Laws of Human Memory

Michael J. Kahana, Nicholas B. Diamond, and Ada Aka
Department of Psychology
University of Pennsylvania

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Despite the complexity of memory and its diverse manifestations in our daily lives, certain mnemonic effects appear to hold across a wide range of conditions. We identify the effects of recency, contiguity, similarity, primacy, and repetition as potential laws of memory, evaluating their explanatory scope and discussing their theoretical significance. We show that apparent violations of these laws occur when different effects come into conflict, as in the situation of opposing physical forces. We see the search for law-like phenomena as guiding the development and refinement of integrative memory theories.

Although many psychological phenomena appear to be fickle, certain memory effects appear to be quite general, even universal. We observe these phenomena across a broad range of conditions, in virtually all people, and even in a variety of non-human animal species. We refer to these phenomena as "laws of memory," using the term "law" to refer to an empirical regularity that possesses great generality (Teigen, 2002). For any law we might identify, however, the domain of applicability need not be infinite; beyond some limits, the law may no longer hold, much like the celebrated laws of physics experience violations at extreme values of speed or mass.

Not all researchers would endorse our thesis that certain memory phenomena exhibit sufficient generality to merit the term "law". For example, Professor H. L. Roediger, in an elegant 2008 survey, suggests that human memory does not posses any such phenomena. Roediger writes "the great truth of the first 120 years of the empirical study of human memory is captured in the phrase 'it depends.' " Roediger goes on to review a great many phenomena, including many of the phenomena discussed below, and concludes that none quite rise to the status of a law of memory — in particular, he suggests that no findings persist across variations in four key factors: subject populations, to-be-remembered materials, encoding conditions, and retrieval conditions. Roediger is not alone in his skepticism; William James, only briefly after publishing the foundational *Principles of Psychology* (1890), wrote that psychology offers "...not a single law in the sense in which physics shows us laws, not a single proposition from which any consequence can causally be deduced. This is no science, it is only the hope of a science" (James, 1984). Though most would agree that the science of memory has developed a great deal since James made this proclamation, the status of the knowledge gained remains unclear. Has the proliferation of empirical studies revealed any robust, generalizable, and law-like phenomena? Before attempting an answer, let us consider some reasons to seek out laws in the first place.

We suggest that the search for laws — invariances across conditions and subjects — is essential to the project of understanding memory. Law-like phenomena exist in spite of variability at the level of individuals or conditions, and indeed an understanding of these law-like phenomena (and their interactions) can help explain ostensible contradictions across studies. By analogy, the observation that different objects fall at different speeds, and occasionally go up, does not refute the universal law of gravity. Rather, these findings call for a deeper understanding of the factors that affect acceleration under the influence of a gravitational force (e.g., air resistance, or in the case of a wing, lift). Discrepancies in the memory literature similarly may arise from interactions of different laws or principles that operate in a given situation. Searching for laws helps us extract knowledge from the scientific literature, cutting across superficial differences across tasks, across the cognitive and neural levels of explanation, and across species.

What criteria, then, might elevate an empirical regularity to the status of a law? Teigen (2002; also reviewed in Roediger, 2008) proposed five such criteria: validity (laws should be well-established regularities), priority (we should doubt observations that conflict with laws), explanatory power (laws should explain phenomena), autonomy (laws should be self-contained, parsimonious, and ideally expressible mathematically), and universality (laws should be independent of time and place, excepting to the probabilistic nature of observations in a given experiment). Our chapter reviews five memory phenomena that we see as meeting these criteria: recency, contiguity, similarity, primacy, and repetition. We suggest that these phenomena may be considered laws of

We dedicate this chapter to the late Professor Bennet B. Murdock, and also to Professor Endel Tulving. Ben and Endel taught the first author about the laws of human memory during his graduate training at the University of Toronto. The authors acknowledge support from NIH grant MH55687 and they thank Brandon Katerman and Madison Paron for editorial assistance.

memory, with the implication that a serious theory of memory should make predictions about these phenomena that appear consistent with the extant data. As implied above, we are not the first to hazard a list of the laws of memory. For example, Roediger presented (and then refuted) the following: repetition, study time, distribution and spacing, generation effects, the mirror effect, imagery and the picture superiority effect, testing, and forgetting. Our laws are in some cases synonymous with these earlier proposals (e.g., repetition), and in many cases imply or subsume them. Our list of laws is not meant to be exhaustive or definitive. Let's begin with the law of recency.

Law of Recency

The Honorable Hiram Denio, chief judge of the New York Court of Appeals (1862-1865), wrote:

> After the lapse of ten years, no careful person of ordinary memory, whose business was somewhat extensive, could speak positively of a transaction of small pecuniary moment, which had not been recalled to his mind in the interim.

Among the ancient wisdom and legal writings of many societies one finds similar quotes referring to our tendency to more easily remember recent events and to forget information that has not been used after some period of time. The movie "Inside Out" provides a mechanistic account of such forgetting: the information gets stored in a large library or archive and every so often a huge vacuum cleaner sucks up and discards those rusty old memories.

In his seminal monograph "Über das Gedächtnis," Ebbinghaus (1885/1913) reported 833 hours of self experimentation, and the study of forgetting figured prominently in his analyses. Ebbinghaus demonstrated the now-famous power-law of forgetting, showing that people forget newly learned information very rapidly at first, but that the rate of forgetting slows with time. The mathematical form of the forgetting function conforms to the equation: Retention = at^{-b}, where the constant numbers, a and b, determine the overall level and rate of forgetting (in a given experiment, you can observe different values for a and b, but under similar circumstances these values will be similar to one another). Power-law forgetting may be distinguished from exponential forgetting, wherein the decay rate is constant over time. The key difference is the sudden decline in memory soon after an event coupled with the slower forgetting at longer delays.

But is forgetting a fundamental principle that governs mnemonic processes in a very wide range of circumstances? Casual experience would seem to suggest otherwise, for as much as we may struggle to remember a phone number moments after we hear it, other information, even after a brief encounter, seems to leave an indelible imprint on the mind; in some cases a powerful image seen once may scar us for a very long period of time. Furthermore, we sometimes forget a new acquaintance's name soon after learning it, but then remember it later on.

Interference as a Mechanism of forgetting

Scientists long recognized that the well-established law of recency (a broader version of the power-law phenomenon) does not imply that all memories decline similarly with the passage of time, or even that time itself causes the erosion or decay of the original memory trace. Indeed, as McGeoch (1942) famously observed,

> In time, iron may rust and men grow old, but the rusting and the aging are understood in terms of the chemical and other events which occur in time, not in terms of time itself.

The classic early work of Georg Elias Müller (1900) (e.g., Müller & Pilzecker, 1900) demonstrated that forgetting largely reflects interference among memories (see chapter 6.1, MacLeod, 2022; and chapter 6.2, Marsh & Anderson, 2022). After an initial experience, subsequent events bearing similarity to the earlier experience pop to mind and block out or compete with the trace of the original memory, a phenomenon we refer to as retroactive interference. Benton Underwood (1957) demonstrated that it is not only interference from subsequent memories, but also interference from earlier memories that confound retrieval. McGeoch (1932) proposed a multi-factor model which saw forgetting as primarily reflecting competition among similar memories. Like the object lost in the attic, it is there, but as the detritus of lifes acquisitions accumulate, finding any particular object becomes increasingly difficult. By this account, our brain does not discard old memories; it just loses the ability to find them.

For example, da Costa Pinto and Baddeley (1991) showed that memory for where one parked their car changes little from two hours, to one week, to one month, if one does not have interfering parking experiences. Yet with multiple repeated parking experiences in the same parking lot, subjects' exhibit a clear recency effect. Under conditions of high associative interference, forgetting becomes very rapid, but it still conforms to the power law described above. Figure 1A shows data from a detailed study of associative memory. Here Rubin et al. showed that recall is above 90% when tested after a very brief delay, drops to around 40% after 20 seconds of distraction, and drops to 20% after about 10 minutes. Rubin reports very similar results for several other memory tasks, including recognition memory and several variants of recall tasks. He also shows that the same mathematical form of forgetting applies to people with very good and very poor memories, though they will exhibit decay at different rates. Figure 1B and C illustrate forgetting functions in two other classic memory paradigms: free recall, and item recognition. In each of these cases, forgetting is illustrated over the course of an experimental session lasting about 50 minutes.

Contextual Change as a Mechanism of Forgetting

The aphorism "One can never step in the same river twice," attributed to Heraclitis, captures the idea that no two experiences can be identical. Memory scientists use the term context, or spatio-temporal context to refer to the cognitive milieu in which an experience occurs. The mental representation of context includes the when and where of our experiences, their emotional backdrop, and the thoughts, feelings, and even physiological states prevailing during the time of encoding. In computational models of memory, context forms the tapestry into which each new memory is woven (see chapter 5.11, Manning, 2022). Like the river of Heraclitis, context always changes; but like a river, it can meander around and come to a nearby location as it wends through the landscape.

McGeoch identifies contextual change as the second major cause of forgetting. He writes:

> The learner is forming associations, not only intrinsic to the material which is being learned, but also between the parts of this material and the manifold features of the context or environment in which the learning is taking place.

As time progresses following an initial experience, the contextual features associated with that experience will slowly change. As a memory ages, its associated context will tend to become more and more dissimilar to the present context and as a result it will become harder to recall or recognize.

Neurobiological studies of memory demonstrate the concept of mental context. Hippocampal neurons represent a person's (or animals) location in space (see chapter 3.3, Becker, 2022). Other hippocampal neurons represent the time at which an experience occurs (see chapter 3.2, Howard, 2022). Neuroscientific studies of memory retrieval have shown that successful recall is often preceded by the reactivation of neurons representing a persons context at the time of memory encoding or storage (Miller et al., 2013). A common assumption of leading memory models is that failure of such contextual reinstatement is one major cause of forgetting (see chapter 5.11, Manning, 2022).

Context effects abound in the human memory literature. In one famous study, Godden and Baddeley (1975) had scuba-divers learn lists of words either on land or under water. They then tested them either in the same or in a different context, trying to recall the words either on land or under water. When the context shifted between study and test, divers exhibited far greater forgetting than when the context was preserved (as a control, divers in the same context condition would submerge or return to land between study and test). Similar demonstrations of context-dependent memory have been shown for mood (remembering a happy memory will likely evoke other happy memories; depressed individuals will tend to remember more sad memories), for physiological states, and for linguistic or semantic contexts. Most leading computational models of memory describe how events become associated with a representation of context and how this context representation guides memory search (see Kahana, 2020). Anderson and Schooler (1991) suggested that this power retention function is optimized to the rate of change in the world; that the similarity of contextual information (for example, the word similarity in news stories) over hours, months, and years, is itself described by a power function. In other words, memory changes because the world changes: the recent past tends to be more memorable because it is more similar to the present. Consider the last few minutes of your life: perhaps you've been sitting in the same chair, and eating the same sandwich, and feeling the same vague discomfort in your left glute that you're feeling at this very moment. Events from this recent time period are likely to be quite accessible in memory. Consider, by contrast, two years ago: the world, and your circumstances, were likely quite a bit different then, and thus your memories less accessible (see discussion of the Law of Similarity below).

Although the above mechanisms – interference and contextual change – account for much of the data on human forgetting, some studies also point to other factors. For example, there is evidence supporting the possible role of inhibition of memories, resulting from the repeated retrieval of similar memories (chapter 6.2, Marsh & Anderson, 2022). Other studies implicate a role for decay in immediate perceptual memory (chapter 2.9, Postle & Oberauer, 2022), though it is very difficult to rule out a contextual-change explanation for such results.

Further Moderators of Forgetting

The above mechanisms together account for the ubiquitous phenomenon of forgetting, seen across all individuals, species, and memoranda. Although forgetting follows the mathematical form of a power law, several factors can affect the rate of forgetting, and some memories retain their vibrancy even across very extended periods of time. People tend to reminisce about memories that have great emotional salience or value, reviewing them in their minds, and thus creating new copies of those memories that preserve aspects of the original experience, but can also distort the memory through its internal retelling. These self-generated repetitions, often called rehearsals or reactivations, re-embed aspects of the original experience (and its previous rehearsals) into the current context, producing a very strong but not necessarily veridical memory of the event.

