

CHAPTER

3

On the Law of Primacy



Endel Tulving

There exists a highly familiar phenomenon in learning and memory: first encounters with new situations, people, events, objects, and facts have greater impact on subsequent thought and behavior than later encounters of similar kinds. These “primacy effects” are well known from everyday life: the first day of school, the first romantic kiss, the graduation day, the first scientific paper accepted for publication, and many other “firsts” of the same kind are remembered vividly, and sometimes for the rest of one’s life.

Primacy effects have been intensely studied under the controlled conditions in the laboratory where they are ubiquitous. They are found in many kinds of memory tasks and situations as diverse as impression formation (Asch, 1946), absolute judgments (Bower, 1971), social judgments (Nisbett & Ross, 1980), updating of beliefs (Hogarth & Einhorn, 1992), abductive reasoning (Wang, Johnson, & Zhang, 2006), and “cognitive access” to unknown, abstract individuals mentioned in laboratory-made sentences (Gernsbacher & Hargreaves, 1988). Primacy effects are found in rats (Kesner, Measom, Forsman, & Holbrook, 1984), pigeons (Wright, Santiago, Sands, Kendrick, & Cook, 1985), and nonhuman primates (Castro & Larsen, 1992), as well as in various subgroups of humans, including amnesiacs (Baddeley & Warrington, 1970), people with frontal-lobe damage (Eslinger & Grattan, 1994), and people under the influence of alcohol (B. M. Jones, 1973).

Primacy represents such a pervasive, regular phenomenon in learned behavior that there ought to be a law of it. At an earlier age in the science of psychology there was, indeed, a law of primacy, along with many other laws. Over time, however, the popularity of psychological laws has waned to the extent that today few practitioners think of the law of primacy even when they are explicitly asked about laws (Teigen, 2002). These days psychologists in various subdisciplines are generating all sorts of phenomena, effects, functions, and principles, but few if any laws. Laws are a vanishing species, and it is a pity. It is true that psychology deals with a subject matter that is exceedingly complex and in which phenomena of interest are almost invariably determined by multiple variables and their interactions, a state of affairs that discourages laws. But surely underneath all the complexity there must be some regularity. It is just a matter of finding them and then taking them seriously. Some psychological laws are accepted even today (Teigen, 2002), and there must be others.

Here I propose that primacy is one such law. It can be thought of as a resurrected version of earlier laws of primacy, although it goes beyond the earlier ones in that it can be derived from a more general law, the law of camatotic encoding, explained later. The thesis of this chapter is that camatosis, as discussed in the latter half of this chapter, can account for the primacy effect in memory as well as a host of other interference-based and novelty-related behavioral phenomena.

This chapter consists of eight sections plus a summary. The sections are labeled law of primacy, serial position curves, events 1 and 2, hypothesis of camatosis, novelty, repetition suppression, and law of camatotic encoding.

THE LAW OF PRIMACY

Scientific laws, like most other things in life, come in different sizes, shapes, and styles. A basic distinction has to do with the generality of the law. Laws, by definition, are supposed to be “general,” but generality, like most other concepts, is flexible. Newton’s well-known laws of mechanics are very general, and in some sense can be thought of as universal. The economists’ equally well-known “law of supply and demand” does not hold in the whole universe at all times but only right now in some parts of our world. And Herrnstein’s well-known “matching law,” which specifies the relation between rather specific variables in rather specific laboratory-based learning situations, is nevertheless general within the specified limits.

The law of primacy I would like to propose here is this:

Of two sequential events the second one tends to be retained less well.

The law is assumed to have some generality. It is meant to apply to all situations in which *perceived events* occur in succession and entail consequences for subsequent behavior that we classify as learning or remembering. This generality

holds within the limited domain of behavior, broadly defined, of living creatures that are capable of perceiving events in their (external or internal) environment. Another limitation of this law is that it is assumed to be true only for long-term retention.

Note that this law describes a scenario containing only two events rather than a whole series of events. We return to this matter later in the chapter. Note also that this law does not define primacy directly but indirectly, in terms of the inferior retention of the later event rather than the superior retention of the earlier event. The reason for this wording becomes clear as we proceed. Some other obvious questions, concerns, and other forms of puzzlement and incredulity engendered from what I have written thus far are also dealt with presently.

SERIAL POSITION EFFECTS

Primacy effects have usually been observed and studied in situations in which there are also recency effects—higher recall of more recent than less recent events. Such situations involve list-learning and list-recall experiments that yield typical, U-shaped serial position curves (or bow-shaped when plotting “errors”) that show graded performance or error scores over the first few and last few positions in the list (e.g., Murdock, 1962). The close proximity of the two empirical phenomena in the observing scientist’s mind, plus the fact that both are defined in terms of temporal variables, have led many theorists to seek an explanation not of primacy and recency as two different phenomena, but rather an explanation of the overall phenomenon of “serial position effects.”

Primacy and recency components of serial position curves in standard memory experiments have been shown to be differentially affected by certain independent variables (Baddeley & Warrington, 1970; Glanzer, 1972; B. M. Jones, 1973; Shallice, 1979). This fact justifies the theoretical treatment of primacy, separate from that of recency. However, recency as an empirical fact—the fact that under certain conditions recent events are better recalled than less recent ones—does become highly relevant to the assessment of the validity, or plausibility, of the law of primacy. As an astute reviewer of the first version of the chapter put it—“There is no generality to primacy; I remember my last night’s dinner very much better than any dinner last week” (my paraphrase of his words).

