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Estimating Unconscious Processes: Implications of a General Class of Models

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Jacoby and his colleagues (e.g., L. L. Jacoby, J. P. Toth, & A. P. Yonelinas, 1993) have shown how the mnemonic contributions of conscious recollection and unconscious familiarity can be separated using a *process-dissociation procedure* based on a comparison of tasks in which consciously recollected material is to be included in vs. excluded from the responses. However, the estimate of unconscious familiarity depends on the assumptions of the model. This article describes a more general class of models in which the ratio of overlap between conscious and unconscious processes remains fixed and shows that this class of models (which includes the redundancy and exclusivity models as extreme cases) yields improbable results.

Jacoby's *process-dissociation* method for separating the contributions of conscious recollection and unconscious familiarity in memory tasks (e.g., Jacoby, 1991; Jacoby, Toth, & Yonelinas, 1993) has received considerable attention in the memory literature. In this method, participants carry out one memory task in which questions are to be answered using any information available (*inclusion condition*) and another task in which items that the participant recalls encountering earlier in the experiment are not to be used as responses (*exclusion condition*). The method produces separate estimates of the proportion of items consciously recollected and the proportion retained unconsciously. The estimates are based on a model that assumes that the conscious and unconscious memory processes operate independently.

Terminology varies but, following Joordens and Merikle (1993) and Debner and Jacoby (1994), in this article, the contribution of the conscious recollection process is termed *C* for modeling purposes and the contribution of the unconscious familiarity process is termed *U*. Provided that the baseline rate of guessing is the same in the inclusion and exclusion conditions, as Jacoby has found, the estimate of C is not in question, but the estimate of U is. In particular, Joordens and Merikle (1993) pointed out that different estimates of U are obtained when one assumes a model in which the conscious and unconscious processes are not independent but instead are redundant, with the consciously recollected set totally embedded in the set that is familiar on the basis of unconscious processes. In the other extreme, it also has been pointed out that U and C theoretically could be totally separate processes with no overlap, an exclusivity assumption that Jones (1987) favored (see p. 233 of his article).

Buchner, Erdfelder, and Vaterrodt-Plünnecke (1995) suggested that the controversy about which model is most appropriate can be circumvented. Even without knowing the relation between conscious and unconscious processes, one still can investigate the conditional probability that an item is unconsciously familiar given that it was not consciously recalled. This conditional probability is the same for the independence, redundancy, and exclusivity models (unlike U, which is indeterminate unless the correct model is known). Although we consider Buchner et al.'s line of argument an important theoretical advance, we still believe that there are good reasons to search for arguments that place logical constraints on the relation between conscious and unconscious processes. The relation between these processes is relevant to an understanding of the general mechanisms of information processing (see Cowan, 1995). For example, the redundancy model implies that one never can consciously recall an item without first experiencing it as familiar. (According to the other models, one still could recall an item and then experience a feeling of familiarity as a secondary result; that surplus familiarity would not alter the estimate of U.). In the other extreme, the exclusivity model seems to imply that the familiarity and conscious recollection systems are separate modules and that information is routed to one or the other of them, but not to both at once. This article examines the logic of various models to compare their adequacy.

Joordens and Merikle (1993) mentioned that neither Jacoby's (1991) independence model nor their own redundancy model may be totally correct, and they suggested that "it may be necessary to develop methods to empirically estimate the degree of overlap" (p. 466) between conscious and unconscious processes. As yet, however, this question has not been formally restated in precise terms. Jones (1987) did describe a hypothetical continuum of models running

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from exclusivity through independence to redundancy. However, one important issue we must address is whether the amount of overlap stays fixed or varies from one situation to the next. It stays fixed in the exclusivity and redundancy models and in many intermediate models, but it does not stay fixed in the independence model; in that model, the amount of overlap covaries with the amount of unconscious familiarity, as we show below.

We present formulas for the general case of a fixed amount of overlap for two reasons. First, a clear formulation of the problem may be the first step toward its eventual solution. Second, we have found that a consideration of this general case leads to evidence against at least some of the fixed-ratio models, and in support of the independence model, at least for the conditions present in the relevant studies by Jacoby that we and others (Jacoby, Toth, Yonelinas, & Debner, 1994; Joordens & Merikle, 1993) have used as cases in point.

