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Consciousness, Control, and Confidence: The 3 Cs of Recognition Memory

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The contributions of recollection and familiarity to recognition memory performance were examined using the process dissociation, remember–know, and receiver operating characteristic (ROC) procedures. Under standard test conditions the 3 measurement procedures led to process estimates that were almost identical and to similar conclusions regarding the effects of different encoding manipulations. Dividing attention led to a large decrease in recollection and a smaller, sometimes nonsignificant, decrease in familiarity. Semantic compared with perceptual processing led to a large increase in recollection and a moderate increase in familiarity. Moreover, the results showed that familiarity was well described by classical signal-detection theory but that recollection reflected a threshold process. The convergence observed across the 3 measurement procedures shows that the 3 procedures tap similar underlying processes and that recollection and familiarity differ in terms of conscious awareness, intentional control, and the manner in which they contribute to the shape of response confidence ROCs.

The distinction between recollection and familiarity underlies several contemporary theories of human memory (e.g., Atkinson & Juola, 1974; Jacoby, 1991; Jacoby & Dallas, 1981; Mandler, 1980; Tulving, 1985; Yonelinas, 1994), it has played a critical role in characterizing memory-impaired populations, such as amnesics (e.g., Aggleton & Shaw, 1996; Huppert & Piercy, 1976; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998), and it has proven useful in accounting for results from recent neuroimaging studies of memory (e.g., Gabrieli, Brewer, Desmond, & Glover, 1997; Henson, Rugg, Shallice, Josephs, & Dolan, 1999). The distinction has also played an important role in theories of the medial temporal lobe that aim to account for the results of lesion and single cell recording studies of rats and nonhuman primates (e.g., Aggleton & Brown, 1999; Eichenbaum, Otto, & Cohen, 1994). Central to all of these dual-process theories is the claim that recognition memory judgments can be based on two distinct memory retrieval processes: familiarity and recollection. The familiarity process reflects the assessment of the memory strength or experimental familiarity of a test item. Because recently encountered items are more familiar than novel items, individuals can accept the more familiar items as having been studied. Recognition memory judgments, however, are not limited to assessments of familiarity. If an individual can recollect some aspect of the study episode, such as where or when the event occurred, this can also serve as a basis for recognition judgments. Recollection reflects a search of memory whereby qualitative information about the study event is retrieved.

There are, however, important differences between existing dual-process theories, and there are several unresolved issues about the underlying nature of recollection and familiarity. Most important is that the theories differ in the way they distinguish between recollection and familiarity, and as a consequence, there are critical differences in how these processes are measured. For example, Jacoby (1991) has distinguished between recollection and familiarity in terms of intentional control. If an individual can recollect information about a previous event, then he or she should be able to accurately discriminate between items from different episodes or sources. In contrast, assessments of familiarity should support recognition judgments (i.e., old items are more familiar than new items), but they should not be useful in discriminating between equally familiar items from difference sources. On the basis of this distinction, Jacoby developed the *process dissociation procedure* to measure recollection and familiarity. Recollection is measured as the ability to retrieve a specified aspect of the study event (e.g., where or when an item was presented) and to use this as a basis for intentionally controlled responding. Familiarity is then estimated by algebraically removing the contribution of recollection from overall recognition performance.

In contrast, Tulving (1985) argued that the fundamental difference between the components underlying recognition memory is in the nature of the conscious experience associated with each component. Recollection is associated with autonoetic consciousness (i.e., self-knowing or remembering), in which the episodic aspects of the study event are consciously reexperienced. In contrast, familiarity is associated with noetic consciousness (i.e., knowing), whereby the individual knows that the item was studied but does not reexperience any specific information about the study event. To measure these different types of recognition, Tulving developed the *remember–know procedure,* in which individuals are required to introspect about the basis of their recognition judgments and to report whether they recognize items on the basis of recollection or familiarity.

An alternative way of distinguishing between recollection and familiarity was proposed by Yonelinas (1994), who developed a dual-process signal-detection model and a method based on the analysis of *receiver operating characteristics (ROCs)* to measure recollection and familiarity. By this model, recollection is defined

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as a *threshold* process whereby qualitative information about a study event is retrieved, and familiarity is defined as a *signal-detection* process in which the most familiar items are accepted as having been studied. In tests in which both processes contribute to performance, recollection is assumed to lead to high-confidence responses, whereas familiarity assessment is assumed to support a wider range of memory confidence responses. This model can be quantified and fit to recognition memory confidence data (e.g., data from ROC experiments) to derive estimates for recollection and familiarity.

A consideration of these different theories suggests that recollection and familiarity can be separated in several different ways: in terms of intentional control, conscious awareness, and response confidence. However, it is not yet clear whether these three theories refer to the same underlying memory retrieval processes. It may be that these theories have captured different aspects of the same two processes: Recollection may be a threshold process that is associated with autonoetic consciousness that supports accurate source memory discriminations, whereas familiarity reflects a signal-detection process that is associated with noetic consciousness and does not support accurate source discriminations. Alternatively, it may be that these three characterizations of recollection and familiarity are not isomorphic. For example, the processes that are available to subjective experience as recollection and familiarity may not be threshold and signal-detection processes, respectively, and they may not differ in terms of their support of intentional control in the process dissociation procedure.

One aim of the current study is to directly contrast these models and their associated measurement procedures to determine whether they refer to similar retrieval processes. The general strategy is to compare the parameter estimates derived from the different measurement procedures under a variety of conditions. If the procedures do index similar processes, then they should lead to similar parameter estimates and to similar conclusions regarding the effects of experimental manipulations. If these three procedures produce similar estimates, then it would suggest that recollection and familiarity are separable in terms of intentional control, conscious awareness, and response confidence.

The second aim of this study is to use the remember–know and process dissociation procedures to directly assess the individual assumptions underlying the dual-process signal-detection model: that recollection and familiarity reflect threshold and signal-detection processes, respectively. Consider the familiarity process first. The idea is that studied items tend to be more familiar than nonstudied items, and thus individuals can set a response criterion and accept the most familiar items as having been studied. The familiarity process is assumed to be well described by an equal-variance signal-detection model. Although this signal-detection model (see Macmillan & Creelman, 1991; Swets, 1964) provides a reasonably simple way of describing familiarity, there is good reason to suspect that it may not provide a perfectly accurate account of this process. Most important is that it assumes that the old item familiarity distribution has the same variance as the new item distribution (i.e., the equal-variance assumption). There is no a priori reason why the assumption must be correct. For example, if there is a great deal of variability in the degree to which studied items increase in memory strength due to encoding, then one would expect the old item distribution to be associated with greater variance than the new item distribution. Alternatively, there may be some upper limit on the familiarity level that an item can reach, and this could lead the variance of the old item distribution to be less than that of the new item distribution.

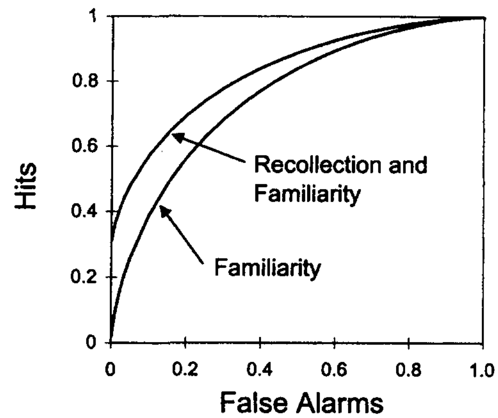

Figure 1. Receiver operating characteristics produced by familiarity alone (an equal-variance signal detection model) and by a combination of familiarity and recollection.

The most direct way of testing whether familiarity is well described by an equal-variance signal-detection model is to plot familiarity ROCs (i.e., estimates of familiarity as the response criterion is varied). The lower function in Figure 1 shows the ROC generated by the equal-variance signal-detection model. The function is curvilinear and symmetrical along the diagonal. One way of assessing the model is to directly fit it to the observed data to evaluate how well it accounts for performance. Another way is to replot the ROC in z-space (i.e., the z-ROC). If the distributions are normal, then the z-ROC should be linear, and if the variance of the old item distribution is equal to that of the new item distribution, then the z-ROC will have a slope of 1.0. Both methods were used in the current study.

The current experiments examined familiarity as a function of response confidence to determine whether the process is well described by signal-detection theory. Note that the equal-variance signal-detection model in itself cannot account for overall recognition performance, because overall, recognition ROCs are usually not symmetrical; they appear to be pushed up as in the upper function in Figure 1, and they typically have a slope in z-space of between .6 and .9. According to the dual-process model, the asymmetry is due to the fact that recollection contributes to performance and effectively pushes the hit rate up. Thus, only when recollection is removed from overall performance should the ROC be perfectly symmetrical (i.e., z-slope = 1.0). An alternative model (i.e., an unequal-variance signal-detection model) can also produce asymmetrical ROCs; this model is discussed in more detail later.

The dual-process signal-detection model makes an additional critical assumption that recollection is a threshold process. Moreover, in standard recognition tests, it is assumed that recollection supports high-confidence recognition judgments relative to familiarity. One can assess these assumptions by examining the recognition confidence associated with remember and know judgments and by plotting estimates of recollection and familiarity against false alarms as a function of response confidence. Recollection should lead to high-confidence recognition judgments. Moreover, when lower confidence responses are included, this should lead to large increases in false alarms and estimates of familiarity, but recollection estimates should remain relatively unaffected.

The current study included three experiments. Experiments 1 and 2 examined the effects of dividing attention on recollection and familiarity using the remember–know and the ROC procedures. Experiment 3 examined the effects of semantic versus perceptual encoding on estimates of recollection and familiarity using the process dissociation, the remember–know, and the ROC procedures. If the three procedures are measuring similar processes, then they should lead to similar parameter estimates and similar conclusions regarding the effects of dividing attention and levels of processing on recollection and familiarity. On the basis of previous studies that have examined these variables using the process dissociation and remember–know procedures (e.g., Gardiner, 1988; Gardiner & Parkin, 1990; Jacoby, 1991; Toth, 1996), I expected the two experimental manipulations to have larger effects on recollection than familiarity.

The signal-detection and threshold assumptions underlying the dual-process signal-detection model were assessed in two ways. First, estimates of recollection and familiarity were derived from recognition confidence ROCs based on the assumptions that familiarity and recollection are signal-detection and threshold processes, respectively. These estimates were then compared with those derived using the remember–know and process dissociation procedures. If the assumptions are correct, then the parameter estimates that are derived using those assumptions should parallel those found using the other measurement methods. Second, the remember–know procedure was used to estimate recollection and familiarity as a function of response confidence to determine whether familiarity produced the type of ROC that is predicted by the equal-variance model and whether recollection led to high-confidence recognition responses that remained relatively constant as false alarms increased.

