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Automatic processing influences free recall: converging evidence from the process dissociation procedure and remember-know judgments

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Abstract Dual-process theories of retrieval suggest that controlled and automatic processing contribute to memory performance. Free recall tests are often considered pure measures of recollection, assessing only the controlled process. We report two experiments demonstrating that automatic processes also influence free recall. Experiment 1 used inclusion and exclusion tasks to estimate recollection and automaticity in free recall, adopting a new variant of the process dissociation procedure. Dividing attention during study selectively reduced the recollection estimate but did not affect the automatic component. In Experiment 2, we replicated the results of Experiment 1, and subjects additionally reported remember–know–guess judgments during recall in the inclusion condition. In the latter task, dividing attention during study reduced remember judgments for studied items, but know responses were unaffected. Results from both methods indicated that free recall is partly driven by automatic processes. Thus, we conclude that retrieval in free recall tests is not driven solely by conscious recollection (or remembering) but also by automatic influences of the same sort believed to drive priming on implicit memory tests. Sometimes items come to mind without volition in free recall.

Keywords Memory · Recollection · Familiarity · Process dissociation · Free recall · Remember-know

Dual-process models of retrieval distinguish between consciously controlled and automatic memory processes (Jacoby, 1991; Yonelinas, 2002). Recollection involves consciously controlled retrieval of past events, whereas automatic processes influence retention with little effort or attention. The bulk of research on dual process theories of memory has employed variants of recognition memory tests in which subjects identify items as studied or not studied. Both recollection and automaticity (often referred to as *familiarity*) are believed to influence performance on recognition tests, and much research has focused on separating the contributions of these underlying processes (e.g., Jacoby, 1991; Mandler, 1980; Wagner, Gabrieli, & Verfaellie, 1997; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). Similarly, considerable effort has been devoted to separating the controlled and automatic influences on cued recall (Hay & Jacoby, 1996; Jacoby, Debner, & Hay, 2001; McBride & Dosher, 1999; Pompéia, Lucchesi, Bueno, Manzano, & Tufik, 2004). By contrast, free recall tests, in which subjects are free to produce studied items in any order, have not been used to investigate recollection and automaticity, based at least partly on the oft-mentioned assumption that recall tests represent relatively pure measures of conscious recollection (Aggleton & Brown, 1999; Gelbard-Sagiv, Mukamel, Harel, Malach, & Fried, 2008; Quamme, Yonelinas, Kroll, Sauve, & Knight, 2004; Tsivilis et al., 2008; Yonelinas et al., 2002). For example, Yonelinas et al. (2002) claimed that, “Recall requires recollection, whereas recognition judgments can be based on either recollection or on assessments of test-item automaticity” (p. 1236). Similarly, Quamme et al. (2004) suggested that, “...two memory processes, recollection and

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automaticity, contribute to recognition, whereas only recollection contributes to recall" (p. 672). The purpose of the experiments we report was to investigate a novel approach for examining the extent to which both recollective and automatic processing influence retrieval during free recall tests using the process dissociation procedure (Jacoby, 1991) and the remember-know paradigm (Tulving, 1985).

Prior research hinting that automatic processes influence free recall

Although many researchers have assumed that free recall is completely based on conscious recollection, hints abound in the literature to indicate otherwise. One such hint comes from work in which the performance of amnesic patients is compared to that of matched control subjects. The classic form of dissociation showed that dense amnesics could learn new skills and even retrieve previously studied words on implicit memory tests despite no apparent conscious recollection of the learning episodes (Warrington & Weiskrantz, 1970). Nonetheless, these patients performed above chance on most explicit memory tests (even free recall).

An elegant example of the dissociation between direct and indirect tests was reported by Graf, Squire, and Mandler (1984). They had amnesic and control subjects study words that were tested for free recall, word-stem cued recall, or word stem completion. The primary finding of interest was that performance of control subjects was substantially better than amnesics' performance on explicit tests of free recall (37% vs. 14%, respectively) and word-stem cued recall (69% vs. 58%, respectively), but that performance was equivalent on the word stem completion test - and actually the patients did somewhat better on this test (49% vs. 57%, respectively). The comparison between word-stem cued recall and word-stem completion suggests that control subjects' performance benefited from explicit instructions to use recollection on the cued recall test (performance rose from 49% to 69% with explicit instructions), but amnesics' performance showed no such benefit (57% and 58% on the two tests). Presumably, this null result for the patients occurred because they lacked the ability to recollect. On the other hand, amnesics' recall performance was well above zero in both free and cued recall. The usual explanation given for such performance in the literature is that some amnesics may have a partial sparing of conscious recollection or have some "residual declarative memory." However, we suggest an alternative possibility: Performance on free and cued recall tests may be partly driven by automatic influences from prior experience. Consequently, amnesic patients can produce 14% correct performance on a free recall test and 58% on a cued recall test despite showing no evidence of conscious recollection (i.e., when given explicit instructions on the word-stem cued recall test, they could not improve their performance as control subjects did). In fact, one conjecture that might be made in examining these data closely is that perhaps cued recall in normal subjects is mostly driven by automatic processes: On the explicit test, they recalled 69% of the items, but of course they could produce 49% even under implicit test instructions.

Another body of work suggesting that automatic processes influence even cued and free recall comes from the remember–know paradigm (Tulving, 1985). In his first demonstration experiments, Tulving had subjects engage in free recall, cued recall, and recognition tasks. He found that although the proportion of responses in these tasks deemed to be "known" and not "remembered" decreased from free recall to cued recall to recognition, know responses did occur for both free and cued recall. If one assumes that know responses indicate response production without conscious recollection (e.g., Gardiner, 1988; Rajaram, 1993; Tulving, 1985), then know responses indicate an automatic influence on recall tests (as well as recognition tests). Further, the automatic influence on recall tests is replicable and systematic (Hamilton & Rajaram, 2003; McDermott, 2006). We consider the remember–know procedure more fully below, but the point for now is that know responses in free recall, coupled with the above zero free recall of amnesic patients, hints that automatic processing likely influences free recall even in healthy normal subjects. These lines of research suggest that the conscious experience associated with automatic processing influences free recall, rather than an automaticity process per se. The purpose of our experiments was to provide much stronger evidence that automatic processing influences free recall.

