Research Article

EXPLAINING "MEMORY FREE" REASONING[1]

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Abstract—*Cognitive theorists generally assume that reasoning depends on memory; accurate reasoning requires access to critical informational inputs. Although memory dependency seems self-evidently true, it has been disconfirmed in recent studies of children's logical, mathematical, and pragmatic inferences. These studies have led to a new account of cognitive development, fuzzy-trace theory, that stresses the unfolding of gist-driven intuitive reasoning processes, and that reformulates traditional conceptions of the relationship between verbatim and gist memories. Fuzzy-trace theory also identifies circumstances in which reasoning accuracy depends on memory accuracy.*

In this article, we explore an erroneous intuition about higher reasoning processes that has long misled psychologists, especially students of child development: the memory-failure hypothesis. Like many commonsense ideas, this one seems so self-evident that it has rarely been put to the test, and nonsupportive data have been treated as exceptional when it has. Recent studies, however, have made a consistent case against it. These same studies force us to rethink some long-standing assumptions about the interface between memory and cognitive development, about the types of memories that underlie higher reasoning, and about the functional relationship between memory for the verbatim form of inputs and memory for their gist.

DEVELOPMENTAL INDEPENDENCE OF MEMORY AND REASONING

A venerable approach to unraveling the mysteries of human reasoning is to chart the initial emergence of reasoning skills in children's thinking, with a view toward identifying critical enabling processes. According to the memory-failure hypothesis, children's increasing ability to retain faithful copies of recently encoded information is just such an enabling process, either because reasoning must consume those memories on its way to solving a problem or because memory and reasoning are both controlled by some common third variable. Under this hypothesis, which motivates the inclusion of memory items (e.g., digit span) on intelligence tests and other measures of cognitive ability, children's reasoning errors are often nothing more than disguised memory failures.

Although the memory-failure hypothesis has been implemented in numerous theories (Bjorklund, 1989; Howe & Rabinowitz, 1990; Reyna & Brainerd, 1990), recent experimentation has failed to confirm that children's reasoning errors are due, even in part, to memory failures. Remarkably, a task for which the hypothesis seems ineluctable, transitive inference, was the first to produce firm evidence against it. Few other tasks are so deeply woven into the fabric of 20th-century child psychology. Alfred Binet administered such tasks to his daughters as part of his studies of imageless thought, Cyril Burt modified the original Binet-Simon intelligence tests to include problems of this sort, and Jean Piaget's first encounters with child study (work that prompted his great insight that children's reasoning errors are more enlightening than their successes) involved standardizing French translations of Burt's problems. The prototypical problem—also called a three-term series task or a linear syllogism—involves three objects (A, B, and C) that can be ordered along some physical or psychological dimension (length, weight, truthfulness, happiness). The relationships between the adjacent objects (usually called premises) are presented as background facts, with the objective being to deduce the relationship between the nonadjacent objects. It seems so obvious that this deduction demands accurate premise memory that, historically, theorists characterized their task as one of explaining how transitive inferences are made given that premises are remembered (Reyna & Brainerd, 1990).[2]

The nature of reasoning–remembering relationships can be evaluated by simply adding premise-memory probes to the transitive inference paradigm. This probe methodology has now been used in many studies. We assembled those data sets, 98 involving children and 10 involving adults, to determine whether reasoning accuracy generally depends on premise memory. As a group, these studies encompass the major design variations associated with investigations of transitive inference (for a review, see Reyna & Brainerd, 1990). So, it cannot be argued that their findings are due to unique or atypical experimental conditions.

If theoretical opinion were correct, remembering the premises on a particular administration of a specific problem ought to increase a child's chances of solving the problem. (This is normally called horizontal or on-line dependency.) To test this notion, for each of the 108 data sets, we computed the *unconditional* probability of correct transitive inferences on particular administrations of specific problems to individual subjects, and we also computed the *conditional* probability of correct transitive inferences given that the premises could be remembered. Of course, the memory-failure hypothesis indicates that the probability of a correct transitive inference given accurate premise memory will be greater than the unconditional proba-

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1. We dedicate this article to the memory of Michael Chapman. Although still early in his career, Michael made important contributions to topics that are treated here (Chapman & Lindenberger, 1988, 1992).

2. Some normative data on the tenacity of this intuition were reported a few years ago by Brainerd and Kingma (1984). They surveyed conference attendees on the role of memory failures in transitive inference errors. Only 3% of the respondents thought that an inability to remember the premise inputs would not increase error rates.

