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The Role of Conceptual Recoding in Reducing Children's Retroactive Interference

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Reductions in children's retroactive interference were examined with conceptual recoding. Children learned two 10-item lists of toys; items on the 2nd list could also be classified as vehicles. Some children were not told about this 2nd category, whereas others were told either at the end of acquisition or just prior to the retention test 24 hr later. The results showed that (a) children benefited from the recoding instruction, (b) younger but not older children failed to benefit from the recoding manipulation when it occurred just prior to the retention test, and (c) recoding reduced retroactive interference primarily through affecting storage processes. These results provide new evidence concerning the importance of making information distinctive in storage in children's retention.

This research returns to a fundamental question in the memory development literature: Why do children forget things they have already learned? A longstanding theory of forgetting stipulates that learning something new can interfere with, and hence cause the forgetting of, memories of things already acquired. Indeed, interference effects, particularly retroactive interference effects, are a well-known cause of forgetting. This phenomenon even serves as the basis for the much-studied misinformation effect in eyewitness memory. Misinformation effects are particularly bothersome in young children because young children are said to be especially prone to the memory-distorting effects of subsequently presented, postevent misinformation. Because interference impairs memory performance, it is imperative both theoretically and forensically that researchers isolate the causes of retroactive interference and specify how these effects can be diminished or eliminated.

The study of interference effects as a primary source of forgetting has a long tradition in the adult memory literature. Importantly, this literature also underscores the critical role that storage and retrieval processes play in interference-based forgetting (for reviews, see Crowder, 1976; Postman & Underwood, 1973). For example, retrieval theorists proposed that forgetting arose because of response competition between earlier and more recent memories at the time of output (e.g., McGeoch, 1942). Storage theorists, on the other hand, argued that forgetting occurred because more recently acquired memories displaced, modified, or corrupted earlier memories, altering them in such a fundamental way as to make them unavailable for output (e.g., Melton & Irwin, 1940). More modern research has provided support for the involvement of storage factors alone (e.g., Ackley, Hinton, & Sejnowski, 1985; Metcalfe, 1990; Murdock, 1982), retrieval factors alone (e.g., Gillund & Shiffrin, 1984; Mensink & Raaijmakers, 1988), as well as a mixture of both storage and retrieval factors (e.g., Bower, Thompson-Schill, & Tulving, 1994) as sources of interference-based forgetting. Similar views have been espoused in the literature on misinformation effects in eyewitness memory (Bruck & Ceci, 1999).

Unlike the adult literature on forgetting, there are few studies in which retroactive interference effects have been examined directly in children. Despite considerable research on misinformation effects in children's recollection (for a review, see Bruck & Ceci, 1999), understanding the more fundamental properties of retroactive interference effects in children's forgetting is critical to an understanding of the development of memory. The need for this research is made more urgent given the counterintuitive findings in an early study of children's retroactive interference by Koppenaal, Krull, and Katz (1964), who found that interference effects increased with age. That is, contrary to what has been found more recently about children's misinformation effects (e.g., Bruck & Ceci, 1999), Koppenaal et al. (1964) found that older (8-year-old) children were more susceptible to retroactive interference effects than were younger (4- and 5-year-old) children. The enigma is enhanced by more recent findings showing that retroactive interference effects neither increased (as in the Koppenaal et al., 1964, study) nor decreased (as in the misinformation effects study of Bruck & Ceci, 1999, although there are exceptions in which no age differences [e.g., Howe, 1991] or age increases in misinformation effects [e.g., Pezdek & Roe, 1995] have been obtained) with age (e.g., Howe, 1995, 2002; Lee & Bussey, 2001). That is, although older children in these studies were better at recalling information than were younger children, forgetting rates caused by retroactive interference were similar for children regardless of age. In addition, studies in which the contributions of storage and retrieval processes were measured showed that although both factors contributed to retroactive interference effects in children, storage effects tended to dominate. This latter result is consistent with more general findings that storage factors contribute more to the development of children's long-term retention than do retrieval factors (e.g., Howe, 2000).

Although it has been established that retroactive interference is an important source of children's forgetting, little is known about how to temper such effects. An exception to this lack of informa-

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tion can be found in a recent series of studies in which it has been shown that children are able to reduce retroactive interference effects when instructed to forget the interfering material (Howe, 2002). Although the to-be-forgotten material was not actually forgotten, the reduced levels of retroactive interference may have occurred because intentional forgetting instructions made the to-be-forgotten material distinct from the to-be-remembered material. Unlike the effects of similarity, which tend to facilitate trace acquisition and retention by increasing the internal cohesion of elements within a memory trace, distinctiveness can have equally beneficial effects on memory by reducing the probability of interference among like traces.

Although the importance of distinctiveness in children's memory in general is just beginning to be established, even less is known about these effects in children's long-term retention (Howe, Courage, Vernescu, & Hunt, 2000). Despite the difficulties inherent in defining distinctiveness, one way to examine these effects is to look at children's ability to reclassify information that has already been stored in memory. Specifically, rather than asking children to recode previously learned material as "to be forgotten," one can ask children to take material that was encoded in a highly similar way and recode a portion of it in a new and distinctive way in order to see whether interference is reduced.