Estimating recollection and automaticity

One traditional method of trying to examine the influence of recollective and automatic processes during retrieval involves studying dissociations among tests that are presumed to rely on these processes to a greater or lesser degree. For example, free recall and recognition are often compared in order to better understand memory impairments of different subject populations (e.g., younger and older adults). However, these comparisons have led to mixed results. For example, relative to control subjects, in some studies amnesics showed greater deficits in free recall than in recognition (Hirst et al., 1986; Quamme et al., 2004; Yonelinas et al., 2002). Similar findings have been reported for frontal patients compared to controls (Janowsky, Shimamura, Kritchevsky, & Squire, 1989) and for older compared to younger adults (McIntyre & Craik, 1987). On the other hand, other studies have reported similar deficits on tests of free recall and recognition relative to controls for amnesics (Haist, Shimamura, & Squire, 1992; Manns, Hopkins, Reed, Kitchener, & Squire, 2003), frontal patients (Kopelman & Stanhope, 1998), and older adults (James, Fogler, & Tauber, 2008). Thus, comparing free recall and recognition tests in an effort to isolate distinct memory processes has yielded ambiguous results.

The ambiguity associated with results from studies comparing free recall and recognition tests raises an important limitation of the task dissociation approach: namely, no test appears to be a process-pure measure of a single memory process. This issue of process-purity, or lack thereof, has been best articulated in discussions of the process-dissociation procedure (Jacoby, 1991; Jennings & Jacoby, 1993; Yonelinas, 2002). Jacoby (1991) developed the process-dissociation procedure to estimate the contributions of recollection and automaticity to memory performance. There have been many instantiations of the procedure over the years, but the cued recall version reported by Jacoby (1998) is perhaps most similar to the paradigm used in the current study. He had subjects study a list of five-letter words under full- or divided-attention conditions, followed by an inclusion and exclusion task in which three-letter word stems were presented for cued recall. For the inclusion task, subjects were asked to complete the word stem with a word they studied earlier, whereas for the exclusion task, subjects were asked to complete the word stem with a new word. In both conditions, subjects were encouraged to guess (i.e., respond with the first word that came to mind) if they could not recall the word that corresponded to the earlier word stem. Note that according to Jacoby (1998), the instruction to guess is critical to obtaining valid estimates of recollection (R) and automaticity (A) because it encourages the use of automatic processing on both the inclusion and exclusion tests (see also Jacoby, Yonelinas, & Jennings, 1997). The inclusion test is similar to a typical stem cued recall test in that accurate recall can be based on recollection, a controlled process, and automaticity, an automatic process. The influence of recollection and automaticity on inclusion tests is captured in the following equation that describes the influence of recollection and automaticity in accurate performance on an inclusion test:

$$\mathrm{Inclusion} = \mathrm{R} + \mathrm{A}(1 - \mathrm{R})$$

By contrast, errors on the exclusion task are thought to occur when automatic processing influences performance in the absence of recollection. In the present example, this error would represent a failure to recollect that an item was presented in the studied list. This arrangement is captured in the following equation, which describes the processes involved in false alarming in the exclusion condition:

$$\mathrm{Exclusion} = \mathrm{A}(1 - \mathrm{R})$$

In practice, calculating the recollection component of a task is done by simply subtracting the false alarm rate (F) for the exclusion condition, which is based on automaticity in the absence of recollection, from the hit rate for the inclusion condition, which is based on both recollection and automaticity:

$$\mathrm{R} = \mathrm{Inclusion} - \mathrm{Exclusion}$$

Automaticity can then be calculated by dividing false alarms on the exclusion task (automaticity in the absence of recollection), by the inverse of the recollection estimate:

$$\mathrm{A} = \mathrm{Exclusion}/(1 - \mathrm{R})$$

Despite the broad applications of Jacoby's (1991) process dissociation procedure, or variants of it, to address problems in many areas in psychology (Destrebecqz & Cleeremans, 2001; Knight, 1998; Lindsay & Jacoby, 1994; Payne, 2001; Verfaellie & Treadwell, 1993), the procedure has never been applied to free recall tests in which subjects are asked to recall studied items in any order. There are probably several reasons why this issue has not been addressed. First, because free recall is often considered a process pure measure of conscious recollection, researchers might not have bothered to use the procedure to examine the contribution of a process (automaticity, A) that is not believed to be involved in the test. Second, in order to estimate recollection and automaticity using process dissociation, inclusion and exclusion performance must be based on tests that require the production of information in situations that differ only in whether subjects are attempting to include or exclude previously studied items. This comparison is difficult using free recall tests because the number of items produced on a free recall test typically varies for each subject. That is, because subjects are not only "free" to recall items in any order but to produce as many items as they like, differing numbers of items are recalled across subjects. Finally, when unrelated words are used as the to-be-remember stimuli, as is often the case in free recall experiments, avoiding exclusion errors might be quite easy. Subjects would easily be able to generate new words on an exclusion test if they were free to choose any items in their lexicon that had not been presented. They would literally have thousands of words from which to sample, and the possibility of an exclusion error would probably be nearly zero for healthy normal subjects. Thus, even if automatic influences were operating in free recall, their measurement would be obscured by being able to generate many words distant in meaning from the target words.

In order to calculate estimates of recollection and automaticity for free recall using the process dissociation procedure, we created a procedure that circumvents the aforementioned methodological obstacles. First, in order to ensure that recollection and automaticity estimates were based on the same number of items in recall, we used forced recall tests to measure inclusion and exclusion tests that required output of the same number of items as the forced recall test. Forced recall is the procedure in which subjects are asked to recall previously presented material and to produce a fixed number of items, guessing if needed (see Erdelyi & Becker, 1974; Roediger & Payne, 1985). With unrelated word lists, free and forced recall produce equivalent levels of correct responding, although this is not the case when the materials are structured (e.g., Roediger, Srinivas & Waddill, 1989). This design characteristic allowed us to calculate R and A using process dissociation. Note that subjects are still free to recall items in any order, and thus retrieval strategies for free and forced recall are similar.