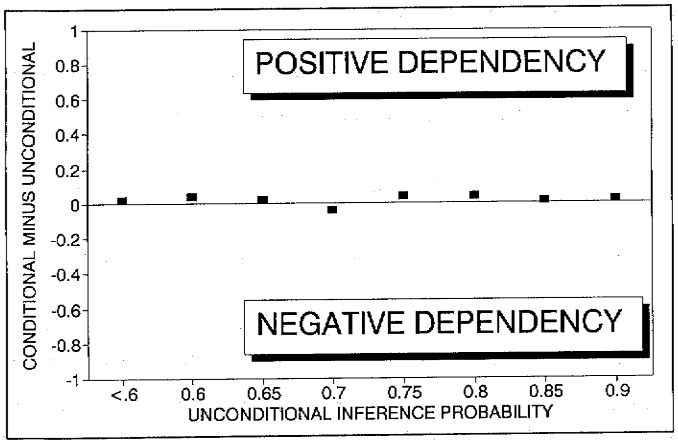

Fig. 1. Degree of stochastic dependency between transitive inferences and memory for premise inputs in three-term problems. Plotted data were drawn from Brainerd and Kingma (1984, 1985), Chapman and Lindenberger (1988), Halford and Galloway (1977), Kingma (1981), and Russell (1981).

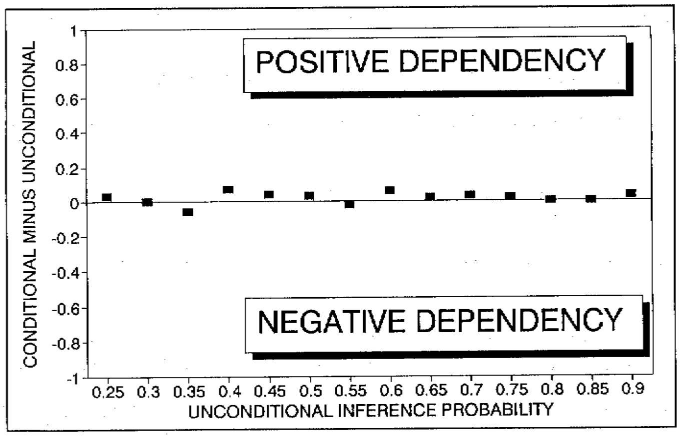

Fig. 2. Degree of stochastic dependency between transitive inferences and memory for premise inputs in problems involving four, five, or more terms. Plotted data were drawn from Brainerd and Kingma (1984), Chapman and Lindenberger (1988), Fisher and Chandler (1991), and Rabinowitz, Grant, Howe, and Mason (1992).

bility of a correct transitive inference. (Statistically, this is a more appropriate procedure than aggregating scores across many premise-memory probes, aggregating scores across many transitive inference problems, and then correlating the two aggregates. Aggregate scores could correlate positively even though individual transitive inferences are not influenced by premise memory [Reyna & Brainerd, 1990].)

We have separated the results into findings for the standard three-term problem (Fig. 1, 20 data sets) and findings for problems involving four, five, or more terms (Fig. 2, 88 data sets).[3] This separation is probative because dependencies ought to become more marked as the premise memory load increases (Brainerd & Reyna, 1992). Two values were calculated for each data set: the unconditional probability of a correct transitive inference (abscissa) and the difference between the conditional probability of a correct transitive inference given that the premises could be remembered and the unconditional probability of a correct transitive inference (ordinate). Under the memory-failure hypothesis, conditional minus unconditional differences should all be positive and should fall well above the zero-difference line (the positive dependency region of the graph). It can be seen in Figure 1 that this was not the case with three-term problems; the mean difference between conditional and unconditional probabilities was only .02. There was also no support for memory failure when the premise memory load was higher; the mean difference between conditional and unconditional probabilities in Figure 2 was again .02.

In addition to evidence that transitive inference is independent of premise memory, parallel findings exist for three other important paradigms: class inclusion, conservation, and probability judgment. These tasks are described in Table 1, along

3. The numbers of data points in Figures 1 through 4 are smaller than the numbers of data sets on which these figures are based because the plotted points are averages of conditional minus unconditional values for data sets falling within the indicated intervals on the abscissas of these figures.

Table 1. *Illustrations of probed versions of class-inclusion, conservation, and probability-judgment problems*

Paradigm	Background inputs	Reasoning problem	Memory probes
Class inclusion	A = 7 cows B = 3 horses C = 10 animals	Are there more animals or more horses?	A = ? B = ? C = ?
Conservation	A = 15-cm row containing 5 blue chips B = 15-cm row containing 5 red chips	Do Row A′ (shortened to 5 cm but still containing 5 chips) and Row B have the same number of chips?	Does Row A′ (or Row B) have the same number as when we started?
Probability judgment	A = 7 red balls B = 5 blue balls C = 3 white balls	On a random sample, which color is most likely to be drawn?	A = ? B = ? C = ?