Experiments like this have been reasonably successful with adult subjects. For example, a number of investigators (e.g., Bower & Mann, 1992; Marsh, Landau, & Hicks, 1996; Zimmerman, 1954) have found that interference is reduced and recall facilitated when adults are provided with a postlearning cue that facilitates the recoding of interfering material. However, it is not clear whether release from retroactive interference effects is due to changes in storage, retrieval, or both. Again, just as for retroactive interference itself, theoretical proposals have been advanced that favor either storage processes or retrieval processes. That is, the postlearning cue may reduce retroactive interference in adults because it facilitates the (a) editing and censuring of information at retrieval, (b) reorganization and segregation of interfering material (e.g., List 2) from earlier learned material (e.g., List 1) in storage, or (c) both.

For an illustration, consider a study by Bower and Mann (1992). In that study, adults learned two lists in succession, each list containing names of cities in the United States. The important thing about the interfering, or second, list was that the city names were also names of U.S. presidents or other famous Americans. Following a retention interval of 3 min, adults were asked to recall the cities from List 1. Subjects who had been informed that the cities on List 2 were also names of famous Americans or presidents exhibited significantly less retroactive interference than those who were not so informed, although performance was not completely devoid of interference because the informed subjects' recall was not as good as that of control subjects who learned only a single list.

Bower and Mann's (1992) results are important because, as noted earlier, previous research has achieved only limited success in finding ways to systematically reduce retroactive interference (e.g., Greene, Flynn, & Loftus, 1982; Postman & Gray, 1979). These findings are also important because, according to Bower and Mann (1992; also see Marsh et al., 1996), they are inconsistent with models of memory in which additional strengthening of recently learned information (i.e., List 2 items in the informed condition) actually produces better recollection of a previously learned set of items (i.e., List 1) than when those same recently learned items are not strengthened (i.e., List 2 items in the uninformed condition). Models in which strengthening of some items should decrease, not increase, the probability of recalling the remaining items include list-strength effects models (e.g., Ratcliff, Clark, & Shiffrin, 1990), part-list cuing effects models (e.g., Nickerson, 1984), and associative memory models (e.g., Raaijmakers & Shiffrin, 1981).

Given the far-reaching consequences of these findings, it is important to point out that they are not ubiquitous. Although similar effects have been reported for nearly half a century (e.g., Brent, 1965; Zimmerman, 1954), others (e.g., Intons-Peterson, 1996), including Bower himself (Bower, Wagner, Newman, Randle, & Hodges, 1996), have failed to find recoding effects. On the other hand, Marsh et al. (1996) argued that recoding effects are generally robust and that failures to obtain them are due purely to methodological artifacts. In three new experiments, Marsh et al. showed that when these artifacts are eliminated, recoding does reduce retroactive interference effects in adults. Moreover, these authors pointed out the importance of storage (segregating information in memory) and retrieval (editing at output) factors in these postinformation cuing effects, arguing that this latter mechanism is also contingent on source monitoring skills (e.g., Johnson, Hashtroudi, & Lindsay, 1993). That is, the effectiveness of the editing mechanism in determining which items should be output is partially contingent on the subject's ability to decide which list the candidate item came from—the first, or to-be-output, list or the second, not-to-be-output, list.

In the current study, the robustness of recoding effects was examined with Grade 2 and Grade 4 children over a 24-hr (not a 3-min) interval. These effects have never been studied in children, and it is important to establish the effectiveness of recoding as an interference-reducing mechanism in a population said to be highly susceptible to misinformation effects (e.g., Bruck & Ceci, 1999). As well, examining these effects in children of different ages provides a way of testing the importance of the different mechanisms alleged to be involved in recoding. Specifically, children of these ages were selected because (a) important changes in source monitoring occur between Grades 2 and 4 (e.g., see Ruffman, Rustin, Garnham, & Parkin, 2001) and (b) categorized lists (see the Appendix) were used as the to-be-remembered materials, and rapid development of spontaneous category utilization in memory tasks also occurs during this age period (e.g., see Bjorklund, 2000).

As in other recent research on retroactive interference effects in children's memory (Howe, 1995, 2002; Lee & Bussey, 2001), both the to-be-remembered and interfering lists were learned to a perfect acquisition criterion. This was done in order to ensure that there were no Age × List Difficulty confounds present following acquisition that would compromise the interpretation of the retention data (see Howe & Courage, 1997). Also, as in Howe's (2002) study of release from retroactive interference due to intentional forgetting, the postlearning cue was provided at two different times: immediately following acquisition or just prior to the test of retention. I included this latter manipulation here to see whether recoding effects would be greater if children recoded immediately following encoding or just prior to tests of retention. Although the effects of this timing manipulation might be construed as measuring the storage (manipulating recoding at acquisition) and retrieval (manipulating recoding at retention) contributions of recoding to release from retroactive interference, such was not the intent.

