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Representational Explanations of "Process" Dissociations in Recognition: The DRYAD Theory of Aging and Memory Judgments

Aaron S. Benjamin
University of Illinois at Urbana–Champaign

It is widely assumed that older adults suffer a deficit in the psychological processes that underlie remembering of contextual or source information. This conclusion is based in large part on empirical interactions, including disordinal ones, that reveal differential effects of manipulations of memory strength on recognition in young and old subjects. This article lays out an alternative theory that takes as a starting point the overwhelming evidence from the psychometric literature that the effects of age on memory share a single mediating influence. Thus, the theory assumes no differences between younger and older subjects other than a global difference in memory fidelity—that is, the older subjects are presumed to have less valid representations of events and objects than are young subjects. The theory is articulated through 3 major assumptions and implemented in a computational model, DRYAD, to simulate fundamental results in the literature on aging and recognition, including the very interactions taken to imply selective impairment in older people. The theoretical perspective presented here allows for a critical examination of the widely held belief that aging entails the selective disruption of particular memory processes.

Keywords: memory, aging, recognition, exclusion, process dissociation

In this article, I challenge the claim that empirical dissociations evident in recognition memory tasks imply process dissociations. The particular test case that I consider involves the effects of aging on memory judgments. I adopt that case as the model for the present arguments for two reasons, one theoretical and one practical. On the theoretical side, there is widespread consensus that older adults suffer a selective deficit in memory for the contextual or source aspects of previously learned stimuli (henceforth, *context memory*; Johnson, Hashtroudi, & Lindsay, 1993). The results underlying this claim are robust in magnitude and highly replicable and have even spurred major reviews and meta-analyses in the literature (Burke & Light, 1981; Spencer & Raz, 1995). This effect is thus arguably one of the most widely accepted claims about the effects of aging on memory. On the practical side, the ramifications of our perspective on memory in older adults for the rehabilitation of memory deficits are socially and financially significant ones. To be clear from the outset, I think that the conclusion of a selective deficit is wrong and that clinical treatments that assume such deficits are misguided. At the very least, I hope to demonstrate that these conclusions and actions are premature, the high degree of consensus among experimental psychologists notwithstanding.

The same logic that has led to a conclusion of impaired context memory in older adults has led to parallel claims of selective deficits of context memory in the intoxicated (Kirchner & Sayette, 2003), the brain damaged (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998), those who are depressed (Degl'Innocenti & Bäckman, 1996), those under the influence of benzodiazepines (Hirshman, Fisher, Henthorn, Arndt, & Passannante, 2002; Mintzer & Griffiths, 2000), those whose attention is divided (Gruppuso, Lindsay, & Kelley, 1997; Yonelinas, 2001), those who have changed contexts between study and test occasions (Macken, 2002), and those whose responses are speeded (Benjamin & Craik, 2001; Hintzman & Curran, 1994; Jacoby, 1999). It is telling that there are no well-established claims of populations that exhibit or manipulations that induce a selective sparing of context memory. I argue here that this asymmetry is no coincidence; rather, there is a principled representational explanation why any variable that compromises memory should selectively impair one putative component of recognition and not the other. Any reduction in general memory efficacy—whether by virtue of population membership or experimental exposure—yields a behavioral profile of the relative resistance of specific mnemonic tasks to compromised or noisy input. Those tasks that require the subject to address memory representations that are the least redundant are those that are affected earliest and most dramatically by such deficient input. I argue here that context is typically more sparsely represented than content and thus that memory for context will be more significantly affected by a global reduction in memory fidelity than memory for content.

To preview the contrast between the process-dissociation view and the representational view by analogy, consider two tribes of humans, both of which are confronted with a novel virulent patho-

Aaron S. Benjamin, Department of Psychology and the Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana–Champaign.

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Correspondence concerning this article should be addressed to Aaron S. Benjamin, Department of Psychology, University of Illinois, 603 East Daniel Street, Champaign, IL 61820. E-mail: asbenjam@illinois.edu

gen. This agent might cause disease in only one population, perhaps owing to some fortuitous arrangement (from the microorganism's perspective) of chemical or biological factors that make one group a potential host and the other not. Alternatively, both tribes might be infected by the pathogen, but only one group—perhaps the one weakened by other circumstances, such as malnutrition or a particularly sedentary lifestyle—is unable to combat the germ as effectively and thus contracts the disease at a higher rate. This latter profile is analogous to the representational view of dissociations of recognition presented here: Variables act to reduce memory efficacy generally, not specifically, but the interaction of the deficit with differing degrees of representational density across memory traces yields a pattern of selective deficits.

The Tricky Relationship Between Empirical and Theoretical Variables

The central message of this article is one that has been argued in other empirical domains: that the rather widespread practice of inferring the number and stability of latent processes from patterns of empirical interactions is fraught with danger. The underlying problems arise from a number of issues, including the unsophisticated treatment of measurement issues in traditional experimental analyses and the limited application of theories that serve an explicit linking function between hypothesized latent variables and response variables. It is perhaps a fortuitous time to reconsider these issues because major advances have been made on both of these methodological fronts in the past decade (for a review, see McCarley, Mounts, & Benjamin, in press). These tools have made limited inroads in experimental memory, particularly in the domains of perception, attention, and aging.

On the measurement front, *state-trace theory* (e.g., Bamber, 1979; G. R. Loftus, Oberg, & Dillon, 2004) provides a means by which to evaluate the contributions of latent variables to performance under conditions in which only ordinal characteristics of the data are assumed. The theory and the analytic technique that follows from it have been profitably applied to understanding, for example, the effects of task switching and selective attention on aging (Verhaeghen & Cerella, 2002). Related techniques by which the functions relating accuracy to either presentation time or response speed are evaluated have also been applied to interpreting interactions between task complexity and aging in processing verbal materials (Kliegl, Mayr, & Krampe, 1994) and basic arithmetic (Verhaeghen, Kliegl, & Mayr, 1997).

On the modeling front, well-validated theories exist that serve to translate common experimental measures in memory tasks into theoretically interesting latent variables in choice tasks. Most prominently, the *theory of signal detection* reparameterizes response accuracy in detection and discrimination tasks into sensitivity and decision components (e.g., Green & Swets, 1966; Macmillan & Creelman, 2005) and has been widely employed in memory research. Sequential sampling models (Ratcliff & Smith, 2004), which provide an account of response times as well as accuracy, have also been used in memory research (Ratcliff, 1978) and even applied to understanding the effects of aging on recognition (Ratcliff, Thapar, & McKoon, 2004), though the use of such models has been more limited than is desirable. Such models explicitly articulate the processes underlying responses and so provide a strong basis for inferring whether a population exhibits a selective impairment in one of those component processes.

Within the experimental aging literature, the application of such explicit process theories has been quite rare. Theories that have information leakage (Myerson, Hale, Wagstaff, Poon, & Smith, 1990), slower processing (Cerella, 1985; Salthouse, 1996), and deficits in controlled processing (Jacoby, Bishara, Hessels, & Toth, 2005) have all been proposed, but only the latter has been applied directly to experimental data. None have made explicit the specific processing stages involved in a given task, as is standard for detection-theoretic (e.g., Benjamin, Diaz, & Wee, 2009) or sequential sampling models (Ratcliff & Smith, 2004).

The rather limited manner by which measurement issues have been considered in the mainstream literature on aging and memory is revealed by the technique of equating performance between age groups on a control or baseline task and then measuring differences relative to that common baseline. This approach is common in other literatures, including the study of amnesia (e.g., Huppert & Piercy, 1978; Wais, Wixted, Hopkins, & Squire, 2006), and appears to solve some of the thornier problems—by placing the age groups at a common point on the response function, any quirky translational issues between latent and response variables act on both groups more or less equivalently. However, it does so at a very major cost: loss of control over the exposure or study conditions. By exposing older subjects to additional study time, for example, an experimenter concedes the only aspect of a cross-sectional design over which he or she has experimental control: equating exposure duration. It is impossible to know exactly how this extra study time is used in service of equating performance between the groups. It may be the same processing applied for a longer time or different processing. This technique is particularly questionable in the present paradigms because there is evidence that the tradeoff of item and context processing may change with increased study duration (Malmberg & Shiffrin, 2005).

The conclusion that older adults suffer a selective deficit on memory judgment tasks comes primarily from the interpretation of empirical interactions, as is reviewed shortly. In this article, I specifically address whether those interactions necessarily imply process deficits by demonstrating that they can arise in a model system without such deficits. Central to this alternative explanation is a closer consideration of how items and contexts are represented in memory.

Implications and Overview

The contrast between process-based and representation-based views of dissociations in recognition is an important theoretical distinction, but that fact should not lure the reader into assuming that such a debate does not have significant practical implications as well. Consider, for example, how a clinical neuropsychologist might approach the question of rehabilitation in a memory-impaired patient. Process views, which maintain that selective deficits of memory underlie aging and memory pathology, imply cognitive interventions that address the specific disruption in the patient (Jennings & Jacoby, 2003). Representational views promote two general approaches to cognitive rehabilitation. First, because impairment is thought to be nonspecific, interventions that improve memory efficacy generally should lead to the same patterns of selective improvement as memory disruption leads to selective impairment. Second, addressing nonmnemonic cognitive characteristics that lead to differences in representational density across representations—such as selective attention or impaired perceptual acuity—should help ameliorate selective memory deficits but have the potential to introduce undesirable consequences. These ideas are discussed more fully later in this article.

The organization of this article is as follows. First, I briefly examine the broad discrepancies in the conclusions reached about the effects of aging on memory by researchers in the psychometric tradition and researchers in the experimental tradition. The divergence between these fields is revealing of an unwarranted assumption made by experimental psychologists that empirical interactions imply selective influence. Second, I review the experimental data that are the foundation of the claim of the selective deficit in context memory. The third part of this article lays out and defends three interrelated assumptions that are the core of the representational theory of age-related deficits in memory for context. The fourth section implements a process model that instantiates these principles and demonstrates the viability of that model by showing how it can naturally reproduce critical single, double, and even triple dissociations in recognition without making additional assumptions about the selective effects of variables on individual processes. The fifth section of the article provides empirical support for the model by confirming its essential prediction of a nonmonotonic function relating manipulations of learning or forgetting and performance. The final portion of the article revisits claims in the literature about selective impairment in light of the simulations presented earlier.

The general arguments presented here, in and of themselves, do not dispute the view that multiple processes can and maybe even do contribute to the recognition decision. That is an important and current debate but one that is outside the purview of the present work. Rather, I confront the ancillary claim that those processes are selectively impaired by the catalogue of variables delineated above and by aging in particular.

Psychometric and Experimental Approaches to the Study of Aging

Reconsidering the evidence that has been marshaled in support of the selective deficit hypothesis provides an opportunity to broadly reflect on one of the major inconsistencies in our current understanding of aging and memory. On the one hand, psychometric approaches to the evaluation of age-related deficits have consistently and unequivocally revealed evidence for a single, global, mediating effect of aging on memory performance. On the other, experimental approaches have revealed a panoply of dissociations that have been taken to imply selective process deficits of multiple types, including, most prominently for present purposes, context memory. I review these sources of evidence; the theory articulated later in this article provides a reconciliation between these views.

Historically, theories postulating global effects of aging on cognitive performance began to encourage experimental research in the 1950s (e.g., Birren & Botwinick, 1955). Various causal factors were considered, including age-related perceptual decline (e.g., Birren, 1955; Birren, Allen, & Landau, 1954) and general slowing (Welford, 1977; Salthouse, 1980). Many of these theories were tested in their ability to describe the function relating mean response times for older adults to mean response times for younger adults across varying conditions (i.e., a *Brinley plot*; Brinley, 1965). These endeavors have increased in scope and sophistication over the years and now make use of some of the most powerful analytic tools in multivariate research, though they are almost exclusively applied to individual-difference analyses and there are few direct applications to the experimental paradigms that are reviewed here.

The general consensus from this literature is that the age-related effects on memory performance—in fact, many measures of general cognitive performance—are best explained by models that postulate a single, global, mediating influence between age and cognitive performance (e.g., Lindenberger & Baltes, 1994; Salthouse, 1998, 2001). Suggestions as to what that influence is have included working memory capacity (Engle, Kane, & Tuholski, 1999), cognitive control or context maintenance (Braver et al., 2001), and processing speed (Hertzog, Dixon, Hultsch, & MacDonald, 2003; Salthouse, 1996). Even within the limited domain of source memory, and contrary to the conclusion drawn by experimentalists, there is no evidence for a selective effect of age (Siedlecki, Salthouse, & Berish, 2005). The aspect of these conclusions relevant to this current proposal is the preponderance of evidence in support of a global mechanism underlying age-related declines in cognition. This evidence has, however, not been widely considered in the experimental literature, in part because it is not entirely obvious how such a theoretical claim can be applied to understanding the basic currency of experimental tasks—empirical interactions.

