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The process-dissociation approach two decades later: Convergence, boundary conditions, and new directions

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Abstract The process-dissociation procedure was developed to separate the controlled and automatic contributions of memory. It has spawned the development of a host of new measurement approaches and has been applied across a broad range of fields in the behavioral sciences, ranging from studies of memory and perception to neuroscience and social psychology. Although it has not been without its shortcomings or critics, its growing influence attests to its utility. In the present article, we briefly review the factors motivating its development, describe some of the early applications of the general method, and review the literature examining its underlying assumptions and boundary conditions. We then highlight some of the specific issues that the methods have been applied to and discuss some of the more recent applications of the procedure, along with future directions.

Keywords Process dissociation · Recollection · Memory · Recall · Control · Automaticity · Aging · Amnesia · Familiarity

Jacoby (1991) advocated the use of a process-dissociation procedure that was designed to separate the contributions of automatic and cognitively controlled forms or uses of memory to performance on memory tasks. In this article, we report on the progress that has been gained since publication of the 1991 article. Upon the writing of this progress report, the original article had received over 2,400 citations, as indexed by Google Scholar. The large number of citations reflects general interest in showing the existence of and separating different forms or uses of memory, and much of the progress on that general topic is not owed to the process-dissociation procedure. Indeed, some of the articles citing Jacoby (1991) have questioned the assumptions underlying the process-dissociation procedure and have advocated its dismissal. Regardless, the high citation rate excuses us from providing an exhaustive review of the literature. Instead, we will illustrate the process-dissociation procedure and its general utility by describing a somewhat small number of experiments and by highlighting a few key articles, including articles by critics.

We begin by briefly describing the background research that led to the development of the process-dissociation procedure and then describe the specific methods that have been based on the procedure, including the inclusion/exclusion, congruence/incongruence, subjective report, and receiver operating characteristic methods. Research on special populations, including older adults and amnesics, has played an important role in the development and use of process-dissociation procedures. We will discuss some research of that sort when describing process-dissociation procedures and their applications. We will also discuss the important challenges that have been raised about the various procedures, and end by highlighting several extensions and promising new directions.

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Background

In an influential series of experiments, Warrington and Weiskrantz (1968) gave amnesics repeated exposures to lists of words followed by tests of recognition memory and recall after varying intervals. The surprising finding was that amnesics showed high levels of proactive interference by falsely recalling words that were presented in earlier lists. Warrington and Weiskrantz interpreted this result as evidence that amnesics were unable to forget or suppress memory for earlier events, resulting in their high vulnerability to interference effects. Weiskrantz and Warrington (1975) developed a fragment-completion task to eliminate interference and, thereby, to show savings in the memory performance of amnesics. For that task, presentation of a list of words for study was followed by the presentation of word fragments that had only a single completion. The important finding was that earlier studying of a word increased the probability of its being produced as a completion of its corresponding fragment, even for very dense amnesics. This was true even though amnesics were unable to recognize or recall the word as having been studied earlier. Tasks such as the fragment-completion test were later referred to as "indirect" tests of memory. For a direct test of memory, such as a test of recognition memory or recall, participants are directly instructed to report on memory for a prior episode. In contrast, for an indirect test, participants are not instructed to report on a particular prior episode, but rather, they engage in a task that can reveal the effects of memory for the prior episode. Fragment- and stem-completion tasks, along with other tasks, became popular as measures of what came to be called "implicit" memory. Numerous dissociations have been obtained between the effects of different variables on direct and indirect tests of memory (for reviews, see Richardson-Klavehn & Bjork, 1988; Roediger, 1990; Schacter, Chiu, & Ochsner, 1993).

Jacoby and Dallas (1981) employed a perceptual identification test as an indirect test of memory. For that test, participants were asked to identify briefly flashed words, some of which had been presented in an earlier phase of the experiment. The results revealed that "old" words were much more likely to be correctly identified when flashed than were "new" words. Furthermore, processing semantic as compared to perceptual aspects of the items during study (Craik & Lockhart, 1972) had a large effect on recognition memory performance, but the level of their prior processing did not influence the gain in perceptual identification of old words. The finding of such dissociations in people with normally functioning memory (for a review, see Schacter et al., 1993) converged with results found for amnesics and led to research aimed at identifying the neurological bases for different forms or uses of memory (e.g., Gabrieli, 1998).

Jacoby and Dallas (1981) followed Mandler (1980) and others (Atkinson & Juola, 1974) by advocating a dual-process model of recognition memory that holds that familiarity and recollection serve as alternative bases for calling an item "old." *Recollection* refers to a cognitively controlled, effortful use of memory, whereas *familiarity* refers to a more automatic use of memory, which was said to be reliant on processes of the same sort that underlie performance on indirect tests of memory. Jacoby and Dallas showed that words that appear with a low, as compared to a high, frequency in the language revealed a larger effect of prior presentation on their later perceptual identification, and such words were also more likely to be recognized as "old" on the test of recognition memory. The researchers interpreted this relationship as evidence that the feeling of familiarity relies on an attribution process, with the relative ease of perceptual identification—that is, perceptual fluency—being attributed to an item being old. The notion of a fluency heuristic serves to relate performance on direct tests of memory to forms or uses of memory preserved by amnesics. A good deal of evidence now supports the suggestion that subjective experience can reflect reliance on a relative-fluency heuristic (for a review, see Kelley & Rhodes, 2002).

To account for memory dissociations, others have identified performance on indirect tests with procedural or implicit memory, whereas performance on direct tests was identified with declarative or explicit memory (e.g., Squire & Zola-Morgan, 1988; Tulving & Schacter, 1990). In the same vein of identifying forms or uses of memory with different tasks, Mandler (1980) sought to separate the bases for recognition memory by defining recollection as corresponding to performance on a recall test. However, the practice of identifying processes with tasks encounters the *process-pure problem.* For the implicit/explicit distinction, the problem is that performance on indirect tests might be "contaminated" by intentional, aware uses of memory. Conversely, performance on direct tests can be contaminated by automatic, unaware uses of memory. In this vein, amnesics show evidence of memory on a direct test when encouraged to guess (Weiskrantz & Warrington, 1975). Results of that sort suggest that a recall test cannot be used as a process-pure measure of recollection (cf. Mandler, 1980). Although both forms of contamination are likely common, most research has focused on the possibility that performance on indirect tests is contaminated by intentional use of memory, and that such contamination might be responsible for apparent memory deficits in groups such as older adults, as compared to young participants, on indirect tests of memory (e.g., Howard, Fry, & Brune, 1991; Light, Prull, La Voie, & Healy, 2000).

Problems for interpretation arise because of the reliance on paradigms in which aware and unaware influences of memory would both facilitate performance, making it difficult to separate their effects. As an example, for a fragment-completion task used as an indirect test, a finding of a higher probability of completing a fragment with an earlier-presented word might arise either from an automatic use of memory, of the sort preserved by amnesics, or from an intentional use of memory (recollection). Similarly, for a direct test that provides word fragments as cues for recall, correct responding could result either from recollection or from an automatic influence of memory of the same sort revealed by an indirect test.

Early experiments adopting a process-dissociation approach used an inclusion/exclusion procedure that is described in the next section. Interpretation of the results from those experiments gave rise to controversy concerning the assumptions underlying the measurement procedure that was employed. Most importantly, critics have rejected the assumption that controlled and automatic influences of memory *independently* contribute to overall performance. After describing the inclusion/exclusion procedure along with the results gained using that procedure, we will briefly respond to the critics. To anticipate, we have shown that, contrary to claims made by others (Curran & Hintzman, 1995, 1997), correlations cannot be used to directly test the validity of the independence assumption underlying the process-dissociation procedure.