The issue of the relation between primacy and recency is complex because, in terms of behavioral observations, it depends on a large number of variables and their interaction. A glimpse of the complexity is provided by the results of a series of clever experiments by Wright and his associates (1985). These investigators tested pigeons, monkeys, and human beings on a yes–no recognition task. On a given trial, the subject would see four visual patterns that they had never seen before, presented one at a time. The presentation series was followed by a single probe pattern that either matched (“old”) or did not match (“new”) one of the four

presented patterns. The stimuli were colored "travel pictures" for the two non-verbal species and colored kaleidoscopic images for the humans. This latter feature was adopted to eliminate verbal mediation and to force the humans to rely on pure perceptual memory as did the pigeons and monkeys. The nonhuman animals were provided instructions as to the rules of the game through extensive practice that preceded the experiment proper whereas the humans were instructed verbally.

The critical independent variable manipulated in the Wright et al. (1985) studies was the length of the retention interval: the duration of the time between the presentation of the last item in the inspection (study) series and the test probe. This interval ranged from 0 to 10 seconds for pigeons, 0 to 30 seconds for monkeys, and 0 to 100 seconds for humans. Extensive data, systematically covering the intermediate stages of all these intervals, were collected.

The results, graphically summarized in Figure 3-1, were striking, remarkably consistent, and highly informative. (More complete data are reported in Wright et al., 1985.) They can be summarized by saying that all three species exhibited a "pure recency" effect when tested immediately after the presentation of the

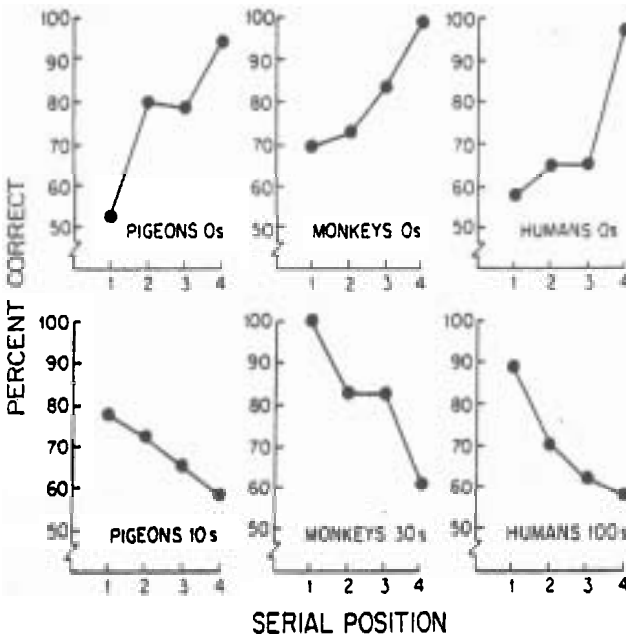


Figure 3-1. Percentage of correct recognition (50 is chance) shown as a function of the serial presentation position of complex visual stimuli in pigeons, monkeys, and human beings as reported by Wright et al. (1985). Immediate tests (no retention interval, upper bank) yielded pure recency effects whereas delayed tests (longer retention intervals, lower bank) yielded pure primacy effects in all three species.

to-be-recognized visual patterns, that all three exhibited “pure primacy” effects when tested after a longer retention interval (the length of the interval varying with the species), and that all three species exhibited both primacy and recency with intermediate retention intervals (these latter data are not shown in Fig. 3-1).

Data rather reminiscent of those of Wright and colleagues (1985), but based on auditorily presented verbal paired associates, have been reported by Madigan, McCabe, and Itatani (1972): Immediate recall shows the primacy effect overshadowed by the recency factors, whereas delayed recall shows a pure primacy effect throughout the eight-pair list.

The Wright et al. (1985) findings provide at least four lessons relevant to the story told here.

First, the fact that clear primacy effects occur in birds and nonhuman primates is at variance with one of the most venerable and most popular explanations of primacy, namely that primacy results from rehearsal of the material. The rehearsal hypothesis can be saved only if one is willing to assume that pigeons and monkeys, and even humans, are capable of “rehearsing” complex colored patches of light.

Second, varying the length of the retention interval, while holding constant all other variables, produces either primacy, recency, or both. This general fact is not unknown (Neath & Crowder, 1990), but it is worth emphasizing in the present context.

Third, whatever processes determine recognition performance as measured immediately after the presentation of the four-item inspection series can completely overpower or overshadow the processes that subserve the primacy effect. Whatever these processes are, and however the overshadowing works—and a number of possibilities, as always, suggest themselves—the important lesson is to observe and measure primacy, one has to keep it out of the reach of recency. The situation is analogous, say, to the measurement of the power of the Earth to attract a paper clip: One should not do so when a magnet is near the clip. The law of primacy is limited to “long-term” retention to stay clear of the strong powers of the determinants of recency.

Fourth, the Wright et al. (1985) data are incompatible with the idea that primacy is a phenomenon of episodic memory (T. Jones & Roediger, 1995), unless one is willing to agree that pigeons possess episodic memory. This fact is worth noting, although its more detailed pursuit does not fit into the present chapter.

EVENTS 1 AND 2

The proposed law of primacy deals with two sequentially occurring events. This is the simplest situation in which primacy can be observed. Thus, one event occurs, then another, and the learner witnesses them. Call them Event 1 and Event 2. Some time after witnessing Event 2, the learner’s knowledge of the fact of the occurrence of the two events is measured. Frequently the measurement takes the form of free recall, although other measures of retention such as cued recall,

recognition, “remembering,” “knowing,” and judged confidence (Lockhart, 2000) may also be used. In what follows, I use the generic term recall as a placeholder for all measures. Higher recall of Event 1 than Event 2 is referred to as “primacy effect,” or simply “primacy.”