The experimental approach to aging and memory relies not on the measurement of individual differences and their relationships but on the careful construction and comparison of tasks hypothesized to differ in the degree to which various cognitive abilities are necessitated for fast or accurate performance. Age-related effects are inferred from interactions between experimental variables and age groups rather than from individual models of task performance or cognitive processes. So, for example, the conclusion that measures of source or context memory are especially disrupted in older adults is drawn from the fact that measures of source memory show a larger age-related disruption than do certain other measures of memory (Spencer & Raz, 1995).

One danger inherent in the experimental approach lies in the failure to consider the larger theoretical context in which a particular task or set of tasks resides. As argued by Salthouse (2001, p. 94), "a narrow focus on a single task may lead to a proliferation of inferred specific deficits that are treated as though they are independent of one another." There have been attempts to unify the array of age-related deficits into a parsimonious structure (e.g., Craik & Byrd, 1981; Hasher, Zacks, & May, 1999; Hay & Jacoby, 1999), but the application of theoretical principles is often arbitrary and thus validation is quite difficult (for a review, see Kester, Benjamin, Castel, & Craik, 2002), leading Cronbach (1957) to comment that the success of the enterprise "depend[s] wholly on the creative flair of the theorist to collate the experiments and to invent constructs" (p. 677).

As a consequence, the experimental literature on age-related deficits in memory provides an excess of reliable dissociations but no accepted comprehensive framework within which to unify them. Older adults, for example, are known not only to be deficient in context memory but also to exhibit disproportionate impairment in associative memory compared to memory for single items (Naveh-Benjamin, 2000), direct compared to indirect uses of memory (Fleischman & Gabrieli, 1998; Light & La Voie, 1993), episodic compared to semantic memory (Park et al., 2002), recall compared to recognition (Craik & McDowd, 1987), self-initiated compared to environmentally driven processing (Craik, 1994), and recollective memory compared to familiarity or habit memory (Hay & Jacoby, 1996; Jacoby, 1999); they also show an enhanced tendency, relative to their younger counterparts, for their memory to be biased by the effects of postevent suggestion (Cohen & Faulkner, 1989; Schacter, Koutstaal, Johnson, Gross, & Angell, 1997), semantic similarity (Benjamin, 2001; Norman & Schacter, 1997; Rankin & Kausler, 1979; A. D. Smith, 1975; Tun, Wingfield, Rosen, & Blanchard, 1998), and phonological similarity (Watson, Balota, & Sergent-Marshall, 2001).

A reasonable charge for researchers is to reconcile these two seemingly antithetical views of how memory changes with age. Is aging better conceptualized as a global deficit, as suggested by psychometricians, or as a host of specific deficits, as claimed by experimental psychologists? Traditionally, researchers have chosen a stance on this issue consistent with their methodological allegiances, but this seems a uniquely poor means to resolution. Because a major strength of the individual-differences approach is the well-validated means of assessing the latent variables needed to understand the relationship between predictors (including age) and performance, it would seem that the results from that literature indicating a single latent variable should be given considerable weight.

This may be a case, however, like others within psychology, where the two sides of the debate are at cross-purposes in part because they have little common ground in their fundamental intent. For example, though Siedlecki et al. (2005) demonstrated that age-related effects on source memory tasks exhibited little discriminant validity from other cognitive tasks (and, indeed, that source memory itself—independent of age variables—did not have discriminant validity), Johnson (2005) argued that such a demonstration was beside the point and that source memory tasks were useful by virtue of the specific aspects of memory that are queried. Both conclusions seem to be correct within their limited domain, but this interchange reveals the somewhat orthogonal nature of the argument and, not surprisingly, fostered no resolution of underlying discrepancies.

In this article, I address a discrepancy in the limited domain of memory judgments. Can the interactions in the experimental data that are thought to reveal selective failures of memory in older adults actually be the consequence of a global deficit? If this is the case, then both perspectives are correct, but in different ways: Psychometric research reveals the action of a global deficit, but experiments reveal the critical dimensions by which that global deficit is translated into an empirical interaction. This is the solution that is pursued here.

Dual Processes in Recognition: Theory and Evidence

The claim that processes can be selectively impaired by age or by any variable takes as a starting point the assumption that there are multiple processes that contribute to the recognition decision. This section briefly reviews the nature of the evidence that underlies that widespread assumption (for a wide-ranging and thorough review, see Yonelinas, 2002).

Results from a wide variety of paradigms investigating recognition memory have suggested the necessity of postulating two distinct contributions of mnemonic evidence to a recognition decision.[1] Mandler (1980) illustrated these multiple sources with the oft-cited example of an imaginary encounter with one's butcher on a local bus. The butcher is familiar by virtue of prior meetings at the deli, perhaps, but although the familiarity is suggestive of past experience with the person, the inability to remember specific past encounters with him (or her) makes the source of that familiarity ambiguous. Should one greet the butcher? Shun him? Kiss him on the cheek? Retrieving related memories about pork loins, white paper wrapping, and his extensive facility with slicing devices allows one to correctly recognize the man in question as the butcher and interact appropriately.

Although butchers have gone somewhat out of vogue, postulation of those processes that underlie his recognition—and presumably that of any previously experienced event or stimulus—has not. Broadly speaking, those two components are *familiarity,* or the subjective strength of mnemonic evidence for a recent or potent exposure to a stimulus, and *retrieval,* or the ability to recover mnemonic details of a particular prior exposure that are relevant to the recognition decision. Familiarity is a time-correlated source of evidence: Recent events and recently seen stimuli are more likely to enjoy high levels of familiarity. Thus, to the degree that experiments require subjects to recognize recently exposed stimuli, familiarity is a reasonable basis for the recognition decision.

It is hardly a basis for perfect performance, however, because familiarity can also be conferred by a recent extraexperimental exposure, by a potent but not necessarily recent event (Benjamin & Craik, 2001), by frequent prior exposures (Jacoby, 1999), by exposures to conceptually (Deese, 1959; Roediger & McDermott, 1995) or phonologically (Watson, Balota, & Roediger, 2003) related stimuli, or even by deliberate imagination (E. F. Loftus, 2004). Because tests of recognition memory almost invariably require subjects to localize stimuli to a specific prior encounter—for example, to a recently studied list—familiarity is in general an unreliable source for the decision. Unstudied but nonetheless familiar stimuli can only be correctly rejected if the subject retrieves sufficient information about specific prior encounters with that stimulus or other related stimuli so as to reject it, its high familiarity notwithstanding. Without such ability to retrieve context, we would be trapped in a world in which our most famous television and movie personae were constantly being selected in eyewitness lineup situations as perpetrators of criminal acts, including ones that they were not actually guilty of.

Recovery of a context that is consistent with the prior study episode can lead subjects to correctly endorse items even when the level of familiarity is ambiguous. Trying to decide whether I have taken my medication today provides a good example. Because I take the same pills every morning, the familiarity of such an event

[1] Many or perhaps even all of these data can also be explained within the framework of models that possess only one explicit memory process, but I do not review those approaches here. This article takes as its target the claim of dissociable processes, not multiple processes in general.

is always high, regardless or whether I have taken them today or not. Remembering a news story I watched on the television while taking my pills helps me make a better decision: If the story I remember occurred today and not yesterday, then I know that I took my pills this morning, even in the absence of a clear familiarity signal.

Empirical Support for Dual Processes

The empirical evidence for the contribution of at least these two general mnemonic sources of evidence to the recognition decision derives from a range of different recognition tasks, subject populations, and experimental manipulations. The body of data includes dissociations between item recognition and source identification (for a review, see Spencer & Raz, 1995), including disordinal dissociations (Benjamin, 2001; Benjamin & Craik, 2001; Jacoby, 1999), dissociations between recognition and recall (e.g., Anderson & Bower, 1974; Mandler, 1980), analyses of the linearity of Gaussian transformed receiver-operating characteristic functions (Yonelinas, 1999; but see Qin, Raye, Johnson, & Mitchell, 2001; Slotnick & Dodson, 2005), analyses and manipulations of response speed (Benjamin & Bjork, 2000; Hintzman & Curran, 1994), investigations of the anatomical, biophysical, and biochemical correlates of the two putative processes (Curran, 2000; Davachi, Mitchell, & Wagner, 2003; Düzel, Yonelinas, Mangun, Henize, & Tulving, 1997; Yonelinas et al., 2002), and dissociations in reports of the phenomenological states underlying recognition (e.g., Gardiner, Gawlik, & Richardson-Klavehn, 1994).

It is not my purpose here to review or comprehensively evaluate this literature nor to weigh these evidential bases against one another (the report by Yonelinas, 2002, provides a review of many of these data). I take as a starting point the two contributions to recognition performance described earlier and concentrate instead on the question of whether a psychological dissociation between the processes is necessary to produce the statistical dissociations that are evident. My working example is the dissociation of retrieval and familiarity in older adults, but the logic applies to a considerably wider range of phenomena. The target data for my analysis are the most compelling examples of dissociations: double and triple population-based and experimental disordinal interactions in recognition and related tasks.[2]

Disordinal Triple Dissociations in Recognition

One major source of evidence for the distinction between these two contributions to the recognition decision is the occurrence of interesting double dissociations in false-alarm rates (FARs), particularly in the exclusion version (Jacoby, 1991, 1999) of the recognition paradigm. In such an experiment, a subject studies two lists of words that are differentiated during presentation in some manner. One list might be read to subjects, and another displayed on a computer screen. Alternatively, the lists might differ only in the time of their presentation, with one presented prior to the other. The exclusion task is to endorse items from one, and only one, of the lists. Thus, the subject is instructed to reject both new items and items previously studied in the contraindicated list. Needless to say, this task is considerably more difficult than the traditional recognition task, and it is easy to see why. Discriminating between items that were seen equally recently renders time-correlated indices such as familiarity almost useless for the decision.

Figure 1a displays a triple interaction from an experiment that used the exclusion paradigm (Benjamin & Craik, 2001). In that experiment, younger and older subjects studied two lists of words. In each list, each word was presented twice, in either a massed or a spaced fashion. Although spacing increased the hit rates from the to-be-endorsed list for both groups of subjects, it decreased the FARs to to-be-excluded items for younger subjects and increased the FAR to to-be-excluded items for older subjects.

Figure 1b shows a similar result (Benjamin, 2001) from a paradigm in which subjects were asked to endorse studied items and reject items that were associatively related to the lists of studied items (Deese, 1959; Roediger & McDermott, 1995). In this experiment, lists of items were studied either once or thrice. Hit rates increased for both younger and older subjects with increasing repetition. However, although FARs were higher to unstudied items associated with lists studied once than thrice for younger subjects, the opposite was true for older subjects: The FAR was higher for items associated with lists studied thrice.

These two data patterns illustrate the manner by which such triple dissociations in recognition occur.[3] These data are not unique; similar effects have been shown in paradigms in which younger and older subjects are asked to discriminate between read and heard items (Jacoby, 1999), between studied nouns and their plurality-reversed complements (Light, Chung, Pendergrass, & Van Ocker, 2006), and between pairs of words studied together and pairs of words studied separately (Light, Patterson, Chung, & Healy, 2004). The critical component of such data is that the interaction they reveal is of a disordinal nature. Such interactions provide strong support for multiple contributions to the relevant behavior because no single underlying monotone function relating performance on the two types of items (to-be-endorsed and to-be-rejected) to one another can yield such data. This fact can be illustrated in a straightforward way be examining state-trace plots (Bamber, 1979), in which performance in one condition is plotted against performance in the other. These are shown in Figures 1c–1d. As discussed by Dunn and Kirsner (1988), plots in which no monotone function can relate performance in one condition to the other reveal the presence of a reversed association and indicate the necessity of either multiple or nonmonotonic underlying processes. It would do serious violence to single-process memory models to postulate a nonmonotonic relationship between memory strength and endorsement probability in recognition; thus, it is assumed that multiple processes are involved. The conclusion that these processes are differentially affected by aging is not compelled by such data, however.

[2] Throughout this article, *disordinal interactions* or *disordinal dissociations* refer to interactions in which no monotone transformation of the ordinate can remove the interaction without compressing all responses to a single point. Such interactions are sometimes called *crossover interactions.*

[3] These dissociations are often considered double dissociations by those who examine performance only on to-be-rejected items. Such an analysis is occasionally incomplete because it cannot exclude single-process models in which performance in the two conditions depends on the same underlying process but relies on two different tasks or measures that are negatively associated (Dunn & Kirsner, 1988).