Jacoby et al. (1993) examined performance on a word-stem completion task. Each word stem could be completed with more than one word, and often one of the words had been presented during an earlier study phase of the experiment. The dependent measure was the proportion of trials in which the stem was completed with the target word. The model component U first was calculated without considering the role of guessing, and then it was adjusted across participants by subtracting the proportion of trials in which the stems were completed with the target words on baseline trials in which none of the viable responses had been presented during the study phase of the trial. The rationale essentially was that U represents a sophisticated guessing process that includes responding on the basis of both (a) a sense of familiarity that is based unconsciously on the experimental stimulus exposures and (b), the *a priori* probability that participants would have provided the target words as solutions in the word-stem completion task if those words had not been presented in the study phase. The latter could only be based on the participant's preexperimental history of exposure to the stimulus items. For the sake of simplicity, in this article, we do not consider the validity of various methods of correcting for guessing, which has been considered elsewhere (Buchner et al., 1995; Cowan, 1995), but rather base the present concepts on an uncorrected estimate of U reflecting all sources of information other than conscious recollection. Guessing processes do not affect our line of argument.

The question posed by Joordens and Merikle (1993), namely how much overlap exists between conscious and unconscious processes, is formalized below in terms of the general class of models that we term *fixed-ratio models.* The quantity C, representing the proportion of items consciously recalled, can be divided into two portions, C_F and C_R. C_F refers to the proportion of cases in which there is redundant conscious and unconscious information. The quantity C_R, on the other hand, reflects the proportion of items that are not in unconscious memory (i.e., do not automatically produce a sense of familiarity) but nevertheless are available to conscious processes.[1] Models in the general case differ from one another in the ratio $C_F/(C_F + C_R)$, the proportion of conscious information that is also represented in unconscious processing.

An overall graphic model of performance, showing the relation between the basic components U, C_F, and C_R, is shown in Figure 1. The ratio $C_F/(C_F + C_R)$ is fixed at some value between 0 and 1. Two extreme special cases can be derived from this general model. In the redundancy model of Joordens and Merikle (1993), $C_R = 0$ and $C = C_F$, so that the above ratio equals C/C, or 1, and all conscious memory is embedded in unconscious memory. In an exclusivity model, the opposite occurs: $C_F = 0$ and $C = C_R$, so that the above ratio equals $0/C$, or 0, and the conscious and unconscious processes cannot overlap. There are infinitely many other models for which $0 < C_F/(C_F + C_R) < 1$.

In Figure 1, one can see that performance in the inclusion condition should equal the sum of unconscious memory (U) and the proportion of conscious recall that occurs when unconscious memory is insufficient (C_R). That is,

$$I = U + C_R. \quad (1)$$

The exclusion condition is based on the same information as the inclusion condition but, compared with I, E is reduced by conscious recall, or the quantity $C_R + C_F$, resulting in

$$E = U - C_F. \quad (2)$$

Rearranging Equation 2 yields

$$U - E = C_F, \quad (3)$$

and combining Equations 1 and 2 yields

$$I - E = C_F + C_R. \quad (4)$$

Dividing Equation 3 by Equation 4 and rearranging terms yields

$$U = E + (I - E)[C_F/(C_F + C_R)]. \quad (5)$$

This equation indicates that, as the ratio $C_F/(C_F + C_R)$ varies from 0 to 1, the value of U increases linearly from E to I. If this ratio were known, then U could be calculated from the empirically determined values E and I.

One complication in discussing the ratio is that Jacoby's (1991) independence model is not a member of the fixed-ratio class. For the independence model, the ratio covaries

[1] $C_R > 0$ implies that the participant sometimes was able to figure out consciously which item was presented, though the item was not automatically familiar. This often occurs according to independence or exclusivity models. The situation can be opaque to intuition, so it may be helpful to describe a way in which it could occur in the word-stem completion task that Jacoby and his colleagues (e.g., Jacoby et al., 1993) have used. To give one possible scenario, a participant might reason as follows: "I can think of two acceptable completions of this stem (A and B). If I received Completion A in the study phase, I am sure I would have recalled it, and I do not recall it at all; so, it is likely that I received Completion B, even though it does not seem familiar."

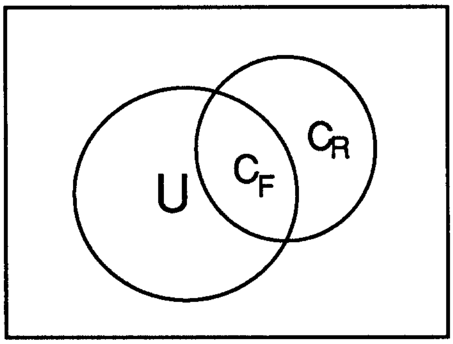

Figure 1. Illustration of a general class of models, which we term *ratio models. U* refers to the unconscious memory process. C_F refers to the portion of conscious memory that also is part of the unconscious memory process, and C_R refers to the remaining portion of conscious memory, such that $C_F + C_R = C$.