Our converging-operations approach to gaining support for the assumptions underlying the process-dissociation procedure is of the sort advocated by Garner, Hake, and Eriksen (1956) for perception and by Roediger (1980) for memory theorizing. According to that approach, support for a theory is produced by showing that results gained from several independent measuring operations converge on the same conclusion. In later sections, we will describe the use of additional tasks and measures that have produced results that converge with those gained by the inclusion/exclusion procedure. The overall goal of our research is to develop a relatively simple model that is useful for applied problems such as the diagnosis and treatment of memory deficits (e.g., Jacoby, Jennings, & Hay, 1996), as well as for basic research in a variety of domains. This goal differs from the more typical goal of developing a complex, quantitatively sophisticated model with a large number of parameters to describe performance on a particular task (e.g., recognition memory). We believe it better to broaden the arena by including converging evidence, heuristic value, and potential utility for applied purposes when considering the utility of an approach.

For both recognition memory and recall tasks, we use the term “recollection” to refer to controlled processing. For automatic influences of memory, we use the term “familiarity” for recognition memory tasks, and simply refer to “automatic influences” for recall tasks. For both recall and recognition memory, “automatic influences” refers to the contribution of a “strength-like” mechanism.

Although indirect tests of memory do not always provide a process-pure measure of automatic influences of memory, under some conditions they apparently do, or nearly do, so. Requiring fast responding and arranging the situation such that recollection is unnecessary and does not aid responding increases the likelihood of an indirect test being process pure (for a review, see MacLeod, 2008). This allows us to use indirect tests of memory that are arguably process pure as a source of converging evidence for estimates of automatic influences coming from process-dissociation procedures. In a similar vein, subjective reports are not reliably a process-pure measure of recollection but, under some conditions, are sufficiently so to provide a source of converging evidence for measures of recollection.

As we indicated earlier, problems for interpretation arise from arranging a situation such that recollection and the automatic influences of memory both facilitate performance. Much can be gained by placing automatic influences in opposition to cognitive control to show the existence of the two bases for responding. Opposition procedures have been shown to be useful for revealing automatic and controlled processes as bases for responding in a variety of paradigms, such as false-fame tasks (Jacoby, Woloshyn, & Kelley, 1989), subliminal perception (Merikle, 1992; Visser, Merikle, & Di Lollo, 2005), false memory (e.g., Benjamin, 2001), and illusions of truth (Begg, Anas, & Farinacci, 1992).

Process-dissociation procedures

The general aim of the process-dissociation approach is to separate the contribution of different processes within a single task, rather than to rely solely on task dissociations. One way of doing that is to put processes in opposition. Jacoby (1991) combined results from an opposition condition with those from a condition in which automatic influences facilitate performance to separately measure the contributions of the two bases for responding to recognition memory performance. To illustrate opposition procedures along with the inclusion/exclusion procedure used by Jacoby (1991), we will describe the results from experiments done by Jacoby, Toth, and Yonelinas (1993) that examined effects on cued-recall performance, and then we will respond to critics regarding the underlying assumptions of the inclusion/exclusion procedure.

Inclusion/exclusion In the first phase of an experiment reported by Jacoby et al. (1993, Exp. 1b), participants were presented a list of words that were to be read under conditions of either full or divided attention. For an inclusion test, which corresponds to a standard direct test of memory, participants were presented with the stem of a studied word (e.g., mot__ for “motel”) as a cue for its recall. As is shown in Fig. 1, correct responding on the inclusion test could result from recollection (R), from automatic influences of memory (A), or both. If it is assumed that R and A served as independent bases for responding, the probability of a correct response is $P(\text{Inclusion}) = R + A - RA$ or, rearranging

Inclusion: R ⇧ A ⇧ R + A - RA

Exclusion: R ⇩ A ⇧ A - RA

Inclusion – Exclusion = R

Exclusion/(1-R) = A

Fig. 1 Illustration of the inclusion/exclusion procedure (Jacoby, 1991). Recollection (R) and automatic (A) processes are assumed to contribute independently to inclusion and exclusion performance.

terms, R + A(1–R). In contrast, for an exclusion test, participants were instructed to complete stems with words that had *not* been presented earlier for study. For the exclusion test, recollection and automatic influences of memory act in opposition. An earlier-studied word would mistakenly be given as a completion for the exclusion test only if recollection failed (1–R), in combination with automatic influences of memory (A). Again, if we assume independence, *P*(exclusion) = A(1–R). To obtain estimates of recollection, one subtracts the probability of completing stems with earlier-studied words in the exclusion condition from the probability of completing stems with earlier-studied words in the inclusion condition. Obtaining an estimate of R by means of the above equations rests on an assumption that R is equal in the inclusion and exclusion conditions and on an assumption that A is also equal in the two conditions, as well as on the independence assumption. With these assumptions, once an estimate of R is obtained, the equations can be used to solve for an estimate of A.

The results (Fig. 2) showed that dividing attention during study decreased the probability of an earlier-studied word being produced as a completion for an inclusion test, but increased that probability for an exclusion test. Use of the above equations revealed a process dissociation by showing that dividing attention during study reduced recollection to zero while leaving the estimated automatic influences of memory largely unchanged. The finding that dividing attention during study reduced recollection to zero corresponds to a total absence of recollection, performance of a sort that might be expected from a dense amnesic.

The inclusion/exclusion procedure has been used to examine a wide variety of different manipulations across many different memory tasks and has produced a remarkably consistent set of findings. For example, the finding that dividing attention reduces recollection but leaves automatic influences relatively unchanged is a general one (e.g., Schmitter-Edgecombe & Nissley, 2000; Wolters & Prinsen, 1997; Yonelinas, 2001). A finding that age-related differences in memory reflect a decline in older adults' ability to employ recollection as a basis for responding, while leaving automatic influences of memory unchanged, has also been found for a variety of tasks (Hudson, 2008; Jacoby, 1999; Jennings & Jacoby, 1993; Rybash & Hoyer, 1996), as has the finding that requiring fast responding preferentially reduces the use of recollection as a basis for responding (Toth, 1996; Yonelinas & Jacoby, 1994, 1995). Jacoby, Yonelinas, and Jennings (1997) summarized the results from 20 different comparisons of effects for the variables described above as selectively influencing recollection. The comparisons included tests of recognition memory and tests of cued recall. Averaged across the comparisons, the effect of variables that were expected to selectively influence recollection was to produce a difference of .24 on estimates of recollection, and a difference of .002 on estimates of automatic influences. The confirmation of these expected