Experiment 1

Experiment 1 examined the effects of dividing attention during encoding on recognition memory. Participants studied words either while they conducted a secondary math task or under conditions in which no secondary task was required. During a subsequent recognition memory test, participants made a recognition confidence judgment on a 6-point scale and a remember–know judgment for each test item. Recollection and familiarity were estimated using the ROC and remember–know procedures. Estimates of recollection and familiarity were then plotted as a function of recognition confidence to examine the underlying process ROCs. If the dual-process ROC model and the subjective reports of remembering and knowing refer to the same underlying processes, then the estimates from the ROC and remember–know procedures should be similar, and they should lead to the same conclusions regarding the effects of dividing attention. Based on the dual-process signal-detection model, the overall recognition ROCs should be asymmetrical, but the familiarity ROC should be symmetrical (i.e., it should be well fit by the equal-variance model, and the z-ROC should be linear and have a slope of 1.0). In contrast, recollection should lead to high-confidence responses and should remain relatively constant as false alarms increase.

Method

Participants and materials. Nineteen undergraduates participated for an experimental credit in an introductory psychology course. The data from one participant were discarded, because that participant reported having misunderstood the test instructions. The study and test words were randomly selected from the Toronto word pool.

Design and procedure. Each participant completed four study–test blocks, and the experimental session took approximately 40 min. Each study list contained 58 words. Half of the words in each study list were presented under full attention conditions, and half were presented under divided attention conditions. The full and divided attention items were mixed randomly within each study list. The first and last 4 words of each study list served as buffer items and were not tested. For all the study items, participants were instructed to read each word aloud as it was presented on the screen and to try to remember each word for a later memory test. Each word was presented on the screen for 1.5 s, followed by a blank 2-s interstimulus interval. For the divided attention condition, each word was presented on the screen along with two randomly generated numbers between 1 and 9 that were presented to the left of the word. After 0.5 s of blank screen, a third random number was presented for 1 s, followed by 0.5 s of blank screen. The participants were required to press a *yes* key if the final number was between the first two numbers in value and to press a *no* key otherwise. They were instructed to make their response as quickly and accurately as they could. They were also told that the computer was counting the number of errors, but in fact, it was not.

Following each study list, participants were presented with a recognition memory test. The test list consisted of 25 items studied under full attention, 25 items studied under divided attention, and 25 new items mixed in a random order. Participants were required to make two responses to each item. First, they made a recognition judgment on a 6-point confidence scale (1 = *sure it was new;* 6 = *sure it was old*). Participants were instructed to use all six response keys. Immediately after making each confidence judgment they made a remember–know judgment, pressing either an *R*, *K*, or *N* key for each item. The remember–know instructions were based on those used by Gardiner (1988). Participants were told that they were to respond *R* only if they could remember some qualitative information about the study event. They were told that this could include such things as recollecting what they were thinking about when the word was presented, what the word looked like, or what it sounded like. Moreover, they were instructed that they should respond *R* only if they could, if asked, tell the experimenter what they recollected about that study event. Participants were told to respond *K* if they thought the item was studied but could not recollect any details about the study event. They were told to respond *N* if they thought the word was not in the study list. To ensure that participants understood the test instructions, they were asked to describe the remember–know distinction back to the experimenter, and the instructions were repeated if the participant appeared to have misunderstood the distinction.

ROCs were plotted as a function of response confidence (see Macmillan & Creelman, 1991). For example, the leftmost point on the ROC reflects the items that received a *6* response, and the second point reflects the items that received either a *6* or a *5* response. Note that the study and test procedures were piloted to ensure that the points on the participant ROCs would be well spaced and to avoid floor and ceiling effects. An examination of the participant ROCs in the current experiments verified that these potentially biasing effects were avoided.

Results and Discussion

Remember–know analysis. The recognition scores for Experiments 1 through 3 are presented in Table 1. The significance level for all statistical tests was $p < .05$. Estimates of recollection and familiarity were derived using the remember–know responses (see Yonelinas & Jacoby, 1995). Because participants were instructed

Table 1
Average Recognition Performance in Experiments 1 Through 3

Experiment and condition	Procedure								
	Remember–know		ROC $P(\text{response} \geq n)$					Process dissociation	
	$P(R)$	$P(K)$	6	5	4	3	2	P("yes"|inclusion)	P("yes"|exclusion)
Experiment 1									
Full attention	.45	.38	.49	.65	.76	.84	.92		
Divided attention	.29	.45	.31	.47	.62	.75	.89		
New	.02	.26	.02	.05	.13	.28	.56		
Experiment 2A									
Full attention	.57	.26	.69	.77	.83	.89	.94		
Divided attention	.39	.32	.51	.63	.71	.80	.89		
New	.01	.14	.04	.08	.15	.25	.46		
Experiment 2B									
Full attention	.23	.40	.38	.50	.63	.75	.88		
Divided attention	.15	.42	.27	.42	.57	.69	.83		
New	.02	.26	.06	.14	.28	.43	.61		
Experiment 2C									
Full attention	.36	.34	.49	.60	.70	.80	.91		
Divided attention	.21	.37	.33	.45	.58	.71	.87		
New	.03	.24	.09	.16	.27	.45	.38		
Experiment 3									
Deep	.54	.27	.68	.76	.83	.90	.95	.77	.14
Shallow	.19	.32	.42	.54	.63	.76	.89	.52	.18
New	.03	.18	.10	.18	.28	.45	.71	.19	.11
Seen								.61	.60

Note. In Experiment 2 the remember responses were treated as confident recognition responses; thus, the most confident recognition condition (i.e., 6) in the receiver operating characteristic (ROC) includes the remember responses. The *K* responses in Experiment 2 were estimated as the probability of a recognition response (i.e., 6, 5, or 4 response) minus the probability of a remember response.

to respond *remember* (*R*) whenever they recollected an item, the probability of a correct remember response was used as an estimate of recollection. Because participants were instructed to respond *know* (*K*) whenever an item was "familiar and not recollected" (i.e., $F[1 - R]$), familiarity was estimated as the probability of a know response to an old item, given the opportunity to make such a response (i.e., $F = K/[1 - R]$).

An examination of the estimates of recollection and familiarity (see Figure 2) indicated that dividing attention led to a decrease in recollection and a similar but slightly smaller decrease in familiarity. The probability of a remember response was greater for items studied under full compared with divided attention, $F(1, 17) = 42.66$, $MSE = 0.006$. Because the proportions of remember responses were used as estimates of recollection, the results indicate that dividing attention led to a decrease in recollection. The probability of a know response was significantly lower for items studied under full attention than those studied under divided attention, $F(1, 17) = 4.75$, $MSE = 0.007$. Note that because the probability of a know response is mathematically constrained by the proportion of remember responses, the latter statistical comparison is not directly interpretable. However, this statistic is reported to facilitate comparison with previous studies. Most important, an examination of the familiarity estimates (i.e., $K/[1 - R]$) indicated that dividing attention led to a decrease in familiarity, $F(1, 17) = 7.94$, $MSE = 0.008$.

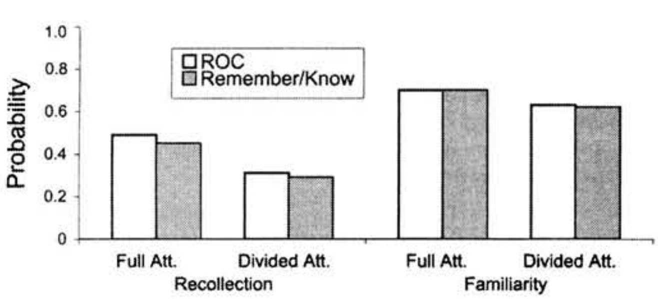

Figure 2. Estimates of recollection and familiarity derived using the receiver operating characteristic (ROC) and the remember–know responses for items studied under conditions of full and divided attention (att.) in Experiment 1.

ROC analysis. Estimates of recollection and familiarity were derived by fitting the dual-process signal-detection model to the observed confidence ROCs. The procedure is based on a regression method in which a nonlinear equation representing the dual-process model is fit to the observed points in the ROC. As with a standard linear regression, the method finds the parameter values that provide the best fit to the observed data points by minimizing the sum of squared errors. However, rather than estimating the slope and intercept parameters of a line, the method produces estimates of the recollection and familiarity parameters. The model equation is based on the following assumptions. A participant will accept an old item as studied if it is recollected or if it is not recollected but its familiarity exceeds the participant's familiarity response criterion ($P[\text{"yes"}|\text{old}] = R + [1 - R]\ \Phi\ [(d'/2) - c]$). Moreover, a participant will accept a new item as studied if its familiarity exceeds the response criterion ($P[\text{"yes"}|\text{new}] = \Phi$

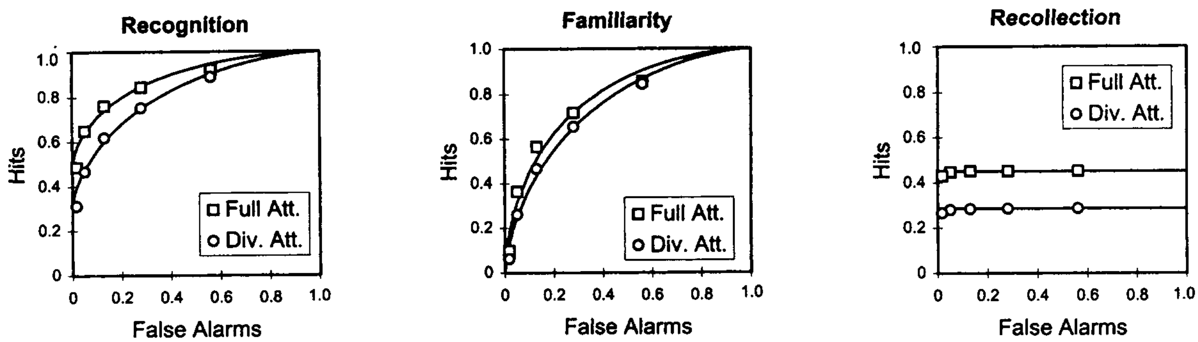

Figure 3. Recognition receiver operating characteristics for full and divided attention (div. att.) conditions in Experiment 1 (left panel). Estimates of familiarity (middle panel) and recollection (right panel) as a function of response confidence.

$[-(d'/2) - c]$). These two equations are combined to arrive at a single equation that relates the hit rate to the false alarm rate ($P[\text{"yes"}|\text{old}] = P[\text{"yes"}|\text{new}] + R + [1 - R]\,\Phi\,[(d'/2) - c] - \Phi\,[-(d'/2) - c]$). R represents the probability that an old item is recollected, d' represents the difference between the familiarity of the old items and the new items measured in z scores, and c represents the response criterion. The Φ functions represent the proportion of the old and new item familiarity distributions that exceed the response criterion (c), respectively, given that the distance between the means of the two normal distributions is d' (for a more detailed discussion of the method, see Yonelinas et al., 1998; Yonelinas, 1997, 1999a).