In the scenario as described, there can of course be many reasons why Event 1 is more memorable than Event 2, reasons orthogonal to the temporal relations of the two events. Many “material variables” that affect recall have been identified in memory research. If higher recall of Event 1 were attributable to such a material variable, it would be of little interest, and it should not be called primacy. Or, it could be that Event 1 might “catch” more attention than Event 2 because of its distinctive position at the beginning of some sequence. Or, Event 1 might receive more rehearsal, because the learner has greater opportunities to do so, with appropriate consequences for retention. Now, although there is no doubt that special attention and rehearsal can produce primacy effects, the Wright et al. (1985) data mentioned earlier in the chapter prove that rehearsal is not necessary for such effects. In cases where primacy appears as a result of such special processing, I would suggest that what looks like primacy is a mere side effect of more fundamental processes and therefore theoretically uninteresting.

Here I am concerned with “true” primacy, primacy that occurs solely in virtue of Event 1 preceding Event 2 in time, and nothing else. Keeping firmly in mind the standard *ceteris paribus* clause—that always, automatically, applies to any scientific laws—may help minimize misunderstanding in this respect.

The proposed law tolerates many variations of the basic scheme. The nature of the events does not matter, the length of the temporal intervals involved does not matter, cognitive environments in which Events 1 and 2 occur are not supposed to matter. The law says nothing about what qualifies as an event. In practice, an event can be defined in many ways. The presentation of a word in a word list could be an event; the first three adjectives in a description of a person could be one event, and the next three, as in classic experiments of Asch (1946), another; one whole to-be-learned list could be an event. Indeed, the first half of one’s life could be one event and the second half another, although for practical reasons the memorability of these two “successive events” cannot always be compared. In principle, however, as far as the law of primacy is concerned, “anything goes.” As long as Events 1 and 2 are objectively identifiable and their retention measurable—and the *ceteris paribus* clause satisfied—the law of primacy is expected to hold.

The first and second items in experimental lists conform to the paradigm of two successive events, and in that sense the explanation of primacy that we are seeking would have to apply to them, too. But the beginning of a typical list represents only a special instance of a more general case; it is simple to create primacy effects in the middle of a list, and it is this more general case that is the object of interest in the present story. And it better be, too, because there are no experimenter-made “lists” in real life, yet real life is replete with primacy effects, and we want to understand those as much as their laboratory analogues.

ACCOUNTS OF PRIMACY

Memory theorists have proposed explanations for findings that have been interpreted as primacy effects. These explanations have targeted the higher recall of earlier events rather than the lower recall of later ones, as I am doing here. That is, rather than targeting the impoverished recall of the later events, the perspective taken by the “cramming hypothesis” I describe in the next section, explanations for primacy have focused on the superiority of recall for the earlier events. The most common and popular explanation of this sort is one that invokes the concept of “rehearsal.” It comes in different varieties, but the basic idea is that the learner rehearses (thinks about, reviews in her mind) earlier list items while studying later ones. This kind of extra “practice” spent on the early items makes for stronger “memory traces” that translate into higher recall.

The rehearsal idea is one that is easy to think of because it is obviously true—surely extra practice spent on or extra thought paid to a to-be-remembered item helps its subsequent recall. The idea has been around from the 19th century (Madigan & O’Hara, 1992) and its popularity has continued unabated to this day. It has been bolstered by experiments in which the extent of item-by-item rehearsal is observed and has been seen to be correlated with recall (Rundus, 1971).

Problematic aspects of the rehearsal theory of primacy have also been registered from time to time, long before Wright and his colleagues reported their findings. In his classic book, *The Psychology of Human Learning* (1942), McGeoch writes that the suggestion is “frequently made that the rapid rate of learning at the initial position or positions may be a function of rehearsal” (p. 107). However, after considering the available evidence, especially the fact that the primacy effect occurs under conditions where materials are presented at rapid rates (thereby making rehearsal impossible), he gives the theory short shrift.

Similar doubts about the validity of the rehearsal theory of primacy continue to be expressed in our day and age (Sikstrom, 2006). However, in the absence of a better explanation, the intuitive appeal of the rehearsal theory of primacy has remained high.

An alternative approach to explaining primacy is based on the idea that items at the beginning and the end of a given list are more discriminable, or more distinctive, than those that come in the middle. As such, items that come earlier in a given list receive more “attention,” making them more memorable (Johnson, 1991; McGeoch, 1942; Murdock, 1960; Ribback & Underwood, 1950). This type of explanation takes care of the situations in which primacy occurs in the absence of rehearsal. Like the rehearsal theory it, too, makes intuitively good sense: surely an item that receives extra attention, together with attendant extra “processing,” has a memorial advantage over other items.

The discriminability theory also has the additional virtue of parsimony: it also explains the recency effect (Murdock, 1960). The discriminability idea has fared

better than the rehearsal idea in the theoretical sweepstakes, although it too has some problems (Hunt, 2006). Apart from anything else, it is at odds with data from experiments where there are only two to-be-remembered events, which, according to the discriminability theory, occupy equally distinctive positions. These data show primacy: the first event is remembered better than the second. Moreover, there is nothing much that the experimenter or subject can do to change the inferiority of recall for the second event (Peterson & Peterson, 1962).