Examples of circumstances where retention is not found to decline generally involve such rehearsals of those past memories. This phenomenon has been thoroughly studied in the memory literature and helps to explain the persistence of traumatic memories which people relive repeatedly. Such memories may change over time as the remindings connect the original memory with the mental context at the time of each recurrence (Cohen & Kahana, in press). Such preserved retention generally applies to exceptional experiences and not to the type of everyday circumstances that results in power-law forgetting, as described above.

Memories learned in a unique and salient context can sometimes jump to mind when circumstances strongly reinstate the context of the original experience. Imagine walking into a restaurant after the pandemic and suddenly remembering your last visit to the restaurant. Although this event was distant in time, it was proximate along other dimensions (e.g., space, emotion, meaning), which can help to reinstate the memory. Although such reinstatement can happen in our daily lives, experimental manipulations of context generally produce modest improvements in memory because it is difficult to reinstate the unique context of an original experience when contextual information is relatively static over time (e.g. when encoding many words on the same screen while sitting in the same room). In laboratory experiments, therefore, recency effects (i.e., the power law of forgetting) dominate over context reinstatement effects. If one disrupts context it is possible to significantly impair memory; however, it is much easier to disrupt the current context than to bring back an old context.

Forgetting over very long intervals

Since the time of Ebbinghaus, students of memory have largely examined forgetting using laboratory methods, with encoding-retrieval delays on the order of seconds or minutes, or on rare occasion, days. Yet most readers of this chapter will be able to retrieve memories of events that occurred many years ago. If recency is a truly law-like principle in memory, the same underlying mechanisms should explain forgetting across widely varying timescales, from seconds to minutes to years. Indeed, even in autobiographical memory tasks where the search space spans subjects' life histories, the power-law of forgetting holds.

A common method of investigating forgetting in autobiographical memory is the cueing approach originated by Galton (1879), formalized for the study of episodic memory by Crovitz and Schiffman (1974), and developed further by Rubin (1982). This approach asks subjects to describe specific events from their past in association to cues, typically words (see chapter 5.12, Levine et al., 2022). Even with such unconstrained retrieval conditions and complex memoranda, the distribution of sampled memories over decades reliably conforms to the power function described above. Over a number of studies, Rubin and colleagues rigorously quantified retention over autobiographical timescales, consistently finding that a power function provides the best fit (compared, for example, to linear, exponential, or hyperbolic functions) (e.g., Rubin, 1982; Rubin & Wenzel, 1996; Rubin & Schulkind, 1997). Researchers observe similar functions when analyzing individual subjects, different age groups, and even autobiographical memory search in the absence of cues (though the precise intercept and slope parameters may vary across studies and conditions), notwithstanding two exceptions to the power-law of autobiographical forgetting: the "reminiscence bump", wherein older subjects tend to produce disproportionate memories from their adolescence and early adulthood, and inability to remember events from the first few years of life (infantile amnesia) (Rubin & Schulkind, 1997).

On the other hand, it is not clear how to interpret the distribution of freely recalled autobiographical memories over one's lifespan: does this distribution reflect a forgetting function? For one, events that subjects do not recall may nonetheless be accessible; in a given experimental session (Bahrick, Bahrick, & Wittlinger, 1975), it is likely that more recent memories will tend to out-compete more remote ones. Second, given that the *denominator* in these studies is unclear (i.e., how many memories were *not* retrieved?), it is difficult to relate the overall level of retention to that observed in laboratory studies. Finally, autobiographical memories are highly heterogeneous and typically unverifiable - even their dates, necessary for measuring forgetting, are subject to misremembering. In an effort to address these concerns, Diamond, Armson, and Levine, measured free recall of immersive real-world events that were nonetheless controlled (e.g. an audio-guided art tour) at delays ranging from two days to two years. As a proxy for the total number of recallable bits of information (analogous to the list length in a word-list recall study), the authors tallied each unique verifiable detail recalled across all subjects. Here too, recall quantity declined in the expected curvilinear fashion. Previous real-world studies of forgetting leveraged similar controlled encoding paradigms, prospective diary recording methods, or publicly verifiable memoranda such as news events, to build recognition or cued recall tests, allowing for further points of comparison with the classic laboratory literature (Moreton & Ward, 2010; Rubin & Schulkind, 1997; Diamond et al., 2020).

Figure 2 presents a selection of such real-world forgetting curves; we searched for studies reporting retrieval data over continuous retention intervals spanning at least six months, though this search was by no means exhaustive. For visualization purposes, we fit power functions to the data from each study (raw subject-level data if available, otherwise group-level data as reported in the original studies). The overall levels of forgetting (intercepts) should be interpreted with caution given study-to-study differences in the interpretation of the y-axis, and in chance levels (for recognition and cued recall). Yet, notwithstanding gross differences in the memoranda, encoding and retrieval conditions, and assessment techniques across studies, they all show that memory for real-world episodes decline as a power-like function over months and years.

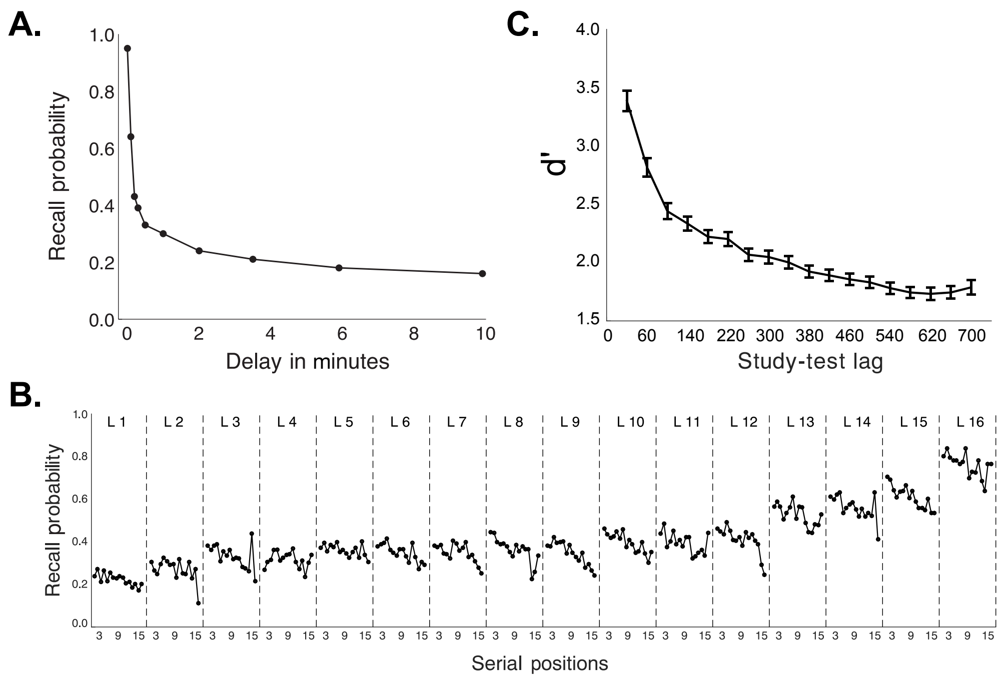

Figure 1. **Forgetting in three classic memory paradigms. A.** Memory for paired associates as a function of the time (and number of pairs) intervening between study and test. Data from Rubin et al. (1999). **B.** Recall probability in final free recall as a function of both serial position and list position. More recent items appear towards the right. **C.** Recency in item recognition with performance measured using d', which is the z-normalized hit rate minus the z-normalized false alarm rate (Data from Experiment 1 of the PEERS study).

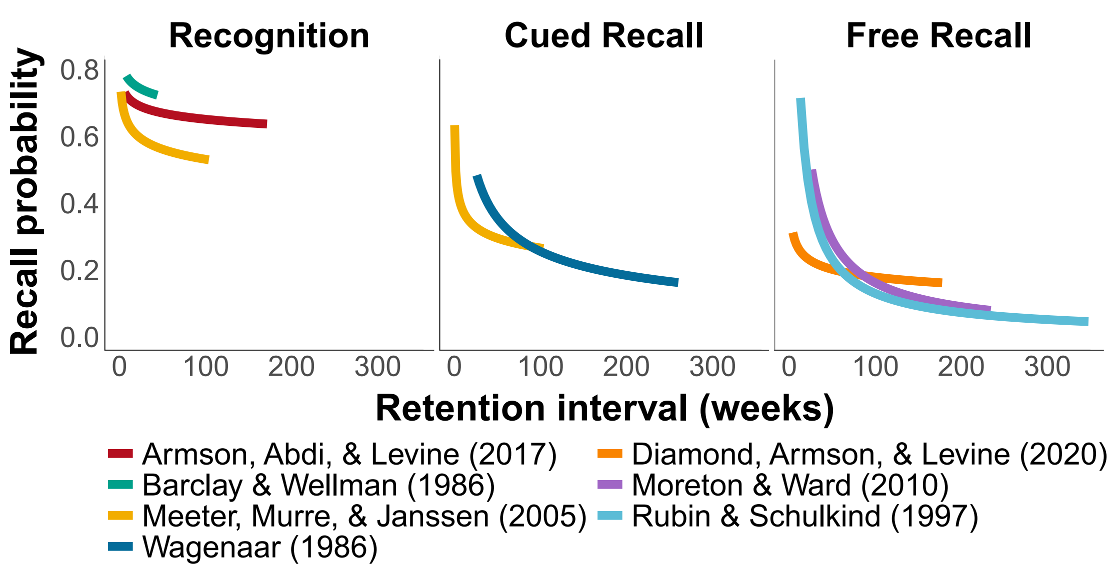

Figure 2. **Forgetting over autobiographical timescales.** Retention of real-world episodic memory information over time (weeks), as measured by recognition, cued recall, or free recall. For studies using recognition or cued recall, the y-axis reflects memory accuracy. For studies using free recall, the y-axis reflects the proportion of all recalled events occurring at each timepoint (Rubin & Schulkind, 1997; Moreton & Ward, 2010) or the proportion of all encoded information that was recalled (Diamond et al., 2020)); accordingly, the overall recall rate is lower in Diamond et al. (2020) . Note that the curves were fit to data either at the level of individual subjects or group means, following the presentation in the original studies. Data were provided by original authors (Armson et al., 2017a; Diamond et al., 2020) or manually extracted from published figures using a free online tool (https://automeris.io/WebPlotDigitizer/).

Law of Contiguity

Scholars throughout antiquity recognized that after experiencing two items in temporal succession, these items will tend to come to mind successively. This recognition led to a rich body of theorizing about the association of ideas (e.g,. Hume, 1739), and how these associative processes may help to explain human thought processes. Building upon this philosophical tradition, Ebbinghaus (1885) sought to investigate associative processes experimentally. To do this, he examined how rapidly he could memorize lists whose sequential structure was similar to previously learned lists. His findings of positive transfer between lists that possessed similar temporal structure (i.e., these lists were learned faster) led to the view that temporal contiguity was an essential ingredient in associative learning. Later scholars challenged this view by showing that without intention to learn, subjects exhibited very little evidence for associative learning of contiguously experienced items (Thorndike, 1932; Hintzman, 2011) (see below for a further discussion and rebuttal of these results).

Whereas early research focused on explicit tests of associative memory, such as serial recall and cued recall, more recent studies have used the free recall procedure to assess the role of contiguity in memory storage and retrieval. Because the order of recall reflects the order in which items come to mind, studies of free recall recall dynamics (the transitions people spontaneously make from one item to another) can help to reveal the organization of memory. To quantify the influence of temporal contiguity on the order of recall, Kahana (1996) asked how the probability of successively recalling items studied in lists positions i and j depends on their temporal separation, or lag = $j - i$. He computed these conditional response probabilities by dividing the frequency of transitions to a given lag value by the possible transitions to that lag, excluding transitions that are outside of the bounds of the list or transitions to already recalled items[1]. This measure is called the *conditional-response probability as a function of lag*, or *lag-CRP*.