The ROC analysis led to conclusions similar to those of the remember–know analysis. Figure 3 (left panel) presents the ROCs for the full and divided attention conditions fit to the dual-process signal-detection model. Note that an examination of individual participants' ROCs showed that the points on the ROCs were well spaced and that floor and ceiling effects were not apparent. An examination of Figure 3 shows that the model provided a good fit for the observed data. The model did not deviate from the average ROC points by more than .02, and it accounted for 99.6% and 99.8% of the variance in the average ROCs for the full and divided attention conditions, respectively. An examination of the parameter estimates derived from the model showed that dividing attention led to a decrease in estimates of recollection (from a probability of .49 to .31) and familiarity (from a d' value of 1.10 to 0.92). To statistically assess the effects of divided attention on recollection and familiarity, the model was fit to each participant's ROCs. As the overall estimates suggested, dividing attention led to a significant decrease in estimates of recollection, $t(17) = 6.30$, and a significant decrease in estimates of familiarity, $t(17) = 3.49$.

To compare the ROC and remember–know estimates, it was necessary to account for differences in false alarm rates. Given that the false remember rates are typically quite low (e.g., 0–4%), correcting for false remember rates does not greatly influence the estimates of recollection. However, given that false know rates are considerably higher (e.g., 10–30%), familiarity estimates must be considered in light of the false alarm rate observed in a given experiment. To compare familiarity estimates with those derived from the ROC method, the d' values from the latter method were used to determine the probability that an old item would be accepted on the basis of familiarity at the specific false alarm rate observed in the remember–know test (i.e., the probability of responding either remember or know to a new item was .28). In this way, recollection and familiarity estimates from both the remember–know and ROC procedures are measured in terms of probabilities, and they can be more easily compared.

A direct comparison of the estimates derived using the remember–know and ROC analyses showed that the two methods produced estimates that were almost identical (see Figure 2). An analysis of variance (ANOVA) conducted on participants' estimates showed that dividing attention significantly reduced the estimates of recollection, $F(1, 17) = 50.95$, $MSE = 0.009$. Importantly, there was no significant difference between the remember–know and ROC estimates, and no Attention × Task interaction ($Fs < 1$). Similarly, estimates of familiarity were significantly reduced by dividing attention, $F(1, 17) = 10.11$, $MSE = 0.009$, and there was no significant difference between remember–know and ROC estimates, and no Task × Attention interaction ($Fs < 1.2$).

To further quantify the ROCs and to facilitate comparison to previous ROC studies, the average ROCs were plotted in z-space, and standard linear regressions were conducted to determine the slope and intercept of the z-ROCs (see Table 2). An additional analysis was conducted by examining each participant's ROCs. Note that for several of the participants, the ROCs included end points that were not defined in z-space (e.g., .00 and 1.00). Although the results of the regression analysis were not greatly affected by these end points, rather than replacing these values (cf. Snodgrass & Corwin, 1988), I did not include these points in those participants' regression analysis. The average slope and intercept values were very similar to the slope and intercepts of the average ROCs in all of the experiments; thus only the values from the average ROCs are reported in Table 2. The intercept for the full attention condition was greater than that for divided attention, $t(17) = 2.84$, suggesting that dividing attention led to a decrease in memory performance. The slope for the full attention condition was less than that for the divided attention condition, $t(17) = 2.75$, showing that the full attention ROC was less symmetrical than the divided attention ROC. The slope was less than 1.0 for both the full, $t(17) = 6.86$, and divided attention conditions, $t(17) = 4.60$, showing that the ROCs were not symmetrical.

Recollection and familiarity ROCs. To assess the threshold and signal-detection assumptions, the overall ROCs were decom-

Table 2
Intercepts and Slopes of the Average Recognition z-ROCs and Familiarity z-ROCs for Experiments 1 Through 3

Experiment and condition	Recognition Intercept	Recognition Slope	Familiarity Intercept	Familiarity Slope
Experiment 1				
Full attention	1.36	0.63	1.08	0.99
Divided attention	1.12	0.75	0.98	1.08
Experiment 2A				
Full attention	1.64	0.64	1.26	0.99
Divided attention	1.29	0.70	1.07	1.02
Experiment 2B				
Full attention	0.86	0.78	0.67	0.99
Divided attention	0.69	0.83	0.56	0.99
Experiment 2C				
Full attention	0.96	0.73	0.61	1.01
Divided attention	0.70	0.84	0.49	1.07
Experiment 3				
Deep	1.33	0.67	0.79	1.00
Shallow	0.81	0.80	0.60	0.96
M	1.08	0.74	0.81	1.01

posed into recollection (Figure 3, right panel) and familiarity components (Figure 3, middle panel). Recollection was plotted by determining the probability of responding remember to studied items as a function of response criterion. For example, the leftmost point reflects the proportion of remember responses that received a *6* confidence rating, and the next point reflects the proportion of remember responses that received either a *5* or *6* confidence rating. Thus the process ROC reflects the probability that an item is recollected as the recognition response criterion is varied from strict to liberal. Similarly, familiarity was calculated on the basis of the observed ROC hit rate and the proportion of *R* responses at each level of response criterion (F = [hits $-$ R]/[1 $-$ R]). The false alarm rate was measured as the proportion of new items receiving either an *R* or a *K* response at each level of response criterion.

Examination of Figure 3 shows familiarity increased gradually as the response criterion was relaxed and formed curvilinear functions that were fit well by the equal-variance signal-detection model. The equal-variance model accounted for 99.5% and 99.9% of the variance for the average familiarity ROCs for the full and divided attention conditions, respectively. Moreover, the slope of the divided and full attention familiarity functions when plotted in z-space (see Table 2) did not deviate significantly from 1.0, $t(17)$ = 0.17 and $t(17)$ = 0.81 for divided and full attention conditions, respectively, as expected if the variance of the old item familiarity distribution was the same as that for the new item distribution (i.e., supporting the equal-variance assumption). In contrast to familiarity, recollection remained constant as the response criterion was relaxed, as expected if it reflected a threshold process that led to high-confidence responses. This means that virtually all of the remember responses were associated with the highest levels of response confidence, whereas the items accepted on the basis of familiarity were associated with a wide range of confidence responses.

Confidence distributions of remember and know judgments. An examination of the confidence distributions for the items judged *R* (bottom panel in Figure 4) showed that more full attention items were remembered than were divided attention items, suggesting that divided attention led to a reduction in recollection. Most important, however, was that most of the items that were remembered were recognized with the highest level of confidence (94%), showing that recollection supported high confidence responses.

An examination of the confidence distributions for items accepted as known (top panel in Figure 4) shows that items accepted on the basis of familiarity were recognized with a moderate level of confidence and that they formed continuous unimodal distributions. The new item distribution peaked at a confidence level of 3, the divided attention distribution peaked at a level of 4, and full attention distribution peaked at level of 5, suggesting that full attention items were the most familiar, the divided attention items were less familiar, and new items were the least familiar. These results are in agreement with estimates derived from the remember–know and the ROC analyses.

In sum, the results of Experiment 1 showed that estimates of recollection and familiarity derived using the ROC data and the remember–know data were remarkably similar, and both procedures showed that dividing attention led to a large reduction in recollection and a smaller, but significant, reduction in familiarity. These results suggest that the two procedures are measuring similar underlying processes. Moreover, familiarity-based responses were distributed in a continuous manner, and the familiarity ROCs increased in a curvilinear fashion across changes in response criterion, in agreement with classical signal-detection theory. In contrast, recollection led to high-confidence responses, and the probability of correct recollection remained constant across changes in the response criterion, as expected if recollection reflected a threshold process.

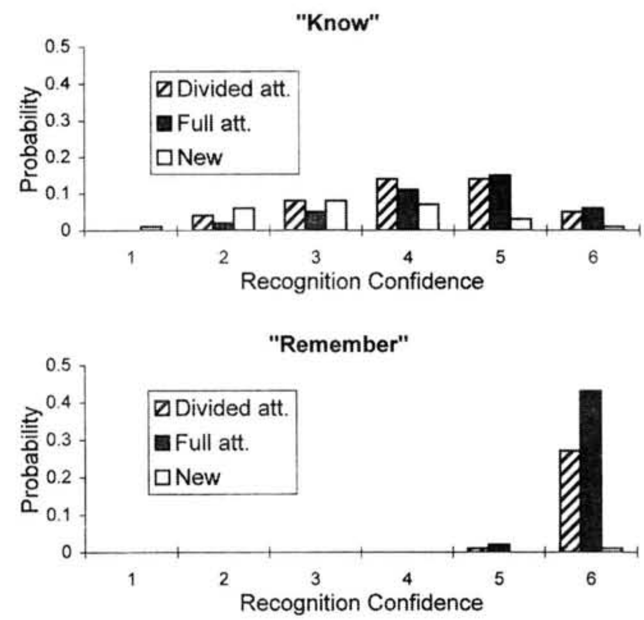

Figure 4. Confidence distributions for remember and know responses to full attention (att.), divided attention, and new items in Experiment 1.

Experiment 2a

Experiments 2a, 2b, and 2c were designed to test the generalizability of the results from Experiment 1 under a variety of different study and test conditions. Experiment 2a was identical to Experiment 1 with the exception that a simplified test procedure was used (see Yonelinas & Jacoby, 1995). Rather than requiring participants to make a recognition confidence judgment and a remember–know judgment for each item, the two procedures were combined. Participants were instructed to respond *R* if they remembered the item; otherwise they responded with a number from 1 to 6 indicating the confidence of their familiarity-based responses. The *R* responses were used as an index of recollection, and the confidence responses were used to plot the ROCs. Given that most of the remember responses in Experiment 1 led to the highest confidence recognition responses, the remember responses were treated as high-confidence recognition responses. Estimates of recollection and familiarity were derived by fitting the ROCs and by examining the proportion of remember responses. Moreover, familiarity estimates were examined as a function of response confidence to assess the shape of the familiarity ROCs.

Method

Participants and materials. Eighteen participants, from the same pool as Experiment 1, participated in the experiment. The materials were the same as those used in Experiment 1.

Design and procedure. The design and procedure were the same as in Experiment 1 except that the test procedure was modified. Participants were instructed to respond by pressing an *R* key if they could recollect having seen the item at study. As in the previous experiment, participants were told that they were to respond *R* only if they could retrieve something about the study event. Otherwise they were to rate how familiar the item was in the context of the experiment, in other words, how sure they were that the item was studied. Participants made familiarity ratings by responding on a 6-point scale from 6 (*sure it was studied*) to 1 (*sure it was not studied*). Participants were instructed to try to spread their responses out such that they were using all of the familiarity response keys. The remember–know and ROC responses were used to derive estimates of recollection and familiarity in the same way as in Experiment 1.