Because neither the rehearsal or discriminability ideas, the two main types of explanations for the primacy effect, are free from problems, more sober suggestions have been made to the effect that primacy is a result of multiple causes that include rehearsal and discriminability. In Anderson's ACT-R model, "The tendency for the earlier items to receive greater rehearsal is one factor that is producing the primacy effect. The other factor is the lower positional confusions among items at the beginning of the list" (Anderson, Bothell, Lebiere, & Matessa, 1998, p. 357). In Baddeley's view, the primacy effect "may reflect a number of variables, but in particular the tendency to give more attention and possibly more rehearsal to the initial item" (Baddeley, 2000, p. 79).

Most traditional explanations of primacy do not explain primacy as much as they explain primacy away. After they are finished there is no real phenomenon left to explain. Primacy is an "artifact," a product of more basic processes.

I believe that primacy is primary: it reflects a basic property of the brain. It can and does occur in situations where rehearsal, attention, and all variables other than the temporal relation between Events 1 and 2 are held constant. We consider this basic property next.

HYPOTHESIS OF CAMATOSIS

When a person witnesses an event, whether a miniature event (such as seeing a word on a display device in the laboratory setting) or a more complex one (like being involved in an automobile accident), information about many aspects of the event is encoded in long-term memory. This encoded or stored information (the memory trace or engram) is one of the critical determinants of what, and how well, the person remembers the event some time later.

Now, let us make a few rather reasonable assumptions. One, that the encoding process is subserved by the activity of (widely distributed, highly complex) cerebral ensembles of neuronal networks. Two, that the isomorphic relation between the witnessed and "cognitively processed" event, on the one hand, and the corresponding widely distributed yet highly specific neural activity, on the other hand, applies to every single feature of the event. Three, as a result of its activity, a network becomes "fatigued," as do many other biological mechanisms and systems as a result of their operations.

Given these assumptions, the components of the network underlying the processing of Event 1 in our two-event scenario can also become fatigued. If now

Event 2 comes along whose processing for long-term retention requires the same components as Event 1, and if these components are in the refractory state engendered by the “fatigue,” the encoding of Event 2 suffers, and so does the subsequent retention.

The kind of neuronal “fatigue” I am talking about here has been dubbed *camatosis*. The term is derived from *kamatos*, a word in classical Greek that can be translated into English as “tiredness” or “weariness”.¹

Camatosis is defined as a “*hypothetical (neurochemical?) process that causes specific activity-dependent reduction in the efficacy of a neuronal network.*” One can assume that *camatosis* affects many different kinds of neural networks. For the sake of simplicity, in what follows in this chapter, however, whenever I use the term I mean *camatosis* of those networks that subservise *encoding of online information for long-term storage*. The concept of *camatosis* was initially introduced to account for the Von Restorff–type distinctiveness effects (Tulving & Rosenbaum, 2006). Its definition there was somewhat different from the one proffered here, but the general idea about it, and about its role in “causing” what appears as superior retention of certain items from within a collection, is very much the same.

Thus, according to the *camatosis hypothesis* proffered here, (true) primacy reflects the lowered memorability of Event 2 because of the “fatigue” of the neuronal networks underlying the processing of Event 1.

The *camatotic* effects of the processing of Event 1 on the processing of Event 2 depend on a number of variables, most of which remain to be identified in future research. A major determinant is the totality of similarity between Events 1 and 2. Such totality includes the context in which the events occur. Another major determinant is the length of the interval between the two events. Because “fatigue” in biological systems usually dissipates with inactivity (rest), it makes sense to assume that *camatotic* effects diminish over time. *Camatosis* is transitory. The rate of dissipation of the *camatotic* fatigue presumably depends on a number of variables, and it need not always be complete.

An explanation of primacy that is in some ways rather similar to the one that leans on the concept of *camatosis* has been proposed in a recent paper by Sikström (2006). Sikström, too, believes that the proper place to look for causes of apparent superiority of recall of certain kinds of events—those that are distinctive, or isolated, or those that appear at the beginning or end of a series—is the brain and its activity, rather than the deployment of attention and other cognitive capacities of the rememberer. Sikström’s account is much more sophisticated and elaborate than the simple one I describe here. It is also more comprehensive. Among other things he proposes an objective, quantitative index of

¹I am grateful to Professor Jaan Puhvel of UCLA for creating the term *camatosis* for the purpose of labeling the process described in this chapter.

primacy that is useful for comparing the magnitude of primacy in different situations, thereby helping adjudicate disputes having to do with issues such as whether or not some experimental treatment reduced or even eliminated primacy.

Here I proffer the camatosis hypothesis as an explanation of primacy in memory; however, the potential domain of application of this hypothesis is presumably larger, perhaps much larger, thereby crossing over the boundary of primacy. This is so, because all cognitively apprehended events, without a single exception, are always processed in the temporal context of other events that have preceded them. In the next section, I briefly consider one obvious target of the camatosis hypothesis—novelty.

NOVELTY AND RELATED PHENOMENA

The concept of camatosis—a hypothetical “fatigue” process that reduces the efficacy of specific task-relevant neuronal circuits—or something like it, may help us to understand numerous memory phenomena. These are phenomena that are covered by the umbrella term of “associative interference,” phenomena explained by concepts such as unlearning, response competition, negative transfer, build-up of proactive inhibition, list-length effects in learning, ineffectiveness of massed repetition, cue overload, fan effect, and the like.

The concept of camatosis extends the concept of interference into the neural realm. It explains why one item, or one collection of items, or the carrying out of one task, interferes with another. We can assume that camatosis is the “cause,” or one of the “causes,” of behavioral and cognitive interference. Camatotic interference effects are more readily discerned in learning (at encoding) than in forgetting (at retrieval), but they are, presumably, always present whenever events occur and are cognitively “processed.” This happens in the laboratory as well as outside it, on a minuscule as well as a broad scale. In my bolder moments, I can imagine that the impaired remembering of life’s events by healthy older people may reflect camatosis of the neural networks subserving encoding of autobiographical happenings chronically built up over a lifetime. So might the impaired ability of the older folks to learn and remember new names—“name-encoding circuits are overloaded,” as we might say.