In order to constrain inclusion and exclusion test performance to a reasonable, known sample of items and to ensure some level of errors on the exclusion test, we used categorized word lists as to-be-remembered stimuli. Because the number of exemplars in a category is limited to a constrained subset of subjects' lexicon, this allowed us to ensure some level of control over subjects' responses, while still requiring them to recall items in any order. The free recall of categorized lists has been studied for many years, and exclusion errors using recall-like exclusion tests are not uncommon, at least using categorized lists (Brown & Murphy, 1989; McCabe, Smith, & Parks, 2007). Data also suggest that the retrieval processes involved in free recall of a single category and free recall of an unrelated word list are qualitatively similar, as measured by changes in subjective organization over time (MacLeod, 1985). Moreover, it should be noted that all retrieval is cued based, whether the cue simply refers to a list just presented or a category label referring to such a list (Tulving, 1974). Of course, the influence of preexisting associations in semantic networks is considerably greater for categorized word lists than for unrelated word lists (Meade & Roediger, 2006). Thus, the paradigm we use is not identical to conditions involved in free recall of unrelated word lists, but the use of categorized word lists was necessary to calculate R and A estimates using our variant of the process dissociation procedure.

Remembering and knowing in free recall

In the current study, we also used the remember–know procedure to examine the subjective experience accompanying retrieval during forced recall (cf., Meade & Roediger, 2006, 2009). The remember–know procedure (Gardiner, 1988; Rajaram, 1993; Tulving, 1985) involves asking subjects to differentiate between responses for which they can recollect contextual details associated with retrieval (i.e., a remember response) and responses that are devoid of these contextual details (i.e., a know response). The assumption is that remember responses are influenced by recollection to a great degree, and know responses are influenced by automatic processing to a great degree (see Clark-Foos & Marsh, 2008; De Goede & Postma, 2008; Kelley & Jacoby, 1998; Rajaram, 1993). Of particular interest was an examination of whether dividing attention reduced the subjective experience of recollection (i.e., remember judgments) but left subjective experience of familiarity (i.e., know judgments) unaffected (Gardiner & Parkin, 1990), a pattern which would parallel findings using the process dissociation procedure (Jacoby, Toth, & Yonelinas, 1993).

We note that because remember–know judgments measure the subjective experience associated with retrieval, but the process dissociation procedure estimates the ability to discriminate between contexts in which items were presented, these measures may not be perfectly aligned (Kelley & Jacoby, 1998). Indeed, we did not use remember–know judgments to calculate process estimates because these judgments are metacognitive judgments that do not necessarily distinguish between recollection and automaticity in the same manner as process dissociation estimates (Kelley & Jacoby, 1998; McCabe & Geraci, 2009; Wais, Mickes, & Wixted, 2008). Rather, we used remember–know judgments to examine whether the subjective experience associated with forced recall was affected in a manner similar to process estimates. Specifically, we were interested in whether dividing attention affected remember judgments, but left know judgments unaffected, which is a pattern found using recognition tests (Gardiner & Parkin, 1990; Yonelinas, 2001).

Interestingly, although hundreds of experiments using the remember–know procedure in recognition have been reported, only a few have used the procedure is used in conjunction with free recall tests (Hamilton & Rajaram, 2003; McDermott, 2006; Tulving, 1985). As noted above, although free recall tests require the conscious production of target items, which would seem to demand controlled processing, the subjective experience of knowing does arise during free recall tests (Hamilton & Rajaram, 2003; McDermott, 2006; Tulving, 1985). If recall of an item is fluent, but recollective details are absent, subjects may feel that a retrieved item "just came into mind" rather than being consciously recollected. Thus, the subjective experience of familiarity, which is captured by know judgments, is largely based on a relatively automatic memory process (Clark-Foos & Marsh, 2008; De Goede & Postma 2008; Rajaram,

1993) and should be evident if there is an automatic component involved in retrieval during a free recall test.

Experiment 1

In Experiment 1 we examined inclusion (i.e., forced recall) and exclusion tests using categorized word lists in order to estimate the influence of recollection and automaticity using the process dissociation procedure. As discussed previously, recollection is dependent on consciously controlled processing, whereas the other component (often called familiarity in recognition experiments) is relatively automatic. Thus, manipulations that reduce the amount of attention available during study or testing selectively affect recollection but often have little influence on automaticity (see Yonelinas, 2002 for a review). Because dividing attention has been shown to affect process estimates for recognition and cued recall tests (Jacoby, 1991, 1998), we compared full-attention and divided-attention conditions in order to determine if we could replicate this pattern using the current recall paradigm.

Method

Subjects Forty-eight undergraduates from Washington University in St Louis participated for course credit. Half were randomly assigned to the full-attention group and the other half were randomly assigned to the divided-attention group.

Materials Subjects were asked to remember words from the following categories: body parts, four-legged animals, sports, and articles of clothing. These categories were selected because they were large, and students could generate many items from them. The words used were taken from both the Van Overschelde, Rawson, and Dunlosky (2004) and Battig and Montague (1969) norms. Two sets of to-be-remembered stimuli were created for each category. We took the 40 most frequent responses for a given category (excluding obsolete and identical exemplars) and divided them into two 20-word sets (sets A and B). Set A included all the odd numbered items between the first and fortieth items, and set B included the even numbered items. These sets were counterbalanced such that half of the subjects studied set A, and the other half studied set B. Studied items were recorded and presented auditorily to subjects at a rate of one word every 3 seconds.

Each subject completed two types of tests, namely, forced recall (inclusion) and exclusion, with a test given following presentation of all four of the categorized lists. Each test was a paper-and-pencil test, with the category name at the top of the sheet of paper, and 20 answer spaces underneath (two columns of ten spaces).

Subjects in the divided-attention group were also required to engage in an odd-digit tracking task (modeled after Craik, 1982) while they listened to the list. For this task, digits appeared one at a time for 1 second each on a computer screen directly in front of the participant. There were 180 digits presented in total, with 24 runs of three odd-digits randomly intermixed. Subjects were asked to press the space bar if three odd-digits appeared consecutively.