Results and Discussion

Remember–know analysis. The remember–know analysis showed that dividing attention led to a decrease in recollection and familiarity. Estimates of recollection and familiarity were derived from the remember–know responses as in Experiment 1, and are presented in Figure 5 (top row). Items eliciting a 4, 5, or 6 response were treated as know responses, and 1, 2 and 3 responses were treated as new responses. This response criterion is arbitrary; however, using more strict or more liberal criteria did not change the pattern of results. Recollection was greater for full than divided attention items, $t(17) = 6.90$. Similarly, familiarity was greater for full than divided attention items, $t(17) = 4.74$. The probability of a correct know response was lower for the full than divided attention items, $t(17) = 2.97$.

ROC analysis. The ROC analysis showed that divided attention led to a decrease in recollection and familiarity. Figure 6 (top left panel) presents the ROCs for the full and divided attention conditions fit to the dual-process model. The remember responses were treated as high-confidence recognition responses (i.e., "6" responses). The model accounted for 99.9% the variance in the average ROCs for both the full and divided attention conditions, and the model did not deviate from the observed data by more than .01. In agreement with the results of the previous experiment, fitting the model to the individual participant ROCs indicated that the probability of recollection was greater under full ($M = .56$) than divided ($M = .39$) attention, $t(17) = 3.74$. Similarly, familiarity, measured in terms of d', was greater under full ($M = 1.31$) than divided ($M = 1.07$) attention, $t(17) = 1.75$.

The slopes and intercepts of the z-ROCs are presented in Table 2. The intercept for the full attention condition was greater than that for divided attention, $t(17) = 5.77$. The slope for the full attention condition was slightly less than that for the divided attention condition, but the difference was not significant, $t(17) = 1.65$. The slope was less that 1.0 for both the full, $t(17) = 7.49$, and divided attention conditions, $t(17) = 7.78$.

As in Experiment 1, the d' estimates of familiarity from the ROC analysis were converted to probabilities to contrast the parameter estimates to those derived from the remember–know analysis. Figure 5 (top row) shows that the remember–know procedure produced estimates of recollection and familiarity that were almost identical to those derived from the ROC analysis. Dividing attention led to a significant decrease in recollection estimates, $F(1, 17) = 26.31$, $MSE = 0.030$; however, there was no significant difference between the remember–know and ROC estimates and no Task × Encoding Condition interaction ($Fs < 1.3$). For estimates of familiarity, dividing attention led to a decrease in parameter estimates, $F(1, 17) = 21.14$, $MSE = 0.005$; however, there was no significant difference between the remember–know and ROC estimates and no Task × Encoding Condition interaction ($Fs < 1$).

The upper right panel in Figure 6 presents the estimates of familiarity for full and divided attention conditions across levels of response criterion fit to the equal-variance signal-detection model. An examination of the figure shows that the familiarity ROCs were well described by the equal-variance model. The model accounted for 99.8% of the observed variance in the average ROCs for both the full and divided attention conditions. Moreover, when the familiarity ROCs were plotted in z-space, they were linear and their slopes (see Table 2) did not differ significantly from 1.0: $t(17) = 0.16$ and $t(17) = 0.25$ for the divided and full attention conditions, respectively.

As with Experiment 1, Experiment 2A showed that the remember–know and ROC procedures produced estimates of recollection and familiarity that were very similar, and both procedures showed that dividing attention led to a large decrease in recollection and a smaller, but significant, decrease in familiarity. Moreover, the familiarity ROC was as expected if familiarity reflected an equal-variance signal-detection process.

Experiment 2b

Experiment 2B was similar to Experiment 2A except that a simpler secondary task was used in the divided attention condition. Participants were required to make a "less than or equal to" judgment about two digits while they were studying the words,

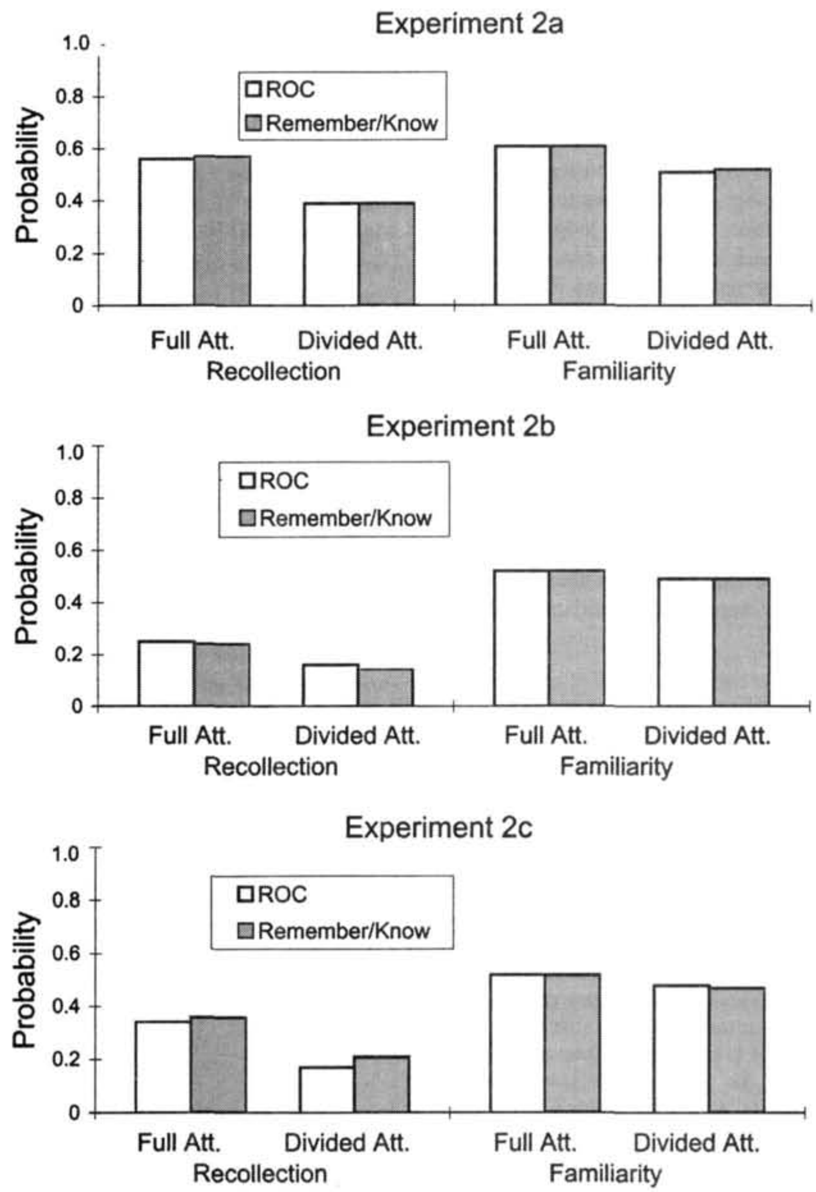

Figure 5. Estimates of recollection and familiarity derived using the receiver operating characteristic (ROC) and the remember–know responses for items studied under conditions of full and divided attention (att.) in Experiments 2a, 2b, and 2c.

rather than the "is it between these two values" judgment they made in the previous experiments. The only other difference was that there was only one long study list followed by a test list, rather than four study–test blocks.

Method

Participants and materials. Eighteen participants from the same pool as the prior experiments participated in the experiment. Three hundred eighteen words were randomly selected from the Toronto word pool. Three sets of 100 words were used as the critical items and were rotated through three experimental conditions. The remaining 18 words served as practice items.

Design and procedure. The design and procedure were the same as in Experiment 2a with the following changes. The study list contained 10 buffer items followed by a random mixture of 100 full attention and 100 divided attention items. Participants read each word aloud and tried to remember the words for a later memory test. Each word was presented for 2 s, followed by a 2-s interstimulus interval. For the divided attention items, participants conducted a concurrent number comparison task. For each divided attention item, a randomly generated number between 1 and 9 was presented to the left of the word. After 2 s the number and the word were removed and replaced by a second random number. Participants were required to compare the two numbers, pressing a ">" key if the first number was greater in value than the second number and to press "<" otherwise. The test phase was the same as in the previous experiment,

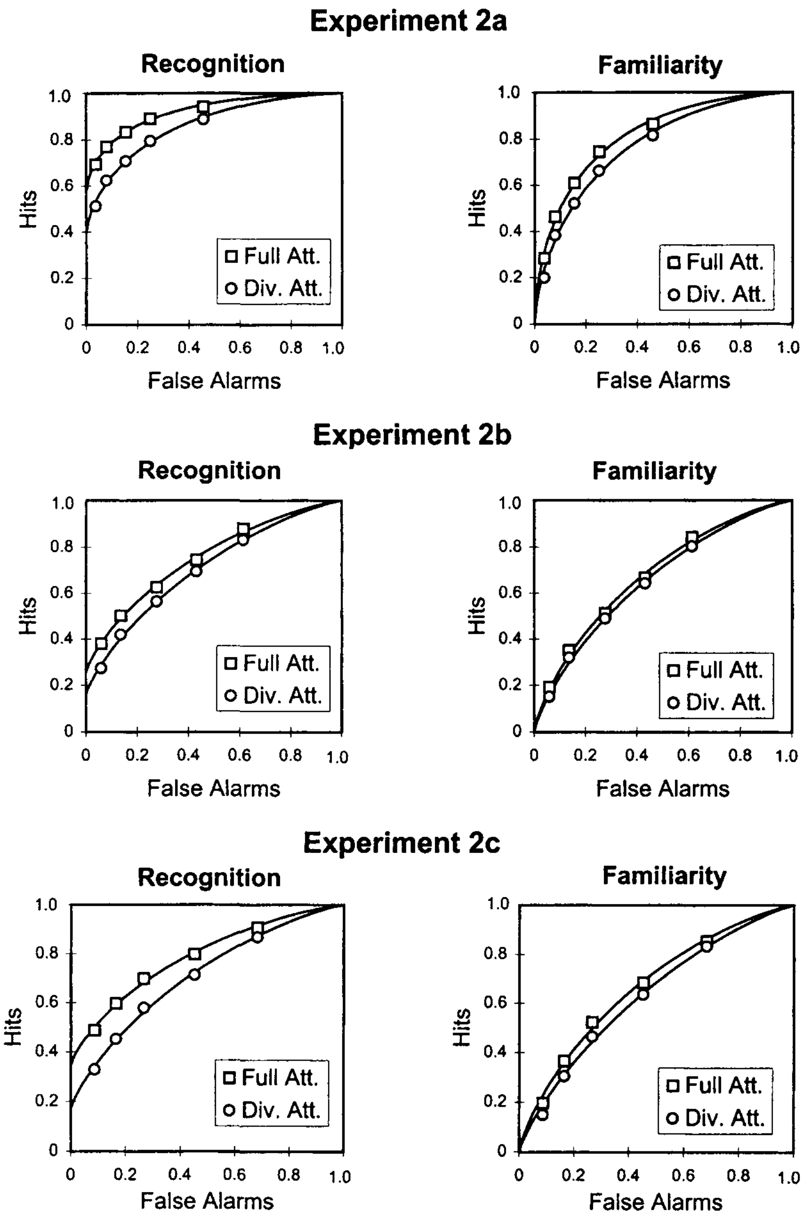

Figure 6. Recognition receiver operating characteristics for full and divided attention (div. att.) conditions (left panel) and estimates of familiarity as a function of response confidence (right panel) for Experiments 2a, 2b, and 2c.

except that the test list contained 8 buffer words followed by a random mixture of 100 divided attention, 100 full attention, and 100 new items.

