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Fuzzy-Trace Theory and Children's False Memories

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Fuzzy-trace theory's concepts of identity judgment, nonidentity judgment, and similarity judgment provide a unified account of the false-memory phenomena that have been most commonly studied in children: false-recognition effects and misinformation effects. False-recognition effects (elevated false-alarm rates for unpresented distractors that preserve the meanings of presented targets) are due to increased rates of similarity or false identity judgment about distractors or to decreased rates of nonidentity judgment. Misinformation effects (erroneous acceptance of misleading postevent information and erroneous rejection of actual events) are also due to variability in rates of similarity, identity, and nonidentity judgment. Two experimental paradigms are presented, one for false recognition (conjoint recognition) and one for misinformation (conjoint misinformation), that allow investigators to tease apart the contributions of these processes to children's false-memory reports. Each paradigm is implemented in a mathematical model that provides numerical estimates of the processes. © 1998 Academic Press

Although the phenomenon of false memory has been well documented experimentally, it is frequently claimed that theoretical understanding has eluded us. For instance, the American Psychological Association's interim report on recollections of childhood sexual abuse concluded that "It is possible to construct convincing pseudomemories for events that never occurred, although the mechanisms by which this occurs are not well understood" (Denton, 1994, p. 9). Similarly, Ceci and Bruck (1993), in their review of developmental studies of false memory, concluded that "the exact mechanisms involved in producing distortion in young children's reports are still being debated" (p. 432).

Recently, progress has been made in formulating an explanation of false memory, and of age variability, within the framework of fuzzy-trace theory. The elements of this account have emerged gradually in a series of research reports (Ackerman, 1992, 1994; Brainerd & Reyna, 1995, 1996; Brainerd, Reyna, & Brandse, 1995; Cassel & Bjorklund, 1995; Cassel, Roebers, & Bjorklund, 1996; Marx & Henderson, 1996; Payne, Elie, Blackwell, & Neuschatz, 1996; Poole & Lindsay, 1995; Poole & White, 1993; Reyna, 1996a; Reyna & Kiernan, 1994,

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1995; Robinson & Roediger, 1997; Salmon & Pipe, 1997; Schacter, Verfaellie, & Anes, 1997; Schacter, Verfaellie, & Pradere, 1996; Toglia, Neuschatz, & Goodwin, in press; Tun, Wingfield, Rosen, & Blanchard, 1998; Warren & Lane, 1995) and literature reviews (Brainerd, 1996; Brainerd & Poole, 1997; Quas, Qin, Schaaf, & Goodman, 1997; Reyna, 1992, 1995; Reyna & Brainerd, 1995; Reyna & Lloyd, 1997; Reyna & Titcomb, 1996; Titcomb & Reyna, 1995). The account focuses on the processes that are involved in the formation, persistence, and ontogenesis of the most widely studied classes of false-memory reports: false alarms and incorrect rejections on recognition tests. Importantly, the account encompasses both spontaneous and implanted false memories.

In the present article, we formalize this theory and provide experimental and mathematical tools to evaluate it. First, we summarize, in general terms, the memorial underpinnings of spontaneous and implanted false reports. Second, we analyze how those memories are processed on recognition tests to yield judgments that reflect underlying identity, nonidentity, and similarity processes. Third, we show how this analysis explains false-recognition effects, misinformation effects, and developmental change. Fourth, we describe two experimental paradigms (conjoint recognition and conjoint misinformation) and two mathematical models (FALSE and MISINFORM) that allow investigators to quantify the contributions of identity, nonidentity, and similarity judgments to children's false reports. Fifth, we apply these models to four studies of false-recognition effects and ten studies of misinformation effects.

FALSE-MEMORY REPORTS: A TAXONOMY

At the turn of the century, Binet (1900) observed that children's false-memory reports can arise in two ways: through spontaneous internal distortion and through implantation (deliberate or accidental) of misinformation. In modern studies, children are first exposed to a series of targets (words, pictures, sentences, narratives). Later, they respond to a memory test, usually a recognition test in which the probes are mixtures of targets and distractors. Distractors are of two sorts: *meaning consistent* (if COLLIE was a target, DOG would be consistent) or *meaning inconsistent.* The latter may either be probes that are completely unrelated to targets or probes that falsify some aspect of the information presented in targets. (If “The collie is sitting under the porch” was a target, “The spider is crawling up the wall” would be an unrelated distractor and “The collie is sitting on the porch” would be a meaning-falsifying distractor). Meaning-inconsistent distractors have usually been of the first type when targets were words or pictures and of the second type when they were sentences or narratives.

Two types of false reports can occur, false alarms (e.g., saying “yes” to DOG) and incorrect rejections (e.g., saying “no” to COLLIE), and they can be produced nonmemorially or memorially. Concerning nonmemorial reports, when a probe does not produce retrieval of target memories, most theorists assume that subjects often resort to a variety of response biases (e.g., Buchner, Erdfelder, & Vaterrodt-Plunecke, 1995), including guessing, response alternation, yea-saying, nay-saying, and inferences about overall proportions of target and distractor probes. Concerning memory-based false reports, even when a probe produces retrieval of memories that were stored when targets were studied, those memories may support incorrect responses rather than correct ones.

Reyna (1995) presented a taxonomy of memory-based false reports that divided the studies that produced them into two basic designs: *false-recognition,* in which false reports arise spontaneously, and *misinformation,* in which false reports may arise both spontaneously and via implantation. The difference between these designs lies in information that is interpolated in the interval between target exposure and test. In false-recognition studies, either no interpolated information is presented, or children perform some irrelevant buffer activity. In misinformation studies, interpolated information is presented that falsifies incidental details of target events (e.g., Bruck, Ceci, Francoeur, & Barr, 1995; Ceci, Ross, & Toglia, 1987). Children in the control conditions of misinformation studies usually receive neutral information that is consistent with the gist of target events but does not falsify details. This procedure has also been adapted for use with infants (see Rovee-Collier, 1995).

Memorial bases for incorrect rejections of targets and false-alarms to distractors are summarized in Table 1. The first point to note is that incorrect rejections of targets in both designs may result from retrieval of verbatim memories of *other* targets, whereas in misinformation designs they may also result from retrieval of verbatim memories of misinformation. (Children in a false-recognition study may retrieve “The bird is in the cage” when “The bird has yellow feathers” is presented for test, whereas children in a misinformation study may also do this or they may retrieve the misinformation “The bird has green feathers.”) When targets are unrelated to each other, it is reasonable to suppose that memory-based incorrect rejections will be uncommon because a target probe will rarely produce retrieval of verbatim traces of other (unrelated) targets. When targets are related to each other, however, memory-based incorrect rejections may frequently occur (Ackerman, 1994; Brainerd & Reyna, 1993).

A second point to note is that false alarms can also be memory-based in both designs. In false-recognition studies, such errors are supported by gist memories that preserve targets’ meanings but not their verbatim forms. In Table 1, an inference, Distractor D, may be falsely accepted because it preserves the meaning of the second and third targets, and Distractor C may be falsely accepted because children remember the gist “something about a bird” or “something about a bird’s feathers.” In misinformation studies, false alarms are supported by gist *and* verbatim memories. Concerning gist, Distractor D may again be falsely accepted because it preserves the meaning of the second and third targets, and Distractor C may again be falsely

TABLE 1
Classification Scheme for Memory-Based Errors in Developmental Studies of False Memory (Based on Reyna, 1995)

	Type of design	
	False recognition	Misinformation
Targets	The cat is on the sofa. The bird is in the cage. The cage is under the table. The bird has yellow feathers.	Same.
Misinformation	None.	Do you remember the bird with green feathers?
Test items:		
target	A. The bird has yellow feathers. B. The bird is in the cage.	Same.
distractors	C. The bird has green feathers. D. The bird is under the table.	Same.
Incorrect rejections:		
verbatim memory	Says “no” to A because the verbatim trace of B is retrieved or says “no” to B because the verbatim trace of A is retrieved.	Same, plus says “no” to A because the verbatim the trace of the misinformation is retrieved.
gist memory	None.	None.
False alarms:		
verbatim memory	None.	Says “yes” to C because the verbatim trace of the misinformation is retrieved.
gist memory	Says “yes” to C because it is consistent with the gist of the last target sentence.	Same.
	Says “yes” to D because it is consistent with the gist of the second and third target sentences.	Same.

accepted because children remember some of the meaning of the last target. However, there is a further gist basis and a further verbatim basis for falsely accepting Distractor C: Children may remember the gist of the *misinformation,* or they may remember its precise verbatim form.

Summing up, it is possible to think of two distinct classes of memory-based false reports—gist supported and verbatim supported—in both false-recognition designs and misinformation designs. However, misinformation designs are more complex than false-recognition designs in two respects. First, during the interval between study and test, misinformation designs provide additional information that falsifies incidental details of target events. Second, owing to the presentation of such information, misinformation designs provide further memorial bases for both incorrect rejections and false alarms.

FOUR MEMORY PRINCIPLES

Now that some general memorial underpinnings for false reports have been considered, we can move on to a detailed analysis of how those memories are initially stored and how they are subsequently processed on recognition probes to yield true and false reports. This analysis turns on fuzzy-trace theory's distinction between responses that are based on identity and nonidentity judgments about verbatim memories versus responses that are based on similarity judgments about gist memories (Brainerd, Reyna, & Kneer, 1995; Brainerd, Reyna, & Mojardin, in press; Reyna & Brainerd, 1995). Four principles are discussed, together with data that support them: parallel verbatim–gist storage; dissociated verbatim–gist retrieval; explicit recollection; and identity, nonidentity, and similarity processes. In the next section of this article, these principles are used to explain how false-memory reports are generated and to explain age variability.

Parallel Verbatim–Gist Storage

Several lines of experimentation converge on the conclusion that children store separate representations of targets' surface forms and other item-specific information (verbatim traces) and of the semantic, relational, and elaborative properties in which targets participate (gist traces) (for a review, see Reyna & Brainerd, 1995). The same types of memories should be stored for the interpolated information that is presented in misinformation designs (Reyna, 1995; Reyna & Titcomb, 1996).

Because these verbatim and gist memories are stored for the *same inputs* (they are alternative representations of those inputs), it is natural to imagine that there will be strong functional connections between them. Indeed, until recently, gist storage was often characterized as a process of serial extraction of gist *from* verbatim traces of inputs. This characterization is found, for instance, in traditional theories of sentence recognition (e.g., Bransford & Franks, 1971). In such theories, verbatim traces of word strings are said to accumulate in memory, followed by periodic extraction of their gist (e.g., at clause boundaries), followed by rapid decay of verbatim traces.

Experimentation has failed to confirm this presumed interdependence of verbatim and gist storage. It appears, on the contrary, that the encoding of targets initiates parallel storage processes. One process generates episodic memories of targets' surface forms (e.g., "COLLIE," "BLUE"), and the other generates gist traces using inputs as retrieval cues to locate relevant concepts (e.g., "dog," "color") in long-term memory and assign local interpretations to them (e.g., "The dog is COLLIE," "The color is BLUE"). The findings that most clearly support parallel storage are ones in which certain meanings are stored *before* the targets that instantiate those meanings have been fully processed (for reviews, see Brainerd & Reyna, 1993; Reyna & Brainerd, 1992). Two examples are the word-superiority effect (Ankrum & Palmer, 1989) and the missing-letter effect (Moravcski & Healy, 1995). The former refers to the fact that subjects can recognize target words (e.g., “COLLIE,” “BLUE”) before they can recognize their constituent letters (e.g., “I,” “U”), and the latter refers to the fact that subjects can recognize the meanings of target words without processing all of their constituent letters. Examples from higher reasoning are provided by problem-solving tasks in which children and adults catch on to relationships between targets after encoding only a fraction of those targets. For instance, this advanced detection of relationships has been reported for linear inference tasks (Reyna & Brainerd, 1990) and for numerical inference tasks (Brainerd & Reyna, 1995).

Dissociated Verbatim–Gist Retrieval

Available evidence (for reviews, see Brainerd & Poole, 1997; Reyna & Titcomb, 1996) suggests that two factors are especially important in determining whether verbatim or gist traces are retrieved on memory tests: (a) the retrieval cues that are supplied by recognition probes and (b) the differential forgetting rates of verbatim and gist traces. Concerning (a), as long as verbatim and gist traces are both accessible, as they normally are on immediate recognition tests, target probes are usually better retrieval cues for the former and distractor probes are usually better retrieval cues for the latter (Reyna & Brainerd, 1995). Thus, target acceptances (hits) are based predominately on verbatim traces, whereas distractor acceptances (false alarms) are based predominately on gist traces (Reyna & Kiernan, 1994). This principle concurs with familiar laws of retrieval, such as the encoding-specificity principle (Tulving & Thomson, 1971). Empirically, the principle is supported by studies of online relations between the retrieval of verbatim and gist memories (Ackerman, 1992, 1994; Brainerd & Gordon, 1994; Marx & Henderson, 1996; Reyna, 1996a; Reyna & Kiernan, 1994; 1995). In such studies, hits for targets and false alarms for gist-preserving distractors were independent, manipulations were identified that affected hits but not false alarms, and other manipulations were identified that affected false alarms but not hits.

Turning to Factor (b), verbatim traces become inaccessible more rapidly than gist traces (e.g., Gernsbacher, 1985; Murphy & Shapiro, 1994), which has straightforward consequences for retrieval of the two memories on recognition tests: The memorial basis for hits (verbatim memory) fails more rapidly than that for false alarms (gist memory), and the memorial basis for hits shifts over time (from verbatim to gist memory) while that for false alarms remains stable (Brainerd, Reyna, & Kneer, 1995). This leads to a counterintuitive prediction. If verbatim traces are the predominate basis for initial hits and gist traces are the predominate basis for initial false alarms, then, under certain conditions, false alarms should be more persistent over time than hits. Those conditions are ones in which initial false alarms, like initial hits, are predominately memory based, as opposed to response-bias based (Brainerd, Reyna, & Brandse 1995). In line with this prediction, Brainerd, Reyna, and Brandse (1995) found that children’s false alarms to distractors that were semantically consistent with target words were more stable across a one-week forgetting interval than hits to the target words themselves. Brainerd and Mojardin (in press) replicated this result using distractors that were paraphrases of previously studied sentences, and Payne et al. (1996) replicated it with thematically related word lists.