Figure 3 illustrates lag-CRP functions obtained in two different variants of the free recall task: In delayed free recall (DFR), subjects perform a demanding distractor task between the final list item and the recall period and in continual-distractor free recall (CDFR), subjects must perform a demanding distractor task following each and every list item. A similar pattern emerges in immediate free recall (IFR) as well, where subjects begin recalling immediately following the final list item.

In all three variants of the free recall task – immediate, delayed, and continual distractor – subjects produce many more transitions among neighboring items than among items studied in more distant list positions. This is seen in the shape of the lag-CRP function, which decreases systematically as absolute lag increases, approaching an asymptotic value at moderate lags; the asymptotic value depends almost exclusively on list length, with lower asymptotic values for longer lists. The lag-CRP is also asymmetric, with transitions to neighbors being more frequent in the forward than the backward direction. A final striking feature of the lag-CRP is the

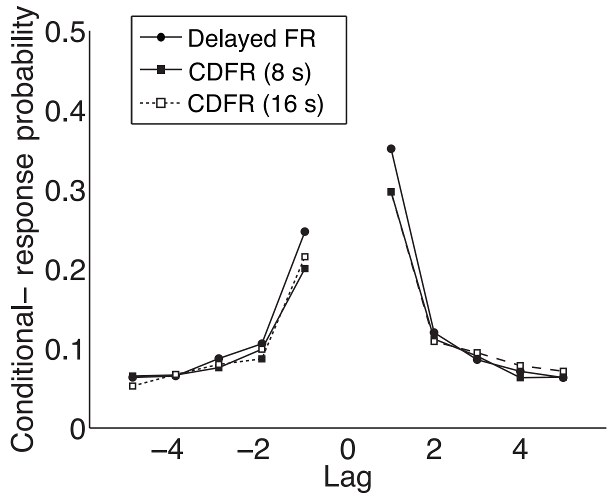

Figure 3. **The Contiguity Effect in Free Recall.** The conditional-response probability as a function of lag exhibits a strong contiguity effect in both standard delayed free recall, and in a continual-distractor free recall, where subjects performed an 8-second or 16-second arithmetic distractor task between each list item, and at the end of the list. Positive values of lag correspond to forward recalls; negative values of lag correspond to backward recalls.

persistence of contiguity across time scales (Howard & Kahana, 1999). Although one might expect that performing a demanding arithmetic task between neighboring items would disrupt their association, the contiguity effect appears to be preserved despite the disruption of the encoding process.

Figure 4 illustrates the generality of the contiguity effect. Figure 4A-C shows that the contiguity effect appears robustly for both younger and older adults (though is reduced for older adults), for subjects of varying intellectual ability, and for both naïve and highly practiced subjects. Figure 4D-F shows that the contiguity effect also predicts confusions between different study pairs in a cued recall task, in errors made during probed recall of serial lists, and in tasks that do not depend on inter-item associations at all, such as picture recognition (see caption for details). The temporal contiguity effect is evident in nearly all healthy subjects (Healey & Kahana, 2014), and persists even under explicit instructions to use other memory search strategies (Healey & Uitvlugt, 2019); it is a universal property of memory.

We can also examine lag-CRP curves for patterns of neural reactivation preceding recall - here too, one observes the classic signatures of contiguity underlying memory. For example, analyzing intracranial recordings from human patients performing a verbal free recall task, Manning, Polyn, Baltuch, Litt, and Kahana (2011) found that patterns of neural activity preceding recall of a given word reinstated the pattern observed during encoding for that word, with similarity also being high for adjacently encoded words and dropping off as a function of lag. This neural contiguity effect

[1] One can also do more sophisticated corrections for autocorrelations in goodness of encoding, as discussed more fully in Healey, Long, and Kahana (2019).

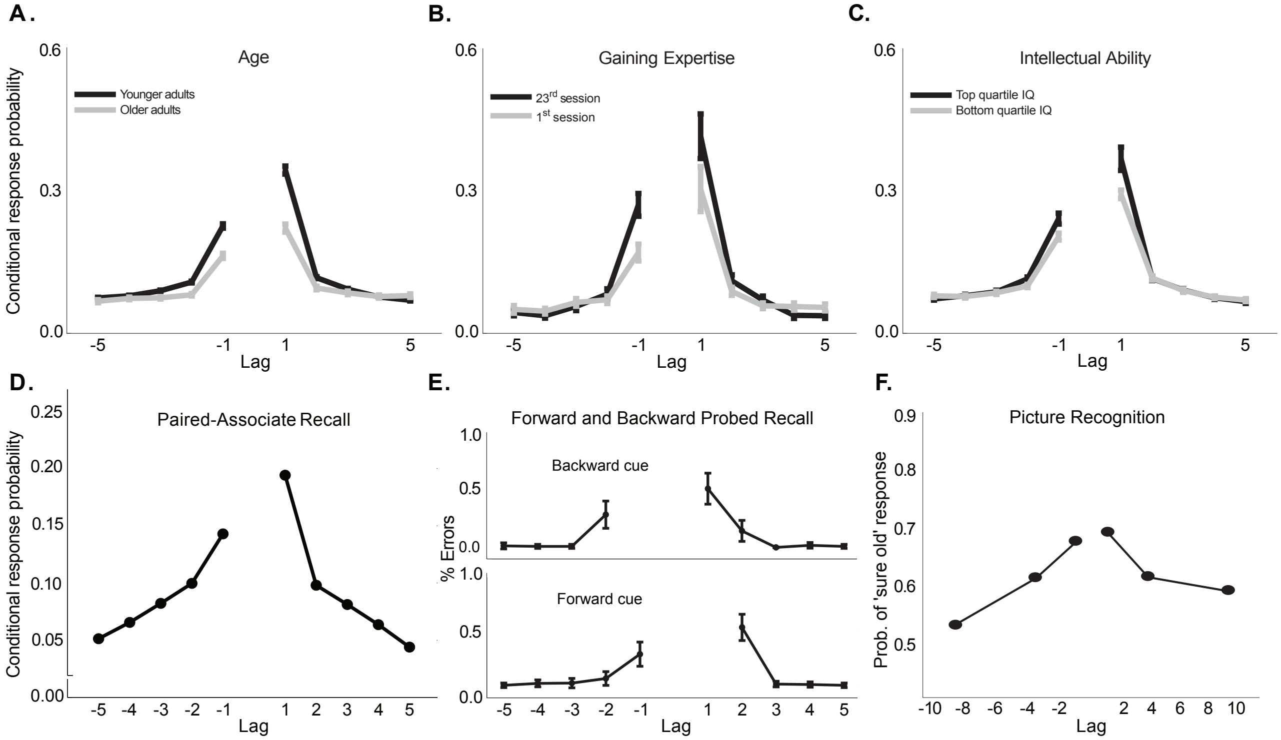

Figure 4. **Universality of Temporal Contiguity. A.** Older adults exhibit reduced temporal contiguity, indicating impaired contextual retrieval **B.** Massive practice increases the contiguity effect, as seen in the comparison of 1st and 23rd hour of recall practice. **C.** Higher-IQ subjects exhibit a stronger contiguity effect than individuals with average IQ. **D.** The contiguity effect appears in conditional error gradients in paired-associate (cued) recall, where subjects tend to mistakenly recall items from pairs studied in nearby list positions. **E.** When probed to recall the item that either followed or preceded a cue item, subjects occasionally commit recall errors whose distribution exhibits a contiguity effect both for forward and backward probes. **F.** The contiguity effect also appears when subjects are asked to recognize previously seen travel photos. When successive test items come from nearby positions on the study list, subjects tendency to make high confidence "old" responses exhibits a contiguity effect when the previously tested item was also judged old with high confidence. Healey et al (2019) provides references and descriptions of each experiment.

also occurs during item recognition in a continuous recognition task (Howard, Viskontas, Shankar, & Fried, 2012) - when we recognize a given item, particularly with high confidence (Folkerts, Rutishauser, & Howard, 2018), our brains reactivate both the neural activity present during encoding of the target item and also that present during the encoding of neighboring items unrelated to the target item.

Researchers have asked whether the same contiguity effect seen in list memory tasks also appears in everyday, autobiographical memory tasks, and at very long time scales. Otherwise, one might reasonably suspect that the striking influence of contiguity on word-list recall might be inflated by task-specific strategies developed across trials (Hintzman, 2015; Healey & Uitvlugt, 2019). Using a smart-phone application, Cortis Mack, Cinel, Davies, Harding, and Ward (2017) presented subjects with a single word each hour as they went through their daily lives; one hour following the final item presentation of that day, they administered a free recall task. Despite the very long inter-presentation intervals subjects exhibited a robust contiguity effect. Although these results indicate that contiguity appears at very long time scales, the fact that subjects deliberately encoded the items - discrete, random words, as in laboratory studies - leaves open the possibility that deliberate rehearsal strategies (see chapter 4.2, Ward, 2022) produced or enhanced these associative effects.

To evaluate whether contiguity generalizes to circumstances where subjects would have no reason to systematically rehearse items, researchers have asked whether contiguity effects appear in the retrieval of autobiographical memories. Moreton and Ward (2010) asked subjects to free recall events that had occurred in their lives within the last five weeks, five months, or five years. Within each targeted recall-period, subjects showed a contiguity effect, a tendency to make recall transitions between events that were within the same relative retention interval (e.g., upon recalling an event from three weeks/months/years ago, subjects were more likely to transition to recalling another event that occurred three weeks/months/years ago than one that had occurred two or four weeks/months/years ago). A limitation of this study is that it potentially confounds semantic similarity with temporal distance (Hintzman, 2015). For example, events that occur during temporally-proximate periods of your life are more likely to involve similar people and places than events that occur during more temporally-distant periods. Uitvlugt and Healey (2019) addressed the confound of semantic similarity on contiguity in a study where subjects were asked to recall news stories - in one study, stories related to the 2016 American presidential election spanning two years, and in another, any news stories spanning four months. Not only did recall dynamics (the order in subjects' recalled news stories) exhibit a clear contiguity effect, but this effect persisted when the authors statistically accounted for semantic similarity between pairs of news stories; semantic similarity, too, influenced recall transitions (see Section 4, below).

The foregoing studies demonstrate that contiguity robustly influences the way we search our memory for distinct events separated by hours, months, and years. These studies, however, operationalize recall of an event in binary fashion - each event is either recalled or not - as in word lists. Conversely, real-world memories are continuous, varying in detail and specificity. Diamond Levine (2020) investigated organization in narrative-style free recall of a single 30-minute real-world event (an audio-guided art tour) after several days or a week. People can routinely recall particular events in great detail, and the autobiographical memory literature offers tools for objectively measuring the types and quantities of details comprising a a given memory (see discussion of the Autobiographical Interview in chapter 5.12, Levine et al., 2022). These studies, however, are usually blind to recall dynamics due to their lack of control. Leveraging control over the sequential structure of a real-world event, Diamond and Levine (2020) found a clear forward-asymmetric contiguity effect, which was reduced in older subjects (65+ years). Furthermore, subjects whose memory search exhibited greater contiguity and forward-asymmetry effects also recalled a greater proportion of episodic (e.g., perceptual) details when controlling for overall verbosity, highlighting a potential link between the dynamics of memory search and the quality of the retrieved content. Figure 5 shows the lag-CRP curves obtained in these real-world studies of recall dynamics.

A contiguity effect also arises in neural representations of real-world events. For example, Nielson, Smith, Sreekumar, Dennis, and Sederberg (2015) asked subjects to wear automatic photo-logging devices during their daily life over the course of a month. They then presented these personal photographic cues, in random order, back to subjects undergoing fMRI scanning. Using representational similarity analysis, Nielson et al. (2015) showed that events occurring closer in space or time evoked more similar patterns of neural activation in the hippocampus, suggesting that recognition of a particular event reinstated spatiotemporally similar events, whether at the time of encoding or retrieval.