Results and Discussion

Remember–know analysis. The estimates of recollection and familiarity based on the remember–know responses are presented in Figure 5 (middle row). Recollection was greater for full attention items than for divided attention items, $t(17) = 5.64$. Estimates of familiarity were slightly greater for full attention items than divided attention items, but the difference failed to reach significance, $t(17) = 1.15$. The proportion of know responses was slightly greater for the divided than full attention condition, but the difference was not significant, $t(17) < 1$.

ROC analysis. Figure 6 (left side, middle row) presents the ROCs for the full and divided attention items fit to the dual-process model. In agreement with the results of the previous experiments, the model provided an accurate fit for the ROCs. The model accounted for 99.9% of the variance for the average ROCs for both the full and divided attention conditions, and the model did not differ from the observed data points by more than .01. Estimates of recollection were greater under full ($M = .25$) than divided attention ($M = .16$) conditions, $t(17) = 2.62$. Familiarity was slightly greater in the full (M = 0.63) compared with the divided attention conditions (M = 0.55); this difference was significant by a one-tailed test, but not by a two-tailed test, $t(17)$ = 1.75.

The ROC estimates of familiarity were converted to probabilities to contrast them to the remember–know estimates. The estimates from the remember–know procedure were almost identical to those derived from the ROC analysis (see Figure 5, middle panel). For recollection, there was a significant effect of divided attention, $F(1, 17)$ = 19.47, MSE = 0.006, but no difference between the estimates derived from the two tasks and no Task × Attention interaction (Fs < 1). For familiarity, there was no significant effect of attention, $F(1, 17)$ = 3.07, MSE = 0.004, no difference between tasks, and no Task × Attention interaction (Fs < 1).

In z-space the slope of the full attention z-ROC was less than that for the divided attention z-ROC, $t(17)$ = 2.29 (see Table 2). The slope was less than 1.0 for the full, $t(17)$ = 5.76, and divided attention ROCs, $t(17)$ = 4.26, and the intercept for the full attention condition was greater than that for the divided attention condition, $t(17)$ = 4.19.

Figure 6 (right side, middle row) presents the estimates of familiarity for full and divided attention conditions as a function of response criterion fit to the equal-variance signal-detection model. The familiarity ROCs were fit well by the equal-variance model; the model accounted for 99.9% and 99.8% of the variance in the average ROCs for the full and divided attention conditions, respectively, and it did not deviate from the observed data points by more than .01. The slopes of the ROCs for the full and divided attention conditions did not differ from 1.0 (ts < 1) for full and divided attention conditions (see Table 2).

The results of Experiment 2b were in agreement with the previous experiments in showing that the ROC and remember–know procedures led to similar estimates of recollection and familiarity. The divided attention manipulation appeared to have a slightly smaller effect in the current experiment than that seen in the previous experiment. Dividing attention led to a significant decrease in recollection and a marginal decrease in familiarity. Consistent with the previous experiments, the familiarity ROCs were fit well by an equal-variance signal-detection model.

Experiment 2c

Experiment 2c was the same as Experiment 2b except that a different secondary task was used and the full and divided attention items were blocked during the study phase rather than mixed.

Method

Eighteen participants from the same pool as the previous experiments participated in this experiment. The materials, design, and procedures were the same as those used in Experiment 2b with the following changes. Participants were presented with two lists of words to study for a later recognition memory test. Each list contained 10 buffer words followed by 100 critical words. Each word was presented on the screen for 1.5 s, followed by 1.5 s of blank screen. One list was studied under divided attention conditions, and the other was studied under full attention conditions. The presentation order of the full and divided attention lists was counterbalanced across participants. For both the full and divided attention conditions, participants read each word aloud as it was presented. However, in the divided attention condition, participants also conducted a number comparison task. Between the presentation of each word, a randomly generated number between 1 and 5 was presented on the screen. The participants' task was to press the space bar whenever they saw three odd numbers presented in a row. Missing a sequence or responding when there were less than three odd numbers in a row was considered an error. After the presentation of the two lists, participants were presented with a random mixture of 100 words for the full attention list, 100 words for the divided attention list, and 100 new words. They were required to press an R key if they remembered the item and to rate their recognition confidence on a 6-point scale for the remaining items.

Results and Discussion

Remember–know analysis. The estimates of recollection and familiarity are presented in Figure 5 (bottom row). Recollection was greater for full attention items than for divided attention items, $t(17)$ = 7.58. Similarly, familiarity was greater for the full attention than for the divided attention items, $t(17)$ = 2.11. The proportion of know responses was slightly greater for the divided than full attention condition; however the difference did not reach significance (t < 1).

ROC analysis. Figure 6 (bottom left panel) presents the ROCs for the full and divided attention conditions fit to the dual-process model. The model accounted for 99.9% of the variance for the average ROC for both the full and divided attention conditions and did not deviate from the observed data points by more than .01. The parameter estimates showed that recollection was greater for full (M = .34) than divided attention (M = .17) items, $t(17)$ = 3.22. Similarly, familiarity, measured in terms of d', was greater for full (M = 0.66) than divided attention (M = 0.55) items, $t(17)$ = 1.83.

The ROC estimates of familiarity were converted to probabilities to compare them with the estimates from the remember–know procedure. As in the previous experiments, the estimates of recollection and familiarity derived from the remember–know procedure were similar to those derived from the ROC analysis (Figure 5, bottom row), and both methods led to similar conclusions regarding the effects of divided attention. For recollection, there was a significant effect of attention, $F(1, 17)$ = 24.11, MSE = 0.018; however, there was no difference between the estimates derived from the remember–know and ROC procedures and no Task × Attention interaction (Fs < 1). For familiarity there was a significant effect of attention, $F(1, 17)$ = 6.60, MSE = 0.008, but no effect of task or a Task × Attention interaction (Fs < 1).

An examination of the z-ROCs showed that the slope of the z-ROC (see Table 2) for the full attention items was less than that for the divided attention items, $t(17)$ = 2.71; the slopes of the full $t(17)$ = 7.32, and divided attention items, $t(17)$ = 4.71, were less than 1.0; and the intercept for the full attention z-ROC was greater than that for the divided attention z-ROC, $t(17)$ = 7.82.

Figure 6 (right bottom panel) presents the estimates of familiarity for full and divided attention as a function of response criterion. The familiarity ROCs were fit well by an equal-variance signal-detection model; the model accounted for 99.9% and 99.8% of the variance for the average ROCs for the full and divided attention conditions, respectively. The slopes of the ROCs (see Table 2) for the full and divided attention conditions did not differ from 1.0: $t(17)$ < 1 for full and divided attention conditions.

In sum, as in the previous experiments, the ROC and remember–know procedures led to very similar estimates of recollection and familiarity, and both procedures showed that dividing attention led to a large reduction in recollection and a smaller reduction in familiarity. Moreover, the familiarity ROCs were fit well by an equal-variance signal-detection model.

Experiment 3

Experiment 3 examined the effects of levels of processing on recollection and familiarity using the ROC, remember–know, and process dissociation procedures. Participants studied one list of words under deep processing conditions (i.e., rate the pleasantness of each word) and one list under shallow processing conditions (i.e., count the number of syllables in each word). Participants were then given a recognition memory test for the studied items using either the ROC, remember–know, or process dissociation procedures to derive estimates of recollection and familiarity. Unlike in the previous experiments, each participant was presented with only one test procedure in order to ensure that performance on one test procedure did not influence performance on the other task. That is, in Experiment 1, participants made a remember–know and confidence judgment for each item, and in Experiment 2 they made a remember or familiarity confidence judgment for each item. It is possible that requiring participants to make remember–know and confidence judgments for each item in those experiments led them to use recollection more often when making confidence judgments than they would have if the remember–know judgments had not been required. By testing each participant on only one test procedure, the current experiment eliminated the possibility that one procedure could influence the other. Each test (i.e., remember–know, process dissociation, and ROC) was conducted as a separate experiment with separate participants, but because the designs and results were so similar they were analyzed as a single study. The estimates derived from the different methods were compared, and estimates of familiarity were examined to determine whether they were fit well by the equal-variance signal-detection model.

The ROC and remember–know procedures were the same as those used in Experiment 1. The process dissociation procedure used in the current experiment was based on the original design of Jacoby (1991), because it provided a more inclusive measure of recollection than that provided by some more recent modifications of the procedure (e.g., Yonelinas, 1994). In the current study, recollection was measured as the ability to determine whether a word was presented in an incidentally encoded heard list or in an intentionally encoded seen list. The measurement of recollection was inclusive in the sense that the two lists in this task were fairly distinctive. Other variations of the process dissociation procedure have been developed in which the discrimination required for recollection is made more difficult by making the two lists more similar (e.g., by presenting all items visually or by using the same encoding task in the two lists). It is now well established that making the recollective discrimination more difficult results in a decrease in the process dissociation estimates of recollection (Gruppuso, Lindsay, & Kelly, 1997; Mulligan & Hirshman, 1997; Wagner, Gabrieli, & Verfaelli, 1997; Yonelinas & Jacoby, 1996). Moreover, when recollection is defined very strictly, the process dissociation procedure provides lower estimates of recollection than those obtained using the remember–know procedure (e.g., Yonelinas & Jacoby, 1995). To determine whether the process dissociation procedure taps similar processes to those measured by procedures that have very inclusive measures of recollection (e.g., anything that the participant recollects about the study episode can serve as recollection in a remember–know test), it is necessary to use a process dissociation method that also has an inclusive measure of recollection.

Method

Participants and materials. Fifty-four students enrolled in an introductory course in psychology served as participants. Eighteen students were tested in each of three test conditions. Two hundred forty words were randomly assigned to three lists of 80 words each. An additional 60 words were selected to serve as "seen" words in the process dissociation condition. Words were between one and four syllables in length, had word frequency counts between 3 and 15 per million (Kucera & Francis, 1967), and had concreteness values between 500 and 670 (Coltheart, 1981).