Camatosis seems to be particularly relevant to the understanding of “novelty effects” in memory, the finding that novel events are remembered better than familiar ones (Kormi-Nouri, Nilsson, & Ohta, 2005.). Novelty is a concept that can assume many forms and that can be defined in a variety of ways, and camatosis need not apply to all of them. But it might apply to some.

Novelty in cognitive memory experiments is usually specified in terms of the appearance of a given item in the experimental situation. An item that appears for the very first time is novel whereas subsequent appearances are less so; they are said to be (more) “familiar.”

Like primacy, novelty is a concept that can be defined only relationally. Primacy refers to higher recall of an earlier, relative to a later, event. Novelty refers to higher recall of a new, relative to an old, event. In relation to an imaginary baseline (the “default state” of the brain/mind; Raichle et al., 2001), primacy and novelty can come about because of the enhanced recall of the first or new event, the lowered recall of the subsequent or old event, or both.

In an earlier paper (Tulving & Kroll, 1995), it was suggested that “familiar items are less well recognized than novel items because the novelty-assessment system screens out familiar items from further processing for subsequent recognition at an early stage of encoding” (p. 389). This screening was assumed to involve the comparison of the incoming information with information already in the long-term memory store. Further processing (for encoding) was assumed to depend on the outcome of this global comparison.

This idea may have had some merit at the time, but it now appears less attractive. The postulated global comparison mechanism, although a popular idea that has found wide application in the cognitive literature (Farrell & Lewandowsky, 2002; Metcalfe, 1993), just sounds too cumbersome a neural mechanism. Comparison and screening may still occur, but a simpler way to produce data that look like better recognition of novel rather than familiar items would be not to encode the familiar information at all, or to encode it less efficaciously. This is where *camatosis* becomes relevant. For the brain, it is not a question of whether or not to encode some incoming information. The question is whether there are resources available to do so. If, and only, the resources are available, encoding occurs, always.

Thus, the concept of *camatosis* provides a solution to the problem of determining the novelty of incoming information, and it does so without postulating any global, systemwide comparison.

REPETITION SUPPRESSION AND CAMATOSIS

The thesis of this chapter is that *camatosis* explains primacy effect in memory, along with a host of other interference-based and novelty-related behavioral phenomena. In this last section of the chapter, I briefly summarize some of the available evidence for a neural process, or set of processes, that produce *camatotic* effects.

The evidence comes from situations in which a stimulus is presented to an experimental subject (Event 1) and then presented again (Event 2), or comparable situations in which Event 2 is similar to Event 1. Brain activity for the repeated event is compared with the brain activity observed for the original presentation. It is measured in a variety of ways—single-cell recording in experimental animals (Miller, Li, & Desimone, 1991), intracranial event-related potentials from depth electrodes in patients (Grunwald, Lehnertz, Heinze,

Helmstaedter, & Elger, 1998), scalp recording of electrical (Henson, Rylands, Ross, Vuillemier, & Rogg, 2004) and magnetic (Duzel et al., 2005) signals, as well as functional neuroimaging (positron emission tomography [PET] and functional magnetic resonance imaging [fMRI]) in human beings. A common observation in these situations is that the activity associated with the repeated stimulus (Event 2) is lower relative to that of Event 1. That is, primacy is commonly observed at the neural level.

Different names have been given to this kind of a finding by different investigators: “adaptive filtering” (Desimone, 1992), “adaptive mnemonic filtering” (Miller, Li, & Desimone, 1993), “stimulus specific adaptation” (Ringo, 1996), “repetition suppression” (Desimone, 1996), “decremental responses” (Brown & Xiang, 1998), “habituation” (Sohal & Hasselmo, 2000), “repetition priming” or “neural priming” (Wagner, Koutstaal, Maril, Schacter, & Buckner, 2000) or even just “priming,” (Buckner & Koutstaal, 1998), “cortical activity reduction” (Dobbins, Schnyder, Verfaellie, & Schacter, 2004), plus, probably, a few others. In the remainder of this chapter, I follow others and use “repetition suppression,” adopted from Desimone (1996), as a single, umbrella term for all forms of experimental observations where neural activity for the repeated stimulus is reduced in relation to that of the first (novel) stimulus.

The highlights of a rapidly growing literature on repetition suppression have recently been lucidly summarized by Grill-Spector, Henson, and Martin (2006). These writers propose several potential neural mechanisms underlying repetition suppression: firing-rate adaptation (reduced excitability of neurons), synaptic depression (reduction in presynaptic neurotransmitter release), long-term depression, and long-term potentiation. They also describe three models of repetition suppression—fatigue model, sharpening model, and facilitation model—that make different assumptions regarding the source or locus of reduced neuronal efficacy. In the present context, the interesting feature of these models of repetition suppression is that every single one of them would be equally appropriate as a summary description of amnesia.

Repetition suppression nicely parallels primacy and novelty effects: neural activity is reduced for the “repeated” stimulus in relation to the original stimulus, as does observed retention of Event 2 in relation to Event 1. But such an encouraging parallel is not sufficient to firmly associate neural repetition suppression to behaviorally observed primacy and novelty effects. A more direct link between the brain and the mind would be highly desirable, especially as there are popular theories that hold that repetition suppression expresses itself behaviorally in the phenomenon of priming, experience-based *enhanced* identification of the repeated stimulus (Schacter & Buckner, 1998; Wiggs & Martin, 1998). Although the priming story is not entirely clear (Habib, 2001; Henson & Rugg, 2003), it needs to be kept in mind as we explore the implications of the reduced memorability of repeated items.