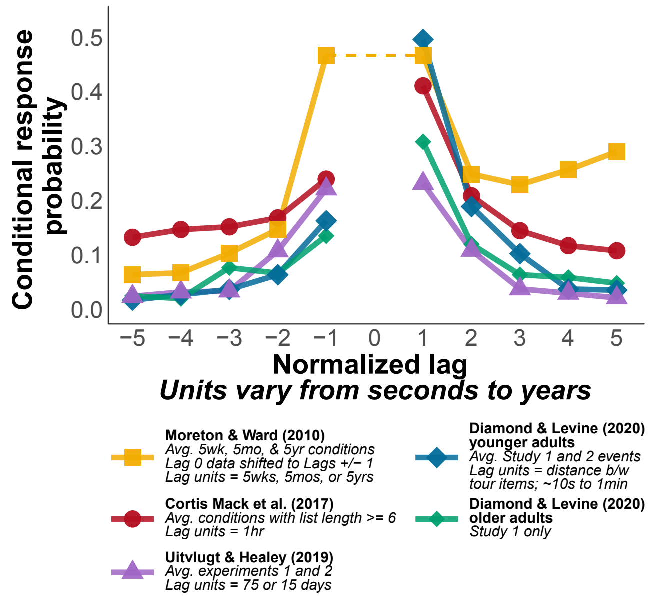

Figure 5. **Contiguity effect in recall of real-world events.** The studies included here assessed lag-conditional response probabilities in recall of real-world events. We averaged over conditions or experiments comprising each study. Moreton & Ward (2010) measured recall of personal autobiographical events; the lag units (and range of retention intervals) were either 5 weeks, 5 months, or 5 years. Note that Moreton & Ward (2010) reported Lag 0 CRP's for transitions made within a relative retention interval (without information about direction); we shifted these Lag 0 values to both Lag +/- 1 symmetrically, likely removing the expected forward asymmetry. Cortis Mack et al. (2017) measured recall of words experimentally presented via smartphone as participants went about their daily lives after a one hour delay; we included their four experiments/conditions with list lengths of six or greater, given that shorter lists produce unreliable lag-CRP's. Diamond & Levine (2020) measured recall of two controlled walking tours of artworks, in younger and older adults, after delays of two (Study 1) or seven (Study 2) days. See above text for more detail. Data were provided by original authors, Diamond & Levine (2020), or extracted from published figures using a free online tool (https://automeris.io/WebPlotDigitizer/).

Contiguity Generating Mechanisms

What produces the contiguity effect seen across varied laboratory memory tasks and autobiographical memory tasks and at widely varying time scales? Healey et al. (2019) evaluated six contiguity generating mechanisms: associative chaining, short-term memory, positional coding, chunking, strategic control-processes, and contextual dynamics and retrieval. Lacking space to discuss each of these mechanisms in detail, we briefly summarize Healey et al.'s main conclusions and discuss how one of these mechanisms – contextual dynamics and retrieval – has provided a parsimonious account of many contiguity -based memory phenomena.

Three features of contiguity challenge some of the earliest, classic, explanations: 1) Contiguity effects not only link neighboring items, but appear graded across many intervening items, 2) contiguity effects appear preserved across widely varying time scales, from seconds to minutes to months, and 3) contiguity effects exhibit a consistent forward asymmetry, with forward transitions being about twice as frequent as backward transitions under nearly all conditions. Classic chaining and short-term memory models, and strategic control-process explanations, cannot account for the full range of contiguity phenomena (see Healey et al, 2019 for a full discussion). In particular, these accounts struggle to explain the appearance of contiguity at widely varying time scales. To preserve any of these explanations one must assume separate explanations for short-term and long-range contiguity. The remaining accounts analyzed by Healey et al. (2019) – positional coding, chunking, and contextual dynamics – can each potentially account for many contiguity results. Here we provide a brief summary of context-based models of contiguity and then we compare this account with positional coding and chunking models.

As noted above, associations in memory form in relation to background elements that fluctuate over time, an idea formalized by Estes (1950) but presaged by McGeoch's (1932) theory of forgetting. Recency arises because the context of a recent experience is more similar to the current context than that of a more remote experience. Howard and Kahana (1999) suggested that the contiguity effect could arise from retrieval of the context in which an item was studied. Their finding of long-range contiguity effects, discussed above, along with earlier work on long-term recency effects (e.g,. Bjork & Whitten, 1974; Tzeng, 1973) led to the formalization of the temporal context model (Howard & Kahana, 2002a), which is a particular formalization of the more general class of retrieved context theories (see, Kahana, 2020, for a review).

In retrieved context theory, the contiguity effect arises because recall of an item activates the context that was associated with that item during list presentation, as well as (preexperimental) contexts associated with the item prior to the most recent study list. These retrieved contextual states combine with the current state of context to serve as the retrieval cue for the next response. Because the list context associated with an item overlaps with the encoding context of the item's neighbors (due to the fact that context slowly drifts over time), a contiguity effect results. Because the preexperimental context associated with an item overlaps with the encoding context of the item's successors in the list, there is a forward asymmetry in recall transitions. Finally, to the degree that the time-of-test context overlaps with the context of recently studied items, there will be a tendency to make transitions to end-of-list items.

In continual-distractor free recall, the distractor activity interpolated between study items will diminish the degree to which the context associated with an item overlaps with the context associated with its neighbors. However, because recall is competitive, the overall reduction in the contextual overlap among items will not significantly diminish the contiguity effect. To the extent that the activations of neighboring list items are greater than the activations of remote list items, a contiguity effect is predicted. The absolute activations of the items are thus less important than their relative activations. This highlights a key feature of context-based explanations of the temporal contiguity effect, once again tracing back to McGeoch: temporal order matters more than absolute time as measured by a clock.

Due to the recursive definition of context (we retrieve prior contexts, which then update the present context, which cues further retrieval), retrieved context theory predicts that multiple prior items serve as part of the cue for the next recalled item. Lohnas and Kahana (2014) tested this *compound cueing* prediction in a meta-analysis of free recall experiments. Consistent with this prediction, they found that following recall of two temporally clustered items, the next recalled item is even more likely to also be temporally clustered. Chapter 5.11 (Manning) in this volume provides a more detailed account of this class of models, including a discussion of neural mechanisms of contextual dynamics and reinstatement.

Positional coding theories and context-based theories can closely resemble one another. Both posit a time-varying representation of time, position, or context. If remembering an item can also recover its position in a sequence, then one should observe graded contiguity that can persist across time scales in the same way as predicted by retrieved context theory. The forward asymmetry of recall, however, does not arise naturally in these models, and would require additional ad hoc assumptions.

A chunking theory that includes positional codes provides an interesting alternative to retrieved context theory. Farrell (2012) provide a detailed analysis of such a model, showing that it can account for a wide range of free and serial recall phenomena. A full discussion of this model is beyond the scope of this chapter but the interested reader is referred to the Farrell paper for a complete analysis.

Law of Similarity

Whereas contiguity refers to the organization of memories governed by their time of occurrence, memories exhibit similarity-based organization along a wide range of psychological dimensions. In contemporary models of memory, similarity between the present and some past experiences (or set of experiences) often triggers memory retrieval (Surprenant, Neath, & Brown, 2006; Kahana, 2020). Because language, along with much of our conscious mental life, involves the "meaning of things," research on similarity effects has largely focused on semantic similarity (cf. Chapter 2.6 for a discussion of perceptual similarity in memory).

Semantic similarity's effect on recall appears in peoples' tendency to make recall transitions among semantically related items (Romney, Brewer, & Batchelder, 1993), even lists of randomly arranged words lacking obvious semantic structure (Howard & Kahana, 2002b). As one illustration of the *semantic similarity effect*, Figure 6 shows how the probability of making a recall transition among two items increases, and the inter-response time decreases, with their semantic relatedness.

The semantic relatedness between items can be computed using various different methods. Traditionally, the pairwise method, where subjects provide their subjective similarity ratings for all possible pairs of items in a given experiments word pool, allowed researchers to use these ratings to construct a metric model of the representational space (Shin & Nosofsky, 1992). Over the years, other tasks such as the odd-one-out (or triadic comparison) test (Westfall & Lee, 2021), card sorting task (Schwartz & Humphreys, 1973), and free association (Bousfield, 1953; Nelson, Schreiber, & McEvoy, 1992) have also been used. While these approaches work well with a limited number of items, they become impractical when the number of items increase.

More recently, however, quantifying similarity between items by evaluating the word co-occurrence statistics in large text corpora overcomes this challenge. Nowadays, Latent semantic analysis (LSA) (Landauer & Dumais, 1997), BEAGLE (Jones & Mewhort, 2007), GloVe (Pennington, Socher, & Manning, 2014), and Word2Vec (Mikolov, Chen, Corrado, & Dean, 2013; Manning, Sperling, Sharan, Rosenberg, & Kahana, 2012) are some of the most widely used computational linguistic methods to derive the semantic relatedness between items. Specifically, once we obtain their semantic relatedness, we can compute the conditional probability of recall transitions between items i and j as a function of this measure. Such an analysis reveals strong semantic organization on recall of random words. In addition to the word-level positive semantic similarity effects, participants find it easier to recall semantically coherent lists as well (Aka, Phan, & Kahana, 2021).

Using these computational linguistic methods allows us to quantify the semantic relatedness between almost any arbitrary word pair. As such, some scholars started to move beyond constrained word lists and study research questions with naturalistic stimuli and direct practical applications. For example, Aka and Bhatia (2021) and Bhatia (2019) used novel paradigms influenced from the memory literature to demonstrate how some of the established memory regularities such as the semantic similarity effect emerge in memory-based preferential choice, when decision makers list any item that comes to their minds (from memory) while deliberating in a variety of everyday choice settings.

Costs and Benefits of Similarity, Within and Across Different Tasks

Similarity promotes both generalization and interference. As such, it can lead to improved or impaired memory depending on the situation (Nelson, Kitto, Galea, McEvoy, & Bruza, 2013). If similarity governs the way a memory, thought, or idea leads to another, then we can expect subjects to exhibit better free recall of semantically homogeneous lists. Experiments bear out this prediction (Romney et al., 1993). Conversely, we would expect the opposite results in tasks such as serial recall, where correct recall requires transitioning between item i and item $i + 1$, whereas similarity between items i and $j \neq i + 1$ serves as a source of interference (Poirier & Saint-Aubin, 1995). Murdock and vom Saal (1967), among others, reported exactly this result: similarity helps item memory but hurts order memory.

As Schacter (1999) notes, the same memory principles can give rise to both correct recalls and memory errors even within a task. More specifically, within free recall we can observe both costs and benefits of inter-item similarity. When subjects commit recall errors (intrusions) these tend to be items semantically related to the recalled items from the target list (Zaromb et al., 2006). This is particularly striking in the Deese-Roediger-McDermott false-memory paradigm (Deese, 1959; Roediger & McDermott, 1993), where lists comprise items that bear strong semantic relatedness to a non-studied critical item. When recalling such lists, subjects exhibit very high levels of false recall and false recognition of the critical item, and this appears to result from both retrieval of the critical item during study and during recall (Kimball, Smith, & Kahana, 2007).

It is important to consider that our experiences vary along many dimensions of similarity beyond time and semantics - for example, space (as discussed above, and in chapter 3.3, Becker, 2022), emotional valence and arousal (see chapter 3.6, Kensinger & Fields, 2022), people, goals, causal connections, and even temporal information beyond the linear time of word lists (e.g. hierarchical structures such as seasons and life phases; (Conway & Pleydell-Pearce, 2000; Farrell, 2012). Previous work demonstrates how these dimensions of similarity structure our autobiographical memory (e.g., N. R. Brown & Schopflocher, 1998; Conway & Pleydell-Pearce, 2000; D. B. Wright & Nunn, 2000). Emotion, in particular, may play a more important role in organizing our personal memories than is typically recognized in laboratory memory studies using experimenter-generated stimuli (Tomita, Barense, & Honey, 2021; Cohen & Kahana, in press).