Design and procedure. During the study phase, two lists of 80 words each were presented auditorily one after another using a cassette player. The words were read by a male voice at a rate of one item every 3.5 s. Participants processed each list of words under deep or shallow encoding conditions. For the deep condition, participants were instructed to judge how pleasant each word was using a 4-point scale ranging from 1 (*very unpleasant*) to 4 (*very pleasant*). For the shallow condition, participants counted the number of syllables in each word. They made their responses verbally. The order in which the deep and shallow tasks were performed was counterbalanced across participants. Additionally, assignment of the three lists of words to the deep, shallow, and new conditions was counterbalanced.

The participants in the ROC and remember–know tests were then given a recognition test in which they were presented with all of the studied items and 80 new items presented one at a time in a random order on an IBM-compatible computer in lowercase letters. Participants in the ROC test made recognition memory judgments on the computer keyboard using a 6-point confidence scale (1 = *sure it was new* to 6 = *sure it was old*). Participants in the remember–know test made an *R*, a *K*, or an *N* response for each item. The remember–know and recognition confidence instructions were the same as those used in Experiment 1.

For the participants in the process dissociation test, immediately after the two heard lists were presented, participants were presented with an additional list of words on a computer screen and were instructed to try to remember those words for a later memory test. Sixty words were presented at a rate of one every 3 s. Participants then received two recognition memory tests. Each test list contained a random mixture of 30 words from the deep encoding list, 30 words from the shallow encoding list, 30 words from the seen list, and 40 new words. In the first test list, participants were tested under exclusion instructions, in which they were told to respond *yes* to words that were in the "seen" list and to response *no* if they recollected the word was from the earlier heard lists or if they thought it was new to the experiment. Participants were told that if the word was familiar but they could not recollect which list it was in, they should respond *yes*. They were then presented with the second test list and were given inclusion instructions, in which they were required to respond *yes* if the word was from earlier in the heard or seen lists and to respond *no* only if the word was new.

The recognition confidence data and the remember–know data were used to derive estimates of recollection and familiarity as they were in Experiment 1. The inclusion and exclusion scores were used to estimate the contribution of recollection and familiarity using the process dissociation procedure (Jacoby, 1991). Participants were assumed to correctly accept a heard item in the inclusion condition if it was recollected (*R*) or if it was not recollected and it was familiar (i.e., $[1 - R]F$). They were assumed to incorrectly accept a heard item in the exclude condition only if it was familiar and not recollected (i.e., $F[1 - R]$). Because the false alarm rates observed in the current experiment were higher under the inclusion instructions than under the exclusion instructions, the original process dissociation equations could not directly be used to derive parameter estimates. The increased false alarm rate in the inclusion condition suggested that participants adopted a more lenient response criterion in that condition. To incorporate response criteria into the estimation procedure, a signal-detection based algorithm was used that compensates for differences in response bias (Yonelinas & Jacoby, 1996; Yonelinas, Regehr, & Jacoby, 1995). As with the ROC estimation method, the method is based on the assumption that familiarity is an equal-variance signal-detection process and thus measures familiarity in terms of d′ values.

Results and Discussion

Remember–know analysis. The remember–know responses were used to estimate recollection and familiarity, and the parameter estimates are presented in Figure 7. Recollection and familiarity were greater for the deep processing condition than for the shallow processing condition: $t(17) = 10.24$ and $t(17) = 4.71$ for recollection and familiarity, respectively. The proportion of know responses was slightly greater for the shallow than for the deep condition, $t(17) = 2.06$, but the effect failed to reach significance by a two-tailed test.

ROC analysis. Figure 8 presents the ROCs for the deep and shallow conditions fit to the dual process model. The model provided a good fit for the ROCs, accounting for 99.9% of the variance for both the average semantic and perceptual encoding ROCs, and the model did not deviate from the observed data points by more than .01. In agreement with the remember–know data, the ROC estimates showed that recollection was greater under deep (M = .50) than shallow (M = .24) encoding conditions, $t(17) = 6.61$, and that familiarity, measured in terms of d′, was also greater under deep (M = 0.94) than shallow (M = 0.60) encoding conditions, $t(17) = 2.75$.

The ROCs were plotted in z-space, and the slopes and intercept values are presented in Table 2. The intercept for the full attention condition was greater than that for the divided attention condition, $t(17) = 6.49$, the slope for the deep processing condition was less than that for the shallow processing condition, $t(17) = 3.08$, and the slope of the semantic, $t(17) = 7.79$, and perceptual, $t(17) = 2.29$, z-ROCs were significantly less than 1.0.

Process dissociation analysis. The results from the process dissociation procedure converged with those of the remember–know and the ROC procedures. Estimates of recollection and familiarity were derived using the process dissociation procedure based on the average inclusion and exclusion scores. The probability of recollection was greater under deep (M = .57) than shallow (M = .25) encoding conditions, $t(17) = 6.44$. Familiarity, measured in terms of d′, was also greater under deep (M = 0.79) than shallow (M = 0.50) encoding conditions, $t(17) = 3.20$.

Comparing ROC, remember–know, and process dissociation data. A direct comparison of the ROC, remember–know, and process dissociation experiments showed that the three procedures led to similar estimates of recollection and familiarity (see Figure 7). As in the previous experiments, d′ estimates were converted to probabilities using the false alarm rate in the remember–know test (.21) to compare them with estimates derived from the different procedures. Across the three test procedures, estimates of recollection were greater under deep than shallow encoding conditions, $F(1, 51) = 160.04$, $MSE = 0.003$, but there was no significant difference between the estimates derived using the three different measurement procedures ($F < 1$) and no Encoding Condition × Procedure interaction ($F < 1$). Similarly, familiarity estimates were greater for deep than for shallow encoding conditions, $F(1, 51) = 40.9$, $MSE = 0.001$, but there was no difference in the estimates derived using the three different measurement procedures ($F < 1$) and no significant Procedure × Encoding Condition interaction, $F(2, 51) = 3.07$, $MSE = .001$.

The estimates of recollection derived using the remember–know and process dissociation procedures were used to assess the familiarity ROCs in the confidence judgment condition. That is, the familiarity ROCs were estimated by separating the recollection component (the average recollection estimate from the remember–know and the process dissociation procedures) from the overall recognition ROCs. The familiarity ROCs are presented in Figure 7 (right panel). The familiarity ROCs were well fit by an equal-variance signal-detection model; the model accounted for 99.8% and 99.9% of the variance for the average ROCs for the deep and shallow encoding conditions, respectively. Moreover, the slopes of the z-ROCs (see Table 2) for the deep and shallow encoding conditions were close to 1.0 (see Table 2).

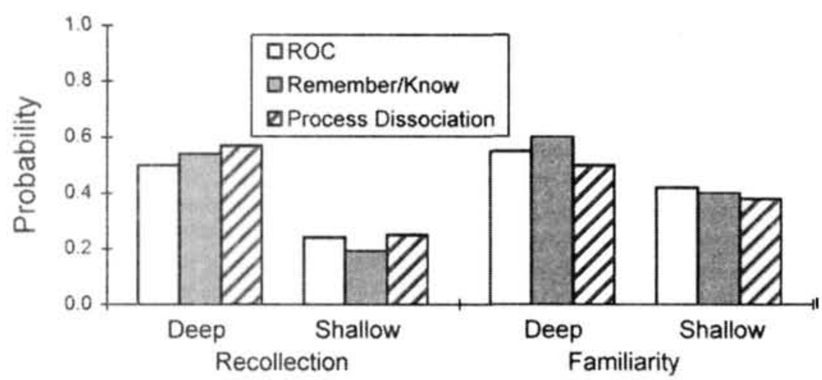

Figure 7. Estimates of recollection and familiarity derived using the receiver operating characteristic (ROC), the remember–know, and the process dissociation procedures for items studied under deep and shallow encoding conditions in Experiment 3.

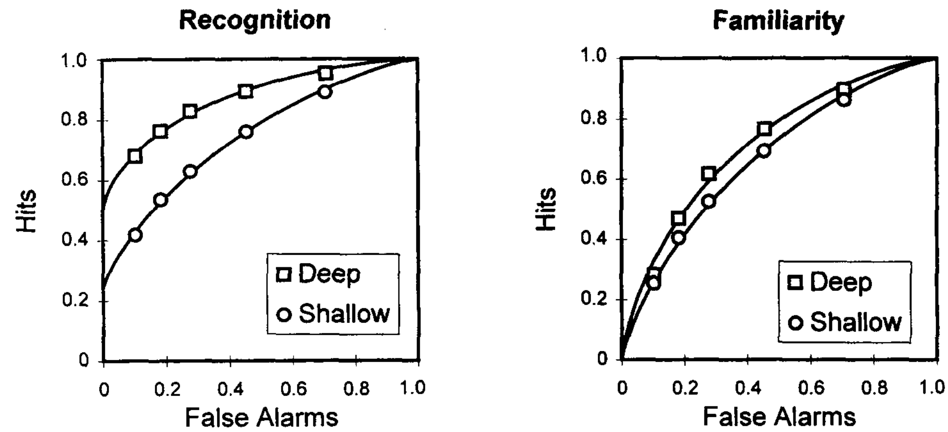

Figure 8. Recognition receiver operating characteristics for deep and shallow encoding conditions (left panel) and estimates of familiarity as a function of response confidence (right panel) for Experiment 3.

In sum, Experiment 3 showed that the remember–know, process dissociation, and ROC procedures produced very similar estimates of recollection and familiarity, and they all showed that semantic compared with perceptual processing at encoding led to an increase in recollection and familiarity. Moreover, as in the previous experiments, familiarity was well described as an equal-variance signal-detection model.

General Discussion

What is the difference between recollection and familiarity? Different recognition memory theories provide very different answers to this question. Jacoby (1991) argued that the two processes differ with respect to the extent that they support intentional control, Tulving (1985) asserted that they differ in terms of their associated states of conscious awareness, and Yonelinas (1994) argued that they differ in terms of the manner in which they contribute to the shape of recognition confidence ROCs. The current results, however, showed that these three characterizations of recollection and familiarity are quite compatible and that the measurement procedures associated with these theories lead to converging conclusions about these two processes. Recollection and familiarity were examined using the remember–know procedure (i.e., subjective reports of different types of conscious awareness), the process dissociation procedure (i.e., measures of intentional control in a list discrimination paradigm), and the ROC procedure (i.e., recognition confidence judgments). Across a range of different study and test conditions, the procedures led to similar estimates of recollection and familiarity, and they supported similar conclusions about the effect of dividing attention and levels of processing. Dividing attention at study led to a large decrease in recollection and a smaller, sometimes nonsignificant, decrease in familiarity (an average decrease of 37% and 10%, respectively). Semantic compared with perceptual processing at encoding led to a large increase in recollection and a moderate increase in familiarity (an average increase of 58% and 27%, respectively).