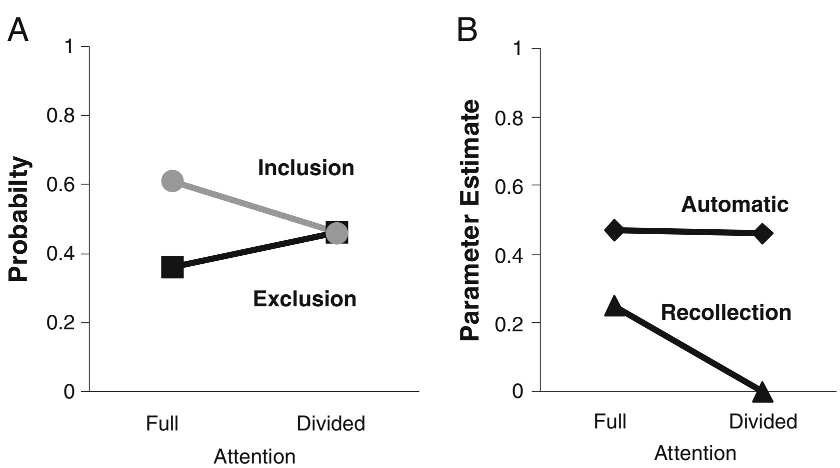

Fig. 2 (**a**) Probability of completing a word stem with a studied word under inclusion and exclusion conditions, and (**b**) estimates of recollection and automatic influences of memory. Data from Exp. 1b of "Separating Conscious and Unconscious Influences of Memory: Measuring Recollection" by L. L. Jacoby, J. P. Toth, and A. P. Yonelinas, 1993, *Journal of Experimental Psychology: General*, *122*, pp. 139–154. Copyright 1993 by the American Psychological Association

dissociations provides strong support for the assumption that recollection and automatic influences operate independently.

Turning to the criticisms and boundary conditions of the process-dissociation procedure, Curran and Hintzman (1995) reported experiments similar to those done by Jacoby et al. (1993) and used correlations among the estimates to supposedly provide a direct test that allowed them to reject the independence assumption underlying the inclusion/exclusion procedure. The subsequent debate (Hintzman & Curran, 1997; Jacoby, Begg, & Toth, 1997; Jacoby & Shrout, 1997) arrived at the conclusion that correlations cannot be used to directly test the validity of the independence assumption. Jacoby and Shrout (1997) did a psychometric analysis to show that this is the case (see also Jacoby, 1998). This is because the process-dissociation method assumes "process independence" at the level of responding to an individual item by an individual subject. Correlations at this subject × item level cannot be computed, because there is only a single observation at that level, making it impossible to compute correlations. The independence assumption cannot be assessed by examining correlations gained by collapsing across subjects or across items, as was done by Curran and Hintzman (l995), because of results that come from aggregation: Some participants may have higher recollection and familiarity scores than others, or some types of items may be more likely to lead to recollection and familiarity than are others, when correlations are measured by collapsing across subjects or items, even when the two processes are operating entirely independently. Thus, these types of correlations are not informative about process independence.

Rather than attempting to directly test underlying assumptions by means of correlations, we have gained support for our assumptions by showing that results are as would be predicted if the underlying assumptions were met, and have then sought converging evidence. Buchner, Erdfelder, and Vaterrodt-Plünnecke (1995) forwarded a multinomial model as a means of gaining unbiased estimates of recollection and the automatic influences of memory that has proven quite useful in addressing this issue. Earlier tests of invariance in automatic influences (e.g., Jacoby et al., 1993) relied on showing that estimated automatic influences were incredibly close across conditions and not significantly different. In contrast, for a multinomial model, a claim of invariance can be supported by showing that the fit of the model is extremely good when parameters that reflect the contribution of automatic influences are constrained to be equal across conditions, and that this fit is not improved by allowing the values of the parameters to vary. If the assumptions underlying the estimation procedure do not hold, predicted invariance measured in this way should not be found. The claims of invariance based on the earlier means of assessing invariance have been found to also be supported by multinomial analyses (e.g., Jacoby, 1998; Jacoby, Bishara, Hessels, & Toth, 2005).

Regarding boundary conditions for the inclusion/exclusion procedure, test instructions are critical for finding results that support the independence assumption (Jacoby, 1998). Some have proposed that recollection might better be described as being redundant with automatic processes rather than the two types of processes being independent (e.g., Joordens & Merikle, 1993, along with responses by Jacoby, Toth, Yonelinas, & Debner, 1994; Jacoby, Begg, & Toth, 1997; see also Curran & Hintzman, 1995). A redundancy relation would result if participants used a generate/recognize strategy—for example, by completing a fragment with the first word that came to mind, and then doing a recognition memory check to see whether the word occurred in the study list. Curran and Hintzman (1995) used the process-dissociation procedure and found dissociations that were described as being *paradoxical* if the independence assumption held. Jacoby (1998) varied the test instructions and showed that giving instructions that encouraged a generate/recognize strategy produced results that were very similar to those reported by Curran and Hintzman (1995), whereas direct-retrieval instructions of the sort that we have used did not produce paradoxical dissociations. Generate/recognize instructions produced results that were fit well by a model based on a redundancy assumption but that could not be fit using our independence model.

The above results show the importance of direct-retrieval instructions for finding support for the independence assumption underlying the inclusion/exclusion procedure. Another concern for the inclusion/exclusion procedure is that baseline performance (e.g., false alarm rates to new items) should not differ for the two conditions. Jacoby (1998) showed that differences in baseline performance could reflect a difference in response criteria (see also Yonelinas & Jacoby, 1996b) or, instead, could result from reliance on a generate/recognize strategy, and he took steps toward providing a user's guide for process-dissociation procedures.

Other assumptions underlying the process-dissociation procedure are that recollection on the inclusion test be equal to recollection on the exclusion test, and that automatic influences also be equal for the two types of tests. For a discussion of the effects of violation of the equal-recollection assumption and means of satisfying that assumption, see Yonelinas (1994) and Yonelinas and Jacoby (1995). In addition, Yonelinas and Jacoby (1996a) provided evidence that "noncriterial recollection" can arise in situations in which the recollection that is required for inclusion/exclusion is extremely difficult. Such recollection can result when two lists are extremely similar, and it can inflate the estimated automatic influences of memory (Dodson & Johnson, 1996; Mulligan & Hirshman, 1997; Yonelinas & Jacoby, 1996a). Relatedly, when using the inclusion/exclusion procedure, it is also critical that one avoid ceiling and floor effects (see, e.g., Jacoby, Begg, & Toth, 1997).

Although these concerns can be addressed through careful experimental design, it was important to develop process-dissociation procedures that serve as alternatives to the inclusion/exclusion procedure as a means of gaining converging evidence for the assumptions underlying the process-dissociation approach. Convergence with results gained by means of other procedures provides evidence for the validity of the assumptions underlying process-dissociation procedures and shows the general applicability of the approach. To produce an alternative, congruence/incongruence procedure, we returned to findings such as those reported by Warrington and Weiskrantz (1968) that showed differences among populations of participants in their vulnerability to interference effects.

Congruent/incongruent: Susceptibility to interference effects Hay and Jacoby (1996, 1999) examined proactive interference effects but sought to separate the contributions of automatic and controlled processes within a task rather than identifying the types of processes with different tasks, as had been done by Weiskrantz and Warrington (1975). To illustrate their procedure, Hay and Jacoby (1996) used an example of an action slip produced by an aged university professor who typically flew to conferences but drove to a conference on a particular occasion. After the conference, the professor mistakenly flew home, leaving his car behind. This action slip resulted from having driven to the conference being *incongruent* with automatic influences (habits) that resulted from typically flying to conferences.