Procedure Subjects were told that they would be studying pre-recorded lists of words from different categories and that they should remember the words for an upcoming memory test. They were told that the name of the category would be read followed by the words from that category. Subjects in the divided-attention group were allowed to practice the odd-digit tracking test before they were given the study instructions and then told that they should listen to the list and remember the words as best they could, but should also ensure that they did not miss any odd-digit runs on the tracking test. After all four categories were studied, subjects played a video game (Pacman) for 4 minutes as a distracter task. Subjects completed inclusion tests for two of the studied categories, and exclusion tests for the other two categories. The categories were tested in the order they were studied (i.e., body parts, four-legged animals, sports, an article of clothing). For half the subjects in each attention group, the forced recall (i.e., inclusion) tests were given for the first two categories and exclusion tests for the last two; for the other half of the subjects, exclusion tests were given for the first two categories and forced recall (i.e., inclusion) for the latter two.

The instructions for the inclusion test were as follows:

> Earlier you heard 20 words from the category ‘x’ [e.g., body parts]. I want you to try to recall all 20 of the words on the answer sheet. If you cannot recall all 20 words (and most people cannot), I want you to guess which words you believe might have been on the list (they should be body parts) to fill in all 20 spaces. Don’t worry if you misspell words, but please do not use any slang words.

The instructions for the exclusion test were as follows:

> On this next test I want you to write down 20 words for the category ‘x’ [e.g., sports], but none of them can be sports that you heard earlier in the experiment. So, you must write down 20 new sports that were not presented. All the words should still fit the category. Don’t worry if you misspell words, but please do not use any slang words.

Subjects were given as long as they needed to fill in all the spaces and were told they had as much time as they needed to finish the tests.

Results

An alpha level of .05 was used for all statistical tests ($p < .05$). In each analysis a one-way ANOVA was conducted with encoding condition (full-attention, divided-attention) as a between-subjects variable. For each ANOVA reported with an F value > 1, we include the F value, mean square error (MSE), and effect size (partial eta squared; $\eta_p{}^2$).

Forced recall (inclusion) test We began the analysis by examining whether the proportion of correct responses on the forced recall tests differed as a function of full- or divided-attention. The proportion of studied items recalled in Experiment 1 is presented in Table 1. A greater proportion of studied items were recalled on the forced recall tests for the full-attention group (.63) than for the divided-attention group (.46), F (1, 46) = 37.12, MSE = 0.33, $\eta_p^2 = 0.45$. A decrease in Inclusion performance in the divided-attention condition is consistent with the notion that recollection was reduced by dividing attention (cf., Jacoby, 1991).

Exclusion test Next, we examined performance on the exclusion tests as a function of attention condition. Table 1 shows the proportion of exclusion errors for Experiment 1. Exclusion errors were less likely for the full-attention group (0.14) than for the divided-attention group (0.20), F (1, 46) = 6.19, MSE = 0.03, $\eta_p^2 = 0.12$. Because exclusion errors are thought to reflect the influence of automaticity when recollection fails, the finding that divided-attention leads to increased exclusion errors provides support for the notion that failures of recollection contribute to exclusion errors (cf., McCabe et al., 2007). However, a more conclusive examination of the influence of recollection and automaticity on free recall requires calculation of process estimates based on inclusion and exclusion performance.

Table 1 Proportion of studied words correctly recalled on the Inclusion tests, and studied items incorrectly output on the exclusion tests for Experiments 1 and 2. Standard deviations are in parentheses

Study Condition	Inclusion	Exclusion
Experiment 1		
Full-Attention	.63 (.11)	.14 (.08)
Divided-Attention	.46 (.07)	.20 (.07)
Experiment 2		
Full-Attention	.61 (.09)	.12 (.07)
Divided-Attention	.51 (.08)	.18 (.08)

Recollection and automaticity estimates As explained in the introduction, recollection (R) and automaticity (A) were computed using the following equations: R=Inclusion - Exclusion, and A=Exclusion/(1−R). The estimates of recollection and automaticity for the full- and divided-attention condition are presented in the top panel of Fig. 1. Estimates of recollection were considerably higher for the full-attention group (0.48) than for the divided-attention group (0.26), F (1, 46) = 32.33, MSE = 0.59, $\eta_p^2 = 0.41$. By contrast, there were no differences in automaticity estimates for the full-attention group (0.25) and divided-attention groups (0.26), $F < 1$.

Discussion

The results of Experiment 1 indicate that studied item recall was reduced when attention was divided during study, but exclusion errors increased. Because forced recall was used, leading to equivalent numbers of items generated on the

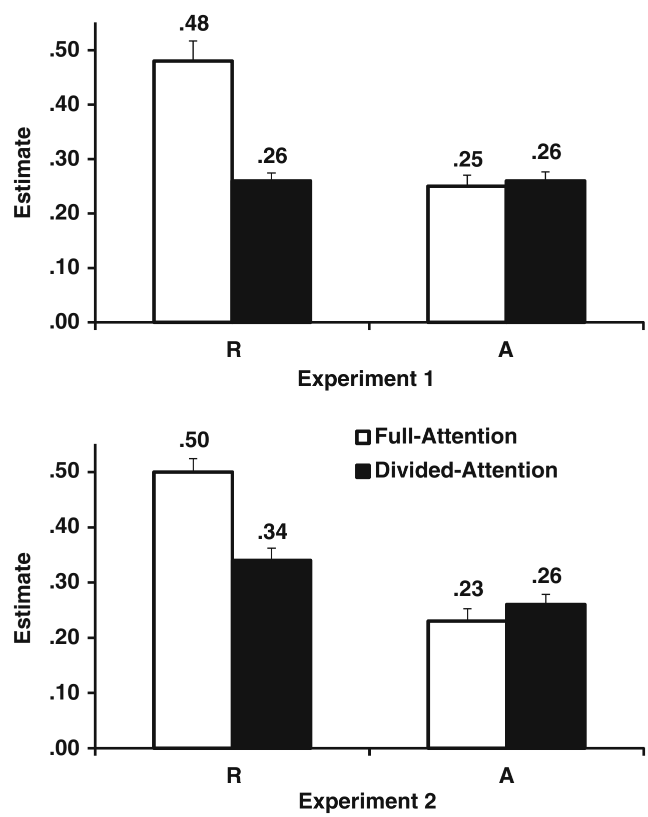

Fig. 1 Recollection (R) and automaticity (A) estimates for Experiment 1 (top panel) and Experiment 2 (bottom panel)