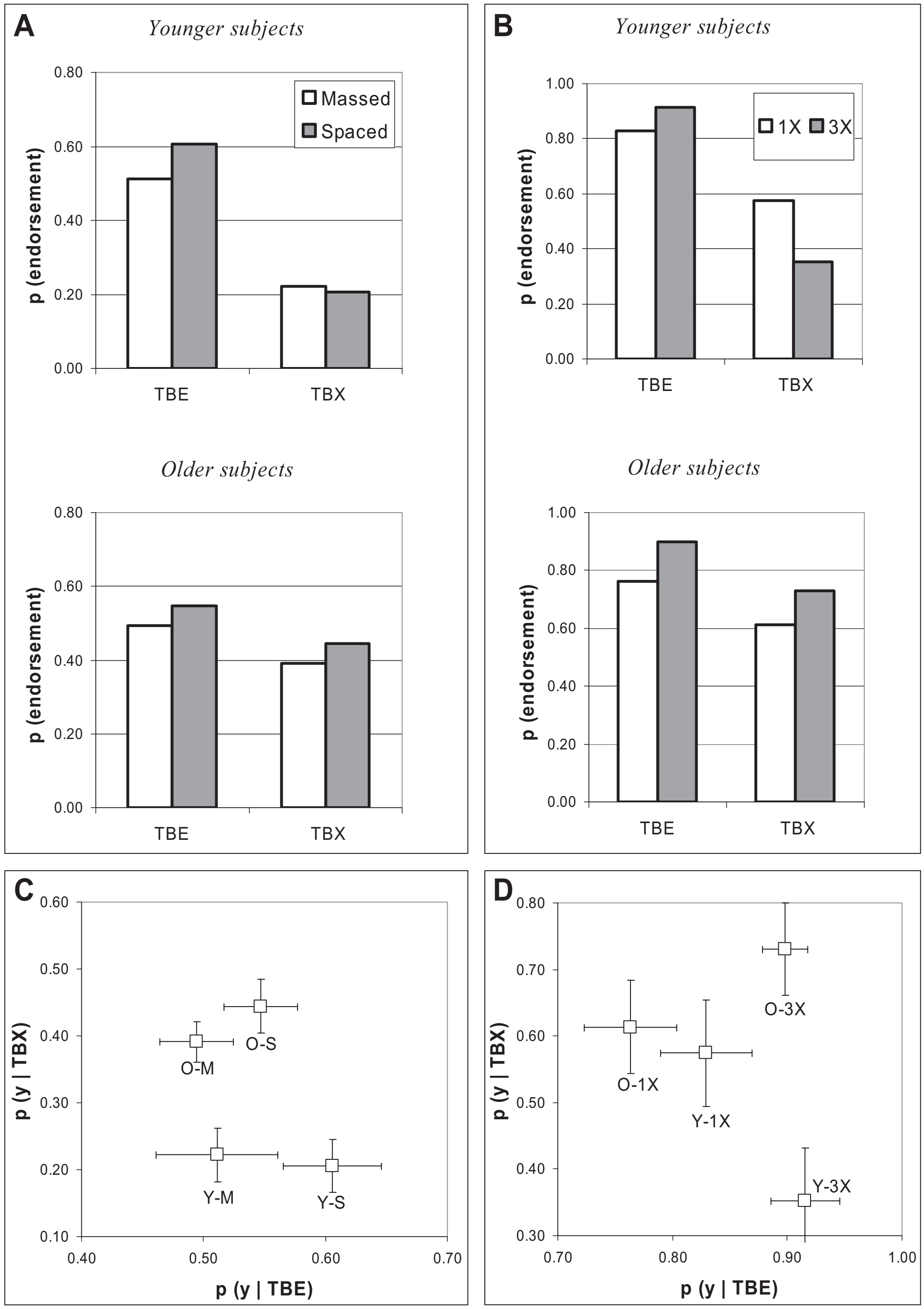

Figure 1. Panels A and B: Data from Benjamin and Craik (2001) and Benjamin (2001) illustrating triple disordinal dissociations in recognition memory. Panels C and D: State-trace plots of the same data. TBE = to-be-endorsed items; TBX = to-be-excluded items; M = massed presentation; S = spaced presentation; Y = young; O = old; 1X = one presentation; 3X = three presentations.

Extant Theoretical Accounts of Age-Related Impairments in Memory Judgments

The data reviewed above have almost exclusively spurred the development of theories that postulate selective impairment in older learners. Three theoretical perspectives are particularly prominent, and I review them briefly here. Johnson and her colleagues (e.g., Hashtroudi, Johnson, & Chrosniak, 1989) suggested that older adults' failure to remember context or source reflects inadequate *source monitoring* processes. Such processes are the ones that someone uses to evaluate the dimensions relevant to discriminating between multiple sources. Their work points specifically to memory for previously performed cognitive operations (Raye, Johnson, & Taylor, 1980) and for perceptual information (Hashtroudi, Johnson, & Chrosniak, 1990), a view that is supported by the finding that perceptually more distinct sources reveal a smaller age-related deficit (Ferguson, Hashtroudi, & Johnson, 1992).

A second perspective on age-related deficits in memory for context is provided by the *associative deficit* hypothesis (Naveh-Benjamin, 2000). By that explanation, older adults exhibit a deficit in memory for any event in which multiple stimuli or aspects of a stimulus must be bound together into a common event. Evidence for this hypothesis comes from results revealing that older adults exhibit little deficit in remembering, for example, words that were studied and fonts that words were previously studied in but show a large deficit in remembering specific word–font pairings (Naveh-Benjamin, 2000). In this perspective, items and contexts are simply one example of the many ways in which the co-occurrence of multiple aspects of stimuli can be tested (Old & Naveh-Benjamin, 2008).

A third view is provided Jacoby and his colleagues, who point to a deficit in the *control processes* by which information is accessed from memory in understanding age-related deficits in memory. Specifically, Jacoby has suggested that familiarity, which operates automatically, remains intact with age whereas the controlled process of recollection suffers an age-related decline. Support for this view comes from a wide variety of paradigms, including from tasks in which enhancing memory for eventually to-be-rejected items leads to opposite effects on false remembering in young and older subjects, as in the pattern shown in Figure 1; from a comparison of exclusion and inclusion memory tasks, in which the demand to produce items from a specific previous context is either required or not (e.g., Jacoby, 1998); from tasks in which subjects are asked to reject items that have been seen but were experienced in a to-be-rejected context (Dywan & Jacoby, 1990; Jennings & Jacoby, 1997); and from tasks in which false recall is revealed to be more affected by pretraining in younger than older adults (Hay & Jacoby, 1999; Jacoby et al., 2005).

Many of the results supporting the automatic–controlled distinction rely on productive memory tasks and are outside the domain of this article. What is critical here is the application of the automatic–controlled distinction to understanding the disproportionate loss in memory for context in older adults in memory judgment tasks. For example, Jacoby et al. (2005) proposed that an inability in the control processes used to develop an effective cue with which to probe memory might underlie the very deficits in source memory that Johnson and others have taken to indicate a failure in the source monitoring process. In this article, I focus on two central findings from these experiments that are relevant to recognition: the disproportionate forgetting of context that leads to false-fame effects (Dywan & Jacoby, 1990) and experiments that reveal ironic (Jacoby, 1999) effects of study manipulations in recognition. It is clear that tasks in which subjects are required to produce responses from memory—ones in which a premium is placed on the very controlled (Jacoby, 1999) and self-initiated (Craik, 1982, 1994) processes that Jacoby's perspective emphasizes—pose a more complicated case than the memory judgment data that are discussed here, a point I discuss at the end of this article when reviewing the limitations of the present model.

Though these perspectives articulate quite different stances on the nature of the age-related deficit in memory for context, they share a reliance on a heuristic common to cross-sectional research: inference of process dissociations from empirical interactions. In the next section of this article, I develop a theory in which there are no selective deficits with age and demonstrate that such a theory is capable of reproducing the very empirical interactions that are the groundwork for much of the prior extant theorizing concerning process dissociations.

A Representational Account of Process Dissociations: Three Hypotheses and Preliminary Evidence

The strong evidence from the psychometric literature that age-related memory effects have a common cause suggests that a fruitful approach to understanding the many empirical dissociations described previously would be to develop and test process models that are widely applicable to a number of experimental tasks and that posit a single, global deficit associated with aging. This approach is not unique; it has been suggested that the magnitude of age-related deficits is a function of task complexity or difficulty (Cerella, 1985; Cerella, Poon, & Williams, 1980; Welford, 1958), information loss (Myerson et al., 1990), the degree to which a task requires self-initiated processing (Craik, 1982, 1994), the extent to which a task requires inhibitory processing (Hasher et al., 1999), or the degree to which novel association or binding is necessary (Naveh-Benjamin, 2000); reflects a usurpation of habit over deliberate recollection (Hay & Jacoby, 1999; Jacoby, 1999); reveals poor encoding strategies (Craik, 1977); or indicates a failure of metamemory (Light, 1991). Of these hypotheses, only one has been implemented computationally (the information-loss hypothesis of Myerson et al., 1990); thus, debates about the inadequacy or adequacy of one or the other rely principally on a shared understanding of principles and a shared language. Although there is an extensive literature that uses mathematical modeling as a tool to understand human memory, this body of work has developed in part independently of empirical advancements, and the lack of prominent roles for such models in empirical development has been noted (Ratcliff & McKoon, 2000).

I start from a similar point as these other theories, with the global deficit hypothesis.

> 1. *Global deficit hypothesis:* The effects of aging on memory can be explained by a global deficit in memory fidelity.

This hypothesis comprises several of the major mechanistic assumptions about the model that are presented below, so there can be no misunderstandings about what is meant by the claim. This model is intended to contrast with claims of selective deficits with aging, so the charge for the model is to reproduce the very data that have motivated the claim of a selective deficit. The keystone data are the high-order interactions shown in Figure 1, but I consider other prominent patterns of results along the way.

There are two other assumptions that the model embodies that are central to the theory underlying its application to memory for context and that are crucial to its functioning. I introduce these assumptions here and then review evidence that they are warranted. First is the representational nonspecificity hypothesis.

> 2. *Representational nonspecificity hypothesis:* There are not separate cognitive systems or processes that govern the encoding and retention of items and contexts in memory.

That is, the mechanisms that govern the encoding and representation of events draw no distinctions between the materials that we, as experimenters, consider aspects of the item and those that we consider aspects of the context. This model eschews those terms, except as constructs of experimental design. Consequently, there are not separable representations of items and contexts, nor are there separate mechanisms for encoding, representing, or storing them. Note that this assumption contrasts sharply with models of memory that assume that a representation of an event involves binding a stimulus to its context (e.g., Murdock, 1993). Because such views require items and contexts to be separate psychological constructs, they are incompatible with the representational nonspecificity hypothesis.

The final claim, the representational sparsity hypothesis, is the feature most directly responsible for the model's ability to account for empirical interactions.

> 3. *Representational sparsity hypothesis:* Stimuli, situations, or events that are less central to the rememberer's tasks, goals, and perceptual and attentional biases are represented more sparsely in memory.

It is this aspect of the theory that allows the model to account for empirical interactions, so it is worth examining the implications of the representational sparsity hypothesis and how it interacts with the model's other hypotheses. The accessibility of memory content that is less redundantly represented is affected most severely by the addition of memory noise, either at learning or retrieval. Thus, the selective effects of age on memory for context reflect the interaction of a global memory deficit in older adults with the fact that task demands and consequent attentional biases lead context to be represented more sparsely than content in both younger and older subjects.

Now that these assumptions have been made explicit, they must be defended. I have claimed that there is nothing special about the presentations of items and contexts except insofar as they elicit differential perceptual and attentional biases that lead memory representations for items to be denser in information than representations for contexts. In addition, I have claimed that there is a global deficit associated with age that leads to a disproportionate memory deficit for poorly learned stimulus aspects, such as context. The next sections review data that are consistent with these claims and inconsistent with the popular alterative views that (a) there are separable systems or processes that represent these two types of information and (b) there is a selective deficit in one of those systems in older adults.

The Age-Related Deficit in Context Memory Has Nothing to Do With Age

The claim of the global deficit hypothesis is that older adults reveal a deficit in memory for context because of a global and not a specific deficit. If this is true, then any manipulations that decrease memory fidelity should elicit a greater deficit in memory for context than memory for items. The first hint that this might be true comes from the disordinal dissociations reported previously. In each of those studies (Benjamin, 2001; Benjamin & Craik, 2001; Light et al., 2004, 2006), forcing younger subjects to respond under a speeded deadline yielded a pattern of results qualitatively identical to that obtained with older subjects. Nonetheless, it is possible that response speeding forces a reliance on the same cognitive mechanisms that are spared with aging (such as familiarity or habit; Jacoby, 1999).