Indeed, it is known in the memory development literature that the timing (study vs. test) of experimental manipulations is unrelated to the theoretical processes of storage and retrieval (for more detailed arguments, see Howe, 2000, 2002). Rather, to determine whether storage or retrieval explanations (or both in combination) are most appropriate, a method of divining theoretical processes from empirical performance is required. Because storage and retrieval are highly interrelated and latent theoretical processes that cannot be directly observed in memory data, normally some formal method is adopted in which the rules that map these theoretical processes onto performance outcomes are made explicit (see Batchelder & Riefer, 1999). One model that has been used successfully in studying the contribution of storage and retrieval processes to the development of children's long-term retention processes is the trace-integrity model. Because a lengthy review of this model and its mathematical and statistical properties has appeared in the literature (see Howe, 2000), only a summary of its key features is provided here (see also the Appendix in Howe, 2002).

The basic assumption of this model, like so many other recent memory models (e.g., Estes, 1997), is that storage and retrieval processes lie on a continuum, with the integrity of the trace varying with the extent to which trace elements (features, nodes, etc.) are bound together into a whole. As traces are learned, their elements are encoded and stored in an increasingly stable structure. Following acquisition, traces can either remain in the same stable state, lose some of their integrity and hence compromise their retrievability, or undergo disintegration of their structural properties in storage over a retention interval. On subsequent tests of long-term retention, traces that do not lose their integrity exhibit correct response rates of 1 (no failures in storage or retrieval). Those that experience some loss of integrity (making them more difficult to access or retrieve) exhibit correct response probabilities that are less than 1 but greater than 0 (retrieval failure only). Finally, those whose structural integrity is severely compromised exhibit correct response probabilities of 0 (failures in both storage and retrieval).

In addition to these forgetting processes, reminiscence probabilities exist both in storage and retrieval. That is, even though a retention session may consist of test trials only, with no additional, explicit learning opportunities (i.e., re-presentation of list items), the possibility exists that traces can be reminisced through reinstating retrieval processes (for those items that underwent retrieval-based forgetting) or redintegrated in storage (for those items that underwent both storage- and retrieval-based forgetting).

These basic ideas have been implemented in a mathematical model that pertains to experiments that use four test opportunities with no further study. A description of the various parameters that measure storage failures (S), retrieval failures (R), storage reminiscence (a), and retrieval reminiscence (the r_i and the f_i) is given in Table 1. In what follows, this trace-integrity model (along with more traditional analyses) is used to examine the role of storage and retrieval processes in young children's 24-hr retention in the presence of interfering information and recoding instructions.

Table 1

Definitions of the Parameters in the Trace-Integrity Framework

Process and parameter	Description
Trace forgetting	
S	The probability of storage failure
R	The probability of retrieval failure of information in storage
Trace reminiscence	
a	The probability that information not in storage is redintegrated to a level above zero recall
r_1	The probability of two consecutive successes
r_2	The probability of three consecutive successes
r_3	The probability of four consecutive successes
f_1	The probability of a success following one error
f_2	The probability of a success following two consecutive errors
f_3	The probability of a success following three consecutive errors

Method

Subjects

The subjects were 77 (39 boys and 38 girls) 7-year-old Grade 2 children (mean age = 7 years 5 months; range = 7 years 0 months to 8 years 4 months) and 76 (38 boys and 38 girls) 9-year-old Grade 4 children (mean age = 9 years 5 months; range = 9 years 0 months to 9 years 11 months). The majority of the children were middle class, White, and from a predominantly metropolitan area. All participated with written parental consent.

Materials

A total of 20 items were used—all were drawn from the "toy" category in Posnansky's (1978) category frequency norms for children. Half of the items (10) were also classified as "vehicles" according to these same norms (items are reproduced in the Appendix). Two additional lists were formed in order to control for the spontaneous discovery of the second, or "vehicle," category. In these lists, half of the items from the "toys" list and the "toys/vehicles" list were randomly conjoined to form a new "mixed toys" list, with the remaining items forming a second "mixed toys" list (these mixed lists are also reproduced in the Appendix).[1]

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[1] A frequent criticism of research on recoding is that results can be obscured because subjects may automatically or spontaneously become aware of the second category associated with List 2. Such awareness can elevate the performance of uninformed groups to near that of the postinformed groups, thereby artificially eliminating performance advantages normally associated with the provision of a recoding cue prior to retrieval (see Marsh et al., 1996). In the current experiment, children (especially the older, Grade 4 children) learning the toys list followed by the toys/vehicles list could spontaneously discover that items from this latter list were also categorizable as vehicles and could use this knowledge to reduce retroactive interference, thus potentially obscuring the recoding effects. In order to eliminate this potential confound, an additional condition (denoted retroactive interference [RI]-mixed) was created in which items from the toys list and the toys/vehicles list were quasi-randomly combined to form two lists that could only be categorized as toys (each list had half of the items drawn from toys that were also vehicles and the other half from toys that were not also vehicles). It is this condition that represents a true retroactive interference condition free of the potential confound of spontaneous cue discovery and that technically serves as the condition of comparison for conditions in which recoding cues were explicitly presented. As can be seen later in this article, because the same items appear in both retroactive interference conditions (RI-mixed and the standard RI-fixed), comparisons of performance between these conditions provide an estimate of the probability of spontaneously discovering (and utilizing) the recoding cue to reduce retroactive interference.