To mimic the above situation, Hay and Jacoby (1996, 1999) employed a training phase that paired cue words with two different responses (e.g., knee–bone, knee–bend), with one of the pairings being presented much more frequently than the other, so as to make it the typical one. In a second phase, participants studied short lists of word pairs. These pairs were either *congruent* pairs, in the sense that they had been the most frequent pairings in the training phase, or *incongruent* pairs, the pairs that had been presented infrequently during training. Following each short list, participants were presented with the left-hand member of the pair, along with a fragment of the right-hand member that could be completed with either of the two responses (e.g., knee b_n_) and asked to recall the response that had appeared in the preceding short list. For congruent pairs, automatic influences created in the training phase and recollection would both serve as bases for correct responding. In contrast, for incongruent pairs, automatic influences would operate in opposition to recollection, and when recollection failed, produce errors akin to the action slip produced by the aged professor.

Performance was examined under either long or short response deadline conditions (see Fig. 3a). For incongruent items, response speeding led to an increase in the likelihood of incorrectly responding with the item that was made typical by training. In contrast, for congruent items, response speeding led to a slight decrease in producing those items (i.e., a decrease in correct responding). Estimates of recollection and the automatic influences of memory (Fig. 3b) were obtained using the same equations as described for the inclusion/exclusion procedure. For gaining estimates, congruent items served in the same role as an inclusion test, whereas incongruent items served in the same role as an exclusion test. The results showed that, in agreement with the results from previous inclusion/exclusion studies, response speeding at test selectively influenced estimated recollection. Moreover, the results reported by Hay and Jacoby (1999) also converged with those from the inclusion/exclusion procedure, by showing that age differences occurred entirely because of a reduction in older adults' ability to recollect.

Hay and Jacoby's (1996) experiments also included "guessing" items that served as an indirect test of memory. For those items, cues were paired with two different responses during training, as was done for congruent and incongruent test items, but neither the cue word nor its response had been presented in the preceding short list. Participants were warned that test items of this sort would occur, and they were instructed to guess on those items. The results from guessing items (see Fig. 3b) showed probability matching and closely agreed with the estimated automatic influences of memory (see Jacoby, Debner, & Hay, 2001, for similar results). This convergence between performance on an indirect test (guessing items) and estimates gained from the process-dissociation procedure provides converging evidence for the assumptions underlying the process-dissociation procedure, since the details of the indirect test were such as to make it likely to be process pure.

Caldwell and Masson (2001) extended the congruent/incongruent procedure to examine age-related differences in memory for object locations, and they found that age differences in performance were fully due to older adults' lessened ability to recollect. Tu, Hampton, and Murray (2011) used the congruent/incongruent procedure to show that perirhinal cortex removal dissociates two memory systems in the matching-to-sample behavior of monkeys. The findings of a convergence of results from the inclusion/exclusion procedure and the congruent/incongruent procedure, along with the convergence with performance on an indirect test, provide support for the underlying assumptions of, and show the general applicability of, the process-dissociation approach. The congruent/incongruent procedure holds advantages over the inclusion/exclusion procedure in that the instructions are less complex and that the congruent/incongruent procedure allows for greater experimenter control of automatic influences, by means of its training phase.

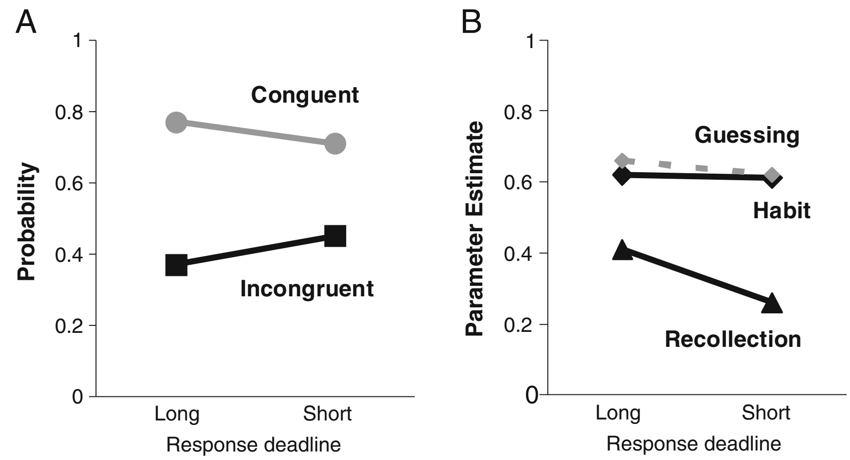

Fig. 3 (**a**) Probability of responding positively with an item made typical by training under congruent and incongruent conditions, and (**b**) estimates of recollection and habit, plotted along with guessing responses to nonstudied items. Data from Exp. 3 of "Separating Habit and Recollection: Memory Slips, Process Dissociations, and Probability Matching" by J. F. Hay and L. L. Jacoby, 1996, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, pp. 1323–1335. Copyright 1996 by the American Psychological Association

Treating an indirect test as process pure Jacoby, Bishara, Hessels, and Hughes (2007) provided evidence of convergence between results from an indirect test that was designed to approximate being process pure and estimates gained from the inclusion/exclusion procedure.

To estimate the contributions of recollection and of automatic influences, Jacoby et al. (2007) combined results from a test of fragment-cued recall with results from an indirect test of memory that asked participants to complete fragments with the first word that came to mind. Given the process-pure assumption along with an independence assumption, estimates could be obtained by holding that correct responding on the direct test of memory could result from recollection (R) or from automatic influences (A) when recollection fails (1–R): $P(\text{List 1 response} \mid \text{direct test}) = R + A(1 - R)$. Since the indirect test is assumed to be process pure, R can be computed by setting A equal to the indirect-test performance.

The results gained by using the direct/indirect test means of obtaining estimates revealed that manipulating interference, in a way similar to that done by Hay and Jacoby (1996), selectively influenced estimated automatic influences, whereas manipulating the amount of List 1 study time produced an opposite dissociation by selectively influencing estimated recollection. Experiment 3 included conditions that allowed estimates to be obtained by the inclusion/exclusion procedure, as well as by the means of combining results from direct and indirect tests. Although the sets of equations differ for the two estimation procedures, they agree in their assumption of independence. The results revealed near perfect convergence of the estimates gained by casting the two estimation procedures in multinomial models, as well as an excellent fit for each of the two models. As an example, estimates of A for the two conditions that were expected to differ in terms of automatic influences produced estimates of automatic influences measured by the inclusion/exclusion procedure (.49 and .69) that were near identical to the results for the corresponding conditions that were given by means of an indirect test (.48 and .68). The convergence of performance on an indirect test that was designed to be process pure with estimates gained from a process-dissociation procedure is the same pattern that was observed by Hay and Jacoby (1996), and it provides further support for the validity of the assumptions underlying process-dissociation procedures.

Independent remember/know (IRK) Yonelinas and Jacoby (1995) argued that an alternative way of measuring recollection and familiarity would be to make use of subjective report procedures. Subjective reports have been used by others to distinguish between different bases for responding on memory tests. In particular, "remember" judgments in the remember/know procedure, introduced by Tulving (1985) and further developed by Gardiner and his colleagues (e.g., Gardiner, 1988; Gardiner & Richardson-Klavehn, 2000; Richardson-Klavehn, Gardiner, & Java, 1996), have been identified with recollection. For that procedure, participants report on experiential states while taking a test of memory. The procedure has most often been used with tests of recognition memory performance. Participants classify items as "old" or "new," and further classify items called "old" as "remember" or "know." Items are to be classified as "remember" only if a detail of the study presentation is recollected. A "know" response is to be given to items that seem familiar, but whose study presentation is not recollected.