with the component U, the proportion of test items retained in unconscious memory. To understand why, consider an extreme situation in which $U = 0$. Then C_F must equal 0 because it is by definition embedded in U, and the ratio denoted above takes on a value of 0. At the other extreme, if $U = 1$, then all conscious memory must be embedded in it, so $C_R = 0$, and the ratio takes on a value of 1. For any value of U, because C is said to be independent of U in the independence model, the proportion of U occupied by C_F

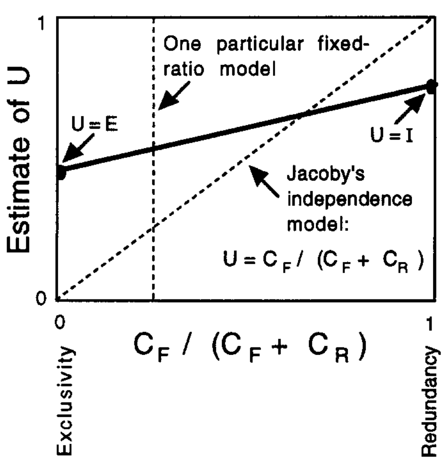

Figure 2. Illustration of theoretically possible estimates from one data set. *I* and *E* refer to the inclusion and exclusion condition scores. *U* refers to the unconscious memory process. C_F refers to the portion of conscious memory that also is part of the unconscious memory process, and C_R refers to the remaining portion of conscious memory, such that $C_F + C_R = C$. The estimate depends not only on the inclusion and exclusion scores, which determine the solid line in the figure (which we term the *estimate line*), but also on the ratio shown on the *x* axis, which determines what point along that solid line must be selected. Estimates that are consistent with Jacoby's (1991) independence model (diagonal dashed line, defined by Equation 7) versus one particular fixed-ratio model (vertical dashed line) differ substantially.

should equal the proportion of the remainder, $1 - U$, occupied by C_R. That is,

$$C_F/U = C_R/(1-U). \quad (6)$$

Through simple algebra, it can be shown that, when Equation 6 holds true,

$$U = C_F/(C_F + C_R). \quad (7)$$

This makes intuitive sense because increasing the magnitude of the unconscious process will increase the proportion that happens to overlap with an independent conscious process.

Figure 2 illustrates the manner in which the models are related to one another. It shows the estimate of U corresponding to data means in a particular matched pair of inclusion and exclusion conditions as a function of the ratio, $C_F/(C_F + C_R)$. Any of the estimates falling along the solid line are theoretically possible according to Equation 5; we refer to it as an *estimate line.* As the equation indicates, the possible estimates vary from the exclusion condition mean, *E*, in the exclusivity model, to the inclusion condition mean, *I*, in the redundancy model. In any of the cases in which the ratio is between 0 and 1, it is assumed that some, but not all, of the items that were consciously recalled and therefore deliberately omitted in the exclusion condition were automatically familiar, also. The figure shows that the estimate of *U* that satisfies the independence model (the height of the intersection of the diagonal dashed line defined by Equation 7 with the solid line) can be quite different from the estimate that satisfies a particular fixed-ratio model (the height of the intersection of the vertical dashed line with the solid line).

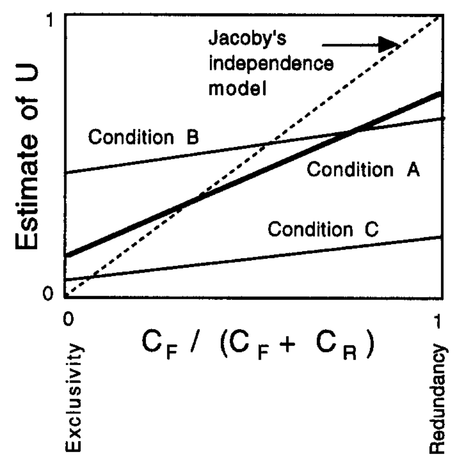

Figure 3. Estimate lines for three hypothetical conditions, each of which can be formed from particular inclusion and exclusion data means. Conditions A, B, and C refer to any three conditions that happen to produce the estimate lines shown in the figure. *U* refers to the unconscious memory process. C_F refers to the portion of conscious memory that also is part of the unconscious memory process, and C_R refers to the remaining portion of conscious memory, such that $C_F + C_R = C$. Notice that the estimate lines need not intersect and that intersections need not coincide with the independence model.