The Nature of Explicit Recollection

There is a long tradition of assuming that recognition probes provoke at least two subjective memory experiences. The first, which has been called recollection (e.g., Jacoby, 1991) or feeling of remembering (e.g., Gardiner & Java, 1991), involves conscious remembrance of having encoded that specific probe earlier in the experiment. The second, which has been called familiarity (e.g., Mandler, 1980) or feeling of knowing (e.g., Strack & Forster, 1995), involves nonspecific impressions of resemblance between the probe and previously studied information that are not anchored in particular targets. Of the many findings that support this distinction, perhaps the most probative ones come from studies showing that remembered information can have opposite effects on performance when the memories are conscious and explicit versus when they are not (e.g., Horton, Pavlick, & Moulin-Julian, 1993; Jacoby & Whitehouse, 1989).

In fuzzy-trace theory, retrieval of verbatim memories supports feelings of item-specific recollection of targets, whereas feelings of nonspecific resemblance are supported by retrieval of gist memories (Brainerd, Reyna, & Kneer, 1995). Retrieval of verbatim traces produces access to representations of well-defined surface structures, leading to feelings of reexperiencing those surface structures (e.g., "I hear COLLIE ringing in my mind's ear"). Retrieval of gist memories produces access to semantic information, which normally leads to feelings of reexperiencing familiar meanings that lack a grounding in specific target experiences (e.g., "I heard the name of a dog of some sort"). Recent studies suggest that, under some conditions, retrieval of very strong gist memories can also support feelings of item-specific recollection (for a review, see Reyna & Lloyd, 1997). In particular, when meanings have been repeatedly cued at study (as when COLLIE, POODLE, and SPANIEL were all presented), retrieval of those meanings is sometimes accompanied by feelings of item-specific recollection (e.g., Reyna & Kiernan, 1994). It is clear that those feelings have a different origin (i.e., gist retrieval) than the feelings of item-specific recollection that accompany the retrieval of verbatim traces *because they occur for unpresented distractors as well as for targets* (e.g., Robinson & Roediger, 1997). Indeed, some investigators have reported that when meanings have been repeatedly cued, feelings of item-specific recollection occur as frequently for distractor probes as for target probes (e.g., Payne et al., 1996; Reyna, 1996b).

Identity, Nonidentity, and Similarity Judgments

Several findings in the recognition literature (e.g., Hintzman, Curran, Oppy, 1992; Israel & Schacter, 1997) suggest that the retrieval of verbatim and gist memories support different types of decisions about probes—namely, all-or-none judgments of identity/nonidentity and graded similarity judgments. When a verbatim memory is retrieved, it is compared to the verbatim representation of the probe, and a categorical judgment of identity or nonidentity of surface forms is made about that probe (Brainerd, Reyna, & Kneer, 1995). When a gist memory is retrieved, two types of judgments can result. Normally, the retrieved gist memory will be compared to the gist representation of the probe, and a judgment of degree of similarity will be made about that probe (Schacter et al., 1997). But when a retrieved gist memory is so strong that it provokes feelings of explicit recollection about the probe (cf. above), a categorical judgment of identity can be made about it (Reyna, 1996b).

Verbatim retrieval supports acceptance of targets coupled with rejection of distractors, *regardless of whether distractors share salient meaning with targets* (Brainerd, Stein, & Reyna, 1998); for a related discussion, see Clark & Gronlund, 1996). For instance, retrieval of the verbatim trace of COLLIE supports acceptance of the probe COLLIE, but it also supports *rejection* of semantically related distractors such as DOG or POODLE. Verbatim retrieval leads to across-the-board rejection of even highly related distractors because no matter how great the meaning overlap is, the remembered surface form of a target such as COLLIE is demonstrably nonidentical to that of distractors such as DOG or POODLE (Brainerd, Reyna, & Kneer, 1995). Phenomenologically, such comparisons can be a basis for the familiar experience of feelings of contrast (Reyna & Lloyd, 1997). Thus, verbatim retrieval can provoke either judgments of identity of surface forms (e.g., when probes are targets) or judgments of nonidentity of surface forms (e.g., when probes are distractors).

Gist retrieval supports acceptance of targets because meaning resemblance is strong. (This is true regardless of whether the accompanying subjective experience consists of nonspecific feelings of similarity (e.g., “I heard the name of a dog of some sort” favors acceptance of COLLIE) or item-specific feelings of identity.) However, gist retrieval, unlike verbatim retrieval, also supports false alarms to related distractors when meaning resemblance is strong enough to exceed some subjective threshold. As with targets, the subjective experience that accompanies gist comparisons can be either nonspecific feelings of similarity or (false) item-specific feelings of identity. Thus, a key difference between gist-based and verbatim-based judgments is that false-alarm rates will increase as the meaning overlap between targets and distractors increases when gist is retrieved, but not when verbatim traces are retrieved.

Although it is assumed that distractors that preserve the gist of targets predominately cue the retrieval of gist memories, they may sometimes cue the retrieval of verbatim memories of their instantiating targets. In that case, how should false-alarm rates react? False-alarm rates should decrease because verbatim retrieval leads to judgments of nonidentity (feelings of contrast) about distractors. Hence, manipulations that facilitate verbatim retrieval should have the counterintuitive effect of reducing false-alarm rates for distractors that preserve the gist of targets (Reyna & Brainerd, 1995; Schacter et al., 1996).

The most obvious manipulations are ones that make verbatim memories of instantiating targets highly accessible when related distractors are presented for test. Two such manipulations have been studied, one in the context of continuous recognition designs and the other in the context of study-test designs. In the former type of design, a list of targets is presented, and subjects must judge whether each succeeding target has already been studied ("old") or not ("new"). For instance, COLLIE might be presented in position 12, a related new item (DOG or POODLE) might be presented at position 30, and an unrelated new item (TOWER) might be presented at position 31. The standard finding is a false-recognition effect: false-alarm rates will be higher at position 30 than at position 31.

Suppose, however, that the number of positions that intervene between the presentation of a target and the presentation of a related new item is reduced. Because verbatim memories become inaccessible more rapidly than gist memories, the effect of such a manipulation should be to increase the accessibility of verbatim memories of the earlier instantiating item when the related new item is presented (Brainerd, Reyna, & Mojardin, in press). If so, there is an increased likelihood that the latter will cue the retrieval of the verbatim trace of the former and produce feelings of contrast. This effect should be maximal when the related new item immediately follows the instantiating old item. This argument was confirmed in broad outline in some experiments by MacLeod and Nelson (1976) and Raser (1972). In both articles, it was reported that false-alarm rates for related new items decreased (while those for unrelated new items remained constant) as the interval between their presentation and that of instantiating old items decreased. In MacLeod and Nelson's research, false-alarm rates for related new items were slightly *lower* than those for unrelated new items when they immediately followed their instantiating old items.

In study-test designs, there is an analogous method for increasing the accessibility of verbatim memories of targets when related distractors are tested that involves presenting a probe for an instantiating target (COLLIE) shortly before its related distractor (DOG, POODLE) is presented. Because target probes predominately recruit their verbatim traces from storage, such traces should be placed in a state of high accessibility for a short time following such probes. If related distractors are presented within this time window (whatever it may be), they will be more likely to cue the retrieval of verbatim traces, leading to judgments of nonidentity (reject) rather than judgments of similarity (accept).

Five experiments that made use of this verbatim-priming methodology were reported by Brainerd, Reyna, and Kneer (1995). Their results were consistent with this prediction—verbatim priming lowered false-alarm rates for related distractors. The detailed findings were these. First, verbatim priming reduced false-alarm rates more when instantiating targets had been multiply presented

TABLE 2
Decisions about Targets and Related Distractors That Are Authorized by Different Memory Processes

	Memory process		
Probe	Identity judgment	Nonidentity judgment	Similarity judgment
Targets	Accept	Reject	Accept
Distractors	Accept	Reject	Accept

(i.e., when verbatim traces were especially likely to still be available) rather than singly presented. Second, verbatim priming reduced false-alarm rates more when related distractors immediately followed instantiating targets than when a few items intervened. Third, verbatim priming reduced false-alarm rates more on immediate recognition tests (high verbatim accessibility) than on one-week delayed tests (low verbatim accessibility). Fourth, verbatim priming reduced false-alarm rates more in older children (better verbatim memory) than in younger children (poorer verbatim memory). Fifth, in some conditions, verbatim priming reversed the usual false-recognition effect; false-alarm rates were *lower* for related distractors than for unrelated distractors.

EXPLAINING CHILDREN'S FALSE-MEMORY REPORTS

We have presented a working taxonomy of children's false-memory reports and described processes that, based on prior experimentation, seem to be implicated in acceptance and rejection of recognition probes. Those processes—the decisions about targets and distractors that are implicated by verbatim and gist retrieval—are summarized in Table 2. In this section, we first consider how those processes figure in both false-recognition designs and misinformation designs. Second, we show how the same processes can explain known patterns of age variability in both paradigms. Last, we comment briefly on the relation between these explanations and earlier theories of false-recognition and misinformation effects.

Identity, Nonidentity, and Similarity Judgments in False-Recognition and Misinformation Designs

False-Recognition Designs

The above principles show how memory-based false reports can occur for both targets (incorrect rejections) and semantically related distractors (false alarms) in false-recognition studies. Concerning targets, if a target probe (e.g., COLLIE) cues the retrieval of the verbatim trace of some other target, verbatim comparison will produce a *nonidentity* judgment (feeling of contrast) that supports an incorrect rejection. Although this would be unlikely to occur if presented targets were unrelated to each other, it could if targets were related. For instance, if COLLIE, POODLE, and SPANIEL were all presented, the probe COLLIE might cue the retrieval of the verbatim trace of POODLE or SPANIEL, leading to a nonidentity judgment and an incorrect rejection. (In most developmental false-recognition studies (e.g., Bach & Underwood, 1970; Brainerd, Reyna, & Brandse, 1985; Felzen & Anisfeld, 1971), the targets were unrelated to each other (e.g., lists of unrelated nouns), so nonidentity judgments were presumably negligible.) Turning to semantically related distractors (e.g., POODLE), we saw that false alarms can occur when distractors cue the retrieval of gist memories of their instantiating targets. Specifically, false alarms can be based on similarity judgments ("I heard the name of a dog of some sort"), or on false identity judgments when the retrieved gist memories are strong enough to produce false feelings of explicit recollection ("I remember hearing POODLE").

Misinformation Designs

Returning to the examples in Table 1, incorrect rejections of targets (A and B) and false alarms to distractors (C and D) can, of course, occur in the same manner as in false-recognition studies. To account for misinformation effects, however, additional routes to incorrect rejections and false alarms must be identified that arise from the interpolated information. Concerning targets, misinformation makes further verbatim traces available that conflict with those of targets (Reyna & Titcomb, 1996). If such a trace ("The bird has green feathers") is retrieved when the corresponding target ("The bird has yellow feathers") is tested, the result will be a false nonidentity judgment. Concerning false alarms to misinformation-embodying distractors, misinformation makes verbatim traces of such distractors available. If a misinformation-embodying distractor's verbatim trace is retrieved when it is tested, the result will be a false identity judgment (Reyna & Titcomb, 1996).

Thus, retrieval of verbatim traces of misinformation can both lower hit rates and increase false-alarm rates for misinformation-embodying distractors. In contrast, retrieval of gist traces of misinformation should have only the latter effect. With targets, the gist of misinformation is consistent with the gist of presented targets (Reyna & Titcomb, 1996). So, reliance on gist that was stored during the misinformation phase would support hits rather than incorrect rejections. With misinformation-embodying distractors, on the other hand, reliance on gist that was stored during the misinformation phase would support false alarms.

These distinctions yield two preliminary predictions on which data are available. First, they predict that misinformation will simultaneously elevate false-alarm rates for misinformation-embodying distractors and lower hit rates for targets. Second, other things being equal, false-alarm rate elevation should be the larger of the two effects: Reliance on either verbatim or gist traces of misinformation elevates false-alarm rates, but only the former suppresses hit rates.

The first prediction is consistent with findings reported by Belli (1989) and by Tversky and Tuchin (1989). In both instances, misinformation had the expected dual effect of lowering hit rates for misinformed targets and elevating false-alarm rates for distractors that embodied misinformation. In addition, Tversky and Tuchin's (1989) data provide support for the second prediction. The false-alarm rate elevation effect of misinformation was roughly one-third greater than the hit-rate suppression effect. In a later experiment by Pezdek and Rowe (1995), false-alarm rate elevation also exceeded hit-rate suppression.

Explaining Developmental Trends in False Memory

Developmental Trends in False Recognition

The false-recognition effect is the phenomenon of interest—that false-alarm rates are higher for distractors that preserve the gist of targets (e.g., POODLE when COLLIE was studied) than for unrelated distractors (e.g., TOWER). The key findings to be accounted for are the now-you-see-it-now-you-don't quality of published age trends in this effect and the fact that age trends have failed to conform to the predictions of traditional theories. The standard theoretical interpretation of the false-recognition effect is constructivism (e.g., Alba & Hasher, 1983; Loftus, 1995; Piaget, 1968), according to which presented targets are integrated with constructive inferences that go beyond experience, so that related distractors are "recognized" as having been experienced. Because inferential abilities increase throughout childhood, so should the false-recognition effect (Piaget & Inhelder, 1973; Prawat & Cancelli, 1976).