forced recall and exclusion tests, we were also able to compute recollection and automaticity estimates using the process dissociation procedure. These data revealed that the effect of dividing attention was confined to reducing the recollection estimate, with the automaticity estimates equivalent across the encoding conditions. Thus, an influence of automaticity on retrieval during free recall was found, and dividing attention selectively affected recollection and not automaticity, as in prior experiments using quite different paradigms.

According to Jacoby (1998), several methodological constraints must be met in order to apply the process dissociation procedure effectively. For example, subjects must understand the instructions for the inclusion and exclusion tests, they must use a direct retrieval strategy (rather than a generate–recognize strategy), and floor effects must be avoided for the exclusion test. In terms of subjects understanding the instructions, the finding that exclusion errors were low and inclusion performance was high suggests that this was the case. It also appears that subjects used a direct retrieval strategy. According to Jacoby (1998), if subjects use a generate–recognize strategy and recollection is dependent on automaticity, similar levels of inclusion performance would be found between conditions that differed in recollection but had similar levels of automaticity. This was clearly not the case, with a large difference between inclusion performance for the full- and divided-attention groups (Cohen's $d = 1.81$). In terms of floor effects on the exclusion test, levels of exclusion errors were low, but they were well above zero. This last issue is addressed using a more detailed analysis following Experiment 2.

Experiment 2

Experiment 2 was conducted in order to replicate the process dissociation findings from Experiment 1 and to examine the subjective experience associated with free recall performance using a variant of the remember–know (R/K) procedure (Tulving, 1985; Gardiner, 1988). The point of the comparison was to see if the pattern of results in these two methods of assessing consciously controlled retrieval and a more automatic form of retrieval would show the same pattern (Prull, Dawes, Crandell, McLeish, Rosenberg, & Light, 2006; Serra et al., 2010). In the remember–the know procedure, subjects were asked to distinguish between retrieval of studied items giving rise to the experience of recollection (i.e., remembering), retrieval that arises from a relatively automatic influence (i.e., knowing), and retrieval that involves guessing. They were asked to report a *remember* response if they could mentally travel back to the moment at which they studied the item, by retrieving some contextual details from the studied episode (e.g., the thought that came to mind when they initially studied it, the word that came before or after it). Subjects were asked to report a *know* response if they were sure the item was presented, but they could not retrieve any contextual details associated with studying the item (i.e., "I just *know* it was presented"). Previous research suggests that factors that affect recollection, such as dividing attention or varying orienting tasks, have little effect on know responses, but they do have dramatic effects on remember responses (see Gardiner, Ramponi, & Richardson-Klavehn, 2002 for a review). Moreover, remember responses and recollection estimates from the process dissociation procedure are typically affected similarly by experimental manipulations; in addition, know responses and automaticity estimates from the process dissociation procedure also typically show parallel effects (Yonelinas, 2002). However, the similar patterns in past research have been derived across experiments. In Experiment 2, we make the comparison within the same experiment using the same materials and the same general procedures.

In Experiment 2, we examined the effect of dividing attention on remember and know responses using a variant of the forced recall paradigm developed for Experiment 1. We structured the task such that we could obtain both remember and know judgments from a paradigm like Tulving's (1985) as well as recollection and automaticity estimates from Jacoby's (1991) process dissociation procedure. In addition to permitting a replication of Experiment 1, this step allowed us to examine possible parallels between the process dissociation estimates and remember–know judgments with respect to dividing attention. If remember responses reflect the subjective experience of recollection, the level of remember responses should be reduced by dividing attention, as should the recollection estimate calculated from the process dissociation procedure. By contrast, if know responses reflect an automatic component of retrieval, the level of know responses should not be affected by dividing attention nor should the automaticity estimate from the process dissociation procedure.

Method

Subjects Forty-eight undergraduates from Washington University in St Louis participated for course credit. Half of the subjects were randomly assigned to the full-attention group, the other half were randomly assigned to the divided-attention group.

Materials and procedure The materials and procedure were identical to those in Experiment 1 except that for each item produced on the forced recall test subjects were asked to indicate the subjective experience associated with retrieval of that item by marking each word with a R, K, or G to indicate remember, know, or guess. The remember and know instructions were closely based on the instructions used by Rajaram (1993), and instructions for the guess response were modeled after those used by Gardiner, Ramponi, and Richardson-Klavehn (1998). We allowed the guess response because the nature of forced recall requires subjects to produce responses that are guesses. The remember–know/guess instructions were quite detailed and included examples of each type of retrieval experience from everyday life. Because the instructions take several minutes to explain, and we wanted to equate the retention interval across experiments, the instructions were given before the study episode. Subjects were told that remember, know, and guess responses would be used later in the experiment. Before the actual recall tests, summaries of each response (R, K, and G) were given to subjects again, and they were asked to write an R, K, or G next to each word on the inclusion test as they produced the items. Thus, subjective experience was examined on-line, during recall.

Results

Inclusion test The bottom portion of Table 1 shows the proportion of studied items recalled in Experiment 2 on the inclusion test. Replicating Experiment 1, there was a greater proportion of studied items recalled for the full-attention group (0.62) than for the divided-attention group (0.51), F (1, 47) = 17.13, MSE = 0.13, $\eta_p^2 = 0.28$.

Exclusion test The bottom part of Table 1 also shows the proportion of exclusion errors for Experiment 2. Replicating the results of Experiments 1, exclusion errors were reliably more likely for the divided-attention group (0.18) than for the full-attention group (0.12), F (1, 47) = 7.60, MSE = 0.04, $\eta_p^2 = 0.14$.