A closer link between repetition suppression and reduced memorability of Event 2 in relation to Event 1 is provided by an ingenious experiment reported by Brenda Kirchoff and her colleagues (Kirchoff, Wagner, Maril, & Stern, 2000). Using functional imaging, they demonstrated the existence of a number of cerebral regions in which novelty detection was found to be tied to effective encoding of to-be-remembered items (words and pictures).

Kirchoff and her colleagues accomplished this feat by combining two powerful methods for studying the brain activity correlated with cognitive tasks. One of the methods (event-related fMRI) makes it possible to track neural activity, as reflected in changes in blood oxygenation, that accompanies the perceptual-cognitive processing of "single" events, such as the presentation of a word or a picture for study (encoding), and thereby provides the "neural signature" of the event (Buckner et al., 1996). The same kind of item-by-item analysis had been available earlier in electrophysiological recordings of event-related potentials, a method with high temporal, but not sufficiently fine spatial, resolution. The other method is dubbed "subsequent memory paradigm" (Paller & Wagner, 2002). It consists of the back-sorting of the "neuronal signatures" of single events recorded at one point in time, such as encoding, into different categories, depending on what happens at a later time, such as subsequent recognition or failure of recognition of the encoded item.

The procedure used by Kirchoff and her colleagues essentially isolated two sets of brain regions of interest: first, "novelty regions" in which encoding activity (expressed in the BOLD signal) was reduced by virtue of an earlier appearance of, and camatosis engendered by, the same item; second, "encoding regions," in which the level of activity at encoding "predicted" subsequent recognizability of the item—"remembered" items versus "forgotten" items. These "encoding regions" were identified while novelty was held constant. The critical finding, supportive of the camatosis hypothesis, was the finding of considerable overlap between the novelty regions and encoding regions. The authors summarized the finding by saying that "the present results provide the first evidence that the same ventrolateral prefrontal and temporal regions that are sensitive to novelty also predict subsequent explicit memory, supporting the hypothesis that these regions contribute to encoding" (Kirchoff et al., 2000, p. 6179).

Kirchoff et al. (2000) focused on a restricted set of cerebral regions, prefrontal and temporal cortex, because they had been marked as "interesting" by the results of earlier encoding and novelty-related fMRI studies. Their full data set, however, reveals a number of additional novelty-encoding regions in other parts of the brain. (Note: I am grateful to Brenda Kirchoff for making the complete data available for inspection and analysis.) Perhaps even more interesting, and important, is the fact that *none* of the "familiarity regions," regions in which repeated items showed greater activity than novel items, coincided with regions in which the encoding activity was higher for "remembered" than for "forgotten" item.

If one believes, as I do, that primacy and novelty reflect the same kind of selectively reduced camatosis-dependent encoding processes, then Kirchhoff's data on novelty encoding are also relevant to primacy. More direct applications of Kirchhoff's procedure, to the first few items in a to-be-remembered list, are awaiting experimenters. One relevant study has already been recently reported (Sommer, Rose, & Buchel, 2006; see also Strange, Otten, Josephs, Rugg, & Dolan, 2002).

CAMATOTIC LAW OF ENCODING

We are now in a position to contemplate the possibility of complementing the descriptive law of primacy with a higher level law that would explain primacy. The idea is that primacy, as manifested in many situations involving learning and memory, comes about because of a basic property of the brain labeled camatosis, a hypothetical neural process that causes specific activity-dependent fatigue-like reduction in the efficacy of the neural networks subserving perception and thought. Physiological research under the umbrella term of repetition suppression encourages me to believe that camatosis may be more than just an idea. At the least, it is not difficult to see how the patterns woven by psychological experiments on phenomena of learning and memory, such as distinctiveness, primacy, and novelty, fit comfortably into the patterns produced by recordings and images yielded by objectively measured activity of the brain.

It is against the backdrop of this kind of a reasonably coherent picture of the brain/mind that I would like to propose another broad generalization, or a law:

Of two events, the one whose encoding is more severely affected by camatosis is less likely to be retained.

We can think of this as the *camatotic law of encoding*. A little thought reveals that it subsumes the descriptive law of primacy as presented earlier, and that it also explains some data that may seem to be at variance with the descriptive law. Further thought reveals that the camatotic law of encoding hides, within itself, a host of issues and questions that may be worth pursuing and that may not be pursued in the absence of the ideas contained in the law. If for no other reason, then, at least for this, the ideas I have presented here—which I know some of my best friends think are not that different from happenings on Alice's journey into the Wonderland—may turn out to have some merit.

ACKNOWLEDGMENTS

My research is supported by an endowment in support of cognitive neuroscience by Anne and Max Tanenbaum. I am grateful to Alice Kim for editorial assistance.