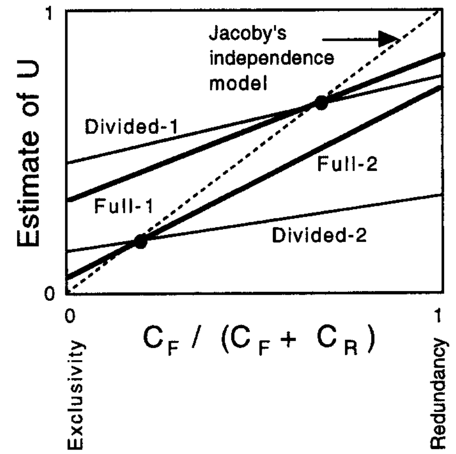

Figure 4. Estimate lines for two hypothetical experiments, each including full- and divided-attention conditions. Full-1, Full-2, Divided-1, and Divided-2 refer to full- and divided-attention conditions from any two experiments (1 and 2) that happen to produce the estimate lines shown in the figure. *U* refers to the unconscious memory process. C_F refers to the portion of conscious memory that also is part of the unconscious memory process, and C_R refers to the remaining portion of conscious memory, such that $C_F + C_R = C$. For these estimate lines, according to Jacoby's (1991) independence model (diagonal dashed line), there is no affect of attention. Notice that the point of intersection with the model can differ markedly from one experiment to the next.

The data of interest are the possible estimate lines for various pairs of conditions. Figure 3 illustrates the potential relations between conditions. The estimate lines can intersect at any ratio; note that the intersection of lines for hypothetical Conditions A and B does not happen to fall on the line representing the independence model. However, estimate lines need not intersect at all. The line for a hypothetical Condition C does not intersect with those for Conditions A or B.

Jacoby's findings place an additional restriction on the estimate lines, however. Across several studies, he and his colleagues have found that the estimates of *U* do not differ when participants devote full attention to the stimuli to be recalled versus when they divide attention between these stimuli and an auditory task (Debner & Jacoby, 1994; Jacoby et al., 1993).

These results greatly limit the plausibility of a number of alternative models. That becomes apparent when one uses the type of representation shown in Figure 4, which depicts estimate lines for two hypothetical process-dissociation experiments that include full- and divided-attention conditions. The equality of full- and divided-attention estimates of *U* according to the independent-processes model implies that the full- and divided-attention estimate lines for an experiment must intersect on the dashed line that defines the model. However, they can do so at very different values of the ratio $C_F/(C_F + C_R)$, that is, at very different values of *U* (see solid points in the figure). If this kind of discrepancy between experiments were to be found, then any fixed-ratio model would seem very unparsimonious. A fixed ratio that indicated no attentional effect on *U* for Experiment 1 in the figure would indicate a large attentional effect for Experiment 2. Even worse, a fixed ratio that indicated no attentional effect on *U* for Experiment 2 in the figure would indicate counterintuitively that, in Experiment 1, *U* was greater for divided than for full attention.

Table 1 presents relevant data on attentional manipulations from experiments in two studies (Debner & Jacoby, 1994; Jacoby et al., 1993). Data are presented also from two conditions in which a different experimental manipulation was used and, unlike the attentional manipulation, the estimate of *U* was affected. Figure 5 shows that the actual case is much like the hypothetical one described in Figure 4. Specifically, the estimates of *U* taken from the independence model (solid points where the dashed line intersects with the estimate lines) are comparable for full and divided attention, but they are rather different from one experiment to the next (see Figure 5A and Figures 5D–5F). The ratio $C_F/(C_F + C_R)$ corresponding to this estimate varies from under .50 in Figure 5A to over .70 in Figure 5D. Finally,

Table 1
Data From Six Experiments Using a Process-Dissociation Procedure

Condition	Condition: Inclusion	Exclusion
Jacoby, Toth, & Yonelinas (1993), Experiment 1b		
Full attention	.61	.36
Divided attention	.46	.46
Jacoby, Toth, & Yonelinas (1993), Experiment 3		
Read	.82	.49
Anagram	.82	.25
Debner & Jacoby (1994), Experiment 1		
500-ms presentation	.96	.10
50-ms presentation	.63	.50
Debner & Jacoby (1994), Experiment 2		
Full attention	.96	.09
Divided attention	.85	.42
Debner & Jacoby (1994), Experiment 3		
Full attention	.90	.16
Divided attention	.71	.60
Debner & Jacoby (1994), Experiment 4		
Full attention	.82	.20
Divided attention	.54	.48

Note. These experiments served as the basis of commentaries by Joordens and Merikle (1993) and Jacoby et al. (1994). From "Separating Conscious and Unconscious Influences of Memory: Measuring Recollection," by L. L. Jacoby, J. P. Toth, and A. P. Yonelinas, 1993, *Journal of Experimental Psychology: General, 122,* pp. 144 and 148. Copyright 1993 by the American Psychological Association. Adapted with permission of the authors. From "Unconscious Perception: Attention, Awareness, and Control," by J. A. Debner and L. L. Jacoby, 1994, *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* pp. 309, 311–313. Copyright 1994 by the American Psychological Association. Adapted with permission of the authors.