However, Reyna and Kiernan (1994) concluded that this prediction had not been confirmed in developmental studies of sentence recognition. They pointed out that although false-alarm rates for related distractors had increased with age in some studies (e.g., Brown, Smiley, Day, Townsend, & Lawton, 1977), they had decreased with age in other studies (e.g., Reyna & Kiernan, 1994) and had been age-invariant in still other studies (e.g., Paris and Carter, 1973). This inconsistent age pattern is also present in developmental studies of word recognition. With elementary school children, Brainerd, Reyna, and Kneer (1995) reported that false recognition of associates (e.g., COLD when ICE had been studied) decreased with age, Bach and Underwood (1970) reported that false recognition of associates increased with age, and Felzen and Anisfeld (1970) reported that false recognition of associates was age invariant. Tun et al. (1998) noted similarly inconsistent patterns in aging studies of word recognition.

The challenge is to explain why the false-recognition effect sometimes decreases with age, sometimes increases with age, and sometimes is age-invariant. Our earlier theoretical analysis suggests an obvious possibility: Opponent processes are operating, one supporting false alarms (gist-based judgments of similarity and false identity) to related distractors and the other supporting correct rejections (verbatim-based nonidentity judgments), *and both processes improve with age.* Therefore, the false-recognition effect (a) should decrease with age if conditions (instructions, materials, etc.) favor retrieval of verbatim traces of targets when related distractors are tested, (b) should increase with age if conditions make verbatim traces of targets inaccessible when related distractors are tested, and (c) may be age-invariant when related distractors provoke a mixture of verbatim and gist retrieval (see also, Reyna, in press). A comparison of sentence-recognition experiments reported by Reyna and Kiernan (1994) and Brainerd and Mojardin (in press) is consistent with this interpretation. Reyna and Kiernan found that the false-recognition effect decreased between the ages of 6 and 9, and Brainerd and Mojardin, using similar sentences, found that the effect increased during the same age range. Reyna and Kiernan's design strongly encouraged the retrieval of verbatim traces because they used a modified continuous-recognition procedure in which memory tests were interleaved between target presentations, whereas Brainerd and Mojardin's design made verbatim traces inaccessible because memory tests were administered a week after sentence presentation. Similarly, Tun et al. (1998) found that age differences in false-recognition effects for younger versus older adults were affected by manipulations that varied reliance on verbatim versus gist memory.

Developmental Trends in Misinformation

There has also been controversy over developmental trends in susceptibility to misinformation (see various chapters in Doris, 1991). Ceci and Bruck (1993) reviewed several studies that detected age declines in misinformation effects. However, there are studies in which misinformation effects were age invariant (e.g., Howe, 1991) and studies in which misinformation effects increased with age. As an example of the latter, Pezdek and Roe (1995) found that misinformation effects increased between the ages of 4 and 10. In one condition, there was a 300% increase in the effect for targets and a 157% increase for misinformation-embodying distractors. In a second condition, the effect for targets was age invariant, but that for misinformation-embodying distractors increased by 57%. In two later experiments with 4- and 10-year-olds, Pezdek and Roe (1996) found that the misinformation effect for targets was larger for older children in both experiments, whereas the effect for distractors was larger for younger children in one experiment and for older children in the other experiment.

As was the case for the false-recognition effect, the challenge is to explain developmental trends in misinformation effects so that variations in their direction can be accommodated. According to our earlier theoretical analysis, misinformation has either or both of two effects: It suppresses hit rates for misinformed targets and elevates false-alarm rates for distractors that embody misinformation. If verbatim-based identity judgments are the normal basis for hits, the first effect is most probably due to the retrieval of verbatim traces of misinformation. If verbatim-based nonidentity judgments are the normal basis for correct rejection of related distractors, the second effect is most probably due to the retrieval of verbatim traces or gist traces of misinformation.

Concerning age variability, memory processes that make performance more accurate and memory processes that make it less accurate are both improving with age in misinformation studies. For misinformed targets, retention of verbatim and gist memories of targets improves with age, which increases hits, *but so does retention of verbatim memories of target-falsifying information*, which suppresses hits. For misinformation-embodying distractors, retention of verbatim memories of instantiating targets improves with age, which decreases false alarms, *but so does retention of verbatim and gist traces of misinformation*, which increases false alarms. In principle, therefore, there is no serious obstacle to accounting for inconsistencies in the direction of developmental changes in misinformation effects. The direction may vary from study to study, for both targets and distractors, because the opponent memory processes that contribute most to performance may vary as a function of design factors (e.g., delay). However, variability should be lawfully related to manipulations that affect reliance on verbatim and gist memory.

AFTER WORD ON EARLIER THEORIES

The elements of fuzzy-trace theory's account of false recognition and misinformation were developed to overcome certain limitations of two prior theories—constructivism, which was briefly mentioned above, and the source-monitoring framework. According to constructivism (e.g., Bransford & Franks, 1971), verbatim information about experience accumulates in working memory, followed by periodic extraction of its semantic content, which includes inferences and elaborations, storage of that content in a unitary semantic code, followed by rapid loss of verbatim information. Thus, inferences and elaborations are stored in the same semantic code as actual experience. Constructivism explains the false-recognition effect on the ground that experience (target presentations) has been integrated with inferences and elaborations: "memory errors occur because experienced events are integrated with other elaborations that go beyond experience" (Loftus, 1995, p. 136). In other words, false alarms occur because distractors tap stored inferences and elaborations that can no longer be discriminated from experience. Constructivism's explanation of misinformation effects is analogous. Later experience (i.e., misinformation), along with inferences and elaborations about it, is assumed to be integrated with earlier experience (i.e., target presentations, inferences, and elaborations), thereby transforming and destructively updating the semantic code. Then, incorrect rejections and false alarms occur because targets tap information that is inconsistent with the updated code, producing hit-rate suppression, whereas distractors tap information that is consistent with it, producing false-alarm rate elevation.

Unlike constructivism, the source-monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993) allows for the possibility that initial experience, later experience, and inferences and elaborations may all have distinct memory representations. Memory errors are explained as confusions and misattributions regarding the origins of the memories that are retrieved at test. The false-recognition effect is explained on the ground that, because related distractors preserve salient aspects of targets' meanings, when these distractors are presented at test, children misattribute retrieved memories that support acceptance to the presented target material rather than to their own cognitive processes. Similarly, misinformation effects are explained on the ground that retrieved memories that are inconsistent with target probes (hit-rate suppression effect) and consistent with distractor probes (false-alarm rate elevation effect) are misattributed to the study phase rather than correctly attributed to the misinformation phase. Reyna and Lloyd (1997) reviewed several empirical results that violate the predictions of constructivism and the source-monitoring framework, results that motivated fuzzy-trace theory's alternative account. Here, we sketch only a few obviously contradictory findings by way of illustration.

The illustrative results for constructivism are target-distractor independence effects and interference effects. Because information about target presentations, inferences, and elaborations are integrated in a single semantic code that is the basis for both hits and false alarms, it follows that hit rates for targets and false-alarm rates for semantically related distractors will be positively dependent (Reyna & Kiernan, 1994). However, they have usually been found to be independent, both with sentences (Ackerman, 1992, 1994; Reyna & Kiernan, 1994, 1995) and with words (Brainerd, Reyna, & Kneer, 1995; Marx & Henderson, 1996). Further, under special conditions that are specified in fuzzy-trace theory's analysis of false memory, acceptance rates for targets and distractors have been found to be negatively related (Brainerd & Reyna, 1993), and manipulations have been identified that have opposite effects on the two acceptance rates (Brainerd & Gordon, 1994; Brainerd & Reyna, 1995; Reyna, 1996b; Reyna & Brainerd, 1995).

The illustrative contradictory results for the source-monitoring framework involve the effects of variations in target-distractor similarity. If errors are due to children's tendency to confuse memories of inferences, elaborations, and misinformation with memories of target presentations, it follows that increasing the distinctiveness of target memories will eliminate or greatly reduce errors. In misinformation studies, for instance, presenting targets and misinformation in different modalities (verbal versus visual) or in different contexts (e.g., in different rooms or on different days) should reduce misinformation effects by increasing the discriminability of the two types of memories. However, robust misinformation effects are often obtained when targets and distractors are presented in different modalities (Ceci & Bruck, 1993; Pezdek & Roe, 1995; Titcomb & Reyna, 1995), and studies have been reported in which same-modality presentation produced smaller misinformation effects than different-modality presentation (Toglia, Payne, & Anastasi, 1991) and in which presenting targets and misinformation in different physical contexts increased misinformation effects (Chandler, 1993). When the context manipulation consists of presenting targets and misinformation on the same versus different days, different-day presentation has consistently produced larger misinformation effects (for a review, see Reyna, 1995). Likewise, in false-recognition studies, presenting studied targets and recognition probes in the same modality or context should produce larger false-recognition effects than presenting them in different modalities or contexts, but this manipulation has usually had the opposite effect in developmental studies (e.g., Brainerd, Reyna, & Kneer, 1995).

MEASURING THE CONTRIBUTIONS OF IDENTITY, NONIDENTITY, AND SIMILARITY JUDGMENTS TO CHILDREN'S FALSE-MEMORY REPORTS

Summarizing the presentation thus far, two processes of memory retrieval and comparison have been used to explain the false-recognition effect, the misinformation effect, and developmental trends in those effects. One process involves retrieval of verbatim traces and comparisons of those traces to the surface forms of test probes. Such comparisons support all-or-none judgments of identity when there is a match between retrieved verbatim traces and the surface forms of probes ("Yes, I heard COLLIE") and all-or-none judgments of nonidentity when there is a mismatch ("No, I couldn't have heard POODLE because I heard COLLIE"). The other process involves retrieval of gist traces and comparisons of those traces to the meaning content of probes. Such comparisons normally support graded judgments of similarity about retrieved gist memories and the meanings of probes. When the retrieved gist is especially strong, however, such comparisons may also support all-or-none judgments of identity, judgments that are false for distractors but true for targets.

Application of these distinctions to children's false-memory reports led to certain predictions about the reasons for developmental variability in those reports. If investigators are to test such predictions, as well as to evaluate fuzzy-trace theory's analysis of false memory more broadly, it is obvious that rates of identity, nonidentity, and similarity judgment will have to be measured. To do this, a mathematical model must be formulated that disentangles the contributions of identity, nonidentity, and similarity judgments to children's responses on recognition tests (for recent examples of successful model-based separation of children's memory processes, see Cooney & Troyer, 1994; Howe, 1995; Howe & O'Sullivan, 1997; Marche & Howe, 1995). In such a model, the three types of judgments will appear as distinct parameters. So that the incidence of each type of judgment can be estimated from recognition data, the model will express such data as algebraic functions of these parameters.

In this section, we present some models that separate the respective contributions of identity judgments, nonidentity judgments, and similarity judgments to children's false-memory reports. The discussion proceeds in two steps. First, we introduce a modified recognition-testing procedure that allows these processes to be measured in false-recognition designs. A mathematical model called FALSE is then defined over such designs that contains separate parameters for identity, nonidentity, and similarity judgment. Second, we extend the testing procedure to misinformation designs. A mathematical model called MISINFORM that measures the three types of judgments in misinformation designs is then described. In the next section of the paper, we present illustrations of how these new procedures and models can be used to explain false-memory reports by applying them to real and simulated data.

FALSE: A Model for False-Recognition Effects

The Conjoint-Recognition Design

In a standard false-recognition study, children make accept–reject decisions about targets, target-related distractors, and unrelated distractors. The model that we now describe is defined over this standard design, the only modification being that children make accept–reject decisions under three instructional conditions. Following experiments reported by Brainerd, Reyna, and Mojardin (in press) and Brainerd et al. (1998), we refer to this modification as a *conjoint-recognition design.* After studying the target material and before responding to a recognition test, children are fully informed as to the types of probes that will be administered (targets, related distractors, unrelated distractors), and examples of each probe type are provided. Children then make recognition decisions under one of three types of instructions: (a) accept targets and reject both related and unrelated distractors (T instructions), (b) accept related distractors and reject both targets and unrelated distractors (R instructions), and (c) accept both targets and related distractors and reject unrelated distractors (T+R instructions).

In a standard developmental study, children make accept–reject decisions under T instructions only. Thus, the conjoint-recognition design adds two instructional conditions to the standard design. It should be stressed that these additional conditions are essential if the relevant theoretical processes are to be measured. Under fuzzy-trace theory's analysis of false recognition, there are six theoretical processes to quantify—namely, the rates of identity, nonidentity, and similarity judgment for both targets and related distractors. As Brainerd et al. (in press) demonstrated, the standard design, with only one instructional condition, supplies far too few degrees of freedom to measure these six processes, which means that their respective contributions to performance cannot be segregated. The conjoint-recognition procedure, on the other hand, provides adequate degrees of freedom both to measure the six processes and, importantly, to conduct goodness-of-fit tests. It should be noted that we have previously studied the R and T+R conditions in experiments with children and adults (cf. below) and have not found that they impose unforeseen task demands.

Because three types of probes are factorially combined with three types of test instructions in the conjoint-recognition design, it supplies at least nine empirical acceptance probabilities: one for each probe type (target, related distractor, unrelated distractor) in each instructional condition. For simplicity, these empir-

TABLE 3
Process Definitions of FALSE's Parameters

Parameter	Definition
Target parameters:	
I_t	The probability that a target produces retrieval of its verbatim trace and an identity judgment (response = accept target).
N_t	The probability that a target produces retrieval of the verbatim trace of some other target and a false nonidentity judgment (response = reject target).
S_t	The probability that a target produces retrieval of its gist trace and a similarity judgment (response = accept target).
Distractor parameters:	
I_r	The probability that a target-related distractor produces retrieval of the gist trace of its instantiating target and a false identity judgment (response = accept distractor).
N_r	The probability that a target-related distractor produces retrieval of the verbatim trace of its instantiating target and a nonidentity judgment (response = reject distractor).
S_r	The probability that a target-related distractor produces retrieval of the gist trace of its instantiating target and a similarity judgment (response = accept distractor).
Bias parameters:	
b_T	The probability that an unrelated distractor produces a false alarm under T instructions (response = accept distractor).
b_R	The probability that an unrelated distractor produces a false alarm under R instructions (response = accept distractor)
b_{T+R}	The probability that an unrelated distractor produces a false alarm under T+R instructions (response = accept distractor).

ical probabilities will be denoted $p_{t,T}$, $p_{t,R}$, $p_{t,T+R}$, $p_{r,T}$, $p_{r,R}$, $p_{r,T+R}$, $p_{u,T}$, $p_{u,R}$, and $p_{u,T+R}$. The first subscript specified the probe type and the second specified the instructional condition. Three further empirical probabilities can be generated using the joint acceptance–rejection probabilities for each pairing of a target with its related distractor. This is necessary to test goodness of fit when all six theoretical processes are estimated.