Our strategy in attacking this question has been to seek out a variable that no theorist would claim has selective effects on item and context memory systems and then to show that that variable elicits the same selective deficit as does age. An important analytic issue that follows from this approach is that, to evaluate whether manipulations of memory invoke greater or lesser effects on memory for context than memory for items, it is necessary to use a compatible metric for both variables. In many experiments, this is not even superficially true: Item recognition is assessed via yes–no recognition, and source recognition is assessed via forced-choice recognition. In addition, there is a thorny problem about whether to conditionalize memory for context on memory for the queried item (Murnane & Bayen, 1996, 1998). Thus, the typical context memory task is ill suited to the purposes of evaluating this hypothesis.

Benjamin, Diaz, Matzen, and Johnson (2010) used a study time manipulation to address this question, assuming that there is no more basic manipulation of memory in the experimentalist's toolbox. If one wished to claim that study time has differential effects on item and context memory systems, then it would seem that no encoding manipulation can be free from such an interpretation. Thus, if behavioral interactions can be elicited as a function of study time, that result would support the representational perspective, in which interactions arise because of the nature of the memory representation rather than the nature of the memory.

Benjamin et al. (2010) collected compatible measures for item and context recognition by soliciting yes–no judgments for both the item task (i.e., "Did you study 'farm'?") and an exclusion variant of the context memory query (i.e., "Was it studied on the right?"). Confidence ratings were used to derive isosensitivity functions for the two tasks, and the detection theory parameter d_a was estimated for different levels of study time (for a more detailed explanation of the metric advantages of such an approach, see Benjamin & Diaz, 2008; Matzen & Benjamin, 2009).

The prediction of the global deficit hypothesis was borne out: Decreasing study time decreased memory for context (where the item was studied) at a faster rate than it decreased memory for the items (whether an item was studied). There is no compelling theoretical reason why we should suppose that a reduction in study time selectively affects memory for context more than memory for items, so why should such an explanation be necessary for the same result when it is elicited as a function of age?

The Age-Related Deficit in Context Memory Has Nothing to Do With Context

The assertion of the representational nonspecificity hypothesis is that contexts and items are not independently represented. Rather, the age-related deficit for contextual information is considered to be a specific instance of a general reduction in memory for information that is sparsely represented. If this is true, then older subjects should show a deficit in memory for any information that is sparsely represented, regardless of the role of that information in the actual environment in which it is studied.

Benjamin et al. (2010) tested this assumption in an experiment in which subjects were instructed to attend to different aspects of sentences. When subjects were instructed to prioritize memory for the subject of a sentence, older subjects showed a deficit, relative to younger subjects, in memory for the object of the sentence. However, when subjects were instructed that they should prioritize memory for the object of the sentence, the opposite result obtained: Older subjects showed a greater deficit, relative to younger subjects, in recognizing the subject of that sentence.

This result shows that older adults have greater difficulty recognizing material that is less well attended during study than material that enjoys greater levels of attention. This is a direct implication of the representational sparsity hypothesis—that sparsely encoded information reveals a greater age-related memory deficit than densely encoded information. The interpretation is that items and contexts have nothing to do with the age-related deficit in question and that the interaction of attentional biases with a global deficit yields that pattern of selective impairment.

The Age-Related Deficit in Context Memory Is Not (Necessarily) a Deficit

The two previous sections suggest that the age-related deficit in context memory is a global deficit selectively magnified by the sparse encoding of contextual information. If this is true, then changing the task or the stimuli so as to induce denser representations of context should eliminate the deficit seen in older adults. We already saw this in one form: Manipulating what subjects are instructed to attend to changed which aspects of the stimulus yielded an age-related deficit (Benjamin et al., 2010). Yet perhaps there need be no deficit at all?

A clever experiment by Rahhal, May, and Hasher (2002) revealed this to be the case. They showed that, although older adults were impaired in remembering whether a male or a female voice source spoke a particular queried statement, they were not impaired in evaluating whether the statement was spoken by someone who was good or someone who was evil—even though gender and character were perfectly confounded in their experiment! This result indicates that source or contextual information that is important to older adults and thus likely to elicit a denser representation does not reveal the canonical age-related deficit.

This hypothesis was further tested by examining source memory for emotional information, which older adults are known to spontaneously focus more on (Carstensen & Fredrickson, 1998). May, Rahhal, Berry, and Leighton (2005) showed that older adults were more likely to remember emotionally laden aspects of context (whether food was fresh or spoiled, whether automobiles were safe or dangerous) than they were to remember perceptual details (the location of food items or the color of automobiles) or even conceptual but nonemotional details (serving temperature of foods or the quality of automobiles). Taken as a whole, these findings help complete an alternative picture of why older adults typically reveal a deficit in memory for context. It need not be the case that there is a specialized breakdown in the memory systems or processes than govern memory for context. Rather, older adults have a general memory deficit that leads to a prominent behavioral deficit for material that is sparsely represented. Because contextual or source information in the typical experiment is uninteresting, perceptually confusing, and susceptible to considerable interference, and because attention is typically directed toward other aspects of the material, contextual information is sparsely represented and is disproportionately more poorly remembered by older adults.

Representational Density as a Consequence of Perceptual and Attentional Factors

The central claim of the representational sparsity hypothesis is that relative density or sparsity of information is determined by ecological, motivational, and attentional factors, rather than by the nature of the information itself. In addition, the typical experimental protocol for investigating context or source memory leads contexts to be represented more sparsely than items. Consider the factors that might influence representational density for items and contents.

Perceptual factors. The typical experiment used to jointly estimate item recognition and context memory takes no care to control for the relative perceptual discriminability of the contexts from one another. It is presumed that, if the discriminability of the sources is well above some reasonable subjective threshold, then there should be no downstream consequences of any perceptual deficits associated with age. However, Murphy, Craik, Li, and Schneider (2000) showed that qualitative age-related effects in a memory task for auditory stimuli were eliminated when the stimuli were psychophysically equated, even though the condition in which differences were obtained used stimuli that were well above normal thresholds for older subjects. Within the literature on memory for context, Ferguson et al. (1992) obtained the typical age-related contextual memory deficit when the two sources were same-gender voices but showed no age-related deficit when the sources were two different-gender voices. This result suggests that memory for context may be compromised by difficulties in perceptually resolving sources from one another, either at time of encoding or retrieval (see also Degl'Innocenti & Bäckman, 1996). Bayen and Murnane (1996) also showed that older adults benefited more than younger adults from additional perceptual and temporal distinctiveness of contexts.

Stimulus factors. The stimuli used in typical studies of context memory have a peculiar arrangement: The items are almost invariably more interesting, more meaningful, and more multidimensional than the contexts that accompany them. Often, the items are words, and the contexts are colors, locations on the screen, voices, or simply list membership. It is thus not surprising that subjects typically exhibit superior memory overall for items than contexts. This can be seen in the previously discussed results from Benjamin et al. (2010): Even though memory for context increased more rapidly with additional study time than did memory for the items, overall memory for the items was far superior. This reflects the fact that the more interesting aspects of the material (items) elicit more attention than the less interesting aspects of the material (contexts).

Another confound results from the repetition of contexts but not items across an experiment. Evaluating whether a particular word has been presented in red is considerably more difficult when many words have been presented in that color, due to cue overload (Watkins & Watkins, 1975). Although some studies have recognized the problem of the many-to-one context-to-item mappings and confronted them by using more multidimensional contextual aspects (Schacter, Osowiecki, Kaszniak, Kihlstrom, & Valdiserri, 1994) or by assigning item and context status with an instructional manipulation (Benjamin et al., 2010), there have been as yet no direct assessments of the degree to which such a confound affects the magnitude of the age-related deficit in context memory. In addition, the amount of proactive interference that such cue overload engenders may also be a problem, in that older adults may be more vulnerable to such interference (Hasher, Chung, May, & Foong, 2002).

Experimental and demand characteristics. The game within the game for subjects in memory experiments is to figure out what will be demanded of them in upcoming tests. Sometimes, experiments explicitly direct subjects' attention to items over contexts; in other cases, no such directions are provided, but the stimulus factors alluded to in the previous section may be taken to indicate relatively greater importance of the item aspects of the stimuli.

The denouement of the arguments presented in this section is that (a) a memory system with sparse representations of context and a global memory deficit may exhibit a disproportionate deficit in memory for those contextual aspects and (b) there are many aspects of the stimuli and experiments used to evaluate context memory that might promote such sparse representations of context. Later in this article, I also consider ecological reasons that such an encoding bias might exist. The next section takes the first claim and evaluates it within the context of a specific process model of the recognition decision.

The Representational Model of Memory Judgments: Implementation and Simulations

The model that is implemented in this section is a hybrid of models that are already prominent in the literature. It is not lack of imagination that motivates this approach: My goal is to demonstrate the general principles of the simulations in as straightforward a manner as possible. So, although the model I present here is a dual-process model (cf. Jacoby, 1999; Yonelinas, 2002), it can also be implemented in a form with a single process. It is a dual-process model because two separate signals—familiarity and retrieved evidence—support responding. The underlying process assumptions are taken from MINERVA2 (Hintzman, 1988) but work equally well with other instance models, such as REM (Shiffrin & Steyvers, 1997). The particular choices have been made for the purposes of clarity; the critical behavior of the model does not depend on any peculiar assumptions hidden with the model's mechanisms. For shorthand, I refer to the model that implements the representation theory as DRYAD, for *density of representations yields age-related dissociations*.[4]

Memory Representations

The model's memory consists of high-dimensional vectors, in which individual dimensions correspond to aspects of the stimuli that can be learned. Values on each dimension come from the set $\{1, 0, -1\}$, which may be thought of as roughly corresponding to the presence, lack of knowledge, or absence of a feature (although nothing about the model itself compels this interpretation). When simulating a context memory paradigm, some dimensions correspond to aspects of the item, and some to aspects of the context. The number of item-related dimensions is indicated by I_n, and the number of context-related dimensions by C_n. The model's representations are noisy copies of the original events, as described in the learning process, below.

Learning and Memory Fidelity

The relationship between actual events and representations of those events is governed by a single memory fidelity factor, F. F is the probability that a given value in the event vector is translated faithfully into the memory-representation vector. If it is not, it is replaced with a 0. The F parameter is the means by which the global age-related memory deficit, as well as manipulations of memory strength or effects of forgetting, is simulated.

Note that such a simple learning mechanism, when combined with assumptions about variable representational density, is still entirely compatible with manipulations of processing that appeal to qualitative changes in encoding, such as levels of processing (Craik & Lockhart, 1972). The specific dimensions attended to (and correctly encoded with probability F) are those determined by a subject's orienting toward the task, as I indicate in simulations in which attention to context is varied (Simulation 2).

Global Matching

The original MINERVA2 model makes recognition judgments by comparing a test probe to all items stored in memory (hence the term *global matching model*; Humphreys, Bain, Pike, & Tehan, 1989). This global matching mechanism provides a means for reproducing the well-known effects of prototypicality on recognition (Arndt & Hirshman, 1998; Hintzman, 1988) and is a summation across all items of a nonlinearly transformed similarity metric relating the probe to each item in memory:

$$M_G = \sum_{i}^{memory} \left(\frac{\sum_{j}^{features} m_{ij} p_j}{Nr} \right)^3 . \qquad (1)$$

Here, m_{ij} is the value in the jth feature position of the ith memory trace, p_j is the feature value of the jth position in the memory probe, and Nr is the number of positions (out of j) for which both the probe and memory trace have nonzero values. M_G indicates that this value is a measure of global matching.

The value M_G yielded by the matching process is translated into an n-ary response by means of a set of $n - 1$ criteria. The model

[4] Code in MATLAB for running the exclusion task in DRYAD is freely available at http://www.psych.illinois.edu/~asbenjam/DRYAD.

contains no built-in process mechanism by which criteria are set (see Benjamin, 2003; Benjamin & Bawa, 2004; Benjamin et al., 2009, for suggestions as to factors that influence criterion placement and variability), but there is nothing about the placement of criteria that is critical to the simulations presented here.

Retrieval

The second process by which MINERVA2 accesses memory traces is through a pattern-completion mechanism that is intended to simulate retrieval:

$$e_j = \sum_{i}^{memory} m_{ij} \left(\frac{\sum_{k}^{features} m_{kj} p_k}{Nr} \right)^3, \quad (2)$$

in which e_j is the jth feature value in the retrieved memory trace (where e signifies evidence). Whereas the global matching process provides a single value as its output, the retrieval process yields a vector of information, **e**. Translating these values into a decision is accomplished by the decision rules described below.

Decision Rules

The model is tested in two ways, each of which has a unique decision rule. These two tests correspond to the two traditional variants of the experimental tasks used to assess memory for context in humans. The first is the recognition and context production task, in which previously studied and previously unstudied items are submitted to the model and it is required to make a yes or no recognition decision followed by a guess as to the previous study context of the queried item (usually only solicited when the recognition decision is positive).