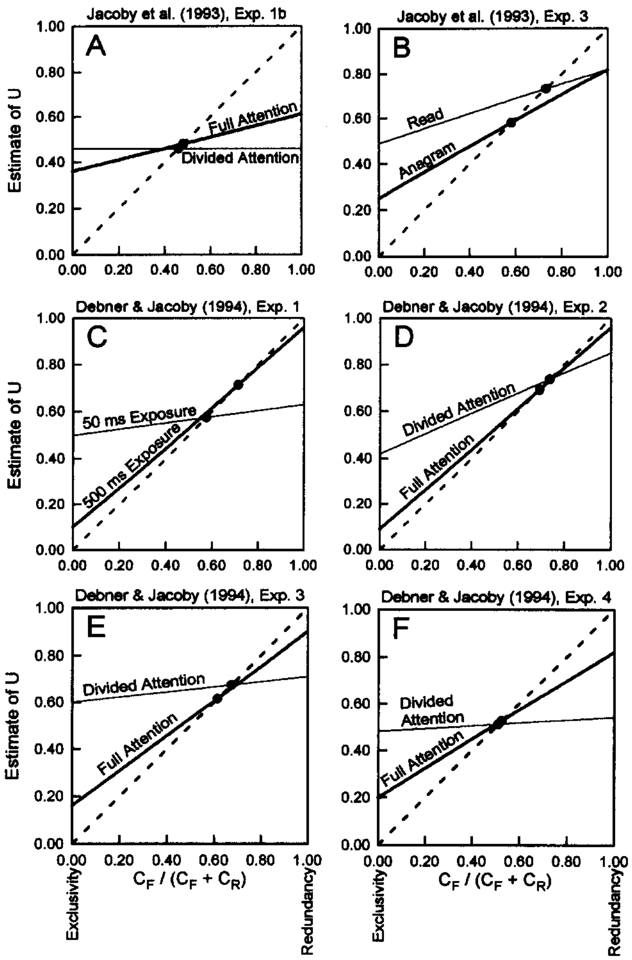

Figure 5. Estimate lines for six actual data sets (A–F), with estimates for Jacoby's (1991) independence model (diagonal dashed lines) marked by solid points. U refers to the unconscious memory process. C_F refers to the portion of conscious memory that also is part of the unconscious memory process, and C_R refers to the remaining portion of conscious memory, such that $C_F + C_R = C$.

nonattentional manipulations show that it is not logically necessary for estimate lines to cross at the independence model; there are indeed cases in which they do not do so and when the manipulation, accordingly, affects the independence model's estimate of U (Figures 5B and 5C).

No fixed-ratio model could describe the attentional results parsimoniously, because it would have to posit very different effects of attention in the different experiments. For example, a fixed-ratio model with a ratio of about .70 leads to the conclusion that there was little or no effect of attention on U in the experiments shown in Figures 5D and 5E, but that there was an effect of about .10 in Figures 5A and 5F.

Fixed-ratio models to the left of the point where full- and divided-attention estimate lines intersect are especially implausible. For those models, the estimate of U is higher for divided attention than for full attention. Thus, fixed-ratio models with a ratio lower than .70 can be ruled out on the basis of the data, and the remaining fixed-ratio models at best lack parsimony.

A remaining caution is that there are likely to be experimental conditions in which the independence assumption clearly does not fit. Currently, there is an ongoing debate about what those conditions are (Curran & Hintzman, 1995; Jacoby, Yonelinas, & Jennings, in press). It is worth emphasizing, however, that for the data in Table 1, none of the models with a fixed ratio across conditions comes close to fitting the data as parsimoniously as the independence model.

It would be possible to apply the current approach more broadly, to a wider variety of experimental conditions, if one could obtain separate estimates of conscious processes with concurrent familiarity (C_F) and without it (C_R). This would allow an assumption-free statement of the amount of overlap between conscious and unconscious processes in a particular test situation. Obtaining these separate estimates is a promising approach for future research. It could be done, for example, if one could find an indirect test that one knew was not influenced by conscious processes and that therefore reflected only U. (For a discussion of when and how this might be possible, see Toth, Reingold, & Jacoby, 1994.) Then, we would have three test results (inclusion, exclusion, and indirect) from which U, C_R, and C_F could be estimated. Searching for such conditions should be an important priority for research in the near future.

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