FALSE is a multinomial model (for a general exposition of multinomial modeling, see Riefer & Batchelder, 1988) that expresses these nine empirical probabilities as functions of identity, nonidentity, and similarity judgment and also of response bias. The model has a total of six memory parameters and three response-bias parameters, which are defined in Table 3. As can be seen, the memory parameters simply give formal expression to the notion of target acceptances based on identity judgments (parameter I_t), target rejections based on false nonidentity judgments (parameter N_t), target acceptances based on similarity judgments (parameter S_t), related-distractor rejections based on nonidentity judgments (parameter N_r), related-distractor acceptances based on false identity judgments (parameter I_r), and related-distractor acceptances based on similarity judgments (parameter S_r). The other parameters measure rates of response bias (i.e., nonmemory-based acceptances) under T instructions (parameter b_T), R instructions (parameter b_R), and T+R instructions (parameter b_{T+R}), respectively.

By estimating the parameters in Table 3 for real or simulated data, investigators can measure rates of identity, nonidentity, and similarity judgment independent of each other and of response bias. In the two subsections that follow, we first present expressions that map these parameters with the nine empirical probabilities and then sketch the statistical procedures that are used to apply FALSE to previously reported data. Readers who are not interested in these developments should skip to Example 1.

FALSE's Equation Set

Figure 1 contains standard multinomial tree diagrams (see Riefer & Batchelder, 1988) that display the distinct ways in which a target may be accepted or rejected on the basis of identity judgments, nonidentity judgments, similarity judgments, and response biases in each of the three instructional conditions (cf. Table 2). Figure 1a contains the acceptance–rejection paths for T instructions, Fig. 1b contains the paths for R instructions, and Fig. 1c contains the paths for T+R instructions. The tree diagrams in Fig. 2 display the distinct ways in which a related distractor may be accepted or rejected on the basis of nonidentity judgments, similarity judgments, and response biases in each of the three instructional conditions. Figure 2a contains the acceptance–rejection paths for T instructions, Fig. 2b contains the paths for R instructions, and Fig. 2c contains the paths for T+R instructions. Finally, the tree diagrams in Fig. 3 display the acceptance–rejection paths for unrelated distractors in the three conditions.

The information in each of these figures may be reduced to equations that express the three probabilities of target acceptance (Fig. 1) or the three probabilities of related distractor acceptance (Fig. 2) or the three probabilities of unrelated distractor acceptance (Fig. 3) as functions of the parameters in Table 3. Those nine expressions, which comprise FALSE's equation set, are exhibited in Table 4.

Overview of Statistical Methodology

We now sketch the statistical procedures that are involved when FALSE is used to analyze and interpret data from a conjoint-recognition design. Three types of analyses are conducted when the model is applied to sample data: parameter estimation, goodness-of-fit, and hypothesis testing. A program, FALSE.EQN, is available upon request from the authors that conducts all of these analyses for sample data that satisfy the minimum conditions of a conjoint-recognition design. This program, which runs on desktop PCs, implements Hu's (1995) general processing tree software.

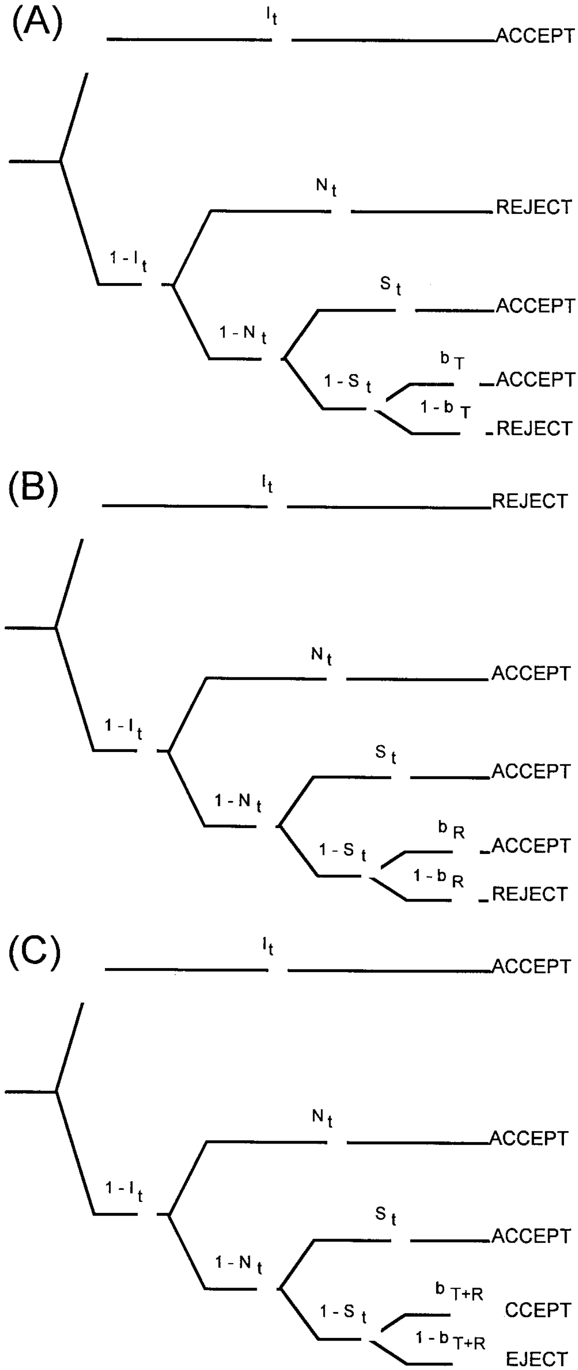

FIG. 1. FALSE's paths to acceptance of targets under T instructions (Panel A), R instructions (Panel B), and T+R instructions (Panel C) in conjoint-recognition designs.

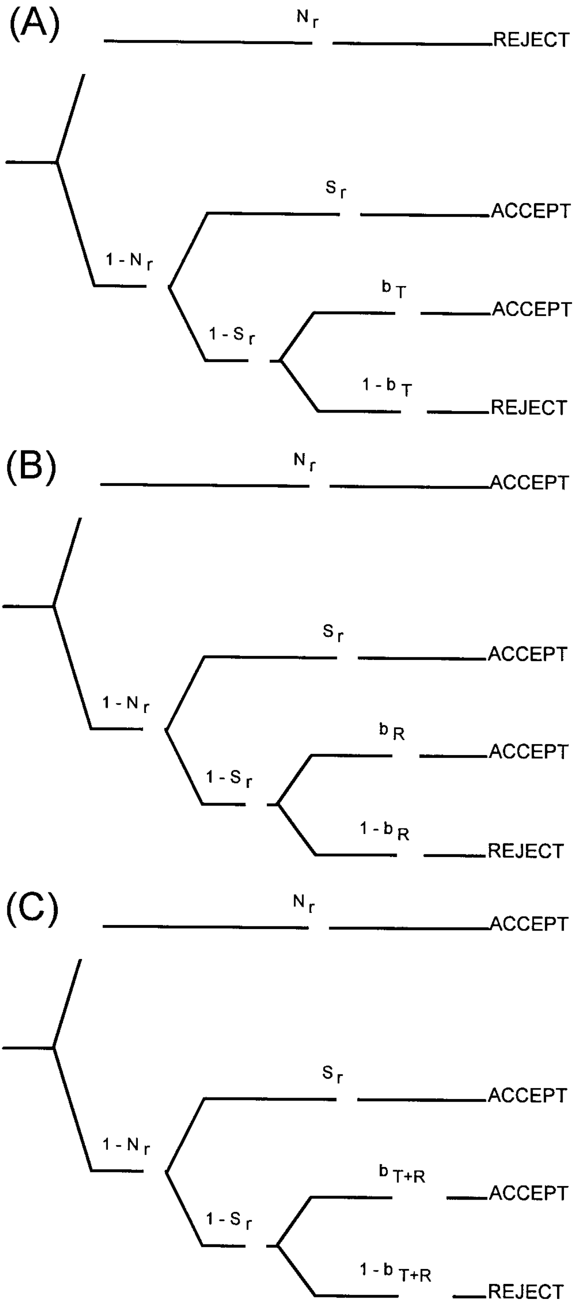

FIG. 2. FALSE's paths to acceptance of related distractors under T instructions (Panel A), R instructions (Panel B), and T+R instructions (Panel C) in conjoint-recognition designs.

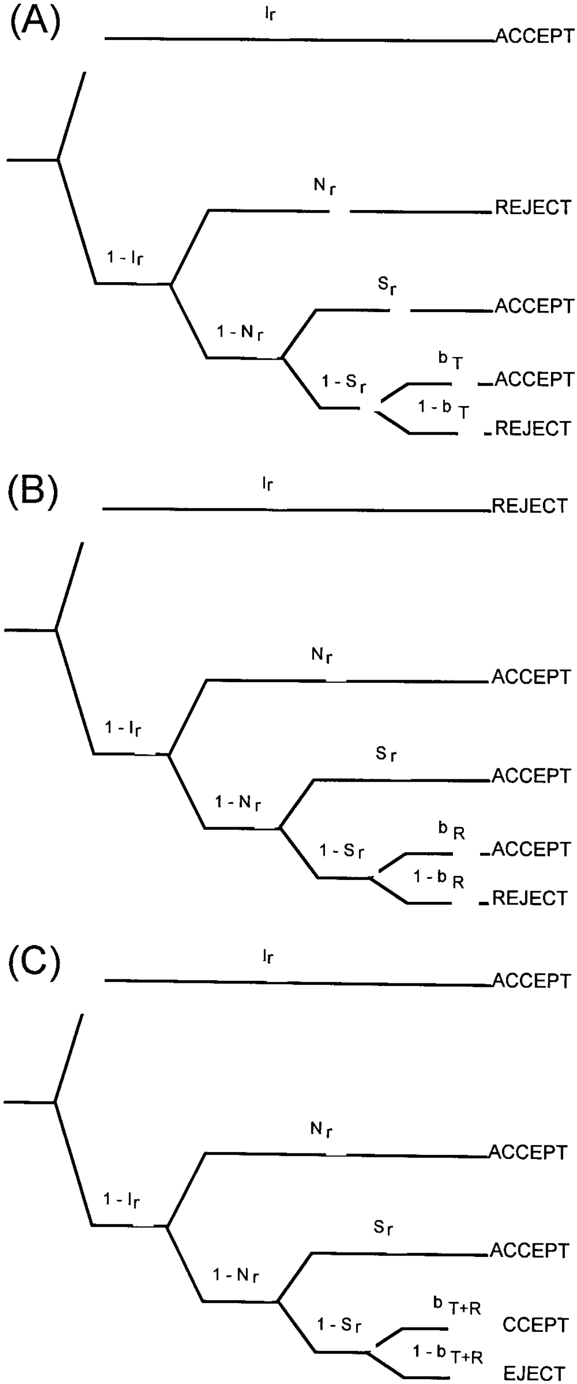

FIG. 3. FALSE's paths to acceptance of unrelated distractors under T, R, and T+R instructions.

TABLE 4
FALSE's Equation Set

Empirical probability	Theoretical expression	
$p_{t,T}$	$I\text{t} + (1 - I\text{t})(1 - N\text{t})S\text{t} + (1 - I\text{t})(1 - N\text{t})(1 - S\text{t})b\text{T}$	(1)
$p_{t,R}$	$(1 - I\text{t})N\text{t} + (1 - I\text{t})(1 - N\text{t})S\text{t} + (1 - I\text{t})(1 - N\text{t})(1 - S\text{t})b\text{R}$	(2)
$p_{t,T+R}$	$I\text{t} + (1 - I\text{t})S\text{t} + (1 - S\text{t})(1 - I\text{t})N\text{t} + (1 - I\text{t})(1 - N\text{t})(1 - S\text{t})b\text{T+R}$	(3)
$p_{r,T}$	$I\text{r} + (1 - I\text{r})(1 - N\text{r})S\text{r} + (1 - I\text{r})(1 - N\text{r})(1 - S\text{r})b\text{T}$	(4)
$p_{r,R}$	$(1 - I\text{r})N\text{r} + (1 - I\text{r})(1 - N\text{r})S\text{r} + (1 - I_{\text{r}}(1 - N\text{r})(1 - S\text{r})b\text{R}$	(5)
$p_{r,T+R}$	$S\text{r} + (1 - S\text{r})I\text{r} + (1 - S\text{r})(1 - I\text{r})N\text{r} + (1 - I\text{r})(1 - N\text{r})(1 - S\text{r})b\text{T+R}$	(6)
$p_{u,T}$	b_{T}	(7)
$p_{u,R}$	b_{R}	(8)
$p_{u,T+R}$	$b_{\text{T+R}}$	(9)

Parameter estimation. To estimate FALSE's nine parameters, a likelihood function is written that expresses the a posteriori probability of sample data in terms of these parameters. The general form of likelihood functions for multinomial models is given in Eq. (7) of Riefer and Batchelder (1988). The specific function from which FALSE's parameters are estimated, which has nine degrees of freedom (the nine parameters) is programmed in FALSE.EQN. That likelihood function is

$$\begin{aligned} L_9 = {} & [(1)(4)]^{N[A(t,T)A(r,T)]} \times [(1)(1-(4))]^{N[A(t,T)K(r,T)]} \times [(1-(1))(4)]^{N[K(t,T)A(r,T)]} \\ & \times [(1-(1))(1-(4))]^{N[K(t,T)K(r,T)]} \times [(2)(5)]^{N[A(t,R)A(r,R)]} \\ & \times [(2)(1-(5))]^{N[A(t,R)K(r,R)]} \times [(1-(2))(5)]^{N[K(t,R)A(r,R)]} \\ & \times [(1-(2))(1-(5))]^{N[K(t,R)K(r,R)]} \times [(3)(6)]^{N[A(t,T+R)A(r,T+R)]} \\ & \times [(3)(1-(6))]^{N[A(t,T+R)K(r,T+R)]} \times [(1-(3))(6)]^{N[K(t,T+R)A(r,T+R)]} \\ & \times [(1-(3))(1-(6))]^{N[K(t,T+R)K(r,T+R)]} \times (7)^{N[A(u,T)]} \times (1-(7))^{N[K(u,T)]} \\ & \times (8)^{N[A(u,R)]} \times (1-(8))^{N[K(u,R)]} \times (9)^{N[A(u,R)]} \times (1-(9))^{N[K(u,R)]}, \end{aligned} \tag{1}$$

where the numerals in parentheses, (1)–(9), are the theoretical expressions in Table 4 and the N[A(i,j)] and N[K(i,j)] are the numbers of acceptance (A) and rejection (K) responses of the indicated type that are observed in the sample data of a conjoint-recognition experiment. Maximization of Eq. (1) using FALSE. EQN yields estimates of the nine theoretical parameters for the sample data plus the estimated likelihood of those data under the model (L_9).