The second and more critical task is the exclusion variant, in which subjects are asked to endorse items previously studied in one (or more) context(s) and reject items from any other previously studied contexts as well as items that were never studied. This task yields a simple yes–no response: Item memory and context memory are separately assessed by evaluating the degree to which subject judgments are accurate for different subsets of items. Discrimination of old from unstudied items reflects item memory, and discrimination of old from previously studied but contraindicated items reflects memory for context.

Recognition response. In this task, the outcome of the global match is compared to a preset criterion, and the outcome of this comparison determines the recognition response:

$$\text{Say "yes" iff } (M_G - c) > 0, \quad (3)$$

in which c represents the decision criterion.

Context production. The context production is achieved by simply reporting which of the previous contexts is more similar to the vector yielded by the retrieval process:

$$\text{Say "Context } X\text{" iff } (e \bullet X) = \max(e \bullet Y), \quad (4)$$

where Y is the set of all previously studied contexts and X is an individual context.

Exclusion. For exclusion, the model responds positively if and only if the global match exceeds the decision criterion and the retrieved context vector is more similar to the to-be-endorsed vector than any other vector:

$$\text{Say "yes" iff } (M_G - c) > 0 \text{ and } (e \bullet X_{TBE}) > (e \bullet X_{TBX}), \quad (5)$$

where X_{TBE} is the specific context to be endorsed and X_{TBX} is the context to be excluded.

Model Simulations

In this section, I use the simple model outlined in the preceding subsections to simulate the dissociations that have been taken to imply process dissociations between younger and older people. I start with the traditional source memory task and work my way toward increasingly complex phenomena, with the final target being the triple disordinal dissociation of exclusion reviewed earlier.

The goal of this modeling enterprise is to demonstrate that the three assumptions outlined previously can yield the very qualitative patterns that have been taken as evidence for process dissociations. In that sense, I am attempting to use the model to make a principled case about the insufficiency of the data for the claim of dissociable processes, rather than as a serious representation of human behavior. So, contrary to the progression of the modal paper describing a cognitive model, it is not my goal to fit actual data, and no such exercises are reported here.

Each model simulation consists of 1,000 simulated subjects per condition, exposed to 40 studied items studied in one of two possible contexts. The dimensionality of the item representation (I_n) and the dimensionality of the context representation (C_n) are varied across simulations. The correlation of the portions of the memory vectors representing contextual information is constrained to $-0.5 < r < 0.5$. Consistent with Assumption 1, the effects of age are simulated by a decrease in the global memory fidelity parameter, F. Consistent with Assumption 2, the effects of that parameter are homogeneous across the memory trace (i.e., they affect item and context dimensions equally). Finally, as per Assumption 3, motivational, perceptual, and attentional variables affecting context representation are implemented as affecting C_n, the dimensionality of the context representation.

Simulation 1: Age-related impairment of source recall. I start with the basic finding that older subjects show a disproportionate deficit in memory for context than memory for items. This is actually a somewhat more complicated issue than it appears, as noted earlier: Many studies measuring item and context memory do so by using wholly different tasks (often, yes–no recognition for item memory and forced-choice recognition for context memory). Notwithstanding a common range, these tasks yield data that exist on wholly different measurement scales, and comparisons are fraught with metric difficulties. There exist decision models that provide a means of extracting compatible parameters (Green & Moses, 1986), but even those models are subject to failure if certain preconditions are not met (D. G. Smith & Duncan, 2004). The best solution is to choose measurements that are directly comparable across the two tasks, as was done by Benjamin et al. (2010). However, the empirical result of older subjects exhibiting a larger decrease in memory for context than memory for items obtains in most conditions, and I simulate that result here.

Consider first the comparison of percent correct for the two tasks. For the yes–no item memory task with an equal number of targets and distractors, this is computed as the average of the hit rate and correct rejection rate. For the context memory task, it is the proportion of correctly chosen contexts conditionalized on a correct recognition response for that item. To indicate a correction for pure guessing, 0.5 is often subtracted from this value (but it is not here).

Figure 2 shows the results from this simulation. The left two sets of bars indicate percent correct on the item memory test and on the context memory test, respectively. Here, the relevant interaction is evident: Decreasing the fidelity parameter affects memory for context more dramatically than memory for items.[5] In other words, a global deficit, combined with representational sparsity for context, leads to a more substantive decrease in the ability to recover source than to correctly identify the item. This replicates the single dissociative interactions that are the most abundant but provide the least convincing evidence for an age-related deficit in memory for context. Below, I turn to more complicated data patterns, but I first consider whether this most rudimentary model can account for other basic results in the literature.

Simulation 2: Manipulations of attention and the age-related deficit. Remember from the earlier discussion that the global deficit model presumes that sparse context representations are a consequence of the experimental, motivational, perceptual, and attentional factors that conspire to lead to less encoding of contextual than item information. I claimed earlier that this explanation can make sense out of the array of results that indicate that the age-related deficit in context memory can be attenuated by manipulations that enhance perceptual source discrimination (Ferguson et al., 1992), that draw attention to contextual factors (Rahhal et al., 2002; Schacter et al., 1994), or that experimentally manipulate which aspects of a stimulus are contextual and which are focal (Benjamin et al., 2009).

The right two sets of bars in Figure 2 demonstrate the viability of this claim in the global deficit model. Additional attention is assumed by the model to result in a denser encoding of contextual attributes, which translates into greater context dimensionality in the model's representation. When that dimensionality is increased (by increasing C_n while keeping I_n constant), as in the right sets of bars, it can be seen that the age-related deficit is attenuated. Again, this occurs at very different overall levels of performance.

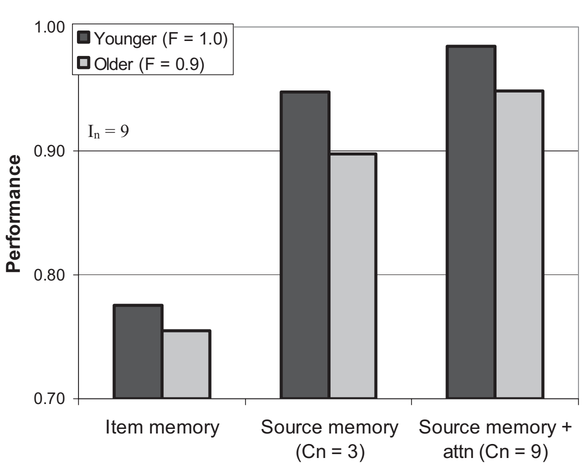

Figure 2. Simulation by DRYAD of context memory deficit in older adults, at two different levels of overall memory. Right pairs of bars reveal a lessening of the deficit when more attention is paid to the context. attn = attention.

Simulation 3: Differential forgetting of item and context information. A number of interesting and well-studied phenomena arise because of apparently rapid forgetting of the context in which information was studied or of the sources that presented a piece of information. For example, *cryptomnesia,* or unconscious plagiarism, is presumed to arise when test takers generate a particular wording and fail to recover from memory the information that that wording was originally provided by an external source (Brown & Murphy, 1989; Marsh & Bower, 1993). People are also more likely to adopt or accept an argument from an unreliable source after a considerable delay, a phenomenon termed the *sleeper effect* (Greenwald, Pratkanis, Leippe, & Baumgardner, 1986). A similar illusion of truth occurs with statements presented by discredited sources under conditions thought to discourage retention of source information (Begg, Anas, & Farinacci, 1992). The *false-fame effect* (Jacoby, Kelley, Brown, & Jasechko, 1989) describes the phenomenon that people are more likely to endorse a previously seen nonfamous name as famous if a fair amount of time has passed since the original exposure. These phenomena are sometimes measured to be more dramatic in older adults (e.g., Dywan & Jacoby, 1990; Law, Hawkins, & Craik, 1998; cf. Parks & Toth, 2006), but interestingly, controlling for the overall degree of encoding appears to ameliorate the effect (Law et al., 1998).

Each of these effects has been presumed to occur because of disproportionately rapid forgetting of source information, and such effects may even underlie the suggestibility of eyewitnesses to postevent questioning and statements (Zaragoza & Lane, 1994). The dominant explanation of this apparent dissociation between memory for a message and memory for the source of that message is a deficit in the processes underlying retention and recovery of memory for source (often called recollection). However, as shown in Figure 3, DRYAD reproduces the effect that the source of information is forgotten more rapidly than the information itself when the message is more densely represented (I_n = 15) than the context (C_n = 6). DRYAD thus explains the disproportionate forgetting of source as a natural consequence of the lesser representational density of source from the moment of encoding, rather than as the specialized workings of a memory system or set of processes that exhibit a qualitatively different forgetting rate.

Simulation 4: Effects of context similarity. In dimensional models like DRYAD, similar contexts are closer to one another and consequently more interfering with one another. Thus, DRYAD should be able to reproduce the finding that sources that are distinctive from one another lead to superior source memory. This simulation is shown in Figure 4, in which the correlation between the two contexts was varied. For dissimilar contexts, the context vectors were orthogonal; for the similar condition, they were merely constrained to have a correlation of less than 0.9. The

[5] Throughout this article, no inferential tests are provided for model fits. Because such a high number of simulated subjects are included per condition and standard errors for differences are consequently very low, effects seen in the data are effects that are "significant."

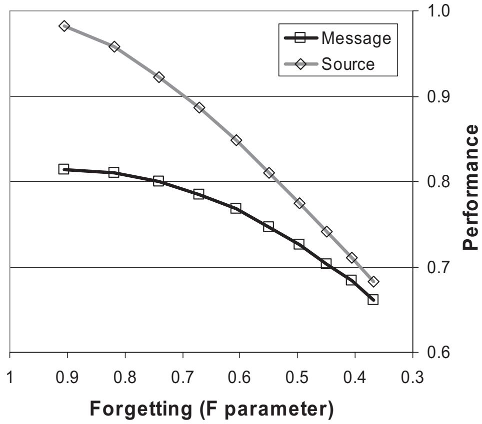

Figure 3. Simulation by DRYAD of differential rates of forgetting message and source information.

two graphs show that, at two different levels of performance, the model exhibits poorer context retrieval when the contexts are similar than when they are not.

Simulation 5: Exclusion. In the memory exclusion task, subjects are instructed to endorse a subset of the previously studied items and reject another subset, as well as unstudied items. The ability of DRYAD to handle the most compelling evidence for process dissociations depends on its ability to perform exclusion adequately—that is, to exhibit the traditional gradient of positive responding on such tasks with highest rates of endorsement to to-be-endorsed old items, next highest to to-be-excluded old items, and lowest to truly new items.

Simulations of exclusion performance are the most important benchmarks of the model's performance, in part because the empirical evidence using this task is so convincing and in part because age-related effects on exclusion do not rely on evaluating differences across incompatible measures. This problem in the empirical literature is no less of a problem in the previous four simulations, in which it is impossible to disentangle the effects of the model's representations on the two tasks from the measurement difficulties inherent in comparing performance on yes–no item recognition and forced-choice context selection.

DRYAD's performance on exclusion in shown in Figure 5, in which it can be seen that FARs to to-be-excluded items are appropriately higher than the FAR to new items and lower than the hit rate. In the model, the familiarity rendered by prior study enhances the allure of to-be-excluded items, but the successful retrieval of the contraindicated context promotes rejection of those familiar lures. This explanation is consistent with the traditional dual-process account of exclusion performance (e.g., Jacoby, 1999).

Simulation 6: Memory strength and exclusion. According to the received dual-process view, retrieval serves a veto function for to-be-excluded items: Familiarity may render such an item compelling, but the retrieval of the appropriate context negates the effects of that familiarity. Consequently, manipulations that enhance the likelihood of retrieval act to decrease the FAR to to-be-excluded items.

Two variables in the model are relevant to this claim. According to the global deficit model, the process of retrieval cannot be selectively affected by a manipulation, but the density of memory representations can be. When more information about a context is encoded, DRYAD treats that act as adding dimensionality to the context portion of a memory trace. As can be seen in Figure 6, the consequence of adding dimensionality is straightforward: it decreases the rate with which to-be-excluded items are incorrectly endorsed and leaves the FAR to new items unchanged. This finding generalizes to the exclusion task the mitigating effect of contextual encoding density on the age-related deficit presented in Simulation 2.