Recollection and automaticity estimates Recollection and automaticity were computed as in Experiment 1. These estimates are shown in bottom panel of Fig. 1. Recollection was considerably higher for the full-attention group (0.50) than for the divided-attention group (0.34), F (1, 47) = 23.05, MSE = 0.31, $\eta_p^2 = 0.33$. By contrast, there were no differences in automaticity estimates for the full-attention group (0.23) and divided-attention group (0.26), F < 1. Thus, as in Experiment 1, dividing attention affected recollection but not automaticity, as estimated using the process dissociation procedure.

Remember–know/guess responses Table 2 shows that there were large differences in the proportion of remember responses reported for studied items in the full-attention condition (0.35) and divided-attention condition (0.16), F (1, 47) = 23.99, MSE = 0.44, $\eta_p^2 = 0.34$, but that the proportion of know responses did not differ between the full-attention condition (0.14) and divided-attention condition (0.13), F < 1. These data show the expected pattern of dividing attention affecting only the consciously controlled component of retrieval.

Table 2 Proportion of remember, know, and guess responses for studied words recalled on the forced recall test in Experiment 2. Standard deviations are included in parentheses

Study Condition	Remember	Know	Guess
Full-Attention	.35 (.15)	.14 (.10)	.13 (.07)
Divided-Attention	.16 (.12)	.13 (.09)	.23 (.12)

We also computed the independence remember–know (IRK) estimate (Know/(1−Remember); Yonelinas, 2001; Yonelinas & Jacoby, 1995), which calculates knowing as a function of the number of opportunities that one has to make know responses. Thus, the IRK estimate determines the proportion of know responses that were made once the likelihood of remembering is accounted for (1−Remember). The IRK estimate did not differ for the full-attention (0.20) and divided-attention groups (0.15), F (1, 47) = 2.27, MSE = 0.03, $\eta_p^2 = 0.05$. Guess responses for studied items were more likely in the divided-attention condition (0.23) than in the full-attention condition (0.13), F (1, 47) = 23.99, MSE = 0.44, $\eta_p^2 = 0.34$. The increase in guess responses in the divided-attention condition is not surprising given the increase in the opportunity to guess due to the declines in recollection in the divided attention group (i.e., on this forced recall test the number of opportunities to guess a correct answer is determined by the level of remember and know responses (i.e., guessing per category = 20−[Remember+Know]).

Discussion

The results of Experiment 2 serve two functions. First, we replicated the findings of Experiment 1 showing substantial estimates of automatic responding in recall using the process dissociation procedure, and we demonstrated once again that dividing attention affected recollection and not the automatic component of retrieval using this procedure. Second, we also showed that when the remember–know procedure was applied to the same experimental paradigm, we obtained comparable patterns of results to those obtained with the process dissociation procedure. That is, remember judgments were strongly affected by dividing attention, but know judgments were not (neither raw know judgments nor those computed using the independence assumption). The finding that dividing attention affected both remembering and recollection, but did not affect knowing or the automatic component, provides converging evidence that is consistent with a dual-process explanation of these findings. As mentioned previously, we do not make the strong claim that remembering and knowing reflect process-pure estimates, but dual process theories and extant data support the idea that remembering and knowing are strongly related to controlled and automatic processes, respectively (Jacoby et al., 2001; McCabe & Geraci, 2009).

Although the remember–know procedure is not often used to examine free recall performance, our results are consistent with previous findings showing that a substantial proportion of know responses are reported during free recall (e.g., Hamilton & Rajaram, 2003; McDermott, 2006). This finding is inconsistent with claims that free recall reflects a process-pure measure of recollective processing and instead suggests that free recall is similar to other measures of episodic memory, like recognition and cued recall, in that retrieval is influenced by both consciously controlled and automatic influences.

Analyses combining data across experiments

In order to better understand if our data conform to the assumptions required for use of the process dissociation procedure, we conducted further analyses combining data across experiments.

Output position for exclusion errors One assumption that is crucial to the validity of the process dissociation estimates is the aforementioned notion of invariance in recollection and automaticity across inclusion and exclusion tests. In order to maintain invariance, the use of an automatic process to generate response candidates on inclusion and exclusion tests must be discouraged (Jacoby, 1998). This issue is particularly important for the exclusion tests in the forced recall paradigm we have developed here. Theoretically, exclusion errors reflect the influence of an automatic process in the absence of recollection and, as such, if subjects deliberately made errors on the exclusion tests, recollective processes would actually increase these errors, which would compromise the validity of the recollection and automaticity estimates reported. Of course, we believe subjects normally follow our instructions, but there is a possible reason why subjects may deliberately make errors on the exclusions test: If subjects experience difficulty in completing the exclusion task and yet still want to comply with the task instructions to fill in all 20 spaces on the answer sheet, they may recall items from the list to do so. One prediction of this *demand characteristic account* (McCabe et al., 2007) is that if exclusion errors were knowingly made when subjects encountered difficulty generating new category exemplars, these errors would have been greatest towards the end of the exclusion test, in the late output positions. The assumption is that early in the exclusion test, subjects can access new category exemplars easily, but when subjects begin having greater difficulty later in the test, they may recall list words (hence making errors) to satisfy task demands. If, on the other hand, exclusion errors were due to periodic failures of recollection, these errors should be made throughout the exclusion test and should not vary as a function of output position.

To test the demand characteristics account of exclusion errors, we examined their output positions. Because the exclusion instructions were identical in the two experiments, the error data were combined to increase power. We also combined the exclusion errors into five bins of four serial positions each, to reduce variability (i.e., serial positions 1–4, 5–8, 9–12, 13–16, and 17–20). Table 3 shows the exclusion errors as a function of serial positions for full- and divided-attention. There was no support for the demand characteristic explanation, as exclusion errors did not increase across serial positions in either the full- or divided-attention conditions (cf., McCabe et al., 2007). This pattern was confirmed by conducting a mixed model ANOVA with study condition (full-attention, divided-attention) and serial position (1–4, 5–8, 9–12, 13–16, and 17–20) as between-subjects and within-subjects factors, respectively. There was a main effect of study condition, $F(1, 94) = 9.69$, MSE = 0.28, $\eta_p^2 = 0.09$, such that full-attention subjects made fewer exclusion errors than divided-attention subjects, but there was no main effect of serial position, $F < 1$, and no significant interaction between the two, $F(1, 94) = 1.07$, MSE = 0.02, $\eta_p^2 = 0.01$. If anything, the data in Table 3 show a slightly higher tendency for errors in the first four items recalled than in the last four. Thus, we can conclusively dismiss the demand characteristic account of exclusion errors.