Goodness-of-fit. A goodness-of-fit test evaluates the null hypothesis that sample data could have been generated by a process that has the same mathematical structure as FALSE. The relevant test, which is a standard likelihood-ratio statistic (cf. Theios, Leonard, & Brelsford, 1977), is computed automatically by FALSE.EQN when it estimates FALSE's parameters for sample data. The test statistic has an asymptotic $\chi^2(3)$ distribution, so a critical value of 7.78 is required to reject the null hypothesis (that sample data could have been generated by a process that has the same mathematical structure as FALSE) at the .05 level.

Hypothesis testing. When goodness of fit is established for sample data, the most informative analyses are tests of hypotheses about the estimated values of FALSE's parameters. For instance, the earlier theoretical analysis implies several predictions about within-condition differences in those parameters: The claim that identity judgments about targets are more prevalent than similarity judgments implies $I_t > S_t$; the claim that false alarms for related distractors are primarily similarity judgments rather than false identity judgments implies that $S_r > I_r$; the claim that a target probe is more likely to produce retrieval of memories that were stored about itself than memories that were stored about some other target implies that $I_t > N_t$ and $S_t > N_t$; the claim that inconsistent developmental trends in the false-recognition effect are due to variability in the rates of identity, nonidentity, and similarity judgment about related distractors implies that age improvements in similarity judgments (S_r) and/or false identity judgments will exceed age improvements in nonidentity judgments (N_r) in conditions that produce developmental increases in the false-recognition effect and that the reverse will be true in conditions that produce decreases in the effect.

Two classes of null hypotheses about FALSE's parameters can be tested, within-condition and between-condition. Null hypotheses of the former sort specify that *different parameters* have the same value *within* a single condition. (For example, the null hypothesis $I_t = S_t$ would be tested to evaluate the claim that, for targets, identity judgments are more prevalent than similarity judgments). To test such a hypothesis, the constraint that is implied by it (e.g., $I_t = S_t$) is imposed on FALSE's likelihood function before FALSE.EQN maximizes it. When the function is then maximized with the constraint in place, FALSE-.EQN delivers a new value (L_8) based on one less degree of freedom than the unconstrained function. The ratio $-21n(L_8/L_9)$ is computed, which has an asymptotic $\chi^2(1)$ distribution.

Between-condition hypotheses specify that the *same parameter* (or parameters) has the same value in *different* conditions. (For example, if we let the subscripts y and o denote a group of younger children and a group of older children, respectively, the null hypotheses that $N_{r,y} = N_{r,o}$, $I_{r,y} = I_{r,o}$, and $S_{r,y} = S_{r,o}$ would be tested to evaluate fuzzy-trace theory's explanation of developmental trends in the false-recognition effect.) To test such a hypothesis, FALSE.EQN is used to maximize the joint likelihood function for both conditions, which produces a new value (L_{18}) that is based on 18 degrees of freedom (9 parameters $\times$ 2 conditions). Next, the constraint implied by the hypothesis (e.g., $N_{r,y} = N_{r,o}$) is imposed on the joint likelihood function before FALSE.EQN maximizes it. When the function is then maximized, FALSE.EQN delivers a new value (L_{17})

based on one less degree of freedom than the unconstrained function. The ratio $-21n(L_{17}/L_{18})$ is computed, which has an asymptotic $\chi^2(1)$ distribution.

MISINFORM: A Model for Misinformation Effects

Although the memory tests in most misinformation studies have involved making forced choices between targets and distractors (e.g., Ceci et al., 1987), children have made separate accept–reject decisions about targets and distractors in a few instances (Pezdek & Roe, 1995, 1996; Warren & Lane, 1995). In misinformation studies, children receive falsifying information about some targets but not about others (control targets) prior to making such decisions. (Therefore, the experimental procedure for control targets is essentially the same as in false-recognition designs.) As we know, the characteristic misinformation effects are lowered hit rates for misinformed targets (e.g., “The bird has yellow feathers”), relative to control targets, and elevated false-alarm rates for misinformation-embodying distractors (e.g., “The bird has green feathers”), relative to control distractors.

MISINFORM is a multinomial model that is defined over designs in which children make accept–reject decisions about (a) misinformed targets, (b) distractors that embody misinformation (and therefore falsify misinformed targets), (c) control targets, (d) distractors that falsify control targets, and (e) unrelated distractors. These decisions are made under the same three instructional conditions that we described for FALSE. That is, following the study and misinformation phases, children are informed as to the types of probes that will be administered, and examples of each probe type are provided. Individual children then make recognition decisions under one of three types of instructions: accept targets (both misinformed and control) and reject all distractors (T instructions), accept target-falsifying distractors (both misinformation-embodying and control) and reject both targets and unrelated distractors (R instructions), and accept both targets and target-falsifying distractors and reject unrelated distractors (T+R instructions). We refer to this procedure as a *conjoint-misinformation design.*

Because two informational manipulations (misinformation versus control) are factorially combined with two types of related items (targets versus target-falsifying distractors) and with three types of recognition instructions, the conjoint-misinformation design produces 12 independent acceptance probabilities for these items: $p_{t,T,C}$, $p_{t,R,C}$, $p_{t,T+R,C}$, $p_{f,T,C}$, $p_{f,R,C}$, $p_{f,T+R,C}$, $p_{t,T,M}$, $p_{t,R,M}$, $p_{t,T+R,M}$, $p_{f,T,M}$, $p_{f,R,M}$, $p_{f,T+R,M}$, where the first subscript denotes item type (target or falsifying distractor), the second subscript denotes instructional condition (T, R, or T+R), and the third subscript denotes informational condition (misinformation or control). There are three further acceptance probabilities, for a total of 15, when the unrelated distractors are added for each instructional condition: $p_{u,T}$, $p_{u,R}$, and $p_{u,T+R}$. Six further empirical probabilities, for a grand total of 21, can be generated using the joint acceptance–rejection probabilities for the pairing of each target with its falsifying distractor. This is necessary to test goodness of fit when all theoretical probabilities are being estimated (cf. Eq. (1)).

MISINFORM, like FALSE, expresses these empirical probabilities as functions of the memory processes of identity, nonidentity, and similarity judgment and also of response biases. MISINFORM, also like FALSE, allows rates of identity, nonidentity, and similarity judgment to be measured independent of each other and of response bias and to be measured separately for targets and for falsifying distractors. MISINFORM has a total of six memory parameters for misinformed items, six for control items, and three response-bias parameters. These parameters are defined in Table 5. MISINFORM's memory parameters, like FALSE's, simply give formal expression to these theoretical distinctions: target acceptances based on identity judgments (parameters $I_{t,C}$ and $I_{t,M}$), target rejections based on false nonidentity judgments (parameters $N_{t,C}$ and $N_{t,M}$), target acceptances based on similarity judgments (parameters $S_{t,C}$ and $S_{t,M}$), distractor acceptances based on false identity judgments (parameters $I_{r,C}$ and $I_{r,M}$), distractor rejections based on nonidentity judgments (parameters $N_{r,C}$ and $N_{r,M}$), and distractor acceptances based on similarity judgments (parameters $S_{r,C}$ and $S_{r,M}$). As before, the other parameters measure rates of response bias under T instructions (parameter b_T), R instructions (parameter b_R), and T+R instructions (parameter b_{T+R}), respectively.

Mathematically, MISINFORM's expressions for control items, misinformed items, and unrelated distractors are the same as FALSE's. Consequently, we omit the tree diagram development of those expressions and simply exhibit them in Table 6.

The same three types of statistical procedures that were described earlier for FALSE are also involved in applying MISINFORM to data—namely, parameter estimation, goodness-of-fit testing, and within- and between-condition hypothesis testing. A program, MISINFORM.EQN, is available from the authors that conducts these analyses for sample data that satisfy the minimum conditions of a conjoint-misinformation design. The only notable difference between this program and FALSE.EQN is that the likelihood function that is used to estimate parameters, evaluate goodness of fit, and test hypotheses contains separate parameters for two conditions (control and misinformation) rather than parameters for only one condition (cf. Eq. (1)). MISINFORM.EQN was used in the worked examples that follow.

Using FALSE and MISINFORM to Understand False-Memory Reports

In the preceding section, fuzzy-trace theory's analysis of children's false-memory reports was implemented in two experimental paradigms, one for false-recognition designs (conjoint recognition) and the other for misinformation designs (conjoint misinformation). Multinomial models were also developed, one for each paradigm, whose parameters measure the specific processes that figured in the theoretical analysis (identity judgments, nonidentity judgments, similarity judgments, response bias) independent of each other. Process definitions of the parameters were also provided (Tables 3 and 5).

TABLE 5
Process Definitions of MISINFORM's Parameters

Parameter	Definition
	Control items
Target parameters:	
$I_{t,C}$	The probability that a target produces retrieval of its verbatim trace and an identity judgment (response = accept target).
$N_{t,C}$	The probability that a target produces retrieval of the verbatim trace of some other target and a false nonidentity judgment (response = reject target).
$S_{t,C}$	The probability that a target produces retrieval of its gist trace and a similarity judgment (response = accept target).
Distractor parameters:	
$I_{r,C}$	The probability that a target-falsifying distractor produces retrieval of the gist trace of its instantiating target and a false identity judgment (response = accept distractor).
$N_{r,C}$	The probability that a target-falsifying distractor produces retrieval of the verbatim trace of its instantiating target and a nonidentity judgment (response = reject distractor).
$S_{r,C}$	The probability that a target-falsifying distractor produces retrieval of the gist trace of its instantiating target and a similarity judgment (response = accept distractor).
	Misinformed items
Target parameters:	
$I_{t,M}$	The probability that a misinformed target produces retrieval of its verbatim trace and an identity judgment (response = accept target).
$N_{t,M}$	The probability that a misinformed target produces retrieval of the verbatim trace of the falsifying information or the verbatim trace of some other target and a false nonidentity judgment (response = reject target).
$S_{t,M}$	The probability that a misinformed target produces retrieval of its gist trace or the gist trace of the misinformation and a similarity judgment (response = accept target).
Distractor parameters:	
$I_{r,M}$	The probability that a misinformation-embodying distractor produces retrieval of the verbatim trace of the misinformation and a false identity judgment (response = accept distractor).
$N_{r,M}$	The probability that a misinformation-embodying distractor produces retrieval of the verbatim trace of the misinformed target or the verbatim trace of some other target and a nonidentity judgment (response = reject distractor).
$S_{r,M}$	The probability that a misinformation-embodying distractor produces retrieval of the gist trace of the misinformation or the gist trace of the misinformed target (response = accept distractor).
	Unrelated distractors
b_T	The probability that response bias produces acceptance under T instructions.
b_R	The probability that response bias produces acceptance under R instructions.
b_{T+R}	The probability that response bias produces acceptance under T+R instructions.