Critically, exclusion differs from source recall tasks in that both sources of information are combined into a single response. It is for this reason that the effects of the *F* parameter are nonmonotonic (also shown in Figure 6). At low levels of memory fidelity,

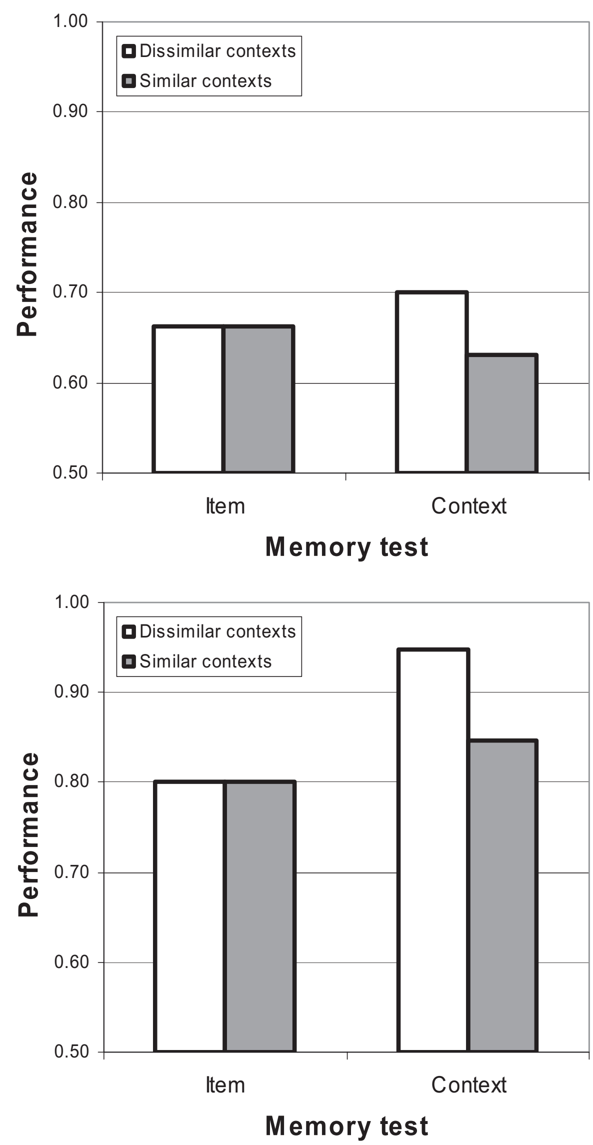

Figure 4. Simulation by DRYAD of the effects of context similarity on memory for items and memory for contexts, at two different levels of overall memory.

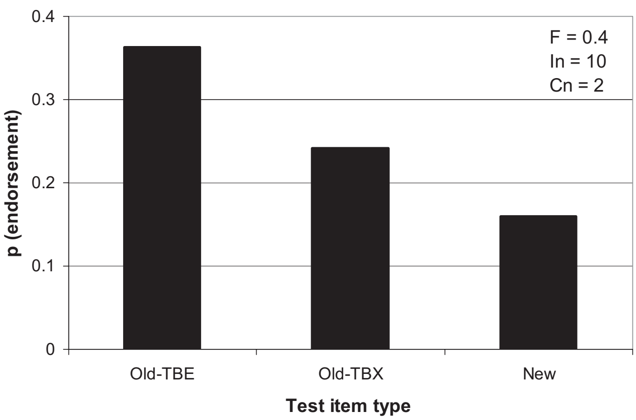

Figure 5. Simulation by DRYAD of exclusion performance. TBE = to-be-endorsed items; TBX = to-be-excluded items.

representations of previously studied items are not sufficient to surpass the familiarity threshold, and the endorsement rates are similar for all item types. As fidelity increases (on the abscissa in Figure 6), endorsements of previously studied items—regardless of context—increase to a level above that for unstudied items. At higher levels of fidelity, hit rates to to-be-endorsed items (not shown in the figure) continue to increase, but FARs to to-be-excluded items display a nonmonotonicity as the representation becomes sufficient to allow recovery of the original studied context. Eventually, FARs to those items drop below the level evident for new items.

Note that the peak of the curve shifts further to the left as the density of the context representation increases (Matzen, Taylor, & Benjamin, 2010). This finding indicates that, with greater representational density, a lower probability of recovering an individual feature is sufficient to support disambiguation of the context.

Simulation 7: Triple disordinal dissociations in exclusion. The nonmonotonicity evident in Figure 6 is crucial to understanding the application of DRYAD to the triple disordinal dissociation data discussed previously. In those results, a manipulation of learning leads to an increased hit rate for both young and older subjects and an increase in FAR to to-be-excluded items for old subjects and decrease for young subjects. In the terms of the model, such an effect can occur whenever the baseline level of learning (as captured by *F*) places the younger population in a range of the function in which the effect of additional learning on the FAR to to-be-excluded items is negative and the baseline level of learning places older adults in a portion in which the marginal effect is positive. An example is shown in Figure 7, depicted in the same manner as the empirical data shown in Figure 1.[6]

In this simulation, older subjects differ from the young only in the degree to which they accurately encode the aspects of the entire stimulus—both item and context. In both groups, the effect of the learning manipulation is equivalent (an increase in *F* of 0.1), and the representational density is equivalent. Thus, this three-way interaction between the learning manipulation, the item type, and the age group arises as a consequence of a single global deficit in memory fidelity in older adults.

Despite the fact that there are no differences in the processes engaged across *F* (the parameter that reflects global memory fidelity), analytic tools used to dissociate between retrieval and familiarity, such as the process-dissociation procedure (PDP; Jacoby, 1991), incorrectly reveal such selective influence. This can be seen in Figure 8, in which the equations of PDP are applied to the data from the low-C_n condition shown in Figure 6.

Several important aspects of these results are apparent. Most critically, PDP does not accurately reveal that the two processes included in DRYAD are not differentially influenced by *F*; in contrast, the functions relating *F* to the two PDP parameters are quite distinct in both form and location. Second, whereas increases in *F* lead to consistent increases in the recollection parameter of PDP, the effects on the familiarity parameter are nonmonotonic—the value increases and then decreases. So, aspects of the PDP analytic procedure can lead to spurious detection of increases in recollection against a background of either increasing, constant, or decreasing familiarity. A vast majority of the applications of that procedure have detected more robust effects of manipulations of memory on recollection than on familiarity; these results suggest that those findings might reflect aspects of the measurement tool rather than realities of the underlying processes (see also Ratcliff, Van Zandt, & McKoon, 1995).

Applications of DRYAD to Other Important Phenomena

DRYAD is intended to be a model system within which to evaluate the global deficit hypothesis. However, it is fair to ask whether its starting assumptions are roughly compatible with other important phenomena in the literature on aging and memory. Although DRYAD is not intended to serve as a to-scale model of memory, I review here how its architecture and representational assumptions are entirely compatible with two central phenomena with respect to aging and memory: preservation of semantic knowledge and preservation of implicit memory.

Preservation of semantic knowledge. The representational system of DRYAD is devoid of semantics, and consequently, it is a somewhat tricky issue to evaluate the preservation of semantic knowledge. To do so here, I assume that semantics reflect the successful generalization across exemplars of a given concept. This simplification treats knowledge and prototype extraction equivalently and allows a means of evaluating how decreased memory fidelity differentially affects prototype extraction and memory for individual exemplars.

To do so, I point to a simulation by Hintzman (1986), in which he examined the effect of forgetting on these two measures across different levels of individual learning. This simulation has all of the characteristics that are critical to understanding how semantic and episodic knowledge are differentially affected by memory fidelity. Although he termed his manipulation of fidelity *forgetting* and I call it *aging,* these are identical from the perspective of the model. In addition, I assume that one relevant characteristic that accompanies aging (but was not needed in prior simulations) is the fact that older people have more knowledge—that is, a greater number of memory traces. Specifically, for the purposes of this

[6] The scale in this figure is in d' units to account for the fact that the FAR increases with *F* when the criterion is held constant across simulations (as it is here).

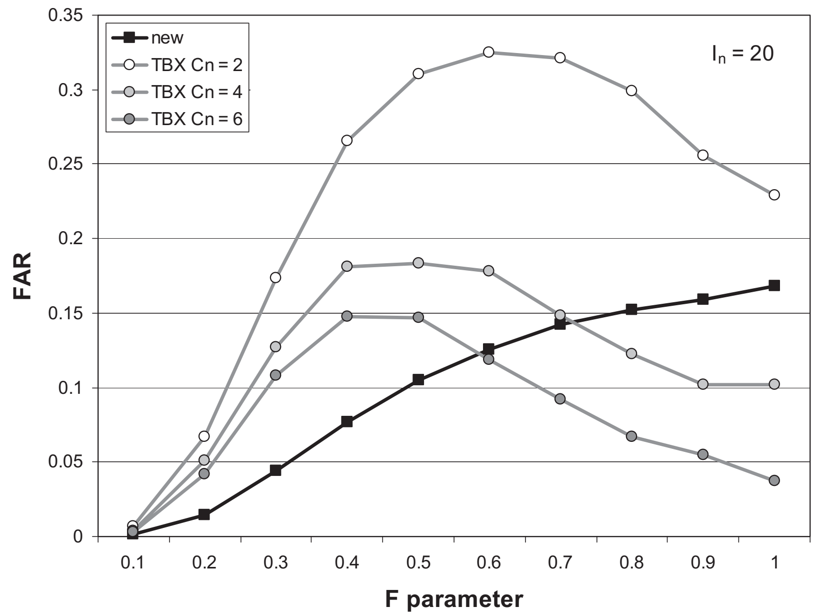

Figure 6. Simulation by DRYAD of the effects of global memory fidelity on exclusion, at three different levels of attention to context. FAR = false-alarm rate; TBX = to-be-excluded items.

demonstration, I point to the simulated data from Hintzman (1986, Figure 5), in which the joint effects of knowledge base and memory fidelity on recognition of the prototype and recognition of individual exemplars are assessed. I have replotted a subset of those data in Figure 9, corresponding to older adults having lower memory fidelity (forgetting = 1 vs. 0 in Hintzman's terminology) but higher knowledge (category size = 9 vs. 3 in his simulation). In that figure, it can be seen that the greater number of memory traces offsets the disadvantages of poorer memory for semantic knowledge: Though recognition of individual exemplars is considerably poorer in older than younger simulated subjects, recognition of the prototype is actually slightly higher. This result is consistent with the finding that older adults have intact or even slightly superior measures of knowledge, such as word meaning (Verhaeghen, 2003; see also Burke, 2006).

Intact implicit memory. Another central result in the literature on aging and memory is the finding that older adults exhibit intact or only moderately impaired implicit memory (e.g., Light & Singh, 1987). Implicit memory tasks are ones in which the effect of a prior experience is measured on performance without an explicit reference to the subjects to use their memory for that prior experience (e.g., Roediger, 1990; Schacter, 1987). On tasks like word-fragment completion, older adults exhibit little reduction in the production of previously exposed words (e.g., Clarys, Isingrini, & Haerty, 2000) unless competitors are primed as well, and then, age-related invariance is still obtained on forced-choice completion tasks (Light, Kennison, & Healy, 2002).

To apply DRYAD to such phenomena, I assume that words are studied within a single experimental context and that the cues used to probe memory differ between the explicit and implicit tasks. In the case of fragment completion, I assume that presentation of the fragment is like presentation of a portion of the vector representing the word information (cf. Metcalfe, Cottrell, & Mencl, 1992). For an explicit fragment-completion test, the study vector is included in that cue, and for an implicit test, it is not. That is, an explicit test specifies the prior context as a retrieval cue, and an implicit test specifies only the fragment itself.

Given these assumptions, it is fairly straightforward to see how DRYAD reveals the effects of aging. Sparse representations of context lead the global deficit to affect the utilization of contextual information more dramatically that utilization of item information. Thus, explicit memory—in which contextual information is heavily involved—is affected by a reduction in memory fidelity (as shown throughout this article), whereas implicit memory is not. Thus, the representational system and process assumptions of DRYAD are fully compatible with the important finding that implicit memory is preserved with age.

General Discussion

The aim of this article has been to provide an alternative to the patchwork theorizing that has characterized the study of age-related dissociations in memory experiments. The test case addressed here concerns the effects of age on memory for contextual information, which has usually been taken to reveal the selective influence of a subset of psychological processes in older adults. The claim here is that the interactions that have been taken to support this conclusion can be explained more parsimoniously by considering the effects of a global memory deficit on representations of variable density.