Yonelinas and Jacoby (1995) argued that if participants made a "remember" response whenever they recollected the occurrence of an item, those reports could be used to estimate recollection (R). In contrast, if they made a "know" response whenever an item was familiar but not recollected (F[1 – R]), familiarity could be estimated as the probability of a "know" response, given that the item was not recollected (i.e., F = K/[1 – R]). On the basis of this logic, they examined estimates of recollection and familiarity derived on the basis of the IRK procedure and found that the estimates were similar to those derived on the basis of the inclusion/exclusion procedure, a pattern that has since proven to be quite general (see below; see also Jacoby, 1998; Yonelinas, 2002). The convergence between the process estimates derived with these different procedures is important in verifying the phenomenological validity of the inclusion/exclusion estimates, in the sense that it shows that these process estimates are not simply convenient mathematical descriptions of overt behavior, but rather reflect processes that are available to subjective experience. Jacoby et al. (2001) used a procedure for cued recall that is similar to the remember/know procedure to compare subjective reports of recollection with estimates of recollection gained by means of the congruent/incongruent procedure. The findings from their experiments revealed high correspondence between the two measures. For example, in their Experiment 2, the probability of a subjective report of recollection for young adults was .43, whereas the probability of recollection measured by the congruent/incongruent procedure was .44.

However, because the remember/know procedure measures recollection on the basis of subjective reports, whereas methods like the inclusion/exclusion procedure measure recollection on the basis of objective task performance, these approaches will not always lead to the same results. This can be illustrated by considering the effects of false recollection. Like signal detection approaches to measuring memory, the inclusion/exclusion method aims to measure the extent to which recollection supports accurate or controlled responding. Thus, incorrect responses (exclusion scores) are subtracted from correct responses (inclusion scores). If a participant were to falsely recollect some proportion of the test items, this would be expected to increase both the inclusion and the exclusion scores, and thus would be effectively subtracted out. In contrast, the subjective-report approach measures the subjective experience of recollection, which can occur for both studied items and nonstudied items. Although under most standard test conditions the likelihood that a new item will be falsely remembered as having been studied is low (e.g., 2 %–3 %), under some conditions—such as when the lures are selected to be highly similar to multiple study items—false recollection is quite prevalent (Roediger & McDermott, 1995). In these conditions, subjective and objective measures of recollection cannot be expected to be identical, and it is necessary to incorporate additional parameters to account for both true and false recollection (Yonelinas & Jacoby, 1995).

This interpretation of results from the remember/know procedure has been challenged by single-process theorists (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). Rather than treating remembering and knowing as qualitatively different states of awareness, the single-process account posits that the two types of judgment both rely on the strength of a unitary trace. A judgment of "remember" is said to reflect only the use of a criterion that is higher than that for a "know" judgment (for a summary of rebuttals to these arguments, see Gardiner & Richardson-Klavehn, 2000; Yonelinas, Aly, Wang, & Koen, 2010). However, the single-process account is insufficient, because it fails to explain the occurrence of these two subjectively distinct states and does not provide an explanation for why different classes of experimental variables have such consistent effects on those states (e.g., Gardiner & Richardson-Klavehn, 2000; Yonelinas, 2002; Yonelinas et al., 2010). But, perhaps more importantly, according to the single-process interpretation, there is no reason to expect a correspondence between "remember" judgments and the estimated probability of recollection or measures of source recollection (e.g., Wixted & Mickes, 2010; Yonelinas, 2001; Yonelinas et al., 2010). In contrast, the process-dissociation approach treats recollection and automatic influences (familiarity) as being alternative bases for responding. Doing so provides a reason to expect a correspondence between objective and subjective measures of recollection.

One obvious limitation of the subjective-report method is that, under this method, it is critical to ensure that participants comply with the remember/know instructions. Participants often confuse remembering with high-confidence recognition and can thus make "remember" responses even when they are unable to report any qualitative information about the study event (Rotello, Macmillan, Reeder, & Wong, 2005; Yonelinas, 2001). Under these conditions, the method no longer produces estimates that converge as closely with other measurement methods. This has likely been responsible for recent claims that remember/know results can sometimes be explained by simple differences in response criterion (Donaldson, 1996; Dunn, 2004). We have found that carefully instructing participants to only respond "remember" if they can report some qualitative information about the study event seems adequate to largely overcome these problems (Koen & Yonelinas, 2010; Yonelinas, 2001).

Receiver operating characteristics (ROC) An alternative way of measuring recollection and familiarity is to examine the relationship between hits and false alarm rates across differences in response bias (Yonelinas, 1994, 2001). The logic underlying this process-dissociation approach is that an old item can be accepted as old if it is recollected (R), or if it is not recollected (1 – R) but its familiarity exceeds the participants' response criterion (F > criterion). Rather than contrasting inclusion and exclusion conditions, though, in this procedure one examines performance across conditions in which the propensity to use familiarity is systematically varied. So, for example, if participants rate the confidence of their recognition responses on a scale from *sure new* (1) to *sure old* (6), one can examine hits and false alarms using a strict scoring criterion (i.e., only the "6" responses are counted as hits or false alarms), as well as a more lax criterion (e.g., both "5"s and "6"s are treated as hits and false alarms). Presumably, when a participant recollects qualitative information about a particular study event, he or she will be confident that it was studied, whereas familiarity will support a wider range of confidence in responses. In this way, the shape of the resulting ROC curve can be used to infer the contributions of recollection and familiarity, in the same way that linear regression is used to estimate the slope and intercept of a line (see Fig. 4a).

The ROC approach assumes that familiarity reflects the assessment of a quantitative memory strength signal, in a manner similar to that described by signal detection theory. Thus, all items have some familiarity value, but those that have been recently studied are, on average, more familiar than those that were not studied. In contrast, recollection reflects a threshold retrieval process whereby qualitative information about a previous event is retrieved. Recollection is not well described by a signal detection process, because individuals do not recollect information about every event that they have studied. Rather, on some trials, recollective strength may fall below a threshold, such that recollection fails to provide any discriminating evidence that an item has been previously encountered. The threshold assumption has been taken as controversial on theoretical grounds (Mickes, Wais, & Wixted, 2009; Slotnick & Dodson, 2005; Slotnick, Klein, Dodson, & Shimamura, 2000; Wixted, 2007), but this is because it has been misunderstood as requiring that recollection be all or none, in the sense that individuals recollect either everything about a study event or nothing about the event. The ROC approach assumes that recollection can vary from weak to strong, and that participants may recollect various aspects of the study event. Moreover, numerous direct tests of the threshold assumption—including studies revealing U-shaped zROC curves (for a review, see Yonelinas & Parks, 2007; for similar results from studies of rats, see Sauvage, Fortin, Owens, Yonelinas, & Eichenbaum, 2008), studies examining process estimates across changes in response bias (Koen & Yonelinas, 2010; Yonelinas, 2001), and results from second-choice forced choice paradigms (Kellen & Klauer, 2011; Parks & Yonelinas, 2009)—have verified that a threshold process does contribute to recognition (but see DeCarlo, 2003, for an attentional-encoding account of the observed memory threshold).