TABLE 6
MISINFORM's Equation Set

Empirical probability	Theoretical expression
Control items:	
$p_{t,T,C}$	$I_{t,C} + (1 - I_{t,C})(1 - N_{t,C})S_{t,C} + (1 - I_{t,C})(1 - N_{t,C})(1 - S_{t,C})b_T$
$p_{t,R,C}$	$(1 - I_{t,C})N_{t,C} + (1 - I_{t,C})(1 - N_{t,C})S_{t,C} + (1 - I_{t,C})(1 - N_{t,C})(1 - S_{t,C})b_R$
$p_{t,T+R,C}$	$I_{t,C} + (1 - I_{t,C})S_{t,C} + (1 - I_{t,C})(1 - S_{t,C})N_{t,C} + (1 - I_{t,C})(1 - N_{t,C})(1 - S_{t,C})b_{T+R}$
$p_{r,T,C}$	$(1 - I_{t,C})N_{r,C} + (1 - I_{t,C})(1 - N_{t,C})S_{t,C} + (1 - N_{r,C})(1 - S_{r,C})(1 - I_{t,C})b_T$
$p_{r,R,C}$	$(1 - I_{t,C})N_{r,C} + (1 - I_{t,C})(1 - N_{r,C})S_{r,C} + (1 - I_{t,C})(1 - N_{r,C})(1 - S_{r,C})b_R$
$p_{r,T+R,C}$	$I_{t,C} + (1 - I_{t,C})S_{r,C} + (1 - I_{t,C})(1 - S_{r,C})N_{r,C} + (1 - I_{t,C})(1 - N_{r,C})(1 - S_{r,C})b_{T+R}$
Misinformed items:	
$p_{t,T,M}$	$I_{t,M} + (1 - I_{t,M})(1 - N_{t,M})S_{t,M} + (1 - I_{t,M})(1 - N_{t,M})(1 - S_{t,M})b_T$
$p_{t,R,M}$	$(1 - I_{t,M})N_{t,M} + (1 - I_{t,M})(1 - N_{t,M})S_{t,M} + (1 - I_{t,M})(1 - N_{t,M})(1 - S_{t,M})b_R$
$p_{t,T+R,M}$	$I_{t,M} + (1 - I_{t,M})N_{t,M} + (1 - I_{t,M})(1 - N_{t,M})S_{t,M} + (1 - I_{t,M})(1 - N_{t,M})(1 - S_{t,M})b_{T+R}$
$p_{r,T,M}$	$I_{r,M} + (1 - I_{r,M})(1 - N_{r,M})S_{r,M} + (1 - N_{r,M})(1 - I_{r,M})(1 - S_{r,M})b_T$
$p_{r,R,M}$	$(1 - I_{t,M})N_{r,M} + (1 - I_{r,M})(1 - N_{r,M})S_{r,M} + (1 - I_{r,M})(1 - N_{r,M})(1 - S_{r,M})b_R$
$p_{r,T+R,M}$	$I_{t,M} + (1 - I_{t,M})N_{t,M} + (1 - I_{r,M})(1 - N_{r,M})S_{r,M} + (1 - I_{r,M})(1 - N_{r,M})(1 - S_{r,M})b_{T+R}$
Unrelated distractors:	
$p_{u,T}$	b_T
$p_{u,R}$	b_R
$p_{u,T+R}$	b_{T+R}

In Table 3 (FALSE), a key point to note is that the characteristic memory-falsification finding of false-recognition studies, the false-recognition effect, will increase (between age levels or between conditions) as similarity judgments about related distractors (parameter S_r) increase and/or as false identity judgments increase (parameter I_r) and/or as nonidentity judgments (parameter N_r) decrease. Further, FALSE accommodates the counterintuitive possibility, which has recently been identified in verbatim-priming experiments (Brainerd, Reyna, & Kneer, 1995), that false-alarm rates for related distractors can be *lower* than for unrelated distractors. This latter situation can occur when N_r is considerably larger than I_r and S_r.

In Table 5 (MISINFORM), there are two key points to note. First, there will be a hit-rate suppression effect of misinformation on misinformed targets *if false nonidentity judgments are more common for misinformed targets than control targets* (i.e., $N_{t,C} < N_{t,M}$) or *if identity judgments are more common for control targets than misinformed targets* (i.e., $I_{t,C} > I_{t,M}$) or *if similarity judgments are more common for control targets than misinformed targets* (i.e., $S_{t,C} > S_{t,M}$).

Second, there will be a false-alarm rate elevation effect of misinformation on misinformation-embodying distractors *if nonidentity judgments are less common for these distractors than for control distractors* (i.e., $N_{r,C} > N_{r,M}$) or *if false identity judgments are more common for these distractors than for control distractors* ($I_{r,C} < I_{r,M}$) or *if similarity judgments are more common for these distractors than for control distractors* (i.e., $S_{r,C} < S_{r,M}$).

In the remainder of this section, we present two illustrations, which show how theoretical conclusions about the specific memorial bases of false-recognition effects and misinformation effects can be extracted from very simple studies via the application of FALSE and MISINFORM. Concerning FALSE, both adult and developmental studies have been conducted using the conjoint-recognition design (Brainerd, Reyna, and Mojardin, in press; Brainerd et al., 1998). In the first subsection below, FALSE is used to reanalyze and interpret the results of those experiments. Because neither developmental nor adult data are yet available using the conjoint-misinformation design, we generated simulated data from the results of previously published developmental misinformation studies. In the second subsection below, MISINFORM is used to analyze and interpret the results of those simulated developmental misinformation experiments.

Example 1: Working with FALSE

In conjoint-recognition designs, accept–reject decisions are made about targets, related distractors, and unrelated distractors under three instructional conditions (T, R, and T+R). T instructions (accept only targets) are, of course, the standard ones in developmental studies of false recognition (e.g., Bach & Underwood, 1971; Felzen & Anisfeld, 1971). T+R instructions have been used in studies of so-called inferential recognition (e.g., Brainerd & Reyna, 1993; Lapointe, 1991; Reyna & Kiernan, 1994, 1995). R instructions appear to have been used in only one study of word recognition (Brainerd et al., 1998). To use FALSE, different instructional conditions must be combined in a single study. This has been done in three adult experiments by Brainerd, Reyna, and Mojardin (in press) and a developmental experiment by Brainerd et al. (1998). In this subsection, we show how FALSE is used to extract information about identity, nonidentity, and similarity from the data of these experiments.

Description of Data Sources

In Brainerd, Reyna, and Mojardin's (in press) Experiment 1, adults studied a list of familiar words and then responded to a recognition test in a standard study-test design. On the test, the related distractors were synonyms of targets (e.g., HILL if MOUNTAIN had been studied, DIRT if SOIL had been studied). The design of Experiments 2 and 3 was the same, except that the related distractors were antonyms of the targets (e.g., COLD if HOT had been studied, SAD if HAPPY had been studied) in Experiment 2 and the names of categories to which targets belonged (e.g., TOY if DOLL had been studied, GIRL if MARY had been studied) in Experiment 3. There was also a repetition manipulation in the first two experiments: Half the targets were studied once, and half were studied twice. In Experiment 3, a priming manipulation was included: Half of the category-name distractors were tested immediately after their instantiating targets (e.g., TOY was tested immediately after DOLL) and half were not. In Brainerd et al.'s (1998) study, second- and sixth-grade children studied a mixed list of meaningful words and nonsense words. On the recognition test, related distractors were rhymes of targets. For word targets (e.g., FLOWER), rhymes could be either meaningful (TOWER) or nonsense (JOWER). For nonsense targets (e.g., DATTLE), rhymes could also be meaningful (CATTLE) or nonsense (LATTLE). The priming manipulation of Brainerd, Reyna, and Mojardin was also included: Half of the rhymes were preceded by their instantiating targets and half were not. Also, a continuous-recognition procedure (cf. Underwood, 1995), rather than a study-test procedure, was used.

The results that would normally be reported in a developmental or adult study of false recognition would be the proportions of acceptance responses under T instructions for targets, related distractors, and unrelated distractors. Those data appear in Table 7. There are two findings of interest for the three adult experiments. First, there was a false-recognition effect (higher false-alarm rates for related than for unrelated distractors) in all conditions of these experiments, except for the target-priming condition of Experiment 3, which has been found to suppress this effect with semantically related distractors (Brainerd, Reyna, & Kneer, 1995). Second, there was between-condition variation in the size of the false-recognition effect. In Experiments 1 and 2, the effect was smaller when targets had been studied twice than when they had been studied once. In Experiment 3, the effect was smaller (indeed, it was reversed) when related distractors were tested immediately after their instantiating targets than when they were not.

There were also two findings of interest in the developmental experiment. First, although hit rates increased significantly with age (from .75 to .81), there was no developmental change in the false-recognition effect; false-alarm rates were virtually the same at both age levels for both unrelated distractors (.06 vs .05) and rhymes (.09 vs .08). Second, the priming manipulation did not affect false recognition; false-alarm rates were virtually the same for primed and unprimed rhymes (.09 vs .08). We now show how FALSE provides memory explanations of the results in Table 7.

Parameter Estimation and Goodness of Fit

We used FALSE.EQN to maximize FALSE's likelihood function and perform goodness-fit-tests for the two conditions in each of Brainerd, Reyna, and Mojardin's (in press) experiments and for the two age levels in Brainerd et al.'s (1998) experiment. Earlier, we mentioned that, based on prior research, false nonidentity judgments about targets (parameter N_t) would be expected if presented targets were related to each other (as when COLLIE, POODLE, and

TABLE 7
Acceptance Probabilities for Targets and Distractors under T Instructions in Brainerd, Reyna, and Mojardin's (in press) and Brainerd, Stein, Reyna's (1998) Experiments

	Type of probe		
Experiment/condition	Targets	Related distractors	Unrelated distractors
Brainerd, Reyna, and Mojardin (in press):			
Experiment 1			
1-study targets	.52	.40	.06
2-study targets	.74	.28	.06
Experiment 2			
1-study targets	.63	.37	.11
2-study targets	.79	.18	.11
Experiment 3			
Priming	.74	.15	.20
No priming	.78	.52	.20
Brainerd, Stein, and Reyna (1998):			
Sixth grade:			
Word/word			
Primed	.94	.08	.01
Unprimed	.94	.03	.01
Word/nonsense			
Primed	.94	.02	.08
Unprimed	.94	.05	.08
Nonsense/word			
Primed	.67	.13	.01
Unprimed	.67	.05	.01
Nonsense/nonsense			
Primed	.67	.06	.08
Unprimed	.67	.18	.08
Second grade:			
Word/word			
Primed	.90	.12	.04
Unprimed	.90	.06	.04
Word/nonsense			
Primed	.90	.02	.08
Unprimed	.90	.07	.08
Nonsense/word			
Primed	.60	.20	.04
Unprimed	.60	.06	.04
Nonsense/nonsense			
Primed	.60	.08	.08
Unprimed	.60	.14	.08

SPANIEL were all presented), and false identity judgments about distractors would be expected if the meanings that they share with targets were repeatedly cued at study (again, as when COLLIE, POODLE, and SPANIEL were all

TABLE 8
Mean Estimates of FALSE's Parameters

Experiment/condition	Statistic I_t	N_t	S_t	I_r	N_r	S_r
Brainerd, Reyna, and Mojardin (1997):						
Experiment 1						
1-study	.40	0	.11	0	.13	.43
2-study	.70	0	.10	0	.31	.36
Experiment 2						
1-study	.59	0	.14	0	.32	.49
2-study	.70	0	.22	0	.50	.27
Experiment 3						
Primed	.69	0	.06	0	.49	.11
Unprimed	.68	0	.19	0	.13	.50
Brainerd, Reyna, and Stein (in press):						
Second grade	.71	0	.10	0	.39	.06
Sixth grade	.76	0	.19	0	.47	.10
Word rhymes						
Primed	.80	0	.18	0	.71	.45
Unprimed	.80	0	.18	0	.08	.03
Nonsense rhymes						
Primed	.80	0	.18	0	.86	.23
Unprimed	.80	0	.18	0	.10	.01

presented). Because neither of these conditions was present in these experiments, we found that the estimates of N_t and I_r were very close to zero in all conditions. Therefore, to simplify subsequent analyses, we formally tested the hypothesis that $N_t = I_r = 0$ for all conditions using likelihood ratios. There were eight tests in all. None produced a value of the test statistic that was near the critical value for rejection of the model at the .05 level (5.99). The mean value of the test statistic for these data sets was 1.18. Maximum likelihood estimates of the remaining seven parameters appear by condition in Table 8, along with confidence intervals for those estimates.

Testing Hypotheses about FALSE's Parameters

Two types of hypotheses about FALSE's parameters are of interest, within condition and between condition (cf. above). The former specify that the values of two different parameters are equal for some condition (e.g., $I_t = N_r$), whereas the latter specify that some parameter (e.g., S_t) has the same value in two different conditions (e.g., 1-study versus 2-study conditions). We first test some within-condition hypotheses to determine whether the parameters behaved in ways that were consistent with our earlier theoretical analyses. Following these validity checks, we test some between-condition hypotheses that show how variations in the false-recognition effect can be explained by variations in nonidentity judgments and similarity judgments about related distractors.

Within-condition tests. Our theoretical analysis expects that (a) targets should be better retrieval cues for their verbatim traces than for their gist traces (at least on immediate tests), that (b) targets should be better retrieval cues for their verbatim traces than related distractors are, (c) that false alarms for related distractors are primarily similarity judgments rather than false identity judgments, and that (d) related distractors should be better retrieval cues for targets' gist traces than for their verbatim traces unless conditions are imposed that make verbatim traces highly accessible (cf. Brainerd, Reyna, & Kneer, 1995; Schacter et al., 1998). Therefore, identity judgments about targets should be more common than similarity judgments (i.e., $I_t > S_t$), identity judgments about targets should be more common than nonidentity judgments about related distractors (i.e., $I_t > N_r$), similarity judgments about related distractors should more common than false identity judgments (i.e., $S_r > I_r$), and similarity judgments about related distractors should be more common than nonidentity judgments (i.e., $N_r < S_r$). Inspection of Table 8 reveals that the parameter values in the three adult experiments were consistent with all four hypotheses. The parameter values for the developmental experiment were also consistent with all four hypotheses.

Hypothesis (c) did not require a formal statistical test because, on the one hand, the preliminary analyses revealed that $I_r = 0$, and, on the other hand, it can be seen in Table 8 that $S_r > 0$ in all conditions, except in Rows 10 and 12. The other three hypotheses were tested as follows. For each set of data that produced the parameter estimates in Table 8, we used FALSE.EQN to maximize FALSE's likelihood function under the restriction that the two parameters specified in the hypotheses were equal. That is, the likelihood function was maximized for each data set under the restriction that $I_t = S_t$, or that $I_t = N_r$, or that $N_r = S_r$, for a total of 36 maximizations (3 maximizations $\times$ 12 sets of parameter estimates). Each maximization produced a new value of the likelihood function, L_6, that had one less degree of freedom than before. This new value was used to compute the likelihood ratio

$$\chi^2(1) = -2\ln(L_6/L_7).$$

For the data of the three adult experiments, this statistic exceeded the critical value of 3.84 for all hypotheses in all data sets. In the developmental study, the likelihood ratio statistic also produced rejections for all hypotheses in all data sets, except in Row 10, where the hypothesis $N_r = S_r$ could not be rejected.