As a further illustration of the law of similarity, consider the everyday challenge of meeting a new person, hearing their name for the first time, and being able to subsequently recall their name when you next see them. Successful learning of name-face associations allows us to address people by their names, which is of great social significance. Sadly, many of us find it very difficult to perform these tasks without considerable effort, and even so we often have difficulty remembering a name that once came to mind with great ease. Reflecting on this challenge leads us to recognize that faces possess a high degree of similarity, having the same basic shape, structure, etc. Thus, for any given name-face pair we have learned, there will likely be other similar pairs in memory.

Using *multidimensional scaling* (MDS) to assess facial similarities (see, Steyvers, 2001), Pantelis, van Vugt, Sekuler, Wilson, and Kahana (2008) asked subjects to study and recall novel name-face pairs over repeated trials. Hypothesizing that people would have greater difficulty associating names with faces that had many "neighbors" in the face space (defined as the number of other faces that lie within a small radius around the target face), Pantelis et al. asked how accuracy at recalling the correct name (when cued with the face) would vary with the number of neighbors. As shown in Figure 7), recall accuracy decreased and reaction times in-

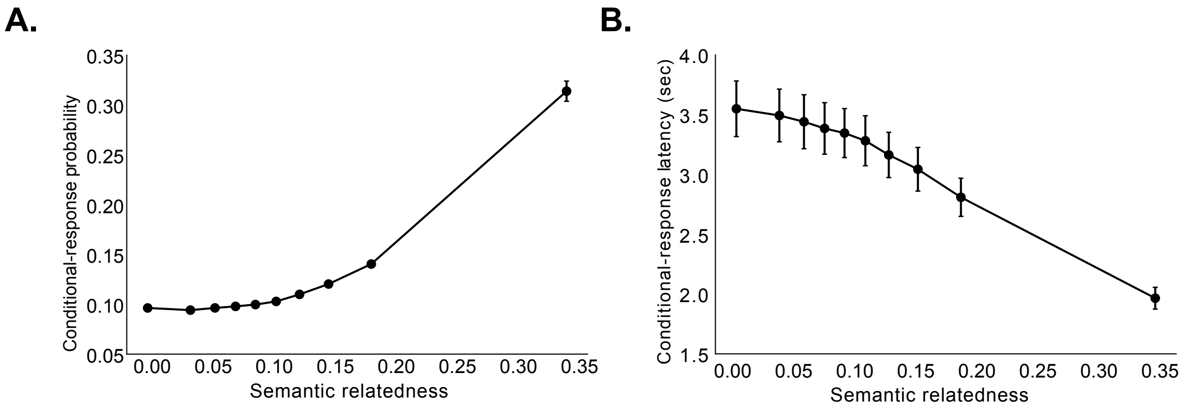

Figure 6. **Semantic similarity effect in free recall. A**. Subjects are more likely to recall items that are semantically related to the just-recalled item. **B**. The inter-response time decreases as the semantic relatedness between the items increases. Semantic relatedness is computed using Word2Vec (Mikolov et al., 2013) and error bars are 95% confidence intervals. (Data from Experiment 4 of the PEERS study.)

creased as the the number of also-studied neighboring faces increased. When cued with a face at test, subjects sometimes mistakenly recalled the name of a different face also presented during study. Such intralist intrusion errors tended to be names associated with faces that were similar to the target face (Figure 7).

Whereas our ability to recall a face-name association suffers when we have learned other names for visually similar faces, recalling an association between two words can benefit when they share similar meaning or other properties (Nelson, McKinney, Gee, & Janczura, 1998; Nelson et al., 2013). Although seemingly opposing results – similarity improving or impairing memory – these two findings reflect the same underlying principle. Similarity benefits memory retrieval when it unifies the target items and separates them from distractors; when similarity pulls you away from the desired memories, it causes interference and retrieval suffers.

Consider another case of similarity's ubiquitous role in memory. In the short-term item recognition task popularized by Saul Sternberg, subjects judge whether a single probe item occurred on a just-presented study list comprising 1-6 items (Sternberg, 1966, 2016). With symbolic items – such as digits, letters and words – subjects perform this task with near perfect accuracy, and RT serves as the primary measure of memory. To study the role of perceptual similarity in recognition memory, Kahana and Sekuler (2002) presented subjects with visual textures created by summing sinusoidal patterns of light and dark bars, as shown in Figure 8A. Figure 8B illustrates how the probability of a *yes* response increased with summed similarity for both targets and lures. Here, and in other studies using lists composed of colors (Nosofsky & Kantner, 2006) and faces (Lacroix, Murre, Postma, & van den Herik, 2006; Yotsumoto, Kahana, Wilson, & Sekuler, 2007) we see that similarity increases the accuracy of recognizing target items but decreases the accuracy of rejecting lure items. As in the recall examples described above, similarity both improves and impairs memory performance. In this case, it produces both effects with a single mechanism: the greater the similarity between the studied items and the test item, the greater the evidence that the items had occurred on the target list. If the test item is a "lure," its similarity to the list causes subjects to produce an incorrect "yes" response. If the test is a "target," greater similarity to the non-target items on the list increase subjects tendency to produce a correct "yes" response.

The recent proliferation of memory studies on event boundaries can be seen as elaborating on the law of similarity. Event boundaries – punctate discontinuities in the similarity structure of ongoing experience – disrupt the formation of associations in memory, whether those boundaries are in the domain perceptual features (Heusser, Ezzyat, Shiff, & Davachi, 2018), category (DuBrow & Davachi, 2013), spatial context (Radvansky & Copeland, 2006; Horner, Bisby, Wang, Bogus, & Burgess, 2016), or narrative structure (Ezzyat & Davachi, 2011). Accordingly, boundaries trigger discontinuities in hippocampal activity dynamics, which in turn predict effects on later memory (Zacks, Speer, Swallow, Braver, & Reynolds, 2007; Ben-Yakov & Dudai, 2011; Baldassano et al., 2017; Ezzyat & Davachi, 2014; Brunec, Moscovitch, & Barense, 2018). On the flipside, greater neural pattern similarity across successively encoded items (greater neural 'lingering') predicts a higher probability that those items will be recalled together later on (Chan, Applegate, Morton, Polyn, & Norman, 2017). These results suggest that neural similarity patterns may track contextual similarity as described in retrieved context models of memory.

Similarity can also produce conflicting outcomes in the brain. Even within the hippocampus, fMRI studies reveal a highly variable relationship between the similarity structure of stimuli, and corresponding similarity in brain activity patterns (e.g., multivoxel activity patterns in fMRI data (Brunec, Robin, Olsen, Moscovitch, & Barense, 2020)). For example, learning that two stimuli share a common indirect association (e.g. learning an A-B pair, and some time later, an A-C pair) increases the similarity in hippocampal representations of the indirectly related pair (A and B) via retrieval-mediated learn-

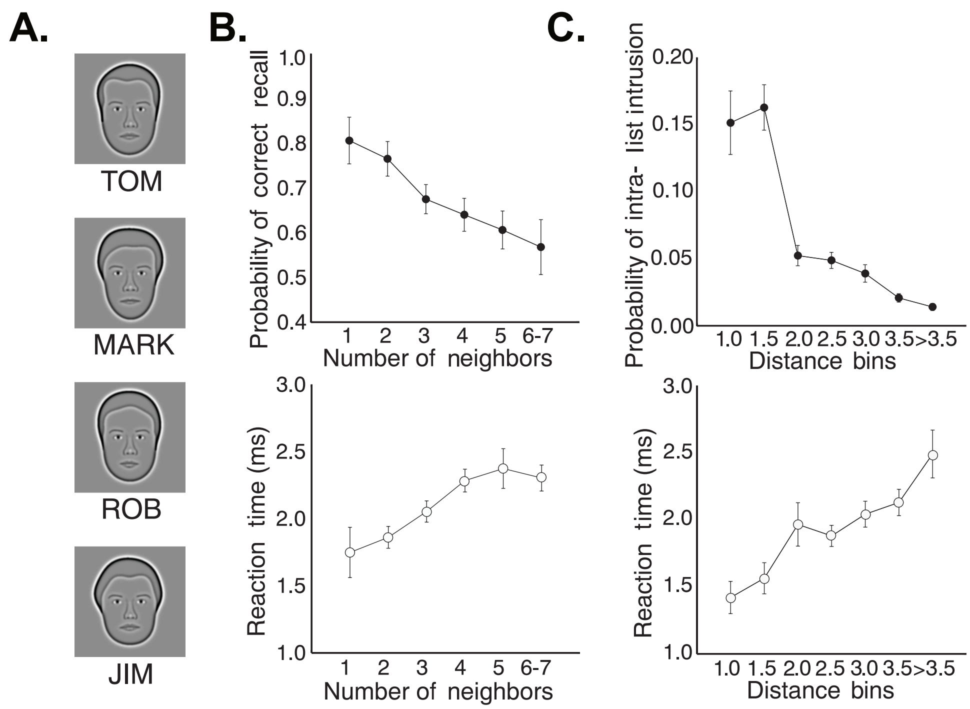

Figure 7. **Similarity and memory for name-face associations. A.** Examples of name-face pairs presented at study. **B.** Neighborhood Effect. The upper panel shows the probability of recalling the correct name when cued with a face at test, as a function of how many neighbors that face had within the study list. The lower panel shows reaction times for correctly recalling names of faces as a function of the number of neighbors. **C.** Each possible intrusion name corresponded with a study face, for which the distance from the cue face in four-dimensional face space was calculated. The upper panel shows the probability of making an intralist intrusion of a particular distance. The lower panel shows the reaction times for intralist intrusions of various distances from the cue face.

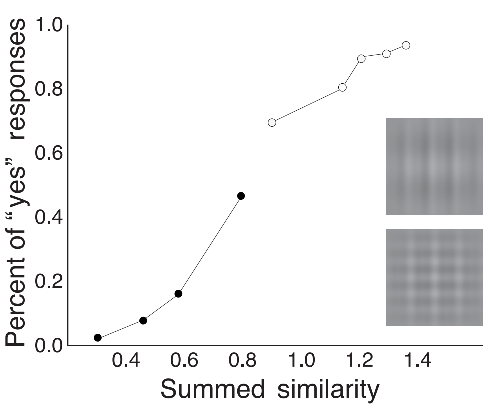

Figure 8. **Similarity effects in recognition of visual textures.** Probability of a *yes* response to targets (open circles) and lures (filled circles) increases with the summed similarity of the probe item with the items in the study list. Inset: Sample textures used in the study of Kahana and Sekuler (2002).

ing (Zeithamova, Dominick, & Preston, 2012). Accordingly, greater hippocampal reactivation of previous similar memories during learning predicts behavioral performance on tests requiring integrated or generalized memory representations (Zeithamova et al., 2012; Shohamy & Wagner, 2008; Richter, Chanales, & Kuhl, 2016). On the other hand, learning similar information can actively emphdifferentiate, or repel, hippocampal representations of that information, reducing interference (Favila, Chanales, & Kuhl, 2016) (see also, chapter 4.3, Wagner et al., 2022). As the similarity across paired-associate trials - and thus potential for memory interference - increases, subjects increasingly exaggerate the differences between stimulus features in memory (e.g., subjects remember two near-identical objects paired with separate scenes as more different than they actually were) (Chanales, Tremblay-McGaw, Drascher, & Kuhl, 2021). The degree to which similarity in the world drives integration vs. differentiation of representations in memory varies both across brain regions, even within the hippocampus (Schlichting, Mumford, & Preston, 2015), and across different task demands (i.e., situations where it is adaptive to integrate information vs. maintain separate representations) (Brunec et al., 2020).