Using the three assumptions that embody this theory, I have shown that DRYAD can account for all of the major patterns of data in the field that have been marshaled in support of the process-dissociation claim. The lynchpin of DRYAD's ability to account for disordinal interactions is the nonmonotonic relationship between memory strength and endorsement probability for

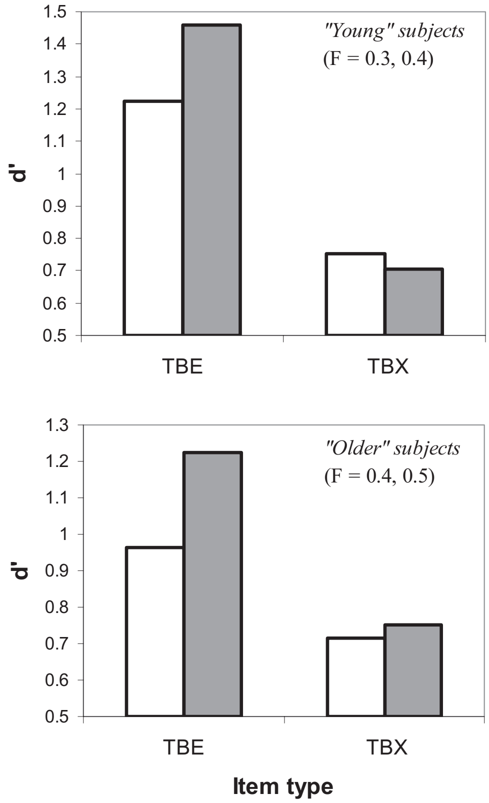

Figure 7. Simulation by DRYAD of a triple disordinal interaction in exclusion (to be compared to the data shown in Figure 1A). TBE = to-be-endorsed items; TBX = to-be-excluded items.

related distractors. Evidence for the existence of that relationship is reviewed below; such a finding is difficult to reconcile with theories that appeal to a process deficit as the source of interaction between age and manipulations of memory strength.

To be clear, these demonstrations should not be taken to reveal that older and younger adults differ in only one way or that a single-factor treatment of age is appropriate in all circumstances. There are a multitude of uncontrolled cohort differences and a host of neurobiological consequences of aging that make it likely, if not certain, that these two groups differ in many ways. The demonstration here concerns itself with the question of how many such factors are needed to understand age-related deficits in memory for context, as revealed by recognition and exclusion tasks. Though the simulations treat the groups equivalently with respect to attention, I do not wish to claim that older people are interested in and attend to the exact same things as young people. In fact, the results previously reviewed concerning differential attention to emotionally laden content indicate that this is not true. The lesson is that none of these potential differences need to considered, or assumed, when making sense of the age-related context memory deficit.

Nonmonotonic False-Alarm Rate Functions

DRYAD's ability to account for disordinal interactions with a global mechanism lies in the fact that memory for context and memory for content respond at different rates to manipulations that enhance or decrease representational fidelity. This plays out in the form of a nonmonotonic forgetting function for the exclusion task, as is evident in Figure 6. Here, I address the viability of this prediction directly by summarizing a recent experiment that measured the form of forgetting in an exclusion task (Benjamin et al., 2010).

Nonmonotonic memory functions have appeared on occasion in the literature and have usually been interpreted as revealing of two processes that are offset in time and that work against one another. For example, McDermott and Watson (2001) demonstrated that false recall of words varied nonmonotonically with the presentation time of a series of semantic associates and attributed the shape of the function to rising activation of the lure being offset by increasingly successful monitoring of the source of that activation. Similarly, Matzen et al. (2010) accorded recall-to-reject processes and lure familiarity opposing roles in a paradigm in which false recognition of semantically related and phonologically related lures was measured over a variety of retention intervals. Gronlund and Ratcliff (1989) interpreted nonmonotonic FAR functions in an associative recognition response-signal procedure as revealing of the later onset of associative information in a recognition decision.

Here, I have shown (see Figure 6) that such nonmonotonicities may reveal something about the nature of representational density and provide an alternative interpretation of interactions evident in memory experiments. A memory effect that is global may elicit behavioral dissociations if representations of information are differentially redundant.

The final experiment in Benjamin et al. (2010) evaluated a standard color-based exclusion task for the presence of such a nonmonotonic trend. In that experiment, subjects engaged in a continuous exclusion procedure, in which they were instructed to endorse items on the list if they had been previously seen in the same color in which they currently appeared. The lag between an item and

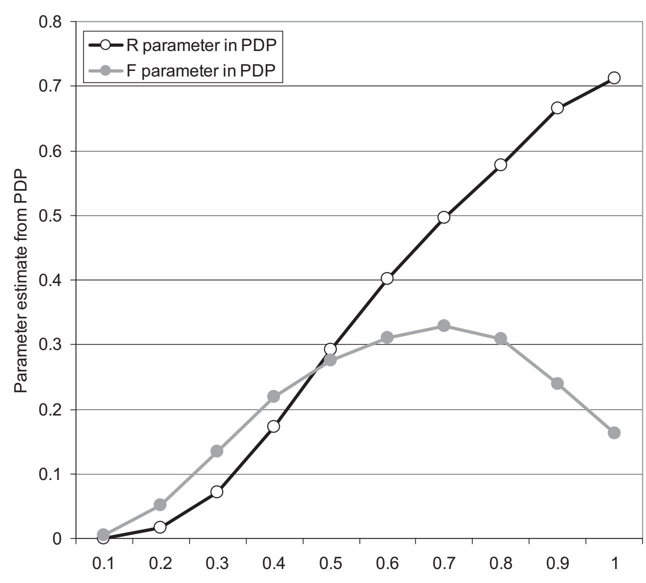

Figure 8. Process-dissociation procedure (PDP) interpretation of the simulation of exclusion by DRYAD.

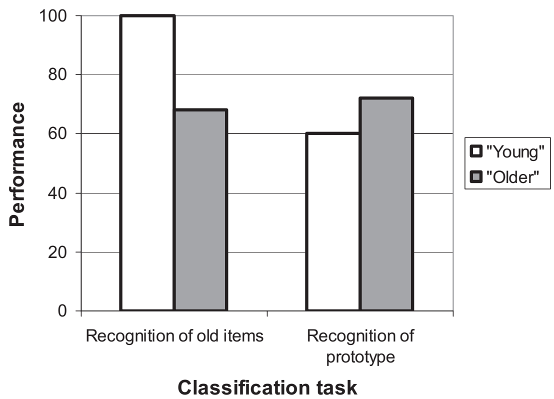

Figure 9. Exemplar recognition and prototype recognition as a function of age.

a test trial was varied, and the results are shown in Figure 10. There, it can be seen that FARs to to-be-excluded items rise and then fall as the interval between the study and test event gets closer.

The data are not entirely incompatible with a process interpretation, but that interpretation is quite awkward here. According to the process view, these data reveal that, when the retention interval is short, retrieval (or recollection) influences judgments but, when the interval is long, it does not. In experiments in which memory fidelity is manipulated at encoding, such interpretations can be compelling, but here one must assume that subjects bring different strategies or information to bear on the recognition judgment depending on when that judgment takes place. In other words, subjects must first know how long it has been since a particular test word was studied prior to knowing whether it was studied at all. An alternative possibility is that the information underlying retrieval is forgotten at a faster rate than is the information underlying familiarity. For a process-dissociation theorist, such an interpretation is ad hoc and empirically rather than theoretically motivated, but from a representational perspective, this is not a conclusion but rather a prediction (as shown in Figure 3). The process-dissociation construal is unconvincing, but the representational view places no unrealistic cognitive demands on the recognizer and provides a straightforward interpretation of the data.

Limitations of DRYAD

Throughout this article, I have emphasized that the logic of using empirical interactions to infer process dissociations is faulty. However, I have only addressed the specific case of age-related interactions in memory judgment tasks. In doing so, I have constructed DRYAD, which serves as a model system in which to evaluate the viability of the global deficit hypothesis. Though DRYAD is not intended as a complete model of aging and memory, it is instructive to consider the complexities that must be faced if DRYAD is to be applied more broadly to understanding age-related changes in memory.

I have roughed out here how DRYAD can be applied to only a small subset of productive memory tasks—that is, tasks in which the subject is required to output the products of memory, rather than make a decision based on those products. DRYAD can choose one of multiple previously studied contexts, and this choice is based on the output of a retrieval system, but it does not have to face the burden of actually producing a response from memory (other than yes–no or Context1–Context2). This burden is decidedly nontrivial when the set of contexts is very large or poorly defined. The process of retrieval, along with some slight augmentations, can yield reasonable recall (Hintzman, 1986), but applying that mechanism to understanding age-related effects on recall requires a theory about how memory is queried during recall, how interference operates during recall, and how context is represented in the search cue. DRYAD and MINERVA2 do not address these issues, though other theories do (e.g., Howard & Kahana, 1999; Raaijmakers & Shiffrin, 1981).

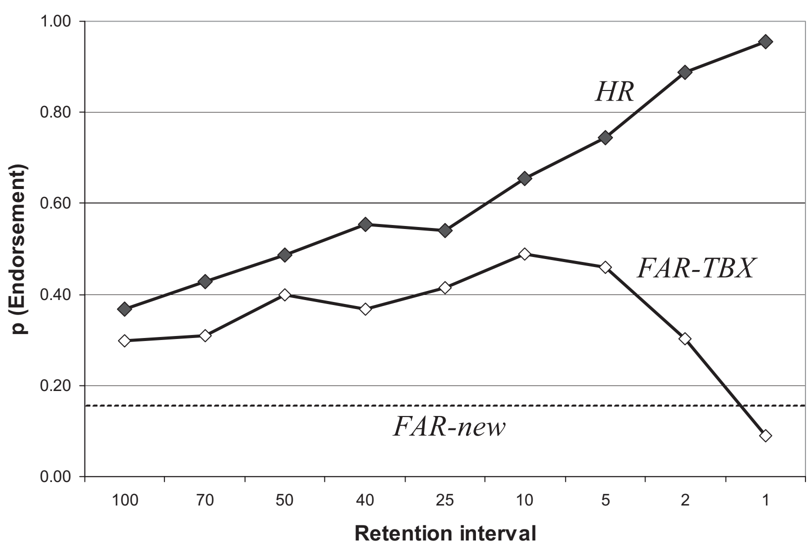

Figure 10. Hit rates (HR), false-alarm rates to to-be-excluded items (FAR-TBX) and false-alarm rates to new items (FAR-new) as a function of interval between study and test trials on color exclusion.

It is evident from examining performance on recall tasks that older adults exhibit a fairly dramatic deficit, one that appears to be larger in magnitude than for memory tasks that do not involve production (Craik & McDowd, 1987). It has been suggested that this deficit reflects a failure of controlled processing (Jacoby et al., 2005), effortful processing (Hasher & Zacks, 1979), or an inability to self-initiate the processes guiding recall (Craik, 1982, 1994). Each of these proposals is a candidate with which to link the postulated global memory deficit in DRYAD to recall phenomena. It might be presumed, for example, that sparse representations of context place an undue burden on the rememberer to very precisely specify a search cue. Alternatively, the deficit might not affect encoding fidelity but rather induce a lower effective fidelity by virtue of less efficient search. Failures in the controlled processes guiding cue construction (Jacoby et al., 2005) are one example of how this could occur.

One extant theory appeals specifically to data relating input order and output order in free-recall tasks (Howard & Kahana, 1999), which reveal a major difference between younger and older adults. In particular, the effects of temporal contiguity appear to play less of a role in the output of older than younger adults (Kahana, Howard, Zaromb, & Wingfield, 2002). Howard, Kahana, and Wingfield (2006) applied a model of recall to the data from the two age groups and concluded that older adults exhibit a deficit in the processes that bind items to temporal contexts. Such a theory might be reconciled with DRYAD if the deficit is reconceptualized as inaccurate representation of context, rather than ineffective binding. In any case, the global memory deficit hypothesis must be tied to a theory of recall before it can take on the effects of aging on productive memory tasks.

Another critical aspect of aging for which DRYAD provides no insight is the ubiquitous slowing evident across a huge variety of tasks (Salthouse, 1985, 1996). However, slowing can be considered as a causal factor in producing a global deficit. If the representations in DRYAD were considered to be the consequence of a sampling process in which the rate of sampling varies with age, then the resulting representations would look much like the ones suggested here. Thus, though DRYAD poses no solution to the problem of age-related slowing, it is entirely consistent with that finding.

Whence the Global Deficit?

At one level, the explanation of age-related effects on memory judgments provided here is a pretty meager one. The global deficit may well be a successful theoretical contender to explain effects under conditions under which deficits were thought to be age specific, but that explanation obliges no particular underlying mechanics by which that general deficit—and not specific ones—arise.

However, there are numerous extant theoretical suggestions that are consistent with a global deficit in memory fidelity. If older adults have lower working memory capacity (Engle et al., 1999), then that limitation may be a bottleneck in the translation of representations into long-term memory. Similarly, as noted before, if the speed with which older adults process information is lower (Salthouse, 1996), then that reduction can be a limiting factor in the rate with which events are encoded into long-term memory. Of course, the theory proposed here—which concerns itself with understanding the potential effects of a global memory deficit—is entirely agnostic as to the source of that deficit. It opens the door to process theorizing that is compatible with the psychometric evidence of an age-related global deficit and views with new skepticism theoretical suggestions that appeal to selective age-related deficits in memory for context. Other suggestions in the literature that appear to be compatible with a global deficit are information loss (Myerson et al., 1990), failures of inhibition (Hasher & Zacks, 1979), and reduced efficiency of controlled processing (Jacoby et al., 2005).