The ROC method has now been used quite extensively, and it has been shown to provide estimates of recollection and familiarity that converge with those derived using the inclusion/exclusion and IRK procedures (for a review, see Yonelinas, 2002). This lends further support to the assumptions underlying the different approaches. In addition, results from ROC studies can provide data sets that are more theoretically constraining than those of methods that include fewer observed response points, such as the remember/know procedure. For example, a single-process account can often fit results from simple remember/know experiments by assuming that "remember" responses are simply stronger than "know" responses (e.g., Donaldson, 1996; Dunn, 2004). However, as those authors acknowledge, accounting for remember/know results in terms of a difference in strength does not disprove the existence of two separable processes in memory. We agree, and argue that only when remember/know results are considered in the light of the broader process-dissociation literature does the importance of those results become apparent. As one example, it is now quite clear that single-process accounts of recognition memory are insufficient, because the shapes of the ROCs seen in recognition—particularly when performance is expected to rely heavily on recollection—contradict those models (e.g., DeCarlo, 2003; Kelley & Wixted, 2001; Rotello, Macmillan, & Van Tassel, 2000; Yonelinas, 1997; for a review, see Yonelinas & Parks, 2007).

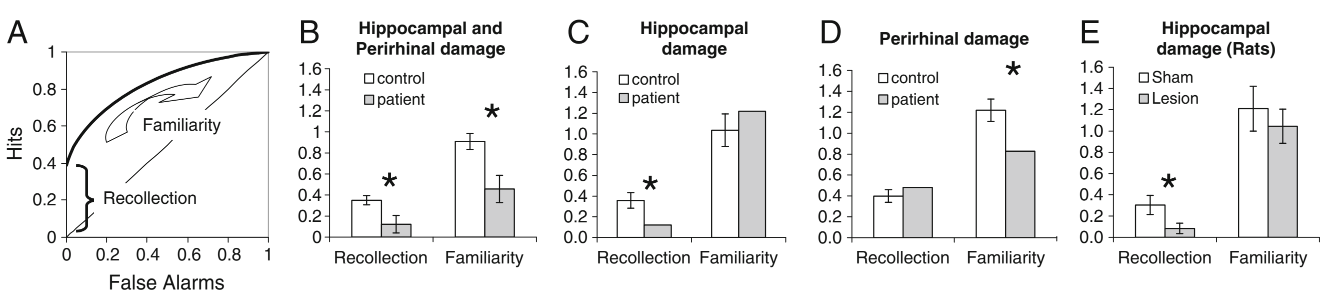

Fig. 4 (**a**) ROC shape and its relationship to recollection and familiarity. Hits are plotted against false alarms across levels of response bias, then fit to the dual-process signal detection model, in which recollection is estimated as the intercept and familiarity is estimated as the degree of curvilinearity. (**b**) patients with hippocampal plus perirhinal damage (Yonelinas et al., 1998, 2002), (**c**) a patient with hippocampal damage (Aggleton et al., 2005), (**d**) a patient with perirhinal cortex damage (Bowles et al., 2007), and (**e**) rats with selective hippocampal damage (Fortin et al., 2004)

Studies based on the ROC method have become increasingly fruitful over the past few years, leading to the development of a host of different dual-process models (see Yonelinas & Parks, 2007). Many of these models are extensions or generalizations designed to address potential limitations of earlier approaches, such as neurocomputational models that consider how these memory processes arise (e.g., Elfman et al., 2008; Norman & O'Reilly, 2003) and models that explore the utility of making more complex assumptions about the nature of the recollection signal (e.g., DeCarlo, 2003, 2008; Kelley & Wixted, 2001; Onyper, Zhang, & Howard, 2010; Parks, Murray, Elfman, & Yonelinas, 2011; Sherman, Atri, Hasselmo, Stern, & Howard, 2003). Other models have aimed to incorporate more detail about the functional contributions of different brain regions to performance (e.g., Aggleton & Brown, 1999; Eichenbaum, Otto, & Cohen, 1994; Eichenbaum, Yonelinas, & Ranganath, 2007). The latter work is discussed in more detail below.

Although the ROC method has been quite fruitful, it does have important limitations (for reviews, see Yonelinas et al., 2010; Yonelinas & Parks, 2007). For example, ROC analysis is predicated on the assumption that memory sensitivity is independent of response bias. As this principle is often used with dual-process models, it means that recollection should lead to high-confidence responses. Empirical tests of this assumption have shown that a vast majority of "recollected" responses are associated with high-confidence responses (e.g., Yonelinas, 2001), but it is likely that conditions can be arranged under which this assumption will be violated, such as when using response scales with a large number of response options. In addition, the ROC approach requires that a large number of responses be collected in each subject condition to provide a reliable measure of the ROC shape, and that may not always be possible. Finally, the method is particularly susceptible to floor and ceiling effects, because performance is measured across a wide range of hits and false alarm rates.

Current and future directions

The neural substrates of memory Early studies of amnesic patients showed that the medial temporal lobe (MTL; see Fig. 5) is critical for episodic recognition memory (Scoville & Milner, 1957). Since that time, however, we have learned a great deal more about how the regions within the MTL are related to memory, and process-dissociation procedures have played a central role in those advances. The earliest views of the MTL assumed that this region served as a single unified memory system. For example, one of the earliest views was that the MTL was critical for recollection, whereas cortical regions outside the MTL supported other forms of memory, such as familiarity and implicit memory (e.g., Huppert & Piercy, 1978; Mayes, Meudell, & Pickering, 1985; Wickelgren, 1979). According to this view, patients with MTL damage should exhibit recollection deficits, whereas familiarity-based recognition should remain unaffected. An alternative proposal was that the MTL was equally important for all forms of declarative memory, including both recollection and familiarity (Squire, 1994; Squire & Zola, 1998). By this view, MTL damage should lead to equivalent deficits in recollection and familiarity.

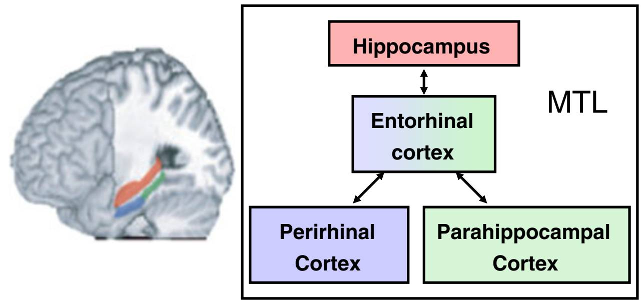

Fig. 5 Medial temporal lobe (MTL) regions thought to be important for recollection and familiarity

Essential in testing these alternative accounts was the development of measurement methods to estimate the contributions of recollection and familiarity to recognition. Several studies using ROC, IRK, and inclusion/exclusion methods all led to the rather surprising conclusion that both of the earlier models of the MTL were wrong. That is, in amnesic patients with extensive MTL damage, recollection was profoundly impaired, but familiarity also showed smaller but consistent deficits (Blaxton & Theodore, 1997; Kishiyama, Yonelinas, & Lazzara, 2004; Knowlton & Squire, 1995; Moscovitch & McAndrews, 2002; Schacter, Verfaellie, & Anes, 1997; Verfaellie & Treadwell, 1993; for an early review, see Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). The results from one such study, which used the ROC confidence procedure, are presented in Fig. 4b. These results are inconsistent with theories that assume that the MTL selectively supports recollection. In addition, the finding that familiarity was often less disrupted than recollection (for a review, see Yonelinas et al., 1998) was problematic for the view that the MTL was equally important for both recollection and familiarity.