As expected on theoretical grounds, therefore, identity judgments about targets were more common than similarity judgments, identity judgments about targets were more common than nonidentity judgments about related distractors, similarity judgments about related distractors were more common than false identity judgments, and similarity judgments about related distractors were more common than nonidentity judgments. The only exception to this statement was the relation between similarity and nonidentity judgments about related distractors in (a) the target-priming condition of adult Experiment 1 and (b) the developmental study. Concerning (a), as would be expected from prior research (Brainerd, Reyna, & Kneer, 1995), priming greatly increased the rate of nonidentity judgment about distractors, so much so that the rate of nonidentity judgment (.49) exceeded that of similarity judgment (.11). Concerning (b), although the null hypothesis that $N_r = S_r$ was rejected for five of the six data sets, it can be seen that the observed relation was $N_r > S_r$ rather than the predicted $N_r < S_r$. Presumably, this was due to a confluence of three factors that should make verbatim traces of targets highly accessible: distractors were physically rather than semantically related to targets (cf. Schacter et al., 1997), the recognition procedure was continuous rather than study-test (cf. Brainerd et al., 1998), and verbatim priming was used (cf. Brainerd, Reyna, & Kneer, 1995).

Between-condition tests. When the size of the false-recognition effect varies between conditions (or age levels), FALSE provides four possible explanations: The rate of nonidentity judgment about related distractors is greater in one condition than in the other, or the rate of false identity judgment about related distractors is greater in one condition than in the other, or the rate of similarity judgment about related distractors is greater in one condition than in the other, or some combination of these possibilities. For the data in Table 8, the second explanation has already been ruled out because the preliminary analyses showed that $I_r = 0$. Interestingly, when the size of the false-recognition effect does *not* vary between conditions (or age levels), it could still be that rates of nonidentity, identity, and similarity judgment differ between conditions *because they are opponent processes.* We shall see that this outcome was obtained in the developmental study. Parenthetically, this illustrates one of the strengths of mathematical models of memory. Specifically, when average levels of performance on some memory measure (in this case false alarms) do not differ between conditions and standard statistical analyses (e.g., ANOVA) produce a finding of "no difference," model-based analyses may still reveal between-conditions differences in underlying memory processes (Brainerd, Howe, & Desrochers, 1982; Howe, Rabinowitz, & Grant, 1993).

In the adult studies, it can be seen in Table 7 that the false-recognition effect was always smaller in one of the conditions than in the other. Why? The explanation is found by testing between-condition hypotheses about the rates of nonidentity judgment (parameter N_r) and similarity judgment (parameter S_r) for related distractors. To test these hypotheses for each pair of conditions, FALSE.EQN was used to maximize the joint likelihood function for the two conditions (cf. above) under the restriction that either N_r or S_r had the same value in each condition. There were 12 of these maximizations (3 experiments $\times$ 2 conditions $\times$ 2 parameters). Each of them produced a new value of the joint likelihood function (L_{13}) that had one less degree of freedom than the unrestricted value of the function (L_{14}). For each pair of values, the likelihood ratio statistic

$$\chi^2(1) = -2\ln(L_{13}/L_{14})$$

was computed, which has a critical value of 3.84.

All of these tests produced a null hypothesis rejection; both N_r and S_r varied between conditions in the three adult experiments. It can be seen in Table 8 that the pattern was for nonidentity judgments to be more frequent for distractors whose targets had been studied twice (Experiments 1 and 2) and for distractors that were primed by their targets (Experiment 3). The pattern for similarity judgments was for such judgments to be more frequent for distractors whose targets had been studied once (Experiments 1 and 2) and for distractors that were not primed by their targets (Experiment 3).

Last, the same likelihood ratio tests were used to localize differences in nonidentity and similarity judgments in the developmental study. It can be seen in Rows 7 and 8 of Table 7 that although the false-recognition effect did not vary with age, *the underlying processes of nonidentity and similarity judgment did.* Likelihood ratio tests showed that the rate of nonidentity judgment and similarity judgment both increased with age. Likelihood ratio tests also showed that the target priming manipulation had the same effect on children's nonidentity judgments as it did in the third adult experiment, but the priming manipulation's effect on similarity judgments was the opposite: Priming increased both the rate of nonidentity judgment and the rate of similarity judgment.

Theoretical Conclusions

Application of FALSE to the data of these experiments leads to five theoretical conclusions. First, consistent with the notion that false nonidentity judgments about targets and false identity judgments about related distractors are encouraged by studying targets that are related to each other, there was no evidence of either type of judgment in these experiments. Second, consistent with the notion that targets are better retrieval cues for their verbatim traces than for their gist traces, target probes always produced higher rates of identity judgment than of similarity judgment. Third, consistent with the notion that targets are better retrieval cues for their verbatim traces than related distractors are, rates of identity judgment for target probes were higher than rates of nonidentity judgment for related distractor probes in 11 of 12 data sets. Fourth, consistent with the notion that semantically related distractors are better retrieval cues for target's gist traces that for their verbatim traces, rates of similarity judgment for such distractors were higher than rates of nonidentity judgment—except, as predicted, when distractors were primed by targets. Fifth, underlying memory processes may vary with age even when the false-recognition effect remains invariant. In the developmental study, false-recognition effects for rhymes were age invariant, but, nevertheless, the rates of nonidentity judgment and similarity judgment both increased during this age range.

Example 2: Working with MISINFORM

We now illustrate how MISINFORM can be used to pinpoint the cognitive bases for misinformation effects in children and thereby test theoretical hypotheses about those effects. Although conjoint-misinformation experiments are currently in progress with children and adults, there are as yet no published reports of such experiments. Consequently, it is necessary to rely on simulated data. We generated these data so as to conform to findings reported in prior developmental misinformation studies. Remember that in conjoint-misinformation designs, children make accept–reject decisions about (a) misinformed targets, (b) distractors that embody misinformation (and therefore falsify misinformed targets), (c) control (i.e., nonmisinformed) targets, (d) control distractors (that falsify control targets), and (e) unrelated distractors. These decisions are made under three instructional conditions (T, R, and T+R). Because the traditional objective in misinformation studies has been to determine whether misinformed children falsely accept misinformation-embodying distractors, only T instructions have been used in prior studies.

Description of Data Sources

In most developmental misinformation studies, memory tests have involved forced choices between misinformed targets and misinformation-embodying distractors (e.g., Ceci et al., 1987). We were able to locate only four developmental studies (Pezdek & Roe, 1995, 1996; Warren & Lane, 1995) in which children made separate accept–reject judgments about targets and distractors. Because Pezdek and Roe's studies were concerned with preschoolers and older children, whereas Warren and Lane's was concerned with older children and college students, we relied primarily on the data of those studies to calculate input values of MISINFORM's parameters for our simulations. In these studies, 4- and 10-year-olds made accept–reject decisions about misinformed targets, misinformation-embodying distractors, and control targets and distractors under T instructions. Misinformation effects, both hit-rate suppression for targets and false-alarm rate elevation for distractors, were detected at both age levels, and the magnitudes of the effects increased with age in most conditions. Mean acceptance rates for each type of probe were reported by age level. Input values of MISINFORM's identity judgment, nonidentity judgment, and similarity judgment parameters for our simulation studies were determined by selecting values that were consistent with these mean acceptance rates. We then used the false-alarm rates for unrelated distractors in Brainerd and Reyna (1993) and Reyna and Kiernan (1994) to determine input values of b_T for the simulations because these distractors were similar in content and because subjects' ages were similar. Last, we used findings about the mathematical relations between b_T and the other two

TABLE 9
Mean Acceptance Rates for Simulated Misinformation Experiments

Type of probe	Age level 4	Age level 10
Targets:		
Misinformed	.50	.47
Control	.56	.63
Distractors:		
Misinformed	.73	.69
Control	.44	.14
Unrelated	.28	.06

bias parameters from prior conjoint recognition studies (Brainerd, Reyna, & Mojardin, in press; Brainerd et al., 1998) to determine input values of b_R and b_{T+R} for the simulations.

Ten simulated developmental conjoint-misinformation experiments were run. The design details of the simulations were as follows. Following Pezdek and Roe's (1995, 1996) choice of age levels, the subjects in each simulation were assumed to be 150 preschool children and 150 fourth-grade children. The children were assumed to have been exposed to a narrative containing 32 target facts, followed by interpolated information that falsified 16 of those facts, followed by a recognition test consisting of 16 target probes and 24 distractor probes. Half the targets had been misinformed and half had not been. Of the distractors, 8 embodied presented misinformation, 8 falsified a detail of one of the nonmisinformed targets, and 8 were unrelated to any of the information presented in the narrative. At each age level, 50 children responded under T instructions, 50 responded under R instructions, and 50 responded under T+R instructions. The ten simulated experiments were run by giving MISINFORM.EQN the selected input values of its parameters and conducting the simulations under these design constraints.

The qualitative results for the 10 experiments, as they would normally be reported in a misinformation study, are shown in Table 9. The reported data are mean acceptance probabilities, by age level, averaged across the 10 experiments for the T condition. When a 2 (age: preschool versus grade four) × 5 (probe type) ANOVA was performed on the acceptance probabilities for each experiment, the main results in all cases were significant ($p < .05$) main effects for age and probe type and an Age × Probe Type interaction. As can be seen in Table 9, the mean acceptance rate was lower in older children than in younger ones (.40 versus .50), and the order of mean acceptance rates was misinformation-embodying distractors > control targets > misinformed targets > control distractors > unrelated distractors at both age levels. As can also be seen, the Age × Probe Type

TABLE 10
Mean Estimates of MISINFORM's Parameters for the Simulated Misinformation Experiments

	Parameter					
Age/item type	I_t	N_t	S_t	N_r	I_r	S_r
Preschool:						
Control	.32	.01	.16	.09	0	.27
Misinformed	.31	.20	.09	.09	.57	.40
Fourth grade:						
Control	.53	.03	.17	.63	0	.33
Misinformed	.40	.51	.20	.18	.61	.55

interactions were due to the fact that only the acceptance rates for control targets, control distractors, and unrelated distractors varied significantly with age.

The questions of primary interest, however, are whether there were misinformation effects and, if so, whether they varied with age. Both questions were answered by conducting post hoc (Tukey HSD) analyses of the Age $\times$ Probe Type interaction. Four results were obtained in all 10 experiments: (a) Comparisons of misinformed targets and control targets revealed a misinformation effect (i.e., hit-rate suppression); (b) comparisons of misinformation-embodying distractors and control distractors revealed a misinformation effect (i.e., false-alarm rate elevation); (c) the misinformation effect for targets increased with age; (d) the misinformation effect for distractors increased with age. To explain these results, we used MISINFORM to compute the contributions of identity, nonidentity, and similarity judgment.

Parameter Estimation and Goodness of Fit

To estimate MISINFORM's parameters, we used MISINFORM.EQN to maximize the likelihood function for the raw data of each experiment. This produced goodness-of-fit tests as well as parameter estimates (cf. Example 1). There were 20 goodness-of-fit tests (2 age levels $\times$ 10 experiments). Only one produced a null hypothesis rejection, which is what would be expected by chance with 20 tests.

Hypothesis Testing

Mean estimates of the rates of identity, nonidentity, and similarity judgment for the 10 experiments appear by age level in Table 10. Because misinformation was manipulated within subjects, all hypotheses about this manipulation could be evaluated with within-condition tests.

Control items. First, consider the parameter estimates for the control items (Rows 2 and 5, Table 10). Because this condition is analogous to a standard false-recognition design, theoretical interest centers on the same four within-condition predictions that were evaluated above for FALSE: (a) Identity judgments about targets should be more common than similarity judgments (i.e., $I_{t,C} > S_{t,C}$); (b) identity judgments about targets should be more common than nonidentity judgments about related distractors (i.e., $I_{t,C} > N_{r,C}$); (c) similarity judgments about related distractors should be more common than false identity judgments (i.e., $S_{r,C} > I_{r,C}$; and (d) similarity judgments about related distractors should be more common than nonidentity judgments (i.e., $N_{r,C} < S_{r,C}$).

Except for Prediction (c), these hypotheses were evaluated in the same manner as before (cf. Example 1). Concerning (a), the null hypothesis that $I_{t,C} = S_{t,C}$ was rejected in all 20 comparisons (2 age levels × 10 experiments), with all differences in the predicted direction. Concerning (b), the null hypothesis that $I_{t,C} = N_{r,C}$ was rejected for the 10 tests involving preschoolers, with all differences in the predicted direction. For fourth grade children, however, this null hypothesis either was not rejected (four experiments), or it was rejected and the difference was not in the predicted direction. The reason is that the ability to make nonidentity judgments about control distractors improved more with age than did the ability to make identity judgments about control targets. Concerning (c), the null hypothesis that $I_{r,C} = S_{r,C}$ was rejected in all 20 comparisons, with all differences in the predicted direction. Concerning (d), the null hypothesis that $N_{r,C} = S_{r,C}$ was rejected in all 20 comparisons. However, inspection of the mean values of the parameters shows that the difference between them was in the predicted direction for preschoolers but in the opposite direction for fourth graders. Again, the reason was that the ability to make nonidentity judgments about control distractors improved more with age than did the ability to make identity judgments about control targets.

Misinformed items. These same four hypotheses were tested for the parameter estimates for misinformed items (Rows 3 and 6, Table 10). Concerning (a), the null hypothesis that $I_{t,M} = S_{t,M}$ was rejected in all 20 comparisons, with all differences in the predicted direction (i.e., $I_{t,M} > S_{t,M}$). Concerning (b), the null hypothesis that $I_{t,M} = N_{r,M}$ was rejected for all 20 comparisons, with all differences in the predicted direction (i.e., $I_{t,M} > N_{t,M}$). Concerning (c), the null hypothesis that $I_{r,M} = S_{r,M}$ was rejected for all 20 comparisons, but the observed relation, $I_{r,M} > S_{r,M}$, was the opposite of that for control items. Concerning (d), the null hypothesis that $N_{r,M} = S_{r,M}$ was rejected in all 20 comparisons, with all differences in the predicted direction (i.e., $N_{r,M} < S_{r,M}$). Thus, at both age levels, children in the misinformation condition more often made identity judgments about misinformed targets than similarity judgments, more often made identity judgments about misinformed targets than nonidentity judgments about misinformation-embodying distractors, more often made false identity judgments about misinformation-embodying distractors than similarity judgments, and more often made similarity judgments about misinformation-embodying distractors than nonidentity judgments.