The influence of floor and ceiling effects on process dissociation estimates When using the process dissociation procedure, scale attenuation is also an important issue to consider because ceiling effects on the inclusion tests and/or floor effects on the exclusion tests compromise estimates of recollective and automatic influences. An examination of the data in Experiments 1 and 2 suggests that ceiling effects were not a problem for the inclusion tests, with a mean inclusion level for studied items being in the middle of the scale (M = 0.55, SD = 0.11), and no participant below 0.30 or above 0.90 in either experiment. However, the exclusion errors were fairly low (means were between 0.12–0.20), so it is worthwhile to examine whether floor effects are a problem for these data. An examination of skewness (i.e., the shape of the distribution of scores) can reveal whether scale attenuation is a problem, with values greater than

Table 3 Proportion of errors on the exclusion tests for output serial position (data combined for Experiments 1 and 2). Standard deviations are in parentheses

	Output Serial Position				
	1–4	5–8	9–12	13–16	17–20
Full-Attention	.16 (.17)	.12 (.13)	.12 (.12)	.13 (.12)	.15 (.14)
Divided-Attention	.20 (.15)	.20 (.15)	.18 (.15)	.18 (.15)	.15 (.12)

twice the standard error indicating that the distribution of responses is abnormal. Collapsed across both experiments, the skewness of the distribution of exclusions errors was 0.21 (SE = 0.34) for the full-attention conditions and 0.05 (SE = 0.34) for the divided-attention condition. Indeed, skewness was less than twice the standard error, indicating fairly symmetrical distributions (see Tabachnick & Fidell, 1996). Thus, we are confident that floor effects were not a problem in these data.

General discussion

We believe our experiments make two important contributions. The first one is methodological in that we have developed a method of applying the process dissociation procedure to free recall in a way that meets many of the assumptions of the procedure. The second contribution is theoretical in showing that tests of recall, even free recall, are affected both by consciously controlled processes and by automatic influences. Retrieval during free recall may occur via consciously controlled processes (often called memory search) or via automatic influences. That is, some target items during free recall will "pop into mind" without conscious control, much as is the case when amnesic patients lacking controlled recollection may recall some items. In support of the latter conclusion, both procedures we used (process dissociation and remember–know) revealed data consistent with an automatic influence. The two methods showed parallel results: Dividing attention during study affected recollection and remembering while leaving automaticity and knowing unaffected.

Although some researchers have assumed that free recall is exclusively a reflection of recollection in a nearly process-pure manner, our results indicate that the automatic contribution to free recall occurs even on tests occurring shortly after study (see also Hamilton & Rajaram, 2003; McDermott, 2006). This conclusion is based on the automaticity estimates from both experiments, and based on the levels of know responses in Experiment 2. In both experiments, estimates of recollection (R) and automaticity (A) were calculated using the process dissociation procedure. Recollection was reduced by dividing attention, but estimates of automaticity were equivalent, consistent with previous studies examining process dissociation estimates in cued recall and recognition (e.g., Jacoby, 1991, 1998; Schmitter-Edgecombe, 1999). Similarly, in Experiment 2, dividing attention reduced remember responses but left know responses unaffected. Thus, assessments of subjective experience were affected in a manner similar to the recollection and automaticity estimates.

Implications of the finding that automatic processes influence recall

The primary purpose of the current experiments was to test the assumption that free recall tests provide a pure measure of recollection or whether these tests were influenced by automaticity as well. Tulving (1972) had originally argued that free recall was an episodic memory test, but in 1985 he reversed himself and argued that episodic memory tests (even free recall) could be boosted by contributions from other sources (such as knowing, from semantic memory in Tulving's (1985) version of his theory). Beginning in 1991, Jacoby argued that no memory test is completely process pure and that all tests reflect a mixture of consciously controlled and automatic components. Although the general point that no memory test is process-pure has become accepted by most experimental psychologists (especially when they consider implicit memory tests), many researchers still consider free recall to be a relatively pure estimate of recollection (Quamme et al., 2004; Yonelinas et al., 2002). Although free recall may typically be more dependent on recollection than is recognition, and, conversely, recognition may typically be more dependent on automatic influences than is free recall, the important point is that each test reflects a mixture of both processes. Thus, comparing recall and recognition performance is a crude approach to comparing recollection and automaticity processes. Raw recall and recognition scores are not decisive in determining whether the effect of a given variable relies on recollection and/or automatic processes. Standard comparisons of recall and recognition, though interesting in many ways, cannot determine the underlying processes responsible for differences in performance.

In our opinion, a more fruitful approach would be to compare estimates of recollection and automaticity derived from the process dissociation procedure. According to dual-process theories of memory, recollection should be affected by certain experimental variables (e.g., levels of processing, divided attention) or subject variables (e.g., aging, brain damage) regardless of whether recollection is indexed using a recall or recognition test. Similarly, automatic influences should be less affected by these variables regardless of the type of test used to query memory.