During the same period, however, work on rats and nonhuman primates was leading to a class of models that provided a natural account of the existing human literature. For example, Eichenbaum et al. (1994) proposed that the hippocampus is critical for recollecting the associations of a memory cue, whereas the parahippocampal region (i.e., the gyrus immediately surrounding the hippocampus) can support recognition of familiar cues in isolation. Related work by Aggleton and Brown (1999) suggested that the hippocampus is critical for episodic recollection, whereas the perirhinal cortex (i.e., the anterior portion of the parahippocampal gyrus) supports judgments about the recency and familiarity of specific stimuli. Both of these models predict that hippocampal damage should disrupt recollection but not familiarity, whereas damage to the surrounding parahippocampal region should lead to deficits in familiarity. These models could account for the existing human amnesia results that showed deficits in recollection and in familiarity, because those studies invariably included patients with damage to the hippocampus and the surrounding parahippocampal gyrus.

However, the strongest prediction of these models is that patients with selective hippocampal damage should exhibit a selective impairment in recollection. Process-dissociation-based methods have since verified that prediction. For example, one study (Yonelinas et al., 2002) examining ROCs showed that mildly hypoxic patients exhibited severe deficits in recollection but demonstrated normal familiarity. The results were verified by using remember/know measures in the same patients. Moreover, the covariation between recall, recognition, and hypoxic severity was examined using structural equation modeling methods in a large sample of hypoxic patients, and this study indicated that hypoxic severity predicted the degree to which recollection, but not familiarity, was impaired. A similar pattern of deficient recollection and preserved familiarity was reported in a patient with relatively selective hippocampal atrophy related to meningitis (see Fig. 4c and Aggleton et al., 2005; see also Bastin et al., 2004; Bird & Burgess, 2008; Brandt, Gardiner, Vargha-Khadem, Baddeley, & Mishkin, 2008; Jäger et al., 2009; Peters, Thoma, Koch, Schwarz, & Daum, 2009; Turriziani, Serra, Fadda, Caltagirone, & Carlesimo, 2008). Thus, as predicted by the animal models, recollection in humans can be selectively disrupted by hippocampal damage. Note that some hypoxic patients do exhibit deficits in both recollection and familiarity (e.g., Cipolotti et al., 2006; Manns, Hopkins, Reed, Kitchener, & Squire, 2003), but these likely result from damage outside the hippocampus (Yonelinas et al., 2004).

An intriguing question is whether it might be possible to find patients with selective deficits in familiarity, and thus whether, neurologically, these two processes might be doubly dissociated. In a recent study, researchers examined a rather unusual patient with a lesion to the perirhinal cortex that did not impact the hippocampus, and they found that in this patient familiarity was selectively disrupted, leaving recollection unaffected (Fig. 4d; Bowles et al., 2007). These results were further supported by studies of aging and mild cognitive impairment that have indicated that hippocampal atrophy is related to recollection but not familiarity, whereas the volume of regions surrounding the hippocampus, such as the perirhinal cortex, is related primarily to familiarity (Wolk, Dunfee, Dickerson, Aizenstein, & DeKosky, 2011; Yonelinas et al., 2007).

Because it is difficult to rule out the effects of undetected damage in studies of human amnesia, it is important to also carefully consider results from other methods, such as those of fMRI studies examining the neural correlates of recollection and familiarity in healthy adults. A large number of such studies have now been published, and they provide converging evidence that the hippocampus is involved primarily in recollection (for reviews, see Eichenbaum et al., 2007; Skinner & Fernandes, 2007; Wais, 2008). Although some individual neuroimaging experiments do not fit this pattern, there is general consensus that the hippocampus is critical for recollection and that it plays little or no role in familiarity. For example, in a review of remember/know, source memory, and ROC studies that included recollection and familiarity contrasts, 16 of 19 studies showed that the hippocampus was involved in recollection, whereas only two showed hippocampal involvement in familiarity (Eichenbaum et al., 2007). In contrast, 13 of 15 studies showed that the perirhinal cortex was associated with familiarity, whereas only four showed relationships to recollection.

Imaging studies have also revealed that the parahippocampal cortex (i.e., the posterior portion of the parahippocampal gyrus) is often associated with recollection rather than familiarity. Although the role that this MTL region plays in recollection is not yet entirely clear, one possibility is that it reflects the retrieval of context, such as spatial or temporal information that is associated with the recollection of prior events (Diana, Yonelinas, & Ranganath, 2007; Eichenbaum et al., 2007).

The results from human studies of amnesia have also been supported by convergent results from studies of rats using ROC procedures (for a review, see Eichenbaum, Fortin, Sauvage, Robitsek, & Farovik, 2010). For example, Fortin et al. (2004) used a procedure in which rats were exposed to odors and, after a delay, were presented with a recognition test for previously presented odors and new odors. Response bias was manipulated by varying the amounts of food a rat received for a correct "old" or a correct "new" response, as well as the difficulty of digging in the test probe cup (i.e., a shallow vs. a deep probe cup). Recognition ROCs were plotted as a function of response bias and were used to derive estimates of recollection and familiarity, and these showed that rats with selective hippocampal lesions exhibited selective reductions in recollection that left familiarity unaffected (Fig. 4e). These results are in good agreement with the earlier human studies showing that amnesic patients with selective hippocampal damage have selective recollection impairments. The results suggest that the analysis of recognition memory ROCs provides a fruitful method to bridge the human and animal memory literatures, and thus opens up the possibility of additional translational work, such as examining pharmacological manipulations that might not be possible with human participants. Related studies have also been conducted that use ROC and other process-dissociation procedures in nonhuman primates (Guderian, Brigham, & Mishkin, 2011; Tu et al., 2011).

These results are important in directly linking the animal and human literatures, and they help address potential concerns that the deficits in human amnesic patients may be due to hidden damage. Moreover, the convergence across these different experiments, paradigms, and species is important because it rules against alternative interpretations that can arise when considering only one experiment or one experimental paradigm. We believe that this type of work is essential for advancing our understanding of the different forms and uses of memory.

Diagnosis and treatment of memory deficits The results reported in prior sections have provided neural evidence to support the distinction between recollection and automatic influences of memory. The distinction between different bases for responding has potentially important implications for the diagnosis and treatment of memory deficits. Such qualitative differences have not typically been acknowledged when assessing memory deficits. However, Tse, Balota, Moynan, Duchek, and Jacoby (2010) provided results showing the advantage of placing recollection in opposition to familiarity for early detection of very mild dementia of the Alzheimer's type (DAT). They found that memory exclusion performance provided predictive power beyond standard psychometric measures of general cognitive abilities in discriminating between healthy older adults and those in the earliest stages of DAT. The high rate of exclusion errors produced by those in early-stage DAT was discussed in terms of the importance of attention control systems for memory retrieval. Further experiments done to examine the utility for diagnosis of specifying qualitative differences in the bases for responding would be useful.

Improved diagnosis of memory deficits is important for guiding treatment. Again, others have not distinguished between recollection and automatic influences of memory when attempting to enhance memory performance (for a recent review, see Hertzog, Kramer, Wilson, & Lindenberger, 2009). In contrast, Jennings and Jacoby (1997) devised an opposition procedure that draws on the common error of mistakenly repeating oneself. The task was designed to require reliance on recollection to avoid repetition errors. The results showed that older adults were much more prone to repetition errors than were young adults, revealing age differences in the ability to engage in recollection. Training older adults' ability to recollect was accomplished by successively increasing the spacing of repetitions so as to gradually increase the difficulty of using recollection to avoid repetition errors. Subsequent research provided evidence that training to avoid repetitions produced transfer to other tasks (Jennings, Webster, Kleykamp, & Dagenbach, 2005). Such transfer effects are important, because it is commonly found that the effects of memory training are largely restricted to the task that was employed for training. Aiming training at underlying processes rather than at tasks holds promise as a means of producing more general transfer effects.