Law of Primacy

People generally exhibit superior memory for the first of a list of experienced items. This mnemonic advantage, which can extend several items into a list, appears across varied memory tasks, in both humans and in animals. In an essay entitled ”The Law of Primacy,” Tulving (2007a) offers compelling evidence for the ubiquity of the primacy effect, arguing that it rises to the status of a scientific law. The present analysis, which may be considered a supplement to Tulving’s gem, offers a different perspective on the data, but draws the same conclusion.

Primacy in free recall

Consider the classic serial position analysis of free recall (Murdock, 1962; Deese & Kaufman, 1957). Here subjects study a series of items presented individually and then attempt to recall as many items as they can remember in any order. Countless experiments have demonstrated superior recall for both early list items (primacy) and end of list items (recency). Whereas recency is the dominant effect in immediate recall, primacy appears more prominently in delayed recall (Kahana, 2012, see chapter 5.1, Hurlstone, 2022, and chapter 5.2, Lohnas, 2022).

The serial position curve in free recall is the result of a dynamic, cue-dependent memory search process that has been described by Kahana (2020) among others. Hogan (1975) may have been the first to specifically look at the distribution of recall initiation across list positions. Hogan found that subjects tend to initiate recall either with the very first list item, or one of the final list items. Initiating at the end of the list appears as the dominant pattern in immediate recall whereas initiating with the start of the list appears to be the rule in delayed recall. But even in immediate recall, subjects begin with the start of the list more often than they begin with almost any intermediate list item. Thus, subjects exhibit a primacy effect in the manner in which they initiate recall in both immediate and delayed free recall tasks. However, even when subjects initiate recall at the end of the list they still exhibit a marked increase in their recall of early list items, so recall initiation appears to be a manifestation of a more basic primacy mechanism rather than its cause.

Primacy is not limited to the very first item in a list. By introducing a change in encoding task, or modality of presentation, during the middle of a list, one observes primacy for the first item following the event boundary. As an example, Polyn, Norman, and Kahana (2009) asked subjects to study a list of twelve items in which they judged each item’s size (”big” or ”small”) or pleasantness (”good” or ”bad”) . In some lists, subjects were asked to make the same judgement on every item. In others, subjects either made size judgements on the first six items and pleasantness judgements on the last six items, or vice versa. On these task-switch lists, subjects exhibited a primacy effect both at the beginning of the list and also after the task-shift boundary. Thus, a change in the manner of item encoding resulted in improved memory for the first few items studied under the new encoding conditions. Similar event-boundary primacy effects appear for manipulations of modality (Murdock & Carey, 1972), category (Polyn, Erlikhman, & Kahana, 2011), and in more naturalistic settings, such as remembering content elements of a film before and after a ”cut” (Swallow, Zacks, & Abrams, 2009).

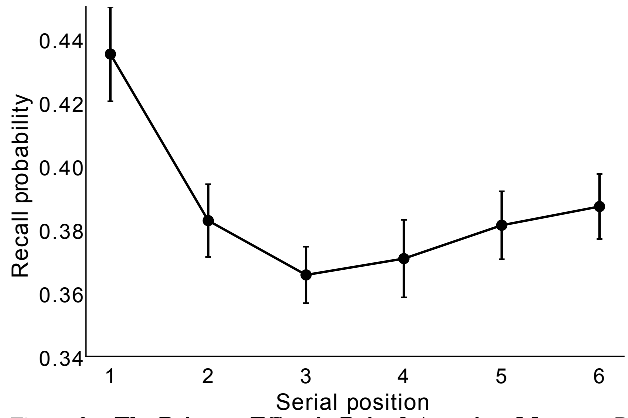

Figure 9. **The Primacy Effect in Paired-Associate Memory.** Recall probability as a function of serial position for lists of six pairs of common nouns tested following a 20 sec distractor task. Unpublished behavioral analysis of data collected as part of a multi-center study of the electrophysiology of associative memory. A subset of these data appeared in Greenberg et al. (2015).

Moderators of Primacy

Several variables modulate the degree of primacy in free recall, but we are not aware of any variable that eliminates primacy entirely. Slowing presentation rate increases primacy, as does any manipulation that encourages subjects to rehearse list items (see chapter 4.2, Ward, 2022). Incidental encoding instructions reduce or eliminate rehearsal and also reduce primacy effects (Healey, 2018). Visual presentation, as compared with auditory presentation, can lead to stronger primacy effects (the inverse modality effect (Grenfell-Essam, Ward, & Tan, 2017; Pazdera & Kahana, 2018) (see, Figure 13). Amnesia resulting from medial temporal lobe damage reliably reduces primacy effects in free recall and recall initiation (Baddeley & Warrington, 1970; Talmi, Caplan, Richards, & Moscovitch, 2015).

The primacy effect is by no means specific to the free recall task, but it tends to be larger in free recall than in recognition and cued memory tasks. Knoedler, Hellwig, and Neath (1999, Experiment 1) found primacy effects in response-times in a delayed-item-recognition task. Paired-associate (see Figure 9) and probe-recall tasks also exhibit primacy effects (Tulving & Arbuckle, 1963; Tsitsiklis et al., 2020; Sahadevan, Chen, & Caplan, 2021) but these often tend to be smaller in magnitude than primacy effects observed in free recall.

Mechanisms of Primacy

While primacy effects exhibit near-universality across memory paradigms and subjects, scientists are still debating the exact mechanisms underlying this phenomenon. Tulving (2006) discusses two of the classic explanations of primacy

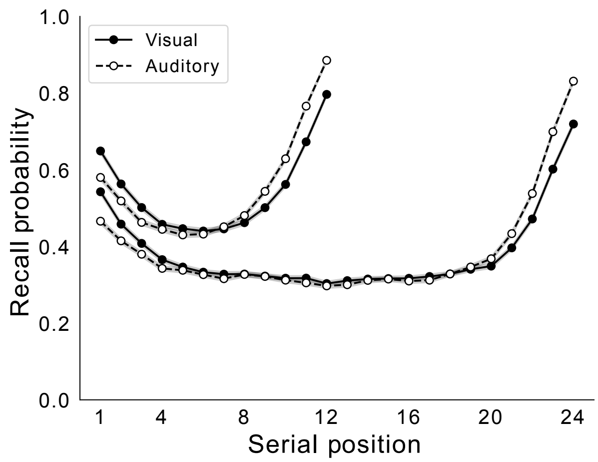

Figure 10. **The Primacy Effect in Free Recall.** Recall probability as a function of serial position for auditorally and visually presented lists of 12 and 24 items. Data from Pazdera et al. (Submitted).

in the memory literature: rehearsal and distinctiveness. We consider each of these explanations below.

Rehearsal. While studying a list of memoranda, subjects often think back to previously studied items (see chapter 4.2, Ward, 2022). This may either happen surreptitiously, or as part of a deliberate rehearsal strategy (Brodie & Murdock, 1977; Tan & Ward, 2000). Strategic rehearsal of items appears to be a dominant strategy during intentional learning paradigms, and especially recall tasks. To study this strategy, Rundus (1971) devised the overt rehearsal procedure. In overt rehearsal, subjects must say aloud all items that come to mind as they study the items on the target list. Counting the number of (overt) rehearsals each list item received, Rundus found that primacy items received the greatest number of rehearsals and that subjects often continued to rehearse the primacy items until the end of the list. Rundus also demonstrated that the number of rehearsals an item received predicted its eventual recall. This finding, coupled with subjects' preferential rehearsal of primacy items, offered support to a rehearsal account of primacy, at least in the free recall task.

Noting previous work reporting that slower presentation rates give rise to stronger primacy effects, Brodie and Murdock (1977) used the overt rehearsal procedure to further elucidate the relation between presentation rate and primacy. They found that with a slow (5 second) presentation rate, early list items also tend to be rehearsed later in the study list than with a fast (1.25 second) presentation rate. They argued that by rehearsing early list items later in the list, those items will benefit from greater *recency*. Thus, the rehearsal process not only leads subjects to devote more time to some items than to others; it also makes items from earlier list positions appear later in the sequence of rehearsals and thus more recent at the time of test. Ward and colleagues (e.g., Tan & Ward, 2000; Ward, 2002) replicated and extended these early findings by showing that in a broad range of experimental conditions, the recency with which an item has been last rehearsed predicts recall success.

There are several limitations to research using the overt-rehearsal procedure. Perhaps the first objection is that asking subjects to rehearse out loud changes the task, making it less natural and leading subjects to behave in a way that they would not otherwise behave in regular free recall. Second, any attempt to explain recall data with rehearsal data suffers from circular reasoning. Unless we know why subjects rehearse items the way they do, we can't use their rehearsal to explain their recall. Instead, their rehearsal data may only provide us with one more thing that requires explanation—namely, what makes rehearsals?

In an elegant analysis of subjects' overt-rehearsal data, Laming (2006; 2008) argued that rehearsals are essentially mini-recalls that subjects make as they study the list. In support of this view, Laming found that the sequence of recalls had the same statistical structure as the sequence of rehearsals once repeats were excluded (see, also, Murdock and Metcalfe (1978) who show that rehearsals exhibit a serial-position curve that looks very much like the serial-position curve in free recall).

Laming's view turns the analysis of rehearsals on its head. Rather than trying to use rehearsals to explain recall, Laming argues that we should be using recall to explain rehearsal. The problem is that any recall task in which subjects are free to rehearse is complicated by the fact that during study, subjects do not merely attend to the presented stimuli; rather, they make use of the study period to also recall previously studied items.

Although rehearsal of early list items constitutes an important factor underlying primacy in the free recall task, this mechanism cannot explain primacy observed under incidental learning conditions or in paradigms that suppress rehearsal. Primacy would also result from a novelty related boost in attention at the start of a list or following an event boundary.

Distinctiveness. Unlike the large primacy effect attributable to rehearsal, a residual primacy effect for the very first list position does not seem to be dependent on rehearsal (Howard & Kahana, 1999; D. Laming, 1999). Similar first-position primacy effects have been reported in item recognition experiments involving difficult-to-rehearse items (e.g., Neath, 1993; Neath & Crowder, 1996; A. A. Wright, Santiago, Sands, Kendrick, & Cook, 1985). This suggests that primacy, though greatly enhanced by the rehearsal process, cannot be entirely explained by it.

Wayne Donaldson conducted an unpublished free recall study in which subjects received a two minute "break" (an interval without any item presentations) before some lists but not others. He found that lists following breaks exhibited a stronger primacy effect than those that did not. This suggests that recalls from the previous list may interfere with memory for early list items when they are close in time. Alternatively, giving subjects a break may increase their ability to pay attention to early list items, thus increasing primacy.

Camatosis. Acknowledging the other potential accounts of primacy in the memory literature, Tulving (2007b) suggests that perhaps primacy reflects a more basic process of neural fatigue, which he refers to as ”Camatosis”. The idea behind camatosis is that the neural circuits involved in doing a particular cognitive operation become fatigued and therefore cannot sustain this function indefinitely. However, these same circuits can quickly recover their ability to perform the task at hand. Much like the human musculature can only maintain a pose for so long before giving out, so too neural circuits require rest after a period of extended use.

Consistent with this hypothesis, measures of high-frequency activity in the human brain – a surrugate for neural firing rate (Manning, Jacobs, Fried, & Kahana, 2009)– exhibit a marked primacy effect (see Figure 11). This neural primacy effect for high frequency activity appears both in cortical regions as measured using scalp EEG methods, for both younger (Sederberg et al., 2006) and older adults (Healey & Kahana, 2020), and in deeper brain structures as recorded from implanted electrodes in patients undergoing neurosurgical monitoring for the treatment of refractory epilepsy (Serruya, Sederberg, & Kahana, 2014).

As a more direct test of the camatosis hypothesis, Lohnas, Davachi, and Kahana (2021) recorded directly from the human hippocampus with intraparenchymal electrodes. They found that following sequences of encoded items that were correctly recalled, neural activity declined for the next encoded item, even after conditioning on correct recall of that item. In other words, non-recalled items that followed recalled items exhibited lower high-frequency activity than non-recalled items that followed other non-recalled items.