Procedure

Grade 2 and Grade 4 children were randomly assigned to one of five conditions with the stipulation that the same ratio of boys to girls exist in each condition. The five conditions were as follows: a control condition in which children learned a single list (either the toys list or the toys/vehicles list) and recalled that list 24 hr later; two standard retroactive interference (RI) conditions, one (denoted RI-fixed) in which children learned the toys list first followed by the toys/vehicles list and then recalled the toys list 24 hr later, and a second (denoted RI-mixed) in which children learned one of the two mixed toys lists first and the other one second, recalling the first list 24 hr later; and two recoding retroactive interference conditions in which children learned the toys list first followed by the toys/vehicles list and then recalled the toys, or first, list 24 hr later. In the first of these recoding conditions (denoted recoding-at-acquisition), children were told about the presence of the second, or "vehicles," category at the end of the acquisition session, whereas in the second recoding condition (denoted recoding-at-retention), children were told about the presence of the second, or "vehicles," category 24 hr later, just prior to the test of retention.

During the acquisition phase, all of the lists were learned to a criterion of two consecutive errorless test trials. Children were tested individually in a small room in their school. The lists were presented visually as well as read aloud by the experimenter, and a free-recall procedure was used in which children studied each item individually for approximately 5 s until they had studied all of the items on the list. In order to avoid potential short-term memory effects, children were required to engage in 30 s of distractor activity (a symbol matching task) and then were asked to recall the list. This study–distractor–test procedure continued until the two-trial criterion had been met. For children learning two lists, the second list was presented for learning immediately after the first list was learned. The same learning procedure and two-trial criterion were used for the second list. It should be noted that all of the children were informed prior to learning each list that each list contained a series of words that depicted concepts belonging to the toy category. This ensured that the children focused on the toy category during acquisition.

Twenty-four hours following acquisition, children recalled the first list (or the only list in the case of the control group) they had learned the day before. Four test trials were used; on each trial, children free recalled as many items as they could. Each of the first three test trials was followed by the same distractor task that had been used at acquisition. This test–distractor–test–distractor–test–distractor–test sequence was completed without additional study opportunities.

Results

Although the main focus of this section is on the trace-integrity model's detailed accounting of the effects of retroactive interference and recoding on the storage and retrieval components of the development of children's long-term retention, I begin by reporting the results of more traditional analyses of the global trends present in these data. Analysis of covariance (ANCOVA) was selected because it is one means by which possible under- and overlearning effects at long-term retention that are due to individual differences that carry over from initial acquisition can be controlled (also see Howe, 1995). By using performance differences during acquisition (e.g., total errors[2]) as a covariate, any confounds that remain following (or might be caused by) criterion acquisition can be eliminated from the dependent variable (total errors per trial at long-term retention) prior to assessing the impact of the manipulations of interest. Of course, specific mathematical models are needed as well because ANCOVAs do not represent a panacea for these problems, particularly inasmuch as they do not contain specific goodness-of-fit mechanisms, are general purpose and hence are not theoretically motivated, and fail to isolate latent cognitive processes such as storage and retrieval (see Howe, 1995). For these and other reasons, mathematical models are more sensitive and considerably more powerful when used to examine specific hypotheses concerning the nature of children's long-term retention. Prior to presenting these analyses, however, I detail the global trends as detected by the ANCOVA.

Global Trends at Retention

In order to evaluate performance at long-term retention, the total errors for each of the four trials at retention were analyzed using a 2 (grade: 2 or 4) × 5 (condition: control, RI-fixed, RI-mixed, recoding-at-acquisition, recoding-at-retention) × 4 (trial: 1–4) ANCOVA in which total errors at acquisition served as the covariate (this tends to be a more sensitive index of acquisition differences than trial of last error and hence was used for the purposes of the ANCOVA). The results indicated that there was (a) no effect for the covariate; (b) a main effect for grade, $F(1, 142) = 16.69$, $p < .001$, $\eta^2 = .105$, in which Grade 2 children made more errors ($M = 4.77$) than Grade 4 children ($M = 3.70$); (c) a main effect for condition, $F(4, 142) = 16.39$, $p < .001$, $\eta^2 = .316$, in which post hoc Newman–Keuls tests ($p < .01$) indicated the following order of difficulty—control ($M = 2.59$) < recoding-at-acquisition ($M = 4.00$) = recoding-at-retention ($M = 4.27$) < RI-fixed ($M = 4.64$) < RI-mixed ($M = 5.68$); and (d) a main effect for trial, $F(3, 426) = 3.80$, $p < .01$, $\eta^2 = .026$, in which post hoc Newman–Keuls tests ($p < .01$) indicated that errors tended to decrease across trials in a reasonably linear fashion (also confirmed in the ANCOVA because only the linear component was significant; *M*s = 4.61, 4.39, 4.06, and 3.89 for Trials 1–4, respectively). Importantly, the effect sizes as reflected in the η^2s indicate that the proportions of the variance in the dependent variable related to the factors in each condition are in the range from moderate to large.

Finally, there was a Grade × Condition interaction, $F(4, 142) = 2.43$, $p < .05$, $\eta^2 = .064$ (see Figure 1). Post hoc tests showed that this interaction occurred primarily because of a decrease in interference effects for Grade 4 children, but not Grade 2 children, when recoding instructions were administered at retention. That is, although all children benefited from the recoding instruction at acquisition, only the older children could use recoding at retention to reduce retroactive interference effects. As well, Grade 4 children, but not Grade 2 children, were able to spontaneously recode items on the fixed list. That is, older children, but not younger children, made fewer errors on the fixed list than on the mixed list at retention.

