces of information provided would either support or falsify that hypothesis). The type B section should include items that utilize both propositional and syllogistic logic. This section should be screened carefully to include only those inferences that are easily intuitive to most healthy controls (i.e., performance by healthy controls without any education in logic around 70–75%). The two sections should be presented within both affect-neutral and affect-laden real-language formats, as well as within purely symbolic formats, all of which are formally identical (in other words, they are symbolically equivalent with different substitutions). Affect, most likely anxiety, should be assessed before and after each section both by self-report and by physiological measures to establish a correlation among emotion, problems with reasoning and/or sorting, and the potential for heightened emotional vulnerability in subjects prone to delusions.

If these correlations are shown to be robust, it would be interesting to determine whether any connection exists between the problems with "sensory gating" that are considered to be so ubiquitous in schizophrenia[34] and the deficiencies in "cognitive gating" that we suggest. New techniques in dynamic brain imaging may be helpful in exploring the roles of the prefrontal cortex and the hippocampus in the sorting of information. Imaging may also be useful in determining the degree to which hyperactivity of the amygdala, inadequate control of the amygdala by the hippocampus, or mediated interactions with the prefrontal cortex are responsible for patient vulnerability. This is obviously only one of many forms that such a study could take. Our larger point is that, despite some limited success to date, logical models have not been fully exploited in mapping the phenomenology of cognitive differences in patients, and it is our hope that future work will explore new and better ways in which these models may be applied.

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