An ecological perspective on sparse representations of context. One standpoint from which to consider the origin of a functional deficit in memory for context is an ecological one. Throughout this article, I have made the claim that sources or contexts in memory experiments are typically uninteresting and more likely to be semantically vacuous than the messages or content they accompany. A similar argument can be made for the structure of information in the world. Tests in school probe knowledge, not memory for where that knowledge was acquired. Although it is true that the source of a message may play a role in the credibility of that message, it is generally more important to remember facts than to remember our experiences with encountering those facts.

Sparse encoding of context affords two major advantages for the use of memory in the real world. First, because the memory representation includes only a small amount of information about the context in which it was encountered, cuing that contextual information is not critical for recovering the content of the memory. That is, to the degree that it is adaptive for memories to be content addressable, it is unadvantageous for the content addressability to be related to serendipitous episodic details of the experience. Retrieving "capybara" in response to the cue "largest rodent" is useful; retrieving it to "the animal we saw at the San Diego Zoo near the restrooms in December," less so. Given a finite capacity for encoding details of our experiences, dropping such meaningless episodic details seems a wise approach.

A second advantage of sparse context encoding is the advantage it provides in generalization. If we learn about categories and concepts through exposure to instances and generalization across those instances (Brooks, 1978; Medin & Schaffer, 1978), then such generalization is facilitated when our representations of those categories contain a minimal amount of superfluous information. A successful conceptualization of rodents depends on capturing critical qualities of such animals, perhaps having to do with teeth, size, and fur. We would not want to inappropriately generalize to rodents unimportant contextual details, such as who we are with or what we are wearing when we encounter them.

Because it is difficult if not impossible to fully anticipate the aspects of our experiences that are likely to be critical for later generalization, however, context cannot be abandoned entirely. The fact that we often encounter some animals during the day and others at night might indicate whether the animal is nocturnal or diurnal or it might simply reflect the fact that we go to different places during the day than at night. Retaining some aspects of context allows us to salvage from memory representations contextual details that later prove critical for use of those categories.

This perspective suggests that the encoding of any particular episodic detail is a gamble. There is a cost because encoding that detail takes time and resources away from attention to other aspects of the stimulus. If the potential benefit of having knowledge of how that detail correlates with other encoded details of stimulus is great enough, however, that piece of information will be encoded. Using such a perspective perhaps allows us to avoid somewhat the paradox of defining what is context and what is content. Instead, any aspect of a stimulus is evaluated for its future information value—a large part of which may be uncertain—and encoding resources are allocated accordingly.

Memory Training and Rehabilitation

As noted at the outset of this article, there is considerable practical consequence to how we conceptualize age-related memory deficits. It determines how best to approach the problem of rehabilitating memory deficits, both in nonpathological older populations (Bottiroli, Cavallini, & Vecchi, 2008; Cavallini, Pagnin, & Vecchi, 2003; Verhaeghen, Marcoen, & Goossens, 1992) and in populations with memory disorders (Rapp, Brenes, & Marsh, 2002). Much of this research involves the teaching of mnemonic strategies (e.g., Kliegl, Smith, & Baltes, 1989; Wood & Pratt, 1987), which do not promote memories that are flexible and rapidly accessible (Benjamin & Bjork, 2000; Lea, 1975), nor do they generalize well to real-life circumstances (Ball et al., 2002; Herrmann & Searleman, 1992).

Recent work by Jennings and Jacoby (2003; Jennings, Webster, Kleykamp, & Dagenbach, 2005) exemplifies an approach to memory training that is, in contrast, undergirded by a strong theoretical perspective. They started from the standpoint that the process of recollection (which is assumed to underlie recovery of memory for source or context) is impaired in older adults and that experience with a laboratory task that places demand upon recollection should decrease age-related deficits (Jennings & Jacoby, 2003) and generalize to other memory skills that benefit from recollection (Jennings et al., 2005). Because their work is some of the best and most theoretically motivated work in memory training, and because their procedure and results are critical to understand in light of the theoretical alternative proposed here, I review their methodology and findings in some detail here.

Their procedure also used a variant of the continuous recognition paradigm. First, subjects studied a list of words that they were instructed to remember. The test consisted of studied words, along with new words, each of which was repeated in the test list. Because the second encounter with a new test word requires the subject to discriminate between the word having been on the original study list and having been seen previously on the test list, Jennings and Jacoby (2003) proposed that correct identification of such words requires recollection—that is, recovery of the contextual elements of the prior presentation.

In their experiments, the lag between the two new presentations was varied, and they showed in very convincing fashion that the maximum lag at which subjects could perform such a discrimination increased over training and that it did so to a greater degree in subjects for whom lag increments were tied to performance benchmarks than in control subjects yoked in a quasi-random way to the experimental subjects (and who did not experience performance-related increments in lag). Later work also showed a benefit of this training regimen over a group that engaged only in recognition practice that did not include repeated distractors (Jennings et al., 2005).

There is no doubt that experience with this procedure dramatically enhanced performance. The issue is whether the subjects are being trained to engage in recollection or whether the procedure biases their attention at study such that more details of the temporal or list context are being encoded. I previously reviewed research demonstrating that perceived importance (May et al., 2005; Rahhal et al., 2002) and instructions (Benjamin et al., 2009) can bias encoding in such a manner. Test experience can also change the manner with which subjects encode information in subsequent study lists (Finley & Benjamin, 2010), and the results of Jennings and Jacoby (2003) and Jennings et al. (2005) are consistent with that interpretation. In addition, Bissig and Lustig (2007) replicated the results of Jennings and Jacoby using a task in which older adults were given more control over the encoding experience (by using self-paced study with feedback), a result that is consistent with an attentional interpretation. It seems as though experience with the task informs the subjects that encoding items from the study list in a way that enables future discrimination from repeated test-list items—whether by temporal coding or by list-marker coding—is the best route to good performance. The consequences of such a strategic shift are likely to be evident in other tasks that have the potential to reveal changes in encoding strategy (Benjamin, 2008).

Jennings et al. (2005) included pre- and posttesting on a number of neuropsychological measures for subjects engaged in their training regimen (as well as subjects in the recognition control condition). The pattern of results is consistent with what one would expect if their training procedure led subjects to encode more details about the contextual attributes of study items. In the experimental training group, performance increased on the *n*-back task (which places a demand on memory for relative list position), the self-ordered pointing task (which places a demand on memory for previous actions on stimuli), and source discrimination (which places a demand on memory for the modality of previously experienced words). Each of these benefits can be understood as a consequence of the training condition leading to a more robust encoding of contextual elements of the stimuli, in terms of either temporal details, performed actions, or presentation modality.

Jennings et al. (2005) did not find a benefit of training on reading span (for which memory for contextual elements would be irrelevant or interfering) and found a mixed pattern on the California Verbal Learning Test–Second Edition (CVLT-II; for which temporal list information would be useful only on a small subset of tests). Performance on the digit symbol substitution task improved in the experimental training condition but also did (to a lesser degree) in the recognition-practice condition. There is no reason why attention to contextual details would enhance performance on either reading span or digit symbol substitution, so it is also not surprising that their training regimen did not affect performance in either case. The CVLT-II provides a more interesting case, however. It requires subjects to study and be tested on a single word list five times and then study and be tested on a second, different list. Following that second list, subjects are once again tested on the original list, both immediately and at a delay, using both free and cued recall.

Only two of the 10 basic measures of memory derived from this procedure place a demand on memory for contextual characteristics of studied stimuli. Free recall of the first list following study and testing of the second list requires subjects to actively exclude competing members from the second list. Notably, these two cases are two of three comparisons that Jennings et al. (2005) reported as revealing a marginal benefit of their training regimen. Thus, even the CVLT-II—a particularly imprecise measurement tool, given its repeated testing and retesting of the same material—reveals data consistent with the hypothesis that what is being trained is attention, rather than recollection.

The perspective that deficits are ameliorated to the degree that attentional filters are trained is also consistent with evidence suggesting that encoding manipulations can reduce memory deficits (Lustig & Flegal, 2008), that attention training plays a role in reducing memory deficits (Neely & Bäckman, 1995), and even that general education about memory can do so (Troyer, 2001). However, if older adults suffer from a global memory deficit, then training them to attend to contextual details—in essence, using attention to offset the consequences of the memory deficit—is likely to have adverse effects on memory for other aspects of the experience. In fact, such a tradeoff is evident in tasks in which attention is specifically directed to contextual attributes (Light & Berger, 1974; Light, Berger, & Bardales, 1975). If inattention to context is an ecologically adaptive behavior, then we must be careful in exactly which situations we train older adults to attend more greatly to context. The forgetting of context is only harmful under limited circumstances, and a general reprogramming to attend greatly to context is not likely to have overall positive consequences.

Advantages of DRYAD Over Other Extant Views

It should be apparent by this point that there is no shortage of theories that can be applied to understanding the age-related deficit in memory for context. What is the value of throwing another contender into the mix? DRYAD might appear to have a more limited scope than some other theories, though this is because it is one of the few theoretical suggestions in the literature that has been fully implemented to simulate results. This is an important advantage because it prevents an excessive degree of misinterpretation and consequently allows for competition between theories and potential falsification.

More importantly, thinking in terms of representations rather than processes sheds some light on why memory for context appears to be so fragile across different populations and circumstances. It is a necessary consequence of sparse representations of context that any variable that influences memory fidelity will impair memory for context most dramatically. Thus, DRYAD is a more general theory about memory fidelity and recognition and can be applied to a wide variety of circumstances.

As a final note, theories that possess explanatory simplicity are in general to be preferred over ones that are more complex. As noted by Cerella (1985, p. 67) in his discussion of theories of age-related deficits, "Integrative theories explaining a range of effects on the basis of a common factor are clearly preferable." Theories that claim a single mediating variable of the effects of age should be preferred to those claiming more. This is especially true when the claim of a single mediating variable reconciles process theories with individual-difference theories, as reviewed below.

Reconciling the Psychometric and the Experimental Views on Aging and Memory

To end the discussion, it is worth revisiting the apparent paradox that I reviewed at the beginning of this article. How is it that the innumerable dissociations revealed by the experimental tradition can be reconciled with the analyses of individual differences from the psychometric tradition that suggests the influence of only a single mediating variable? The answer lies in a hidden assumption, without which these two bodies of findings are not at all incompatible.

That assumption is that empirical interactions reveal process dissociations. This article demonstrates that this assumption is unwarranted when applied to the effects of age on memory judgments, but the deeper theoretical issues here are the treatment of response scales, widely explored in both historical and contemporary research in measurement (e.g., Bamber, 1979; Crocker & Algina, 1986; Dunn & Kirsner, 1988; G. R. Loftus et al., 2004), and the inference of memory-process influence versus memory-representation influence.

Resolving this paradox is then a matter of relaxing this hidden assumption: There is a general effect of aging on memory representations, and that general effect can reveal itself in the form of empirical interactions. How it can do so is laid out explicitly in DRYAD, and the proof is in the simulation results, but the general principles can be understood without delving too deeply into the actual implementation.

Critical is the representational sparsity hypothesis, which simply states that more information is encoded about focal than peripheral aspects of stimuli. In the traditional memory experiment, context is, by virtue of instructions as well as perceptual and mnemonic qualities, less focal. The general deficit in older subjects leads the impoverished representation of such context to be disproportionately less recoverable, which reveals itself in the form of an empirical interaction. When either naturalistic importance (May et al., 2005; Rahhal et al., 2002) or experimental instructions (Benjamin et al., 2010) encourage older adults to pay more attention to contextual information, the traditional deficit disappears. Such findings are predicted by a representational theory of age-related deficits but difficult to accommodate in a theory that starts with process deficits. Such theories must assume that some alternative process—such as extraordinary levels of attention—offset the deficit.

An interpretation of experimental data within theoretical constraints provided by psychometric analyses is a good opportunity to remind ourselves of the tenuous theoretical connections between these traditions in memory research as elsewhere (Cronbach, 1957; Salthouse, 2006). Successful theoretical development hinges on a shared understanding of theoretical terms, an agreement on the qualities of measured variables, and a common set of rules used to determine the sufficiency or necessity of a particular theoretical position. Because those rules are quite different for psychometric and experimental traditions in memory research, opposing conclusions about the effects of age on memory have been reached. Those conclusions are reconciled here by adopting a more stringent stance toward the postulation of process dissociations, one that does not begin and end with empirical interactions.

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