REFERENCES

- Anderson, J. R., Bothell, D., Lebiere, C., & Matessa, M. (1998). An integrated theory of list memory. *Journal of Memory and Language*, 38, 341–380.
- Asch, S. E. (1946). Forming impressions of personality. *Journal of Abnormal and Social Psychology*, 41, 258–290.
- Baddeley, A. D. (2000). Short-term and working memory. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford Handbook of Memory* (pp. 77–92). New York: Oxford University Press.
- Baddeley, A. D., & Warrington, E. K. (1970). Amnesia and the distinction between long- and short-term memory. *Journal of Verbal Learning and Verbal Behavior*, 9, 176–189.
- Bower, G. H. (1971). In M. H. Appley (Ed.), *Adaptation-level theory* (pp. 175–201). New York: Academic Press.
- Bower, G. H., Thompson-Schill, S., & Tulving, E. (1994). On reducing retroactive interference: An interference analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 51–66.
- Brown, M. W., & Xiang, J. Z. (1998). Recognition memory: Neuronal substrates of the judgment of prior occurrence. *Progress in Neurobiology*, 55, 184–189.
- Buckner, R. L., Bandettini, P. A., O'Craven, K. M., Savoy, R. L., Petersen, S. E., Raichle, M. E., & Rosen, B. R. (1996). Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic-resonance-imaging. *Proceedings of the National Academy of Sciences*, 93, 14878–14883.
- Buckner, R. L. & Koutstaal, W. (1998). Functional neuroimaging studies of encoding, priming, and explicit memory retrieval. *Proceedings of the National Academy of Sciences*, 95, 891–898.
- Castro, C. A., & Larsen, T. (1992). Primacy and recency effects in nonhuman primates. *Journal of Experimental Psychology: Animal Behavior Processes*, 18, 335–340.
- Desimone, R. (1992). The physiology of memory: Recordings of things past. *Science*, 258, 245–246.
- Desimone, R. (1996). Neural mechanisms for visual memory and their role in attention. *Proceedings of the National Academy of Sciences*, 93, 13494–13499.
- Dobbins, I. G., Schnyer, D. M., Verfaellie, M., & Schacter, D. L. (2004). Cortical activity reductions during repetition priming can result from rapid response learning. *Nature*, 428, 316–319.
- Düzel, E., Richardson-Klavehn, A., Neufang, M., Schott, B.J., Scholz, M., & Heinze, H. J. (2005). Early, partly anticipatory, neural oscillations during identification set the stage for priming. *Neuroimage*, 25, 690–700.
- Eslinger, P. J., & Grattan, L. M. (1994). Altered serial position learning after frontal lobe lesion. *Neuropsychologia*, 32, 729–739.
- Farrell, S., & Lewandowsky, S. (2002). An endogenous distributed model of ordering in serial recall. *Psychonomic Science & Review*, 9, 59–79.
- Gernsbacher, M. A., & Hargreaves, D. J. (1988). Accessing sentence participants: The advantage of first mention. *Journal of Memory and Language*, 27, 699–717.
- Glanzer, M. (1972). Storage mechanisms in recall. In G. H. Bower & J. T. Spence (Eds.), *The psychology of learning and motivation* (Vol. 5, pp. 129–193). New York: Academic Press.
- Grill-Spector, K., Henson, R., & Martin, A. (2006). Repetition and the brain: Neural models of stimulus-specific effects. *Trends in Cognitive Sciences*, 10, 14–23.
- Grunwald, T., Lehnertz, K., Heinze, H. J., Helmstaedter, C., & Elger, C. E. (1998). Verbal novelty detection with the human hippocampus proper. *Proceedings of the National Academy of Sciences*, 95, 3193–3197.

- Habib, R. (2001). On the relation between conceptual priming, neural priming, and novelty assessment. *Scandinavian Journal of Psychology*, *42*, 187–195.
- Henson, R. N. A. (2003). Neuroimaging studies of priming. *Progress in Neurobiology*, *70*, 53–81.
- Henson, R. N. A., & Rugg, M. D. (2003). Neural response suppression, haemodynamic repetition effects, and behavioural priming. *Neuropsychologia*, *41*(3), 263–270.
- Henson, R. N. A., Rylands, A., Ross, E., Vuilleumier, P., & Rugg, M. D. (2004). The effect of repetition lag on electrophysiological and haemodynamic correlates of visual object priming. *Neuroimage*, *21*, 1674, 1689.
- Henson, R. N. A., Shallice, T., Gorno-Tempini, M. L., & Dolan, R. J. (2002). Face repetition effects in implicit and explicit memory tests as measured by fMRI. *Cerebral Cortex*, *12*, 178–186.
- Hogarth, R. M., & Einhorn, H. J. (1992). Order effects in belief updating: The belief-adjustment model. *Cognitive Psychology*, *24*, 1–55.
- Hunt, R.R. (2006). The concept of distinctiveness in memory research. In R. R. Hunt & J. B. Worthen (Eds.), *Distinctiveness and memory* (pp. 3–25). New York: Oxford University Press.
- Johnson G. J. (1991). A distinctiveness model of serial learning. *Psychological Review*, *98*, 204–217.
- Jones, B. M. (1973). Memory impairment on the ascending and descending limbs of the blood alcohol curve. *Journal of Abnormal Psychology*, *82*, 24–42.
- Jones, T., & Roediger, H. L., III. (1995). The experiential basis of serial position effects. *European Journal of Cognitive Psychology*, *7*, 65–80.
- Kesner, R. P., Measom, M. O., Forsman, S. L., & Holbrook, T. H. (1984). Serial-position curves in rats: Order memory for episodic spatial events. *Animal Learning and Behavior*, *12*, 378–382.
- Kirchhoff, B. A., Wagner, A. D., Maril, A., & Stern, C. E. (2000). Prefrontal-temporal circuitry for episodic encoding and subsequent memory. *Journal of Neuroscience*, *20*, 6173–6180.
- Kormi-Nouri, R., Nilsson, L. G., & Ohta, N. (2005). The novelty effect: Support for the novelty-encoding hypothesis. *Scandinavian Journal of Psychology*, *46*, 133–143.
- Lockhart, R. S. (2000). Methods in memory research. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 45–57). New York: Oxford University Press.
- Madigan, S.A. (1969). Intraserial repetition and coding processes in free recall. *Journal of Verbal Learning and Verbal Behavior*, *8*, 828–835.
- Madigan, S. A., McCabe, L., & Itatani, S. (1972). Immediate and delayed recall of words and pictures. *Canadian Journal of Psychology*, *26*, 407–414.
- Madigan, S., & O'Hara, R. (1992). Short-term memory at the turn of the century: Mary Whiton Calkins's memory research. *American Psychologist*, *47*, 170–174.
- Martin, S. J., & Morris, R. G. M. (2002). New life in an old idea: The synaptic plasticity and memory hypothesis revisited. *Hippocampus*, *12*, 609–636.
- McGeoch, J. A. (1942). *The psychology of human learning*. New York: Longmans Green.
- Metcalf, J. (1993). Novelty monitoring, metacognition, and control in a composite holographic associative recall model—implications for Korsakoff amnesia. *Psychological Review*, *100*, 3–22.
- Miller, E. K., & Desimone, R. (1994). Parallel neuronal mechanisms for short-term memory. *Science*, *263*, 520–522.