Our finding that free recall has an automatic component also calls into question the experimental strategy of equating free recall performance between groups on initial learning task (e.g., younger and older adults) in order to make sounder inferences. This approach of equating initial learning is often used in neuropsychological studies investigating memory performance between younger and older adults (Giambra & Arenberg, 1993; Harwood & Naylor, 1969; Wheeler, 2000), control subjects and amnesics (Isaac & Mayes, 1999; Kopelman & Stanhope, 1997), older controls and dementia patients (Kopelman, 1985; Reed, Paller, & Mungas, 1998), as well as other subject populations (DeLuca et al., 2004). For example, DeLuca et al. found that subjects with chronic fatigue syndrome (and no co-morbid psychiatric disorders) took twice as many trials to learn a list of categorized words to a criterion of two perfect recalls. The subjects with chronic fatigue syndrome also showed more forgetting relative to controls, which led to the conclusion that chronic fatigue syndrome led to deficits in retrieval. However, although the initial level of free recall for the two groups was equated, the processes underlying performance may not have been equated. In fact, given the finding that repetition has the ironic effect of increasing automaticity-based errors in populations with less recollective ability (e.g., older adults; Jacoby, 1999), equating performance by means of repetition almost certainly increases the influence of automatic processes on recall in subject populations with memory deficits (relative to controls).

One possible approach to addressing the issue of equating performance would be to attempt to equate the processing estimates at initial learning and then examine the rate of forgetting for process estimates over time (e.g., McBride & Dosher, 1999). One could then compare forgetting for both processes separately to gain a better understanding of the retrieval processes underlying performance. From the perspective of dual-process theory, this alternative approach to examining forgetting would provide a more precise method of equating performance and could be compared to more traditional methods of equating performance as well. Moreover, the free recall paradigm used in the current study could easily be coupled with a traditional recognition version of inclusion and exclusion tests in order to compute process estimates for both tasks, and thus forgetting in different subject populations or different experimental paradigms could be compared.

In addition to showing an influence of automatic processes in free recall, the finding that exclusion errors increased with divided attention in both experiments indicates that recall-based exclusion tasks can be used to examine failures of recollection. The finding that errors on an exclusion-based recall task are affected by dividing attention is similar to findings from the unconscious or inadvertent plagiarism paradigm (Brown & Murphy, 1989) showing increased exclusion errors resulting from response deadlines (Marsh, Landau, & Hicks, 1997) and aging (McCabe et al., 2007). Thus, the present experiments using inclusion and exclusion tests in free recall converge with other data supporting the notion that errors on recall-based exclusion tasks reflect failures of recollection.

The relationship between subjective experience and memory processes

An examination of the subjective experience associated with free recall also sheds light on the processes involved in free recall. The finding that remember responses are affected by dividing attention, but know response are not (cf., Gardiner & Parkin, 1990; Yonelinas, 2001), provides important converging evidence supporting the idea that recollection is not the only process that influences free recall performance. According to one theory, know responses are believed to reflect the fluency with which items are processed in the absence of recollective experience, which is associated with automatic processing (Kelley & Jacoby, 1998; Rajaram, 1998). When the source of that fluency is ambiguous, subjects are likely to attribute it to memory if the current goal they are engaged in is a memory task (Jacoby et al., 1989). In the current experiments, all items were retrieved in response to a list cue, but some of these items were retrieved without access to specific contextual details. Thus, because all memory tests - even free recall - are assumed to be cue-dependent (Tulving, 1974), it is possible that items can be recalled in response to a list cue without retrieval of recollective details.

The remember–know data from the present study are consistent with findings from other studies indicating that the subjective experience of knowing occurs during free recall (Hamilton & Rajaram, 2003; McDermott, 2006; Tulving, 1985). The finding that dividing attention did not affect the proportion of know responses in Experiment 2 converges with the invariance of automaticity estimates for full- and divided-attention conditions in both experiments. Although some previous research has shown nearly exact correspondence between the estimates of objective and subjective measures of recollection under some circumstances (Jacoby et al., 2001; Jacoby, Begg, & Toth, 1997), remember and know judgments in the present study were substantially lower than the recollection and automaticity estimates. However, because the recall of studied items and the subjective experience of remembering are based on different information to some extent, the two estimates will not necessarily converge (Jacoby et al., 2001; Kelley & Jacoby, 1998).

In Experiment 2, guess responses also increased in the divided attention condition as compared to the full attention condition. However, subjects presumably only guessed in the absence of recollective experience, which was more likely to occur in the divided attention condition. Indeed, guessing should have had similar effects on inclusion and exclusion tasks for both full- and divided-attention conditions. This may occur due to chance or because guessing is influenced by automatic processing.

Limitations of the process dissociation method used in the current experiments

In the Results section of Experiment 1 and in the section analyzing the combined data across both experiments, we noted that several patterns in the data suggested that we met the assumptions required to employ the process dissociation procedure. However, we should also note that there were limitations to the current methodology as it relates to these assumptions. In particular, one method of ensuring that subjects used similar strategies on the inclusion and exclusion tests is to compare baseline false alarms for the two types of tests. The method we employed here did not allow for a proper baseline to be calculated. Consequently, this lack of a baseline represents a limitation of the current methodology, and additional research will be required to definitively address this issue. However, we should also note that the methods we were able to employ to examine whether we met the assumptions required for use of the process dissociation procedure indicated that we had met those assumptions. Also, the pattern of recollection and automaticity data following full- and divided-attention is consistent with previous research in which baseline false alarms did not differ.

Conclusion

Consideration of the issue of whether memory tasks are process pure has most often been directed toward research using implicit memory tests with researchers having to conduct numerous analyses to convince skeptics that they are indeed studying implicit memory. Roediger and McDermott (1993) reviewed a variety of strategies that researchers have used to accomplish this goal, including the process dissociation procedure. However, the comparable criticism of explicit memory research on the grounds that it may not really be "explicit" (i.e., consciously controlled) has primarily been raised by Jacoby and colleagues, and at least in the case of free recall, their points have mostly been ignored by the field. As long ago as 1993, Jacoby et al. stated that researchers "interested in performance on direct tests of memory can no longer justifiably ignore evidence of unconscious influences" (p. 152). At that time, little evidence existed indicating that free recall tasks were influenced by automatic processing, and even today free recall is still considered by many to represent a process-pure measure of recollection. We have presented converging evidence from the process dissociation procedure and remember–know judgments to demonstrate a contribution of automatic processing in free recall. Thus, we can reiterate with more confidence Jacoby et al.'s claim that those interested in studying explicit (conscious) recollection must consider automatic or unconscious influences that also influence such tests.

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