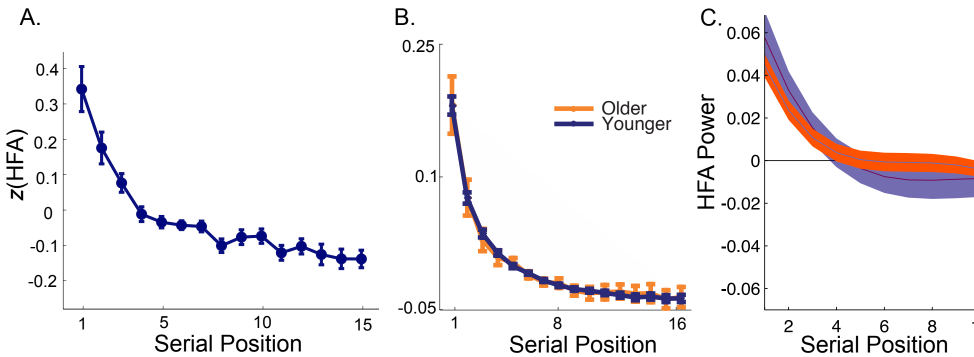

Figure 11. **Neural correlates of the primacy effect. A.** High frequency EEG activity (44-200 Hz spectral power) declines with serial position (Data from Sederberg et al., 2006). **B.** The same decline in high-frequency activity appears for both younger adults (orange) and older adults (navy); data from Healey et al (2021). **C.** Intracranial recordings from nearly 7,000 electrodes in widespread brain regions (N = 84 subjects) shows a similar decline in HFA power with serial position (Data from Serruya et al. 2012). This result is evident for both subsequently recalled items (red) and subsequently non-recalled items (blue). Error bars represent ± 1 standard error of the mean.

Law of Repetition

The *Law of Repetition* refers to what may be seen as the most obvious property of memory; namely that the speed and accuracy of remembering improve with repeated opportunities to study and retrieve the to-be-remembered material. With repetition, bicycles become easier to ride, facts become easier to recall, and routes become easier to navigate. To evaluate the impact of repetition on learning, we must consider the circumstances at encoding, retrieval, and retention, and the type of information stored in memory. In normal conversation, we easily remember an early clause in a sentence while listening to a later clause, and we rarely repeat ourselves over and over out of forgetfulness. Yet, walk into a classroom and meet 50 students for the first time and few of us will be able to remember all of the students' names without ample repetition and retrieval practice.

Although all major memory tasks demonstrate the benefits of repetition, experimental procedures in which a retrieval cue uniquely targets a particular memory allows scientists to evaluate repetition effects while minimizing interference from contextually-overlapping memories. Figure 12 shows a learning curve for a college student who had extensive practice learning randomly paired common words (Murdock, 1989). On each of 40 training sessions, this student learned a different list of word pairs by the method of alternating study and test trials. During a study trial, each of the 100 word pairs was shown for a 2-sec study period. During a test trial, one member of each pair was shown and she attempted to recall its mate. Each pair was tested in this manner. Study and test trials alternated until the student could recall all 100 word pairs. Under these conditions, the fraction of correctly recalled pairs increased nearly linearly across the first four study-test trials. By the sixth trial (not shown), all 100 pairs were recalled (naïve subjects would exhibit a much slower learning rate than the highly trained subject in this study). The linear increase in performance with repetition is not uncommon in cued recall tasks. Such linearity

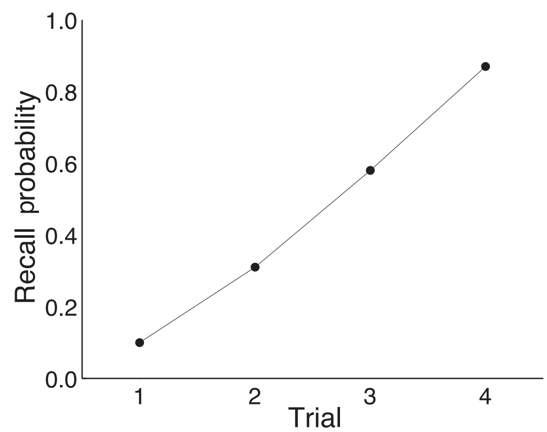

Figure 12. **Learning curve for word pairs.** Data from a highly practiced college student learning a list of 100 word pairs presented at a rate of 30 pairs per minute (Murdock, 1989).

would result if subjects acquired a constant number of new pairs on each trial and very rarely forgot pairs that they had previously learned. If, however, each learned pair has some chance of being forgotten from trial to trial, then as more pairs are learned, one would expect a larger absolute number of pairs to be forgotten (and assuming that the rate of new learning does not increase over study trials one would see a negatively accelerated learning curve, indicating diminishing returns from each learning trial. Other laboratory methods used to study learning, such as multi-trial free recall, often exhibit the property of diminishing returns (Tulving, 1962).

As one might expect, practice not only leads people to correctly recall and recognize a greater proportion of items, it also leads them to do so more quickly. In a paired-associate task, subjects may require an average of 2–4 seconds to correctly recall an item during the initial stages of learning. With practice, however, subjects will consistently recall the same item in around one second (Waugh, 1970; Anderson, 1981). Initially, response time (RT) decreases very rapidly, but the rate of decline in RT slows with practice until subjects approach their fastest possible rate of responding. The decrease in RT with practice is one of the most universal properties of human and animal learning. Anderson (1981) demonstrated that even when accuracy is near ceiling, additional practice opportunities lead to faster response times — a finding that appears consistently in diverse studies of repetition effects in both episodic memory and skill learning (see chapter 10.4, Healy et al., 2022).

Intention to learn

Repetition clearly increases retention, but this depends on many variables, among which intention to learn is possibly the most potent. Radossawljewitsch (1907) conducted an early replication and extension of Ebbinghaus' original (1885/1913) experiments on serial learning of random series of syllables. Apparently, one of the subjects, due to his imperfect German, did not understand that the experiment required that he memorize the sequence of syllables. After 46 repetitions he still had not indicated mastery of the list. When asked by Radossawljevitch if he could recite the series he replied "What! Am I to learn the syllables by heart?" (as related by McGeoch, 1942, p. 275). In a more recent example, only one out of 85 undergraduate students was able to correctly draw the Apple logo despite its ubiquity, and fewer than half correctly recognized it in an eight-alternative forced choice task (regardless of whether the subjects were themselves Apple users); subjects' confidence in their memory far exceeded their actual memory accuracy (Blake, Nazarian, & Castel, 2015). These findings build on classic work from Nickerson and Adams (1979) showing peoples' surprisingly poor memory for the visual features of an American penny.

Thorndike (1932) used a clever experimental manipulation to illustrate the crucial role that intention plays in human learning. He presented subjects with 1,304 word-number pairs (e.g., *BREAD–29*, *TEXAS–78*; presented sequentially), in which four pairs were repeated 24 times amidst other non-repeated word–number pairs. Unbeknownst to subjects, the list was ordered so that the word in each of the four repeated pairs always followed the same number. After studying the list, Thorndike asked subjects to recall the numbers that followed certain words or the words that followed certain numbers. For word–number pairs repeated 24 times, subjects correctly recalled 38% of target numbers. In contrast, subjects recall did not exceed chance levels when cued to recall words that followed the numbers in the repeated word–number pairs. This led Thorndike to conclude that repetition without intention to learn did not produce stable memories.

Decades later, Craik and Lockhart (1972) introduced the concept of maintenance rehearsal – thinking about an item, or items, to maintain them in memory without actually trying to learn about their occurrence in a particular context. They suggested that associative learning depends upon elaborating the meaningful relation between memoranda. Without elaborating and attending to these relational features, subjects exhibit very poor associative memory (for a detailed discussion of attention and memory, see chapter 4.1, Turke-Brown & Sherman, 2022). Researchers modified the maintenance-rehearsal procedure to assess whether incidental repetition produces learning. In this procedure, subjects first study a list of target items and then, during a retention interval between study and test, they repeat a set of distractor items which they do not believe they need to remember. By giving subjects a surprise test for the distractor items, at the end of the experiment, researchers could see whether maintenance rehearsal produces learning. Hartshorne and Makovski (2019) conducted a thorough meta-analysis of 61 prior experiments examining the effect of repetition on learning in the maintenance rehearsal procedure. They also conducted 13 large online experiments whose data represent nearly half as many total trials as the prior 61 published studies. Across both the prior literature and their own experiments they demonstrate a significant positive effect of maintenance rehearsal on long-term learning. They conclude, in line with an earlier review by Underwood (1983), that although intention certainly facilitates learning, even in the absence of intention the processing of an item or set of items can have long-lasting effects on memory.

Repetition Effects in Short-Term Memory Paradigms

The effect of repetition on memory appears even in short lists that do not exceed the span of immediate memory. Theoretically, many researchers regard memory for such short lists as largely reflecting the operation of a specialized short-term memory system that can hold a small number of items and support recall without forging long-term associations (but, see Kahana, Sederberg, & Howard, 2008). In one such procedure, invented by Sternberg (1966), subjects study a short list of items and then, prior to immediately recalling the items, they perform a single-item recognition judgment, indicating whether or not the item occurred in the just-presented list. Consistent with a short-term memory account, subjects rarely make errors and their response times (RTs) suggest an exhaustive serial scan of the contents of memory. This inference draws on the finding that lengthening the study list from 2 to 6 items produces a linear increase in mean RT for both targets (studied test items) and lures (non-studied test items). Such a result would arise if subjects searched through a set of stored items, comparing the probe item with the contents of memory in serial order. If each additional item requires a fixed comparison time, this should appear as a linear relation between list length and RT. Sternberg found just such a linear relation, with the observed slope of the RT-list length relation being around 40 ms for digits, 50 ms for letters, and 60 ms for words, irrespective of whether the test item is a target or a lure. This latter result led Sternberg to rule out many simple self-terminating search models (Sternberg, 2016). Baddeley and Ecob (1973) and Young (1979) both manipulated repetition in this procedure. They found that repeating items resulted in faster RTs (see Figure 13).

In another short-term memory paradigm, Hebb (1961)

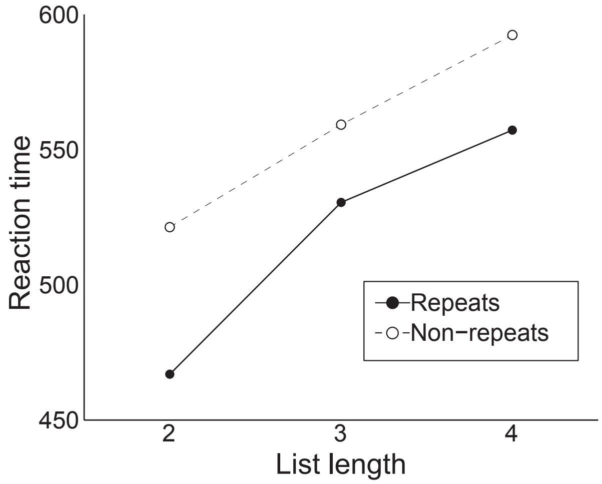

Figure 13. **Repetition effects in the Sternberg short-term recognition procedure.** As in the classic procedure, RTs increased with list length, but with repetitions subjects responded more quickly at each list length condition. Data from Baddeley and Ecob (1973) and Young (1979).

tested subjects' immediate serial recall of 9 digit lists. Most lists were unique, but every third list was a repeat of a particular target sequence (subjects did not know that this was the structure of the experiment). Not surprisingly, performance on the repeated list improved across repetitions. This is an interesting case of repetition because according to some theories of memory, immediate recall of a short list can be performed without accessing long term memory. Thus, if subjects know that they are unlikely to see the same list again, they will not need to form long-term representations of the sequential information. Yet, even if lists repeat very rarely and with very long delays between repetitions (e.g,. Page, Cumming, Norris, McNeil, & Hitch, 2013) they still exhibit superior recall for the repeated lists months after initial learning. Thus, we see that a brief study-test trial produces a lasting effect on memory, and each successive repetition of the list strengthens the associative structures that support recall, even after a very long delay. Kalm and Norris (2016) show that when measured with sufficient sensitivity, one also finds that initial recall is not necessary to produce the Hebb repetition effect.