The convergence observed across the three procedures indicates that they are measuring similar underlying processes, and these findings are important in characterizing the behavioral nature of recollection and familiarity. They suggest that recollection reflects a threshold retrieval process whereby qualitative information is retrieved, such as when or where an event occurred. Moreover, it appears that the products of recollection support confident responses and are available to subjective awareness as "remembering." In contrast, the familiarity process reflects an assessment of quantitative memory strength information, the products of which are well described by classic signal-detection theory and are available to subjective experience as familiarity or "knowing." Thus, although the models proposed by Jacoby (1991), Tulving (1985), and Yonelinas (1994) focus on very different aspects of recollection and familiarity, they do appear to refer to similar underlying processes.

The results indicate that subjective reports of conscious experience during recognition memory tests correspond to objective measures of memory retrieval. Developing a scientific understanding of consciousness is one of the most challenging goals of modern science (see, e.g., Crick & Koch, 1995), but tools that can be used to assess conscious experience have been lacking. The remember–know procedure provides a promising experimental method; however, introspective reports are often treated with skepticism (for a classic example, see Watson, 1924). Coupling introspective methods such as the remember–know procedure with objective measures of accuracy such as the process dissociation procedure provides a way of validating these subjective reports and increases our confidence in the reliability of these reports.

Conversely, the convergence provides a validation of the process dissociation and ROC methods in showing that the theoretical processes of recollection and familiarity derived using these latter methods are psychologically real. For example, one concern with the ROC procedure is that the parameter estimates that it produces may be no more than a convenient mathematical description of the ROC data, and that they may not capture any real psychological processes. The fact that the parameter estimates that describe the shape of the ROC matched those from the remember–know procedure indicates that the ROC estimates provide an accurate index of the memory processes that participants report using when making recognition judgments.

The convergence observed across the test procedures also indicates that both recollection and familiarity contribute to recognition memory, even when the task instructions do not explicitly require participants to use both processes. That is, in the ROC recognition test, participants may have used familiarity alone and either ignored or failed to engage in recollection. This strategy would have been suboptimal in the sense that overall performance would have suffered, but given that they were not explicitly instructed to use recollection, it is possible that they may have adopted such a strategy. However, the finding that the estimates of recollection and familiarity in the recognition ROC test were the same as those in tests in which participants were explicitly required to recollect information about previous study events indicates that recollection and familiarity contributed to performance even under simple recognition memory instructions.

The results reveal that there are direct relationships between research areas that have often been treated as quite separate. For example, in studies of recognition ROCs, results from remember–know or process dissociation experiments are only rarely discussed. The current results indicate that each procedure can provide important insights into the other test procedures. For example, in the study of recognition ROCs, it has become clear that the shape of the ROCs can vary in several ways. That is, (a) overall level of performance can change, (b) the degree of ROC asymmetry can change, and (c) the extent to which the functions are linear or curvilinear can change (e.g., Yonelinas, 1994, 1997). The current results show that the shape of the ROC is determined by the relative contributions of recollection and familiarity to overall recognition memory performance. Thus, it is not necessary to plot an entire ROC in order to determine its shape. Rather, asking a participant to make remember–know judgments or inclusion and exclusion judgments appears to provide the same information. Conversely, it does not appear to be necessary to ask participants to report on the subjective experiences of recollection and familiarity in order to determine the likelihood that they will have these conscious experiences. Rather, the ROC or process dissociation procedures can be used in conjunction with the dual-process model to predict the occurrence of these conscious states.

The finding that deep compared with shallow encoding led to an increase in both recollection and familiarity is consistent with a growing body of research showing that both processes benefit from semantic processing. For example, results from studies that used the process dissociation procedure indicate that deep compared with shallow encoding increases both recollection and familiarity (e.g., Experiment 3 in the current study; Jacoby, 1991; Toth, 1996; Wagner et al., 1997; Yonelinas et al., 1995). Similarly, studies that used the remember–know procedure indicate that reports of remembering generally increase with semantic compared with perceptual encoding, demonstrating that recollection increases with deep encoding (e.g., Experiment 3 in the current study; Gardiner, 1988; Rajaram, 1993). In these same studies, knowing (i.e., familiarity in the absence of recollection) either remains constant or decreases slightly with deep compared with shallow encoding. If recollection increases with deep processing, and familiarity in the absence of recollection remains relatively constant, then it follows that familiarity must have increased with deep compared with shallow processing (Experiment 3 in the current study; also see Wagner et al., 1997; Yonelinas & Jacoby, 1996).

These results are in disagreement with several early dual-process theories that suggested that recollection and familiarity could be equated with semantic and perceptual memory processes, respectively. For example, Mandler (1980) argued that familiarity reflected the "sensory and perceptual integration of the elements of the target event" (p. 255), whereas recollection reflected elaborative connections between items. Similarly, Jacoby and Dallas (1981) argued that perceptual experience with a stimulus often enhances the later perceptual reprocessing of that stimulus, and that this "perceptual fluency" is experienced as familiarity. Although there is a large body of literature showing that perceptual fluency does influence familiarity (e.g., Jacoby & Whitehouse, 1989; Johnson, Dark, & Jacoby, 1985; Whittlesea, Jacoby, & Girard, 1990), the current results indicate that familiarity is not limited to perceptual processes, as was once thought.

In the current experiments, dividing attention led to a consistent decrease in recollection and a smaller and less consistent decrease in familiarity. In general, the results are in agreement with previous findings indicating that recollection is more sensitive than familiarity to the effects of divided attention (e.g., Gardiner & Parkin, 1990; Jacoby & Kelley, 1992). However, the extent to which familiarity is disrupted by dividing attention appears to depend on the specific manner in which attention is divided. In the current experiments, divided attention generally led to a decrease in both recollection and familiarity. This is consistent with several previous remember–know studies indicating that both recollection and familiarity benefit from full compared with divided attention. That is, dividing attention decreases remember responses, and it either leaves know responses unaffected (e.g., Gardiner & Parkin, 1990; Parkin, Gardiner, & Rosser, 1995) or leads to a slight increase in know responses (Reinitz, Morrissey, & Demb, 1994), which indicates that familiarity is disrupted by dividing attention. However, Jacoby and Kelley (1992) used the process dissociation procedure and found that dividing attention at time of study led to a decrease in recollection but did not influence estimates of familiarity. Exactly why the results of Jacoby and Kelley differed from those of the other studies is not clear; however, one obvious difference between the studies was in the encoding tasks that were used. Unlike in the other studies of divided attention, Jacoby and Kelley controlled the type of encoding that participants engaged in during the study phase. For example, participants were required to make semantic decisions about the studied words in both the full and divided attention conditions. Thus, semantic processing was required in both the full and divided attention conditions. In contrast, when the type of encoding strategies that participants used are not controlled, they may encode items more semantically in the full attention condition than in the divided attention condition, thus giving rise to an increase in familiarity in the full compared with divided attention conditions. Thus it appears that dividing attention can disrupt familiarity, at least under conditions in which participants are free to more deeply encode the items in the full compared with divided attention conditions.

Procedural Limitations

The fact that these different measurement procedures converge suggests that it may be possible to use one method in conditions in which others are problematic or impractical. For this reason it is useful to consider the limitations of each method. An important requirement of the remember–know procedure is that participants understand the distinction between remembering and knowing. In the current study, care was taken to ensure that participants understood the instructions by having them explain the distinction back to the experimenter before initiating the recognition test. Previous experience with the test instructions has suggested that participants can sometimes misinterpret the instructions as meaning that they should respond *remember* whenever they are confident that an item was old, and this usually leads to an inflated rate of remember responses to new items. In the current study, the rate of false remember responses was on average quite low (2%). If participants were to misunderstand instructions and the false remember rates increased, it is unlikely that the estimates derived from the procedure would converge with those from the other measurement procedures. The dependence on understanding a complex linguistic distinction suggests that the remember–know procedure may be of limited use in studies with children or individuals with language deficits; in these cases the other procedures may be more useful.

The process dissociation procedure also has important limitations. The logic of the procedure requires that in the exclusion condition participants respond *yes* to target items and *no* to new items or items from the incorrect list. Because of the necessity of understanding the verbal instructions, the process dissociation procedure may also be problematic for language-impaired individuals. Note, though, that alternative process dissociation methods have been developed in which the test instructions are much simpler (see Hay & Jacoby, 1996).

A potential limitation associated with all three methods is estimation bias related to floor and ceiling effects. If participants perform perfectly in the remember–know or exclusion conditions, this can lead to distortions in the parameter estimates provided by those procedures (see Jacoby, Yonelinas, & Jennings, 1997). Floor and ceiling effects can be particularly problematic with the ROC procedure. For example, if a participant's ROC includes points with a hit rate approaching 100% or a false alarm rate approaching 0%, this can artifactually distort the shape of the ROC and can lead to biased parameter estimates. As an extreme example, if a participant makes very few false alarms in the two highest confidence response categories, the resulting ROC may intercept the *y*-axis and then drop, producing a hockey-stick shaped function. If this participant's ROC is averaged with those of other participants, it will produce an artifactually downward curved ROC. To assess this, one must plot individual participant ROCs, which requires a large number of responses (e.g., each participant responded to no less than 80 test items in each condition in the current ROC experiments). It may not be possible or practical to collect this number of responses in some contexts or with some participant groups. Moreover, other averaging artifacts may arise if participants adopt greatly varying ranges of response criteria. To use the ROC method it is important that a large number of responses are collected from each participant so that individual ROCs can be examined and averaging artifacts can be assessed.

Differences Between the Process Dissociation, Remember–Know, and ROC Procedures

The convergence across the three measurement methods was striking. However, there are cases in which these measurement procedures do not agree, and examining the boundary conditions for this convergence will be important in future studies. One critical difference is that the remember–know estimates are subjective measures, and the process dissociation and ROC estimates are, in a sense, objective. That is, the remember–know procedure relies on the participants to decide what will count as recollection and what will count as familiarity. The consistency that is observed across different remember–know experiments suggests that there is some commonality across participants in how the remember–know distinction is interpreted. The process dissociation procedure, on the other hand, provides an objective measure of recollection in the sense that it measures recollection as the ability to accurately determine where or when an item was studied. The cost of this objectivity, however, is that the experimenters must specify exactly what will count as recollection, and in so doing, they risk excluding some types of recollection. For example, if a participant remembers having coughed during the presentation of a study item, this would not count as recollection in the version of the process dissociation procedure that was used in the current study, but it might count as recollection in the remember–know procedure. Finding that the two methods led to similar parameter estimates suggests that such "noncriterial" recollections were relatively rare in the current studies. However, as mentioned earlier, there are versions of the process dissociation procedure in which the required recollective discrimination is made very difficult, for example by making the study lists very similar, and this results in a decrease in the estimates of recollection (Gruppuso et al., 1997; Mulligan & Hirshman, 1997; Wagner et al., 1997; Yonelinas & Jacoby, 1996). Under these conditions the estimates of recollection derived using the process dissociation procedure will not converge with those from methods like the remember–know procedure (e.g., Yonelinas & Jacoby, 1995).