What these findings indicate is that there was marked retroactive interference (children in the RI-fixed and RI-mixed conditions committed more mean errors than those in the control condition). This interference was reduced (although not eliminated) when children were given recoding instructions. For older children, who performed better overall than the younger children, it did not matter whether the recoding instructions were given following acquisition or at the time of retention testing—in both cases older

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[2] An error, either at acquisition or retention, was defined as anything other than a correct response. That is, errors could be omissions, intrusions from the other list (in the retroactive interference conditions), or extralist intrusions.

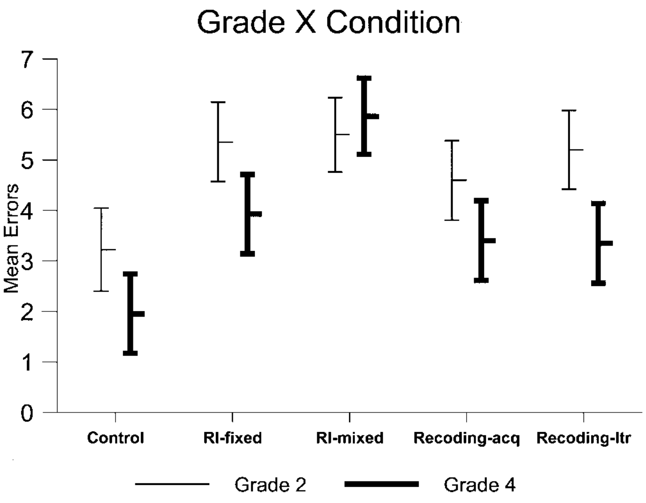

Figure 1. Mean errors (with associated error bars) for the Grade × Condition interaction. RI = retroactive interference; acq = acquisition; ltr = long-term retention.

children could use the recoding instruction to reduce retroactive interference. However, for the younger children, the recoding manipulation was effective only following acquisition.

The finding of retroactive interference in young children's long-term retention is not unexpected and is consistent with previous reports (Howe, 1995; Howe et al., 2000). What is new is the finding that children, like adults (e.g., Bower & Mann, 1992), can benefit from recoding information in memory to reduce retroactive interference effects. That there was no reduction in retroactive interference for the younger children when this instruction was given just prior to the 24-hr retention test is somewhat curious but does provide for a theoretically interesting limiting condition on these effects. Importantly, what the Grade × Condition interaction showed was that all children could use recoding to reduce retroactive interference. Although it might be tempting to conclude that these effects are primarily storage based because retroactive interference was reduced for Grade 2 children when recoding instructions were administered following acquisition but not at retention, such a conclusion is not warranted by this outcome. This is because storage and retrieval are theoretical processes, not points in time during an experiment, and both storage and retrieval processes are involved in acquisition and retention. Similarly, because older, Grade 4, children could benefit from recoding instructions at the time of retention does not mean that these effects are retrieval based. In order to determine the storage and retrieval loci of these effects, the trace-integrity model can be applied to the long-term retention data.

Trace-Integrity Analyses

As already noted, the statistical and mathematical mechanics of this model are provided in Howe (2000, 2002) for the interested reader. In this section, a brief summary of the steps involved in the application of this model to the data is presented and followed by a report of the relevant findings from the present experiment. Before the trace-integrity model can be used to interpret the impact of these manipulations on children's long-term retention, the goodness of fit of the model to the current data set must be evaluated (the machinery for these tests is shown in the Appendix to Howe, 2002). Specifically, it must be shown that the model, with only 9 parameters, does as good a job of accounting for the data as does a purely empirical model in which all 15 degrees of freedom ("empirical parameters") are used in accounting for the data. The likelihood ratio tests, which are conducted for each condition and contain 6 degrees of freedom, evaluate the null hypothesis that the theoretical model does as good a job of accounting for the data as does the empirical model. The results of the 10 tests for this experiment failed to reject the null hypothesis, indicating that the model provided an adequate fit to the retention data generated across the conditions [all χ^2s(6) < 10.26].[3]

The numerical values of these parameters for this experiment are presented in Table 2. In order to see whether the values of the theoretical parameters of the trace-integrity model differed significantly across the various conditions in this experiment, an *experimentwise* test was conducted. Like the omnibus *F* test, the experimentwise test evaluates the null hypothesis that, on average, the