Training under conditions of high interference, as is done in the avoiding-repetitions procedure, might be generally useful for enhancing recollection. In this vein, prior experience with proactive interference in a situation reduces later proactive interference in a similar situation for both young and older adults (Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010). Wahlheim and Jacoby (2011) provided evidence that the later reduction in proactive interference produced by a prior encounter resulted from increased reliance on recollection as a basis for responding.

Improved diagnosis of memory impairments using process-dissociation methods can also be useful in tailoring training protocols to build on individual's preserved memory abilities. For example, as described earlier, process-dissociation methods have indicated that patients with hippocampal damage exhibit pronounced deficits in recollection yet show preserved familiarity-based recognition. The recollection deficits lead these patients to perform extremely poorly on tests that require the retrieval of novel associations, such as recognition tests that require them to remember that two randomly selected words, such as sea–cube, were paired together. These impairments can be greatly reduced, however, under conditions in which the preserved familiarity processes are able to support associative learning (Diana, Yonelinas, & Ranganath, 2008; Quamme, Yonelinas, & Norman, 2007)—for example, under conditions in which the word pairs are treated as single units (i.e., "a 'sea-cube' is a new compound word that refers to a liquid-filled paper weight") rather than as separable items (i.e., "he looked out at the 'sea' as his ice 'cube' melted"). Similar improvements in memory might also be seen in aged participants who exhibit selective recollection deficits, but such techniques might be less useful in patient groups such as those with early Alzheimer's disease, in whom severe deficits in both recollection and familiarity have been reported (e.g., Ally, Gold, & Budson, 2009).

Recent research has highlighted a potential relationship between memory errors and errors in perception. Older adults are more prone to false remembering than are young adults (e.g., Schacter, Koutstaal, & Norman, 1997) and are also more prone to false seeing (Jacoby, Rogers, Bishara, & Shimizu, 2012) and false hearing (Rogers, Jacoby, & Sommers, 2012). Older adults' greater reliance on context results in increased false seeing and false hearing. For example, in an incongruent test condition, Rogers et al. presented a word in noise (e.g., "pay") following an incongruent context word (e.g., "barn") and asked people to report the word presented in noise. Older adults frequently reported a similar-sounding word that fit the context (e.g., "hay") and mistakenly claimed to have "heard" that word, whereas young adults almost never did so. This was true even though a titration procedure was used to equate the performance of the young and older adults on baseline trials in which a biasing context was not provided. Just as older adults are more likely to falsely remember by reporting what usually happened rather than reporting what happened on a particular occasion (e.g., Hay & Jacoby, 1999), they are also more like to falsely see and falsely hear by reporting what was expected rather than a presented perceptual stimulus.

Age-related deficits in recollection have been shown to correspond to a deficit in the ability to constrain retrieval processing in ways that is optimal for remembering a particular prior event (e.g., Anderson, Jacoby, Thomas, & Balota, 2011; Jacoby, Shimizu, Velanova, & Rhodes, 2005). Similarly, age differences in false seeing and false hearing might reflect a deficit in the ability to constrain processing to a present physical stimulus, putting aside expectations. This potential similarity suggests that those who are extremely prone to false remembering might also be highly prone to false seeing and false hearing. As reported by Jacoby, Jennings, and Hay (1996), Jennings and Hay found that memory complaints in everyday situations were highly correlated with a measure of recollection gained from a process-dissociation procedure ($r = –.56$), but were uncorrelated with automatic influences ($r = .08$). Similarly, perhaps recollection measured in a memory task will be found to correlate with false seeing and false hearing. Such correlations would suggest that a decline in cognitive control that reflects frontal-lobe functions is common to false memory, false seeing, and false hearing. Another reason for interest in the relation between perception and memory is that false remembering can originate from false seeing and/or false hearing. Perhaps a measure of false perception would be an even better diagnostic measure for early DAT than was the exclusion test used by Tse et al. (2010).

Moving beyond memory As the prior section indicates, the process-dissociation approach has been found to be useful in domains other than memory, and future work in these areas seems particularly promising. For example, in an early study using the inclusion/exclusion procedure, Debner and Jacoby (1994) showed that conscious and unconscious effects of perception could be separated in subliminal-perception paradigms. More recently, Aly and Yonelinas (2012) examined ROCs in perception and short-term memory discrimination tasks for complex images and found that the results were inconsistent with classical signal detection models. Moreover, those results suggested that performance reflected the contributions of two functionally independent processes: one of conscious perception and another of knowing. The results were interpreted as providing evidence for a unified model that links the domains of memory and perception.

Process-dissociation methods have also been used to separate the effects of prejudice in social psychology paradigms (e.g., Stewart & Payne, 2008), automatic and controlled word reading processes in Stroop interference tasks (Lindsay & Jacoby, 1994), and repetition effects on reasoning tasks (Begg et al., 1992), to mention only a few applications. An experiment that is yet to be done further illustrates the general utility of opposition procedures. Mauboussin (2009) noted that in gambling tasks, it is often difficult to determine whether a success is due to skill or to luck, because both would lead to the same outcome. To better measure the contribution of skill to gambling, he suggested that one should look at the effects of attempting to lose, which is essentially an opposition procedure. By adding a facilitation condition, it might be possible to gain estimates of the contributions of skill and luck. As an example, the results of attempting to lose when playing the slot machines would likely not differ from those produced by attempting to win, showing a zero contribution of skill. Similarly, it would be interesting to see how financial advisors fare when attempting to pick losing versus winning stocks from a specified set.

Concluding comments

We have found converging evidence using a host of process-dissociation procedures that, on their surface, appear to be very different. Doing so provides support for the assumptions underlying the process-dissociation approach and for its general utility. We have also specified boundary conditions for dissociations of the sort that we have found. For the inclusion/exclusion procedure, it is critical that the instructions encourage direct retrieval rather than reliance on a generate/recognize strategy. Jacoby, Bishara, Hessels, and Toth (2005) and Jacoby, Shimizu, Velanova, and Rhodes (2005) reported results to support a distinction between source-constrained retrieval and source monitoring that is relevant to the distinction between direct retrieval and use of a generate/recognize strategy. The instructions for the remember/know procedure are also important for finding our converging evidence.

For some, the quantitative aspects of process-dissociation models are too simplistic, and more complex models are desired. We believe that multiple levels of modeling are essential, that they provide complementary information, and that in many cases they are found to be in good agreement. We value the simplicity of the process-dissociation approach, in part because of its potential utility for addressing applied problems such as the diagnosis and treatment of memory deficits. A more complex model with, for example, 30 parameters might provide more exact measurement of some aspects of performance. Such approaches are particularly useful when they allow one to incorporate knowledge of the underlying neurobiology (e.g., Elfman et al., 2008; Norman & O'Reilly, 2003). However, such models are often narrow in focus, in that they deal with only a single task (e.g., recognition memory), and their complexity makes it difficult to relate them to applied problems. We believe that our success in finding converging evidence across a variety of tasks, along with the extensions of our procedures, shows the value of the process-dissociation approach. However, it should be noted that our procedures cannot be "taken off the shelf" with no regard for meeting boundary conditions. The same can be said for estimation procedures for all models.

The Jacoby (1991) article ended by saying "There is good reason for abandoning the practice of equating processes with tasks. Doing so provides hope for progress" (p. 538). We believe that that ending is also suitable for the present article.

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