Further differences may arise between the estimates provided by these procedures under conditions in which false recollection is likely to occur. In the current study, false recollection in remember–know procedure was low. However, under conditions in which participants falsely recollect many items that were not studied (e.g., Roediger & McDermott, 1995), subjective measures of recollection may exceed those provided by the process dissociation procedure. Task orientation may also lead to differences in some cases. For example, when participants are making recognition confidence judgments they may retrieve different information about the study event than they would if they were making remember–know judgments or list discrimination judgments.

More interesting, however, is that there may be specific populations for which memory measures based on control and conscious awareness dissociate. In healthy participants, conscious awareness and control are closely related in the sense that when participants are aware that an item was in a certain experimental context they can use that as a basis for controlled responding. However, frontal patients sometimes exhibit intact awareness in cases where they are unable to successfully control behavior. For example, these patients typically perform poorly on the Wisconsin Card Sorting Task, yet surprisingly they can explicitly state the principles of the underlying task, and they are often aware that they are sorting the cards incorrectly; thus they may respond "That's the wrong shape" as they place the card in the incorrect pile (e.g., see Kimberg, D'Esposito, & Farah, 1997; Stuss & Benson, 1984). Studies are underway that contrast subjective and objective measures of memory in frontal patients, to determine whether control and awareness can be dissociated in this patient group.

Recollection and Familiarity as Threshold and Signal Detection Processes

The results from all the experiments supported the claim that familiarity and recollection reflect signal-detection and threshold processes, respectively. When estimates of familiarity were plotted against false alarms as a function of response confidence, the functions increased gradually and formed symmetrical ROCs that were well fit by the equal-variance signal-detection model. Moreover, the familiarity based z-ROCs were linear with a slope that was close to 1.0 (the average slope across experiments was 1.01). In contrast, the results showed that recollection reflected a threshold process that was associated with relatively high confidence recognition responses. For example, Experiment 1 showed that estimates of recollection remained invariant as the response criterion was relaxed and that recollection was associated with high-confidence recognition responses. Moreover, the ROC estimation method, which is based on the assumptions that familiarity and recollection reflect signal-detection and threshold process respectively, accurately predicted the estimates produced by the other measurement procedures.

These results converge with other recent studies that support the threshold and signal-detection distinction between recollection and familiarity. For example, the process dissociation procedure was used to estimate familiarity and recollection as a function of response confidence, and it showed that familiarity was well fit by an equal-variance signal-detection process and that recollection remained relatively constant, as expected if it reflected a threshold process (Yonelinas, 1994; but for a further discussion of these results, see Ratcliff, Van Zandt, & McKoon, 1995; Yonelinas, 1999a). Moreover, amnesic patients who rely primarily on familiarity to make their recognition judgments produce ROCs that are fit very well by the equal-variance signal-detection model (Yonelinas et al., 1998). Finally, in recognition tasks that rely heavily on recollection, such as memory for source or memory for associative information, the observed ROCs are often linear, as expected if recollection reflects a threshold process (e.g., Rotello, Macmillan, & Van Tassel, 2000; Yonelinas, 1997, 1999a).

What does it mean to conclude that familiarity is a signal-detection process? At one level it suggests that participants can make recognition judgments on the basis of how familiar the item is in the experimental context. This familiarity process is quite consistent with many current recognition memory models, including episodic (e.g., Hintzman, 1986) and distributed (e.g., Murdock, 1982) models, in which recognition decisions are assumed to be based on the assessment of memory strength. However, at a more detailed level, the current results suggest that the variance of the old item familiarity distribution is similar to that of the new item distribution, and thus the results support the equal-variance assumption underlying the dual process model. It is important to realize that the equal-variance assumption may have been incorrect. For example, familiarity may have an upper limit, and thus the old item familiarity distribution may have been less variable than new item distribution. The equal-variance finding is informative because it is consistent with some memory models (e.g., Murdock, 1982), and it is inconsistent with other models that predict that the old item variance will be greater than the new item variance (Gillund & Shiffrin, 1984; Hintzman, 1986). The equal-variance finding is sometimes interpreted as indicating that all the studied items must have increased by some constant amount relative to the nonstudied items. However, it is possible that the variance of the old and new items distributions are similar even when the increase in familiarity is not identical for all studied items. In fact, previous studies suggest that familiarity is influenced by item factors such as word frequency (e.g., Jacoby & Dallas, 1981; Yonelinas et al., 1995).

What does it mean to conclude that recollection is a threshold process? It indicates that participants either retrieve information about a previous study event or they fail to. More specifically, it means that there is a threshold below which participants are unable to retrieve accurate information about a previous event. Thus, if a participant relaxes his or her response criterion below the recollection threshold, additional items can be accepted as having been studied, but accurate levels of recollection will not increase. So, as in Experiment 1, false alarms increased as the response criterion was relaxed, but recollection did not change. This does not mean that recollection cannot occur at different levels or strengths. For items that are above the recollective threshold, participants may recollect different aspects or different amounts of information about a study event. The threshold notion is radically different from most current models of recognition, which are based on signal-detection theory, but, as discussed below, it is consistent with some neural network models.

Alternative Models

Can the recognition results be accounted for using a simpler signal-detection model? The equal-variance signal-detection model that is commonly used in memory studies is an attractive alternative, but it is not consistent with the existing recognition data. The ROCs in the current experiments, and in numerous other studies, are asymmetrical along the ROC diagonal (see the recognition ROCs in Figures 2, 5, and 7), which is in contrast to the symmetrical ROCs predicted by the equal-variance signal-detection model. In fact, the existing ROC data indicate that there are no single-factor models that can account for recognition memory. That is, the degree of ROC asymmetry can vary independently of the level of recognition accuracy. As accuracy increases, the symmetry of the ROC remains constant in some cases (e.g., Ratcliff, Sheu, & Gronlund, 1992; Yonelinas, 1994), but the asymmetry increases in others (e.g., the current experiments; Donaldson & Murdock, 1968; Yonelinas, 1994). What this means is that at least two memory factors are needed to account for the dissociations between accuracy and ROC asymmetry in simple recognition memory paradigms.

A two-factor model that is consistent with the data is the dual-process signal-detection model that underlies the ROC estimation method. In all of the current experiments the dual-process model was found to provide an accurate fit to the observed ROCs. The model can also account for the accuracy–symmetry dissociations observed in recognition studies. For example, increasing recollection will lead to an increase in accuracy accompanied by an increase in the asymmetry of the ROC. In contrast, increasing both recollection and familiarity together can lead to an increase in accuracy while the symmetry of the ROC remains constant (see Yonelinas, 1994).

Another two-factor model that is consistent with some of the recognition data is the unequal-variance signal-detection model.

This model has an accuracy factor (d') and a separate variance factor (the old–new variance ratio). Because the two factors can be varied independently, accuracy and ROC symmetry can behave independently.

The dual-process model and the unequal-variance model can produce ROCs that are very similar (see Yonelinas, 1997; but see Glanzer, Kim, Hilford, & Adams, 1999a, 1999b, and a response by Yonelinas, 1999a). However, previous studies have directly contrasted the dual-process and the unequal-variance models under conditions in which they make very different predictions and have shown that the dual-process model provides a better account of the memory data. For example, as predicted by the dual-process model, under conditions in which recognition performance should be supported primarily by recollection (certain source recognition and associative recognition tasks), the ROCs are relatively linear (e.g., Rotello et al., 2000; Yonelinas, 1997, 1999b). This conflicts with the unequal-variance model, which predicts curvilinear ROCs.

The fact that the familiarity ROCs were symmetrical when recollection was removed from the overall ROCs was predicted by the dual-process model. However, could the symmetrical familiarity ROCs have been obtained simply by removing high-confidence responses in an unequal-variance signal-detection model? A few calculations show that this approach does not work in general. The unequal-variance signal-detection model was used to generate an ROC that approximated the average ROC in the current experiments (slope = 0.74 and intercept = 1.07); then the portions of the old and new item distributions that exceeded the remember criterion (i.e., false alarms = .02, which was the average false remember rate observed in the current experiments) were treated as the remembered items. The familiarity ROCs were then plotted as they were in the current studies. This did lead to an increase in the slope of the z-ROC from 0.74 to 0.86, but it did not lead the ROC to become symmetrical (i.e., slope equal to 1.0), as was observed in all of the experiments (i.e., the average familiarity slope was 1.01).

One common interpretation of remember–know reports is that remember responses simply reflect the most familiar, or strongest, test items and that remember–know performance can be accounted for using a single signal-detection process as described above (e.g., Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). Thus, remembering and knowing do not reflect distinct memory processes, rather they reflect different response criteria; remembering reflects a strict response criterion and knowing reflects a more liberal criterion. In general, these models are inconsistent with what we know about recognition memory, in the sense that the existing literature indicates that such single-factor models are unable to account for the observed ROCs. The current results provide further support for the claim that remember and know reports reflect functionally distinct memory processes rather than differences in response criterion. That is, unlike knowing, remembering was used to support accurate source discriminations. Moreover, remembering, not knowing, led to the asymmetry observed in the recognition ROCs. These results indicate that the conscious experiences of remembering and knowing do not simply reflect different decision criteria, but rather they reflect distinct memory retrieval processes.

The current results provide support for the assumptions of the dual-process signal-detection model. However, the model is an obvious oversimplification. Most problematic is that the model says nothing about how memories are represented or how these retrieval processes are instantiated in the brain. However, the growing neuropsychological and neuroimaging literatures promise to provide important links between memory processes and underlying neural architecture. For example, since the landmark case of patient H.M., it has been known that the medial temporal lobes are critical for recognition memory. Several models of hippocampal function have already been developed to account for the functional deficits exhibited in amnesia (e.g., Gluck, Ermita, Oliver, & Myers, 1997; McClelland, McNaughton, & O'Reilly, 1995). Moreover, recent models of the medial temporal lobe have been developed that account for several aspects of the amnesia literature as well as some of the behavioral data on recollection and familiarity (e.g., Aggleton & Brown, 1999; O'Reilly, Norman, & McClelland, 1997), including the fact that recollection and familiarity reflect threshold and signal-detection processes respectively. These models posit that recollection is subserved by structures within the hippocampal region (e.g., CA1, CA3, and dentate gyrus) and that familiarity is subserved by structures outside this region (e.g., the parahippocampal region). Testing models that incorporate behavioral findings about recollection and familiarity with detailed knowledge of the structures within the temporal lobes will be essential in developing a more complete understanding of recognition memory.

In conclusion, recollection and familiarity were found to differ in several ways: the manner in which they supported intentional control, their related states of conscious awareness, and the extent to which they supported confident recognition responses. Although the distinction between recollection and familiarity is a relatively simple one, it has been useful in understanding a wide range of results from numerous different experimental paradigms, including the process dissociation, remember–know, and ROC procedures. These procedures represent a powerful set of measurement tools that will likely continue to provide important insights into the processes underlying human memory.

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