For the misinformation condition, we tested some further within-condition hypotheses about the parameters $N_{t,M}$ and $I_{r,M}$. These parameters measure the rates of false nonidentity judgment about misinformed targets and false identity judgment about misinformation-embodying distractors, respectively. Here, the question of interest is whether these parameters have nonzero values—whether misinformation sometimes causes verbatim traces of target-falsifying information to be retrieved when misinformed targets are presented for test (producing false nonidentity judgments) and sometimes causes the same verbatim traces to be retrieved when misinformation-embodying distractors are presented for test (producing false identity judgments). When the null hypotheses that $N_{t,M} = 0$ and that $I_{r,M} = 0$ were tested, both were rejected in all tests; misinformation led to false nonidentity judgments about misinformed targets and false identity judgments about misinformation-embodying distractors.

Three further questions of interest about $N_{t,M}$ and $I_{r,M}$ are: (a) the relation between the two parameters, which bears on whether a target or a distractor is a better retrieval cue for the verbatim form of misinformation; (b) the relative magnitude of $N_{t,M}$ and $I_{t,M}$, which bears on whether a misinformed target is a better retrieval cue for its own verbatim trace or the verbatim trace of the misinformation; and (c) the relative magnitude of $I_{r,M}$ and $N_{r,M}$, which bears on whether a misinformation-embodying distractor is a better retrieval cue for the verbatim trace of its instantiating target or for the verbatim trace of the misinformation. These questions were also examined using within-condition likelihood-ratio statistics. Concerning (a), $N_{t,M} < I_{r,M}$ at both age levels in all experiments; distractors were better retrieval cues for verbatim traces of misinformation than targets were. Concerning (b), $N_{t,M} < I_{t,M}$ at the preschool level in all experiments; targets were better retrieval cues for their own verbatim traces than for verbatim traces of misinformation. However, $N_{t,M} = I_{t,M}$ at the fourth grade level. Concerning (c), $N_{r,M} < I_{r,M}$ at both age levels in all experiments; distractors were better retrieval cues for verbatim traces of misinformation than for verbatim traces of their instantiating targets.

Causes of misinformation effects. To determine which memory processes were responsible for misinformation effects, we again used within-condition likelihood ratio statistics—this time to compare the identity, nonidentity, and similarity parameters for misinformed targets versus control targets (to pinpoint the causes of hit-rate suppression) and for misinformation-embodying distractors versus control distractors (to pinpoint the causes of false-alarm rate elevation). We report the results separately by age level.

For preschoolers, the rates of identity and similarity judgment about targets and the rate of nonidentity judgment about distractors were not affected by misinformation. The hit-rate suppression effect was entirely due to the fact that the rate of nonidentity judgment about targets was much higher for misinformed targets than control targets (.20 versus .01). The false-alarm rate elevation effect was due to the fact that the rate of similarity judgment was higher for misinformation-embodying distractors than for control distractors and to the fact that false identity judgments were often made about misinformation-embodying distractors.

For fourth graders, the hit-rate suppression effect was due to the fact that the rate of identity judgment was lower for misinformed targets than control targets and the rate of nonidentity judgment was higher for misinformed targets. Thus, the memorial basis for hit-rate suppression was different in fourth graders than in preschoolers. However, the basis for the false-alarm rate elevation effect was the same: The rate of similarity judgment was higher for misinformation-embodying distractors than control distractors and identity judgments were often made about misinformation-embodying distractors.

Finally, we saw in the earlier ANOVAs that the hit-rate suppression effect and the false-alarm rate elevation effect both increased with age. Why? It is clear from Table 10 that misinformation's effects on some memory processes became more marked with age. With respect to hit-rate suppression, misinformation decreased the rate of identity judgment about targets in fourth graders but not in preschoolers, and it increased the rate of false nonidentity judgment about targets more in fourth graders than in preschoolers. With respect to false-alarm rate elevation, misinformation increased the rate of similarity judgment about distractors more in fourth graders than in preschoolers.

Age differences. Finally, between-condition likelihood ratio statistics (cf. Example 1) were used to determine whether rates of identity, nonidentity, and similarity judgment varied with age for the two types of items (misinformed and control). For control targets, only the rate of identity judgment increased with age. For control distractors, the rate of nonidentity judgment increased dramatically with age, while the rate of similarity judgment increased by a small (but significant) amount. For misinformed targets, rates of identity, nonidentity, and similarity judgment all increased with age. Concerning misinformation-embodying distractors, the rates of nonidentity judgment and similarity judgment both increased with age, but the rate of identity judgment did not.

Theoretical Conclusions

The conjoint-recognition design involves only a slight modification in standard developmental misinformation studies—children make recognition decisions under three different types of instructions rather than one. As can be seen from the foregoing results, this modification delivers a much richer assortment of theoretical conclusions than the standard design. Indeed, the standard design does not allow the processes of identity, nonidentity, and similarity judgment to be separated from each other. Examples of six conclusions about the contributions of these processes to misinformation effects that emerged from our simulated conjoint-misinformation experiments are these.

First, misinformation effects had a specific memorial content locus in that they were predominately due to variation in rates of verbatim comparisons. At both age levels, parameters that measured identity judgments (about misinformed targets and misinformation-embodying distractors) and nonidentity judgments reacted most strongly to misinformation. Misinformation effects for targets (hit-rate suppression) were due to the fact that, relative to control targets, target probes were more often compared to retrieved verbatim memories of misinformation (false nonidentity judgments) and less often compared to retrieved verbatim memories of target presentations during the study phase (true identity judgments). Misinformation effects for distractors (false-alarm rate elevation) were largely due to the fact that they were often judged to be identical to retrieved verbatim memories of misinformation.

Second, misinformation effects for targets were qualitatively different than misinformation effects for distractors. At both age levels, the former were verbatim-memory effects; the similarity-judgment parameter did not react to misinformation. However, misinformation effects for distractors were partly gist-memory effects; the similarity-judgment parameter was larger for misinformation-embodying distractors.

Third, concerning developmental variability, misinformation both increased similarity judgments about distractors and also caused false identity judgments to be made about them, with the former effect increasing with age. Misinformation suppressed fourth graders' identity judgments about targets, but not preschoolers'. So, the overall developmental picture of misinformation effects was one of *broadening access to verbatim traces of target-falsifying information and constricting access to verbatim traces of target presentations.*

Fourth, in the absence of misinformation, targets were better retrieval cues for their verbatim traces than target-falsifying distractors were. Thus, it was found that rates of identity judgment for control targets exceeded rates of nonidentity judgment at both age levels, and the spread between the two parameters increased with age.

Fifth, when misinformation was present, misinformation-embodying distractors were better retrieval cues for verbatim traces of misinformation than misinformed targets were. Thus, it was found that false identity judgments (about distractors) were more common than false nonidentity judgments (about targets).

Sixth, for both misinformed and control items, there were three further relations between the rates of identity and similarity judgment—namely, that identity judgments about targets were more common than similarity judgments, that similarity judgments about distractors were more common than false identity judgments, and that similarity judgments about distractors were more common than similarity judgments about targets. All three relations were present at both age levels for misinformed items. For control items, all three relations were present in preschoolers, but only the first and third were present in fourth graders.

SUMMARY AND CONCLUSIONS

Our overriding objective in this article has been to provide the sorts of process distinctions and research tools that will deepen our understanding of children's false memories by stimulating theory-driven research. In the first three sections, we presented a unified theoretical approach to children's false-memory reports, one that deals with both spontaneous and implanted reports and that is able to encompass age variability, as well as variability due to experimental manipulations. In the remainder of the paper, we described experimental procedures and mathematical models that are necessary to apply the theory systematically in developmental research.

We began by describing a global taxonomy of children's false-memory reports for the two most common types of studies in the developmental literature: false-recognition designs and misinformation designs. A key point of this taxonomy is that valid memories (e.g., of gist) of original target presentations can lead to systematic errors in false-recognition studies and that valid memories of both original target presentations and subsequent misinformation can lead to systematic errors in misinformation studies. Another key point is that error-producing memories in false-recognition studies are a subset of those in misinformation studies. Retrieval of verbatim traces of other targets leads to incorrect rejections of targets and retrieval of gist traces of targets leads to false alarms for related distractors in false-recognition studies, whereas the retrieval of verbatim and gist traces of misinformation also lead to incorrect rejections and false alarms in misinformation studies.

Following the taxonomy, we presented fuzzy-trace theory's account of how these verbatim and gist traces originate and how they are processed on recognition probes to yield false-memory reports. This account made specific assumptions, growing out of prior experimentation, about storage (dissociated verbatim and gist storage), about retrieval (dissociated verbatim and gist retrieval), about the nature of conscious recollection, and about the types of recognition decisions that are supported by retrieved verbatim and gist memories (identity judgments, nonidentity judgments, and similarity judgments).

This account also supplied multiple routes to false-memory reports and to developmental variability in those reports. According to its explanation of the false-recognition effect, the usual finding of higher false-alarm rates for related distractors is due to the fact that such probes are more apt to produce retrieval of gist traces of instantiating targets (leading to feelings of unanchored resemblance or of item-specific recollection and, sometimes, false feelings of identity) than retrieval of verbatim traces (leading to feelings of contrast). Crucially, because these are opponent processes, the now-you-see-it-now-you-don't aspect of previously reported age trends in this effect can be explained. Developmental *increases* in the false-recognition effect occur in contexts where age increases in gist retrieval exceed age increases in verbatim retrieval. On the other hand, developmental *decreases* in the false-recognition effect occur in contexts where age increases in verbatim retrieval exceed age increases in gist retrieval.

According to fuzzy-trace theory's explanation of misinformation effects, hit-rate suppression for misinformed targets can be due to one or more of three factors: (a) reduced retrieval of misinformed targets' verbatim traces (reducing identity judgments about targets); (b) increased retrieval of other verbatim traces, especially of misinformation (increasing false nonidentity judgments about targets); (c) reduced retrieval of gist traces of misinformed targets (reducing similarity judgments about targets). The theory assumes that the false-alarm rate elevation effect for misinformation-embodying distractors also can be due to one or more of three factors: (d) reduced retrieval of misinformed targets' verbatim traces (reducing nonidentity judgments about distractors); (e) retrieval of verbatim traces of misinformation (increasing false identity judgments about distractors); (f) increased retrieval of gist traces of misinformed targets and/or retrieval of gist traces of misinformation (increasing similarity judgments about distractors). Developmental variability in hit-rate suppression and in false-alarm rate elevation can then be explained by differential rates of expression of these factors at different age levels. As was the case for the false-recognition effect, because opponent processes are involved, the conflicting age trends that have been reported for misinformation effects can be explained on the hypothesis that some processes exhibit more age variability in certain experimental contexts, whereas other processes exhibit more age variability in other contexts.

Because fuzzy-trace theory provides multiple paths to false-memory reports and to developmental variability, empirical procedures for deciding which potential paths are the actual ones are fundamental to theoretical advancement. To identify actual paths, one must be able to measure variability in the rates of verbatim-based identity and nonidentity judgment, gist-based similarity judgment, and response bias. We introduced two experimental paradigms, conjoint recognition and conjoint misinformation, that generate data that are sufficiently rich to obtain independent measurements of all of these processes. The only difference between these paradigms and standard false-recognition or misinformation designs is that memory tests are administered under two further instructional conditions ("accept only related distractors" and "accept both targets and related distractors"). We also introduced two multinomial models, FALSE and MISINFORM, that extract estimates of identity judgment, nonidentity judgment, similarity judgment, and response bias from sample data.

Finally, we applied FALSE to the data of four previously reported experiments, and we applied MISINFORM to 10 simulated experiments. These applications produced a number of instructive findings, including confirmations of key predictions (e.g., that target probes are better retrieval cues for their verbatim traces than distractor probes are, that distractor probes are better retrieval cues for targets' gist traces than for their verbatim traces). In addition, two general lessons were learned. First, with both FALSE and MISINFORM, a rich assortment of theoretical conclusions can be derived from fairly simple experiments. In most developmental false-recognition or misinformation studies, which are model-free, monotonicity is the strongest assumption that can be made about the relation between false-memory reports and underlying memory processes (Howe et al., 1993). Under monotonicity, as is well known, the empirical case for any theoretical conclusion must consist of experimental findings on multiple overlapping factors that converge on that conclusion. As we have seen, progress toward theoretical conclusions is much more rapid with FALSE and MISINFORM because the relation between false-memory reports and underlying memory processes can be directly quantified.

The other lesson is that FALSE and MISINFORM are capable of integrating seemingly contradictory findings into a coherent theoretical picture. We saw earlier that false-alarm rates for related and unrelated distractors in developmental false-recognition studies have sometimes been higher for related distractors (standard false-recognition effect), have sometimes been lower for related distractors (false-recognition reversal effect), and have sometimes been equivalent. In addition, the false-recognition effect has sometimes been found to increase with age, has sometimes been found to decrease with age, and has sometimes been found to be age invariant. As we also saw, interpolated misinformation has usually been found to impair accuracy in developmental misinformation studies, but sometimes it has had no effect. Further, although misinformation effects have usually been found to decrease with age, they have sometimes been found to increase with age or to be age invariant. When FALSE and MISINFORM are brought to bear, these surface contradictions vanish because they are explicable at the level of memory processes. The explanation follows from the fact that both models posit opponent memory processes, processes that have opposite effects on hit rates for targets, that have opposite effects on false-alarm rates for distractors, and that vary independently of each other. Consequently, findings that seem contradictory at first glance, such as reversals in developmental trends for the false-recognition effect or for the misinformation effect, can be explained as nothing more than normal variations in opponent memory processes.

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