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[3] When alternative models are available for the same data set, it is instructive to contrast their differing accounts of the outcome from any experiment. For the current experiment, the trace-integrity model's account of the data can be contrasted with a recently developed model proposed by Brainerd, Wright, Reyna, and Payne (2002), one based on fuzzy-trace theory (FTT; e.g., Brainerd & Reyna, 2001). Unlike in the trace-integrity model, in which a single, unitary memory trace is constructed, in FTT there are two traces constructed, one that preserves verbatim information and one that preserves gist. These two types of traces are implemented in a dual-retrieval model where recall can be mediated by direct access to verbatim traces (denoted by the parameter set D_i) or by reconstructive recall based on gist traces (denoted by the parameter set R_i) plus a metamemorial judgment authorizing output of the reconstructed trace (denoted by the parameter J). In order to examine the relative strengths of these two models in the current context, Brainerd et al.'s (2002, see their Appendix) recall model was extended to accommodate the four-trial outcome space used here. Interestingly, in this four-trial space, both models have the same number of parameters (nine); however, because they are not nested in a statistical sense, comparative fits must be judged on how well each model fits the data from the experiment. As noted already, the trace-integrity model fit all of the 10 conditions in this experiment. Unfortunately, because the dual-retrieval model fit only 4 of the 10 conditions at $p < .05$ and only 5 of the 10 conditions at $p < .01$, further comparative development of these models was not warranted in this article. Because the trace-integrity model provided an adequate fit for all of the data in this article, discussion is restricted to the parameters associated with this model. It should be noted that the poorer fit of the dual-retrieval model to these data may be due to differences in the assumptions concerning the role of prior successes and errors on subsequent test performance. Specifically, in keeping with Howe and Brainerd's (1989) observation that learning on test trials occurs mainly following errors in recall designs, Brainerd et al. (2002) implemented a model in which switching from reconstructive recall to direct verbatim memory access occurs following test trial errors but not test trial successes. The trace-integrity model permits learning following both prior successes and errors, something that is consistent with the data from the current experiment. Indeed, more generally, children, unlike adults, tend to exhibit lower error-contingent learning (e.g., Brainerd & Howe, 1978, 1980). Thus, unlike with the adult data sets used in the Brainerd et al. (2002) studies, the poorer fits obtained here may be due to children's greater reliance on successes than on errors for improving test trial performance.

Table 2
Parameter Estimates

Condition	S	R	a	r_1	r_2	r_3	f_1	f_2	f_3
Grade 2									
Control	.22	.14	.09	.91	.94	.95	.46	.27	.10
Retroactive interference									
Fixed	.32	.40	.00	.88	.86	.91	.51	.32	.11
Mixed	.49	.29	.07	.87	.91	.98	.57	.31	.00
Retroactive interference with recoding at									
Acquisition	.36	.15	.13	.83	.84	.86	.57	.20	.00
Retention	.42	.28	.06	.88	.90	.94	.55	.30	.10
Grade 4									
Control	.19	.00	.18	.94	.93	.94	.59	.37	.00
Retroactive interference									
Fixed	.29	.14	.00	.93	.94	.97	.50	.34	.00
Mixed	.49	.21	.05	.85	.94	.88	.49	.20	.00
Retroactive interference with recoding at									
Acquisition	.33	.05	.10	.89	.99	.94	.55	.30	.01
Retention	.09	.36	.00	.96	.99	.98	.44	.24	.04

model's parameters did not vary between conditions. For the data in the present experiment, the value of this test statistic was $\chi^2(81) = 252.91$, $p < .001$.

The next step involved a series of *conditionwise* tests evaluating the null hypothesis that the numerical values of the parameters do not vary between specific pairs of conditions. In this experiment, a total of 25 conditionwise tests were needed, 5 comparisons to evaluate age effects and 10 within each age to evaluate retroactive interference and recoding effects. The numerical results of the tests to evaluate age effects (all ps $< .01$) revealed differences between Grade 2 and Grade 4 children on all lists [all χ^2s$(9) > 21.67$]. The numerical results of the tests evaluating retroactive interference and recoding effects indicated that, for Grade 2 children, the control condition differed from all of the other conditions: control versus RI-fixed, $\chi^2(9) = 26.30$; control versus RI-mixed, $\chi^2(9) = 34.57$; control versus recoding-at-acquisition, $\chi^2(9) = 21.68$; control versus recoding-at-retention, $\chi^2(9) = 23.15$. The RI-fixed condition did not differ from the RI-mixed condition, $\chi^2(9) = 6.63$; the RI-fixed and RI-mixed conditions both differed from the recoding-at-acquisition condition, χ^2s$(9) = 24.40$ and 29.73, respectively, but not from the recoding-at-retention condition, χ^2s$(9) = 8.15$ and 10.79, respectively; and the two recoding conditions differed from each other, $\chi^2(9) = 23.75$. The numerical results of these same tests for the Grade 4 children showed a slightly different pattern. Specifically, the control condition differed from all of the other conditions: control versus RI-fixed, $\chi^2(9) = 29.00$; control versus RI-mixed, $\chi^2(9) = 73.49$; control versus recoding-at-acquisition, $\chi^2(9) = 22.74$; control versus recoding-at-retention, $\chi^2(9) = 32.11$. The RI-fixed condition differed from the RI-mixed condition, $\chi^2(9) = 22.74$; the RI-fixed and RI-mixed conditions both differed from the recoding-at-acquisition condition, χ^2s$(9) = 22.60$ and 32.13, respectively, and from the recoding-at-retention condition, χ^2s$(9) = 24.82$ and 38.63, respectively; and the two recoding conditions did not differ from each other, $\chi^2(9) = 16.90$.