- Miller, E. K., Li, L., & Desimone, R. (1991). A neural mechanism for working and recognition memory in inferior temporal cortex. *Science*, 254, 1377–1379.
- Miller, E. K., Li, L., & Desimone, R. (1993). Activity of neurons in anterior inferior temporal cortex during a short-term memory task. *Journal of Neuroscience*, 13, 1460–1478
- Murdock, B. B. (1960). The distinctiveness of stimuli. *Psychological Review*, 67, 16–31.
- Murdock, B. B., Jr. (1962). The serial position effect in free recall. *Journal of Experimental Psychology*, 62, 482–488.
- Neath, I., & Crowder, R. G. (1990). Schedules of presentation and temporal distinctiveness in human memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 316–327.
- Nisbett, R. E., & Ross, L. (1980). *Human inference: Strategies and shortcomings of social judgment*. Englewood Cliffs, NJ: Prentice-Hall.
- Paller, K. A., & Wagner, A. D. (2002). Observing the transformation of experience into memory. *Trends in Cognitive Sciences*, 6, 93–102.
- Peterson, L. R., & Peterson, M. J. (1962). Minimal paired-associate learning. *Journal of Experimental Psychology*, 63, 521–527.
- Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences*, 98, 676–682.
- Ribback, A., & Underwood, B. J. (1950). An empirical explanation of the skewness of the serial position curve. *Journal of Experimental Psychology*, 40, 329–335
- Ringo, J. L. (1996). Stimulus specific adaptation in inferior temporal and medial temporal cortex of the monkey. *Behavioural Brain Research*, 76, 191–197
- Rundus, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology*, 89, 63–77.
- Schacter, D. L., & Buckner, R. L. (1998). Priming and the brain. *Neuron*, 20, 185–195.
- Shallice, T. (1979). Neuropsychological research and the fractionation of memory systems. In Nilsson, L.-G. (Ed.), *Perspectives in memory research* (pp. 193–218). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sikström, S. (2006). The isolation, primacy, and recency effects predicted by an adaptive LTD/LTP threshold in postsynaptic cells. *Cognitive Science*, 30, 243–275.
- Sohal, V. S., & Hasselmo, M. E. (2000). A model for experience-dependent changes in the responses of inferotemporal neurons. *Network*, 11, 169–190.
- Sommer, T., Rose, M., & Büchel, C. (2006). Dissociable parietal systems for primacy and subsequent memory effects. *Neurobiology of Learning and Memory*, 85, 243–251.
- Strange, B. A., Otten, L. J., Josephs, O., Rugg, M. D., & Dolan, R. J. (2002). Dissociable human perirhinal, hippocampal, and parahippocampal roles during verbal encoding. *Journal of Neuroscience*, 22, 523–528.
- Teigen, K. H. (2002). One hundred years of laws in psychology. *American Journal of Psychology*, 115, 103–118.
- Tulving, E., & Kroll, N. (1995). Novelty assessment in the brain and long-term memory encoding. *Psychonomic Bulletin & Review*, 2, 387–390.
- Tulving, E., & Rosenbaum, R. S. (2006). What do explanations of the distinctiveness effect need to explain? In R. R. Hunt & J. B. Worthen (Eds.), *Distinctiveness and memory* (pp. 407–423). New York: Oxford University Press.
- Underwood, B. J. (1970). A breakdown of total-time law in free-recall learning. *Journal of Verbal Learning and Verbal Behavior*, 9, 573–580.

- Wagner, A. D., Koutstaal, W., Maril, A., Schacter, D. L., & Buckner, R. L. (2000). Task-specific repetition priming in left inferior prefrontal cortex. *Cerebral Cortex*, *10*, 1176–1184.
- Wang, H., Johnson, T. R., & Zhang, J. (2006). The order effect in human abductive reasoning; an empirical and computational study. *Journal of Experimental & Theoretical Artificial Intelligence*, *18*, 215–247.
- Wiggs, C. L., & Martin, A. (1998). Properties and mechanisms of perceptual priming. *Current Opinion in Neurobiology*, *8*, 227–233.
- Wright, A. A., Santiago, H. C., Sands, S. F., Kendrick, D. F., & Cook, R. G. (1985). Memory processing of serial lists by pigeons, monkeys, and people. *Science*, *229*, 287–289.