Factors that Moderate the Benefits of Repetition

Much as Newton's celebrated *Law of Gravitation* tells us that the attractive force between objects with masses m_1 and m_2 depends on their distance ($F = G\frac{m_1 \times m_2}{distance(m_1,m_2)^2}$), so too, the beneficial effects of repetition depend on numerous variables. We have already seen that intention to learn can greatly influence the degree to which repetitions benefit retention, likely by way of changing the manner in which the item is being processed (e.g., whether its meaning is elaborated to produce a richer trace in memory). Here we consider another classic moderator of the repetition effect; namely, the spacing between repeated items.

Both Ebbinghaus (1885) and Müller and Schumann (1894) reported that repetition produced more rapid learning when the repeated trials were spaced apart as compared with when they were massed together. In one of the many studies demonstrating the beneficial effects of spaced repetitions, Glenberg (1976) had subjects study randomly-paired words, with some pairs repeated at varying lags, and found advantages for spaced practice extending out to more than 20 intervening pairs (see Figure 14). Cepeda, Pashler, Vul, Wixted, and Rohrer (2006) reviewed more than a century of research demonstrating that spacing repetitions enhances memory across a very wide range of intervals, tasks, and memoranda.

Roediger (2008) notes that many studies have documented situations where spacing either fails to produce any memorial benefits, or even reverses to produce impaired memory. Perhaps the classic example is the so-called *Peterson paradox*, wherein the spacing effect reverses at very short study-test delays, as would occur when both occurrences of a repeated paired-associate (e.g., a word pair) appear towards the end of a study list (Peterson, Wampler, Kirkpatrick, & Saltzman, 1963). In this case, massed repetition produces better recall than spaced repetition, contradicting the spacing effect described above. This ostensible paradox, however, can be understood through the lens of another famous law of memory: recency. The recency effect illustrates how, all else equal, the more recent an item was encoded the better it will be remembered. In this case, if you studied an A_i–B_i association at time t_1 and then repeat that association at time t_2, then the closer t_1 is to the time of test t_{test} the more easily it will be remembered. Assuming that the repeated association was independently stored and retrieved, memory should be best when both repetitions occurred recently, and thereby close in time to one another (massed). If, however, the two $A-B$ pairs both occurred long ago (i.e., $t_{test} - t_2 >> t_2 - t_1$), then recency will not strongly favor either occurrence and we will observe the influence of other factors that benefit spaced learning, such as variable contexts and/or study-phase retrieval (Siegel & Kahana, 2014).

Whereas we can easily explain the Peterson paradox as reflecting the opposing effects of spacing and recency, it is harder to account for the negative effects of spacing seen in immediate serial recall, as documented by Ranschburg (1902). Following study of a list with a repeated element, subjects exhibit poorer memory when the repetition is spaced than when it is massed, again in apparent contradiction of the more typical positive effect of spacing on recall performance (Crowder & Melton, 1965; Kahana & Jacobs, 2000). The Ranschburg effect, which appears strongest when repetitions occur 3 or 4 items apart within a list, has eluded most theories of serial-order memory (see chapter 5.1, Hurlstone, 2022).

Finally, Roediger reminds us that even in paradigms where one often sees robust benefits of spacing, these benefits do not exhibit monotonic increases with lag as seen in Figure 3. Rather, the benefits appear to plateau quickly, resulting in a phenomenon of limited generality, or they can even reverse at very long lags (Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008). Kahana and Greene (1993) report an example of a null-spacing effect in free recall – a paradigm that almost always produces large and robust benefits of spaced over massed repetition. The authors of that study had subjects learn lists of items all drawn from a single taxonomic category (e.g., animals) with some items presented once and others repeated with either small or large spacings. Three separate experiments involving free recall of such semantically homogeneous lists failed to observe any consistent benefits of spaced over massed repetitions. However, using the same materials, Kahana and Greene found that recognition memory judgements did benefit from spaced repetitions. They concluded that several mechanisms underlie the spacing effect, with some being more sensitive to the semantic organization of the lists. Three decades later it is much easier to understand these results. The free recall task depends on processes that govern the search of memory (e.g., Kahana, 2020). The law of contiguity, described below, tells us that neighboring items will tend to cue one another. This contiguity-based cuing process will naturally provide a mnemonic advantage to spaced items because they will have more unique retrieval cues (Lohnas, Polyn, & Kahana, 2011), thus providing more retrieval paths to the spaced items. However, in the case of semantically organized lists, the positive influence of contiguity will be counteracted by the effects of semantic similarity, which will lead any list item to serve as a cue for every other list item, regardless of how far apart they are in the list. So if contiguity is the mechanism that produces spacing in lists of unrelated items, similarity will render such effects negligible, and thus eliminate the spacing effect entirely. In recognition memory, subjects do not have to search from item to item in a cue-dependent manner, so in this case other variables that will tend to reduce the goodness of encoding for immediately repeated (massed) items will tend to produce a spacing effect irrespective of the semantic organization of the items, as reported by Kahana and Greene (1993).

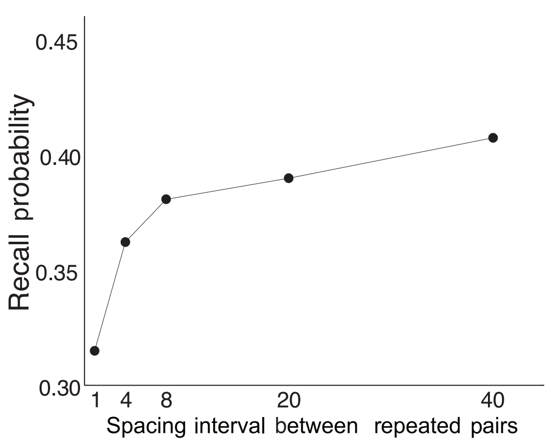

Figure 14. **The spacing effect.** Subjects exhibit superior recall for repeated paired associates when they are spaced apart by other unrelated pairs. This spacing advantage increased for lags extending up to 20 or more pairs (Data from Glenberg, 1976).

Repetition Mechanisms

With the benefits of repetition being self evident to most readers, one may wonder whether we need to ask why repeating an item or association leads to improved retention, as seen in both higher accuracy and faster response times? Plato (429–348 BCE) offered the classic explanation, now commonly known as strength theory, in his analogy of memory as a block of wax. Repeating an item would make a deeper impression in the wax, making the item more resistant to forgetting as when the image on the wax becomes effaced by other related information.

Nearly a half-century ago, Hintzman (1976) offered compelling evidence against theories that assume each occurrence of an item increases the strength of a single representation. Rather, Hintzman's review of data favored models that posit each occurrence of an item laying down its own trace in memory. A vast literature on categorization and recognition tasks demonstrates the superiority of multi-attribute multi-trace theories of memory. In these models, learning occurs in two ways: First, having more replicas of an item or event in memory provides a stronger similarity signal at the time of retrieval. Second, if each learning opportunity yields a slightly different version of the memory, with some features being encoded probabilistically and others omitted, then repeating items leads to a more differentiated and elaborated memory trace (see chapter 1.3, Shiffrin & Cox, 2022).

In models of free recall, where subjects search their memory for items learned in a given context, such as a particular place at a particular time, having multiple copies of the same memory will lead to higher levels of recall by increasing the number of retrieval routes to the repeated items. Repetition also allows traces to interact through study-phase retrieval, or the idea that the repeated occurrence of an item retrieves its prior occurrences, which may then be re-encoded in a later context, thus building a web of associations that support retrieval of the repeated memories (as in, “all roads lead to Rome”). Retrieved context theories embody both of these ideas, and as a result predict both the benefits of repetition and of spacing (see chapter 5.2, Lohnas, 2022; and chapter 5.11, Manning, 2022).

We also find reliable signatures of repetition in patterns of neural activity. For example, in the ”repetition suppression” effect, stronger memory responses are associated with reductions in neural firing. For example, in the perirhinal cortex and surrounding medial temporal lobe regions - often implicated in recognition memory (M. W. Brown & Aggleton, 2001; Miyashita, 2019) - both single neuron firing rates and BOLD signal measured by functional magnetic resonance imaging (fMRI) both exhibit decreases in response to repeated stimuli (Desimone, 1996). This repetition suppression effect is evident after a single exposure, and its magnitude varies with memory strength, or familiarity (Gonsalves, Kahn, Curran, Norman, & Wagner, 2005). Finally, functional brain imaging can provide clues about the mechanisms underlying repetition's effects on memory - particularly in cases where subjects do not provide explicit reports about their memory. Xue et al. (2010), for example, found that greater neural similarity (in BOLD signal patterns) across repetitions of face and word stimuli predicted subsequent memory success, measured both with recognition and free recall. Subsequent work using scalp EEG showed that memory-predictive pattern similarity across study repetitions occurs roughly 500ms after item presentation, perhaps reflecting reactivation of earlier study episodes (Lu, Wang, Chen, & Xue, 2015). These findings align with the idea that repeated encounters with a given stimulus cue retrieval of earlier encounters, and this may be one reason that repetition tends to enhance memory.

Conclusions

Seeking and finding order within the complexity of our everyday experience is not merely intellectually satisfying; it leads to progress in our ability to solve society's most pressing problems. As complex as memory may seem to an everyday observer, under the scrutinizing lens of scientific investigation memory's complexity increases further. Yet, beneath this complexity one also observes regular patterns in the data; phenomena of broad applicability and generality that seem to call for a common explanation.

Our chapter identifies five phenomena of memory whose generality leads us to characterize them as laws. We thus identify as laws the phenomena of repetition, recency, contiguity, similarity, and primacy. In reviewing these phenomena we both describe their broad applicability and discuss the variables that moderate their influence on memory. In several instances we show how violations of a given law of memory simply reflect circumstances in which two laws lead to opposing effects within a single task.

Much as the memory system appears to both generalize and discriminate, so too memory scientists can look for either common patterns across tasks or dissociations between tasks. Although we see value in both approaches, our bias is to seek the simplest possible theoretical explanation for a complex set of phenomena. This approach will undoubtedly fail, leading to theories that are too simple to explain the data. But in seeking simplicity, we gain understanding that would be lost if we rushed to accept more complex explanations.

We recognize that the term law may be seen as provocative. Laws imply a level of generality that is rarely seen in the psychological laboratory. Yet, we believe that the five laws set forth in our chapter appear no less general than laws in other areas of science. That said, we are happy to have the reader substitute a less austere term, such as principle, or property. Debating the exact definition of a term is of less interest than understanding how active scientists use the term to think about their work. We see, at the heart of this terminological debate a difference in beliefs, culture, or orienting views, on the part of the practicing scientist. To those of us who draw inspiration from physics, we look at the complexity of the world, seeking common stands beneath the superficial differences. We imagine some function, that once applied to all of the messy data, will reveal a simple invariance that will guide us in the creation of an explanatory theory. To those of us who draw inspiration from biology, we look to differentiate; to find the categories; to carve the natural universe at its joints. To the latter group, there is an implicit belief that we can learn more by studying differences than similarities, and to the former group, it is the similarities that reveal the underlying principles of nature.

To say that there is a law of repetition, recency, contiguity, similarity or primacy is to seek an explanation that applies in widely disparate domains. This approach gives rise to unifying theories. Which is not to say that these theories need to be simple, or to deny the distinctions that appear across aspects of the data obtained from nearly any paradigm used to study memory. Others, however, would argue that the kind of unifying theories that account for multiple tasks, stimuli,species, etc., hide the differences in the parameters they use to account for the complexity in the data, and in fact they are no more than a mathematical disguise for the true underlying theory, which is a theory of categorical differences.

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