The last sequence of tests, namely, *parameterwise* tests, are used to isolate the specific parameter or parameters whose estimates differed between the conditions. All of these chi-square tests have 1 degree of freedom and, because they are tedious and space consuming to report, are often given in summary form. Consistent with this tradition, only those parameterwise differences that were significant ($p < .05$) are reported next. As well, because grade, retroactive interference, and recoding effects were localized primarily in terms of forgetting, not reminiscence, rates, a phenomenon that is typical in this area (see Howe, 2000, 2002), the discussion of the model-based findings is confined to the parameters that measure storage failures (S) and retrieval failures (R).

Concerning grade effects, parameterwise tests revealed that most of these differences were due to variations in retrieval failures. That is, Grade 2 children were more likely to experience retrieval failures at retention than were Grade 4 children. The one exception occurred in the recoding-at-retention condition, where storage failures were greater in Grade 2 than Grade 4. Although this latter exception is more typical of the literature on age differences in children's retention (see Howe, 2000), the general absence of storage-related age differences at retention is not particularly surprising in the current study. The reason is that there was rich semantic support available in long-term storage concerning "toys" because children in both Grades 2 and 4 were very familiar with the items used here and possessed rich semantic representations of this category in memory. It has been argued that in circumstances such as these, age-related differences in long-term storage should be reduced or eliminated because often such differences arise from age-correlated changes in children's knowledge base (Howe, 2000). That is, as information becomes better organized semantically, it is easier for children to maintain that information in memory for longer and longer periods of time. Of course, like age differences in the initial acquisition of categorized lists (e.g., Bjorklund, 1987), storage-based differences in retention are reduced or eliminated when age differences in semantic knowledge are removed. When these conditions pertain, as they did in this experiment, episodic activation (at acquisition) of well-established representations should not lead to large developmental differences in storage failure rates over a 24-hr interval in the ages studied here. Thus, although storage failures are more commonly associated with developmental differences at retention (see Howe, 2000), the present findings are not unexpected given the semantic richness of the materials, the age of the children, and the brevity of the retention interval.

With regard to retroactive interference and recoding effects, all of the children experienced interference effects in that both the RI-fixed and RI-mixed conditions produced greater storage failure rates than the control condition. Indeed, for both Grade 2 and Grade 4 children, the RI-fixed condition showed a net increase in storage failures of 50% over the control condition, and the RI-mixed condition produced a doubling of the storage failure rate. These latter conditions also varied in their storage failure rates; the probability of storage failure was less in the RI-fixed than in the RI-mixed condition. When more sensitive model-based analyses were used, it was apparent that children in both Grades 2 and 4 were able to spontaneously use the additional "vehicles" category to reduce retroactive interference. However, consistent with the ANCOVA findings, this spontaneous recoding did not completely eliminate retroactive interference because retention performance did not return to the level of that of the children in the control conditions.

Interestingly, this spontaneous recoding did result in the same reductions as those found when children in both grades were explicitly instructed to recode following acquisition. Here, however, the probability of retrieval failure was also reduced, at least compared with the RI-mixed conditions. Thus, when recoding instructions were administered following acquisition, the probabilities of both storage and retrieval failures were reduced.

Finally, but perhaps most important, only Grade 4 children benefited from explicit recoding instructions at the time of retention testing. Here, only storage failures were affected, reducing retroactive interference and resulting in performance levels similar to those seen in the control conditions. No improvement was found for the Grade 2 children, their performance being as poor in the recoding-at-retention condition as in the RI-mixed condition. Thus, as cautioned earlier in the context of the ANCOVA results, the timing (at acquisition or retention) of a manipulation (explicit recoding instructions) does not herald the locus (storage or retrieval) of its effect. Explicit instructions to recode information following acquisition affected both storage and retrieval failure rates, whereas when this same instruction occurred at retention, it affected only storage failure rates.

Discussion

There were three objectives in the current experiment: (a) to establish the presence and locus of retroactive interference effects in Grade 2 and Grade 4 children's retention of semantically related material, (b) to demonstrate recoding effects in these children, and (c) to determine whether recoding instructions reduced interference effects. Concerning the first objective, this experiment showed that Grade 2 and Grade 4 children are as susceptible to retroactive interference effects when learning semantically related concepts as they are when learning well-integrated stories (Howe, 2002) and paired associates (Howe, 1995). As in these previous studies, the primary locus of the retroactive interference effects was at forgetting—particularly, storage-based forgetting. These findings add to the growing consensus that, contrary to some earlier reports (Koppenaal et al., 1964), retroactive interference effects (a) are robust in young children, (b) are localized mainly in forgetting, not reminiscence, and (c) involve changes to information at the level of storage.