Table 2. *Illustration of the probed version of pragmatic inference problems*

	Test items	
Background inputs	Inference problems	Memory probes
The cage is on the table. The bird is in the cage. The cat is under the table.	The cat is under the bird. (true) The bird is under the cat. (false)	The bird is in the cage. (true) The cat is in the cage. (false)

sketch some principles that have emerged from this work that explain memory independence—specifically, that children access gist in parallel with the encoding of background inputs, that gist and verbatim representations of inputs are independent, and that there is a decided preference for processing gist during reasoning. We then show how these principles allow us to predict reasoning–remembering dependency as well as independence in contrasting circumstances.

Parallel Gist Retrieval: Recasting the Modal Model

The first step in explaining memory independence is to acknowledge that, despite the aforementioned data, children's reasoning must process memories that are somehow related to the background inputs. While there are occasional circumstances in which reasoning can succeed by drawing upon stored knowledge without regard to background inputs (Katz, Lautenschlager, Blackburn, & Harris, 1990), the problems that have produced memory independence results cannot be solved unless certain inputs are received. This is why common sense regards memory dependency as self-evident. The way around common sense lies in understanding, first, that memories other than verbatim traces of background inputs are activated on the basis of those inputs and, second, that these other memories, as well as verbatim traces of background inputs, are deposited concurrently. We refer to these two ideas as gist retrieval and parallelism.

Concerning gist retrieval, from an early age, children derive

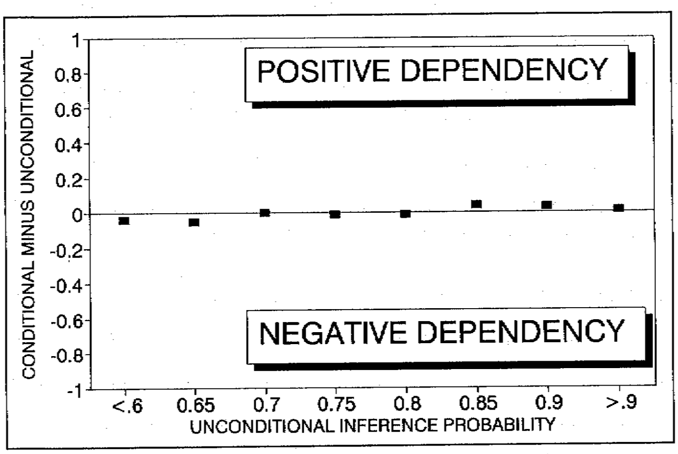

Fig. 4. Degree of stochastic dependency between pragmatic inferences and memory for statements. Plotted data were drawn from Brainerd and Reyna (in press-b) and Lapointe (1991).

a variety of gist from the background inputs on reasoning problems. For example, preschoolers access nominal gists such as "the As are most" and relational gists such as "more As than Bs" on the basis of numerical inputs for mathematical problems that they will not solve correctly until some years later (Brainerd & Reyna, 1990b; Spinillo & Bryant, 1991). They also store patterns of magnitude flow (e.g., "big things start on the left," "things are getting smaller") from the background inputs on linear-order problems (Reyna & Brainerd, 1990). A prominent aspect of children's reasoning, then, is that their working memories contain rich assortments of task-relevant information, ranging from verbatim traces of the surface forms of inputs to traces that capture the senses and patterns of those inputs.[4]

Although it is not remarkable, in itself, that children retrieve gists on the basis of incoming information, understanding how this leads to memory independence demands a reformulation of the conventional view of the relationship between memory for the surface forms of inputs and their gists. This view crystallized 20 years ago in connection with Bransford and Franks's (1971) landmark studies of the abstraction of meaning from sentences (see also Jarvella, 1971). The pivotal assumption in this traditional view is that gist is like the Cheshire Cat's smile; it is the residue of faded verbatim traces. More particularly, verbatim traces of inputs first accumulate in working memory, their gist is derived, and verbatim traces then quickly become inaccessible. Thus, subsequent performance, both answering memory probes and solving reasoning problems, is based on reconstructive processing of gist (Fletcher, 1992).

There is now much evidence that this serial conceptualization—accumulate verbatim traces and then derive gist from those verbatim traces—is wrong (Reyna & Brainerd, 1992). Rather than extracting gist from accumulated verbatim inputs, the process seems to involve retrieving a variety of candidate representations from the start. In this parallel mechanism, background inputs provide access to core gist in semantic memory, as well as leading to the formation of traces of the inputs' surface forms (Brainerd & Reyna, in press-b). Examples of parallel gistification that are well established experimentally include the identification of complete patterns of magnitude

4. Owing to the long preeminence of logic-based theories of cognitive development (especially Piagetian theory), researchers have tended to regard the latter as contaminants that distort the expression of true logical competence, and much methodological ingenuity has been devoted to purifying reasoning paradigms against such contamination (Smedslund, 1963, 1969). Fuzzy-trace theory takes a wholly different position—namely, that the pervasive presence of gist traces is telling us something fundamental about cognitive development.

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(RECEIVED 11/8/91; REVISION ACCEPTED 5/22/92)