The results related to the second and third objectives of this experiment, considered together, provide important and new findings about children's recoding abilities that would not be predicted directly from the extant literature on memory development. Specifically, Grade 2 and Grade 4 children, like adults, can recode recently acquired information, and once recoded, this information produces markedly less retroactive interference. Although not all of the retroactive interference was eliminated, significant reductions in interference were observed for all children. Moreover, according to the model-based analyses at least, these same children were able to spontaneously recode information to reduce retroactive interference. It is particularly significant that the younger children were able to use spontaneous as well as instructed recoding to ameliorate interference effects (although only when instructed at acquisition), because evidence from a variety of sources indicates that it might be as late as 10 or 11 years of age before children can use semantic categories flexibly and spontaneously to aid memory performance (e.g., see Bjorklund, 2000). An important related finding was that the primary locus of these recoding effects, whether spontaneous or instructed, was at forgetting, particularly at the level of storage (with additional reductions in retrieval-based forgetting when recoding was explicitly instructed). That is, recoding reduced retroactive interference primarily by altering the pattern of storage failures. It is more than coincidental that storage was also a primary locus of retroactive interference effects. This pattern is consistent with the more general observations that maintaining information in storage is critical to the development of children's long-term retention (Howe, 2000), that retroactive interference is a storage-related phenomenon and not just localized at retrieval (Howe, 1995), and that manipulations that effectively reduce retroactive interference—recoding and intentional forgetting (Howe, 2002)—do so by reducing information loss at the level of storage.

How does recoding work? Because recoding effects were primarily storage based, one likely hypothesis is that reorganization of to-be-remembered information serves to make it distinct in memory, segregating it from the background noise of other information in memory (e.g., see Howe et al., 2000). For example, in the present study, because the two lists of concepts had considerable internal cohesion ("within-list" similarity) and shared many features ("between-lists" similarity), interference effects might be predictably strong. If confusion between traces is to be avoided, cross-talk or interference among traces needs to be attenuated. As memorability often requires a balance between similarity and distinctiveness, the recoding manipulation may have aided the latter by providing a salient dimension that served to discriminate traces in storage (e.g., see Hunt & McDaniel, 1993). That recoding effects were mainly seen at storage is important because it suggests that identifying one list as belonging to a different category did not simply result in editing information at output but rather led to the reorganization of information in storage, altering it in memory.

An interesting developmental finding that emerged was that retroactive interference was reduced for the younger, Grade 2, children only when recoding instructions were provided following acquisition and not when administered just prior to retention testing 24 hr after acquisition. In contrast, Grade 4 children were able to utilize recoding to reduce retroactive interference regardless of when they were explicitly instructed to recode. This pattern of findings has also been obtained elsewhere, albeit when an intentional forgetting manipulation was used with younger (preschool and kindergarten) children (Howe, 2002). What these results might mean developmentally is that older children are more flexible in using recently encoded information to reorganize information already "galvanized" in storage through consolidation processes. A wealth of other outcomes have shown that older children are more flexible manipulators of information in storage than are younger children, especially when it comes to long-term retention (for a review, see Howe, 2000).

More generally, that recoding instructions reduced forgetting has several interesting implications for eyewitness memory and some of the processes that may underlie it. For example, it may be that explicitly instructing children to reorganize recently acquired information can actually have a memory-preserving function on eyewitness recall. That is, instructions to recode may keep memories more intact than would otherwise be the case. As already noted, this is because such instructions can lead to trace reorganization and greater distinctiveness in memory. This, in turn, reduces the likelihood of interference among memories and, hence, the likelihood that such memories will be forgotten. Interestingly, then, trying to reorganize memories for events, whether they are traumatic or not, may actually improve one's memory for the events.

Distinctiveness effects are also important when it comes to avoiding false memories (e.g., Ghetti, Qin, & Goodman, 2002; Howe, 1998). Theoretically, at least, distinctive information should be less susceptible to false memories because traces for distinctive material are more robust (Howe, 1998). Indeed, Ghetti et al. (2002), using the familiar Deese/Roediger–McDermott paradigm, found that the use of distinctive information reduced children's and adults' susceptibility to the false memory illusion. Again, because recoding is possible even after encoding is complete, making initially similar and potentially confusing information distinctive and hence more memorable may be one way that children and adults can reduce the probability of false recollections when recalling events that have many features in common. Although speculative, particularly given the differences between false memory and recoding paradigms, explorations of recoding in false memory settings might prove fruitful, at least theoretically.

In conclusion, this study establishes that retroactive interference effects are robust in Grade 2 and Grade 4 children and that these effects are most frequently evidenced in increases in storage-based forgetting. In terms of recoding, the results are very clear that even young, Grade 2, children can benefit from instructions to recode and can recode spontaneously, and that these effects are most often observed in reductions of storage-based forgetting. That children so young can benefit from reorganizing information at the level of storage is not easily reconciled with claims that they are less flexible in their use of semantic information to aid memory and retention. These findings are also inconsistent with theories in which the locus of recoding effects is said to be at retrieval. Although these results will need to be replicated with different categories and items before one can be certain of their generality, the findings reported here are more suggestive of the conclusion that recoding instructions produce traces that are better discriminated in storage.

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Appendix

Lists of Items

		Retroactive interference mixed lists	
Toys list	Toys/vehicles list	List 1	List 2
ball	airplane (jet)	airplane (jet)	boat (ship)
baseball bat	boat (ship)	ball	baseball bat
blocks (Lego)	fire engine	blocks (Lego)	doll
doll	helicopter	fire engine	helicopter
football	spaceship	football	jack-in-the-box
jack-in-the-box	tractor	jump rope	puzzle
jump rope	train	spaceship	train
puzzle	tricycle	teddy bear	tricycle
teddy bear	truck	tractor	truck
yo-yo	wagon	wagon	yo-yo

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